

RESEARCH ARTICLE

Variation in hazel dormouse (*Muscardinus avellanarius*) presence in hedge and scrub habitats

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Abstract

1. Habitat restoration at a landscape scale is key to reversing the loss of biodiversity arising from habitat destruction. In landscapes that are intensively used by people, such as for agriculture, valuable restoration efforts might be applied not just to 'prime' habitats that are known to have strong associations with target species, but also to 'sub-prime' habitats that might nevertheless provide sufficient resources to support populations.
2. Hazel dormouse (*Muscardinus avellanarius*) populations are in chronic decline in the UK. The species is typically associated with broadleaf woodland but restoration of this habitat at scale in agricultural landscapes is difficult. Other habitats used by dormice might, therefore, provide opportunities for restoration. We investigated the use by hazel dormice of hedgerow and scrub habitats in southwest England. From June–November 2022, using footprint-recording tunnels, we surveyed 38 hedges and 21 scrub patches in the vicinity of 18 sites known to contain established dormouse populations.
3. We found that dormice were frequently present in scrub (9.3 detections per 100 tunnel checks, 95% confidence interval 6.6–12.0) and less frequently in hedges (4.5 detections, 95% CI 3.2–5.8).
4. In scrub patches, dormice were present more frequently as the abundance of dormice in the closest population increased, and less frequently where bracken (*Pteridium aquilinum*) was dominant.
5. In hedges, dormice were detected more frequently where there was abundant hazel (*Corylus avellana*) and honeysuckle (*Lonicera periclymenum*), as frequency of intersections with other hedges increased, and where an earthen bank was not present.
6. Understanding hazel dormouse association with a wide range of habitats, particularly scrub, offers more opportunities for habitat restoration as part of species conservation strategies.

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KEYWORDS

conservation, dormouse, hedgerows, monitoring, scrub, scrubland, woody linear features

1 | INTRODUCTION

One of the main drivers of current and rapid biodiversity loss is habitat destruction (Dirzo et al., 2014), especially for habitats that are difficult to restore, such as forests. Although habitat loss can result from both natural and anthropogenic causes, the latter is more likely to result in permanent losses due to conversion to other land uses, such as agriculture (Foley et al., 2005). Habitat destruction also fragments the remaining habitat patches. In forested landscapes, anthropogenic habitat fragmentation causes further degradation of the residual woodlands (Wade et al., 2003), as well as loss of total area (Hansen et al., 2020), which together can accelerate the decline of forest-reliant species. Forest fragmentation is a particular issue in temperate areas, where over half of forests had been fragmented by human activities by 1993 (Wade et al., 2003).

Habitat fragmentation has additional effects beyond habitat loss. At the population level, habitat fragments are smaller, decreasing resident population sizes, and more isolated, decreasing population mixing (Haddad et al., 2015). These effects of fragmentation can be exacerbated by the surrounding habitat matrix, as more hostile matrices, with greater contrast between habitats, limit dispersal (Prugh et al., 2008) and reduce population persistence within fragments (Dunford & Freemark, 2005). These small, isolated populations in fragmented landscapes are at greater risk of extinction (Haddad et al., 2015), due to stochastic events (Caughley, 1994) and reduced genetic diversity (Almeida-Rocha et al., 2020), especially if the species has limited dispersal capability.

Conservation actions are, therefore, required to alleviate the negative effects of habitat loss and fragmentation. For species with strong associations with particular habitats, actions tend to focus on linking remaining fragments of 'prime' habitat by creating corridors (Baum et al., 2004) and/or increasing patch size through creating new prime habitat. However, there is often a lack of knowledge about how other habitats, which might not be considered prime as they support small or transitory populations, might contribute to sustaining populations. For example, pine martens (*Martes martes*) are typically associated with forest, but benefit from additional resources from matrix habitats, such as grassland where their food species are frequently found (Caryl et al., 2012). Non-classical, or 'sub-prime' habitats might also provide dispersal routes or supplementary residential habitat if they contain sufficient resources. Though there may be less certainty about how target species use such habitats, they might have equal or greater value than prime habitats by helping to sustain and enhance local metapopulations, and understanding their benefits could increase the opportunities for conservation. A diverse set of actions, targeting multiple habitats, means strategies might be more readily tailored to the restrictions and opportunities of each landscape context.

Hazel dormice (*Muscardinus avellanarius*) are small arboreal rodents, populations of which are threatened by habitat loss and fragmentation (Hutterer et al., 2021). In Great Britain, hazel dormice are in chronic decline (Scopes, Goodwin, et al., 2023), are currently listed as Vulnerable on the Great Britain Red List (Mathews & Harrower, 2020), and are in 'Unfavourable Conservation Status' (JNCC, 2019). Both these latter assessments reference insufficient habitat to support long-term population persistence (JNCC, 2019; Morris, 2021). There is a statutory obligation to return dormice to 'Favourable Conservation Status', which, as currently defined, would require doubling the population in the next 10 years, and again the following 10 years (Scopes, Goodwin, et al., 2023). Increasing dormouse populations will require a focus on restoring viable habitat to alleviate the threat of fragmentation. The recent Environment Act (2021) allows the creation of 'Species Conservation Strategies' which could focus on species conservation at a landscape scale, rather than relying primarily on more localised protection, including of individual animals and their nests. This presents an opportunity to investigate the multitude of actions that could be applied to restore dormouse habitat at this scale.

Conventionally, hazel dormice are thought to use and prefer broadleaf woodland (Bright & Morris, 1996; Fedyń et al., 2021), though there is increasing evidence, including from conservation practitioners, that they use a wider variety of habitats (Phillips et al., 2022). The established view has led to an abundance of research into approaches to woodland management for dormouse conservation, focused on maintaining mid-successional stages. There is a general consensus that woodland creation and active management are key approaches; however, there can also be practical restrictions such as the financial costs of removing land from agriculture and working effectively at scale with inherently small-scale practices such as coppicing (Phillips et al., 2022). There has also been some work on the importance of increasing landscape connectivity (Dietz et al., 2018; Iannarilli et al., 2017), mainly through creating and managing hedgerows.

Hedgerows and scrub have not been extensively studied as dormouse habitats in their own right, though hedge density has frequently been linked to dormouse presence and abundance in fragmented woodland patches (Capizzi et al., 2002; Dietz et al., 2018), and local surveys have frequently found hazel dormice and their nests in these habitats (Bright & MacPherson, 2002; Ehlers, 2012; Phillips et al., 2022). Some studies have also identified habitat factors (such as species diversity and structural complexity) that are associated with more frequent detection of dormouse nests (Dondina et al., 2016). Conservation practitioners frequently indicate that hedges and scrub are important habitats for dormice, and though there is little discussion of the management of scrub beyond its creation, for hedges they suggest that, alongside hedge

creation, changing trimming practices to encourage wider hedges with fewer gaps and increasing species diversity would benefit dormice (Phillips et al., 2022). Surveys in England have also found evidence of dormice using primarily large species-rich hedges (Bright & MacPherson, 2002; Bright & Morris, 1996), as well as some that are more intensively managed (Chanin & Woods, 2003).

Given these expert opinions, additional evidence is required to understand how hazel dormice use these habitats. In this study, we surveyed hedges and scrub in the vicinity of known hazel dormouse populations to estimate and compare occurrence within these sub-prime habitats, and consider how variation in habitat affects detection. Studies so far have employed surveys of natural nests (Berg, 1996; Berg & Berg, 1998; Ramakers et al., 2014; Wolton, 2009) or nest tubes (Chanin & Woods, 2003; Dondina et al., 2016; Ehlers, 2012) to assess presence, which require dormice to reside in the habitat. Instead, we use footprint tunnels which have been shown to be faster (Bullion et al., 2018; Mills et al., 2016) and better for detecting dormice, with five times the occupancy rates from footprint tunnels compared to nest boxes or tubes (Melcore et al., 2020).

2 | MATERIALS AND METHODS

2.1 | Site selection and permission

We selected survey sites based on the locations of National Dormouse Monitoring Programme (NDMP) sites in Cornwall and Devon in southwest England that had evidence of dormice activity in 2020/2021. This acted as a positive control, so that any absences were more likely to relate to habitat use than the wider landscape context. We identified landowners within 1 km of the NDMP site through online resources, and by contacting local businesses that might own land (e.g. farms). Having located landowners and secured survey permission, we selected hedges/scrub patches to cover different management stages (e.g. laid and intact hedges) and clear

differences in structure. We define scrub as patches of shrub, for example gorse *Ulex europaeus*, that are <5 m in height, with no or only occasional trees of greater height.

2.2 | Survey methods

Surveys took place with ethical approval from the College of Life and Environmental Sciences (Cornwall) Ethics Committee at the University of Exeter (Application ID: 513767). All surveys took place between June and November 2022. We surveyed hedge and scrub plots in the vicinity of 18 NDMP sites; 6 in Cornwall and 12 in Devon (Figure 1). Eleven sites were surveyed by volunteers, and the remaining seven were surveyed by ERS. Part-way through the survey, the tunnels in one hedge had to be moved to another to allow for habitat management, and these are treated as separate hedges. One volunteer withdrew from the study after one check, so this hedge was removed from the analysis.

Determination of dormouse presence was based on identification of their footprints recorded in a footprint tracking tunnel (Bullion et al., 2018; Mills et al., 2016). These tunnels comprise a square plastic pipe with a wooden insert on which to place card and ink made of edible charcoal and vegetable oil. Dormouse footprints can be distinguished from other small mammals by their unique pattern (Mills et al., 2016). We placed 20 tunnels in each hedge/scrub patch, with 10–15 m spacing between tunnels. The tunnels were placed in transects along hedges, and grids in scrub, though this was altered according to accessibility. Tunnels were also split across multiple hedges/scrub patches when one was insufficiently large to accommodate 20 tunnels (minimum seven in hedges, 10 in scrub). Such splits were noted as being in different hedges/scrub patches if the vegetation, management and/or structure of the habitat differed.

The tunnels were checked every 2 weeks to allow sufficient time for small mammals to use the tunnels, while not allowing the ink to dry out (Bullion et al., 2018), and were checked for two to 5 months. We recorded hazel dormouse and other small mammal footprints,

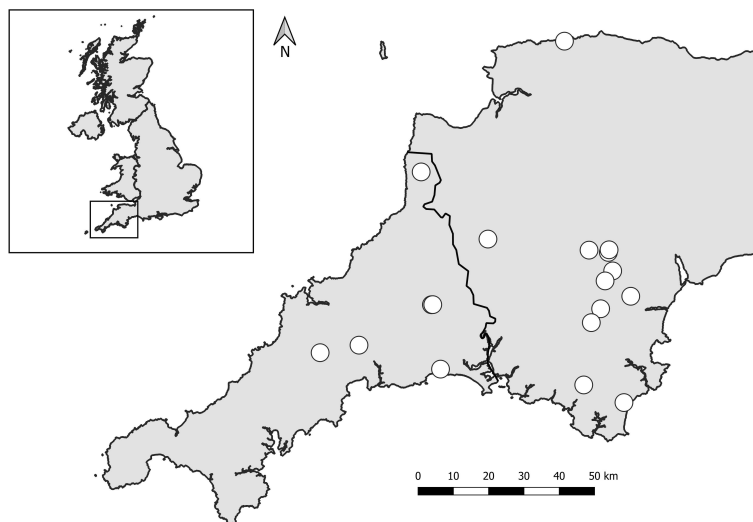


FIGURE 1 A map of the study area in the counties of Cornwall and Devon, with the locations of the National Dormouse Monitoring Programme sites (open circles) around which multiple hedges and scrub patches were surveyed. Inset map shows the UK with a box outlining the location of the study area.

not identified to species, for each tunnel at each check, and changed the footprint card if it had any footprints or was damaged. Checks were removed from the analysis if damage to the tunnels prevented us from ascertaining footprint presence, and damaged tunnels were replaced.

We trained volunteers initially using a protocol and footprint identification document, and then by meeting with them to set up the site. Volunteers were encouraged to identify footprints themselves but were also asked to collect in the footprint cards so we could check for footprints and species identification. As hazel dormice are not disturbed whilst footprint tunnels are checked, volunteers did not require a licence to participate. Volunteers had been instructed to stop surveys if a nest was found in a tunnel; however, due to the timings of the surveys undertaken by volunteers, they did not find any nests. Those nests that were found in tunnels were at sites checked by ERS, who held the relevant protected species licence (Natural England, registration number 2020-49759-CLS-CLS). Nests were counted amongst dormouse presences for as long as the nest appeared used by dormice and not another small mammal species.

2.3 | Habitat and population data

Habitat surveys were completed at the same time as the tunnels were placed, and by the same person for all sites. We collected data at both the tunnel-level and the hedge/scrub patch-level (referred to collectively as plot-level data). For each tunnel we noted the height of the tunnel from the ground, and ranked the five dominant vegetation species within 1 m of the tunnel. For tunnels in hedges we also noted if there was hedge gap within 1 m of the tunnel. For scrub tunnels we noted, as a single variable, whether the tunnel was in the interior of the patch, or the type of surrounding habitat (route/path, pasture, woodland) if it was on the edge.

For each hedge, we collected information based on the Great British Hedgerow Survey methodology (PTES, 2019b) relating to hedge structure and species composition, such as height and whether there was an earthen hedge bank (usually a constructed ridge of stone and soil on which a hedge sits). We also estimated the abundance of the plant species that previous research has indicated are important for dormice (Goodwin et al., 2018), using the DAFOR index (Dominant >75%, Abundant 51%–75%, Frequent 26%–50%, Occasional 11%–25%, Rare 1%–10%, plus Absent). For scrub patches, we collected similar data to the hedge survey (Table 1), and other variables also relating to structure and management (Table 2). A full list of the data collected can be found in the Supporting Information.

We also measured the length of each hedge using GIS and ESRI satellite imagery. Similarly, we measured the minimum distance a dormouse would have to travel from the nearest NDMP site to the hedge or scrub patch, via appropriate habitat such as hedges and woodland. We measured the closest distance, along a putative dormouse path, of each plot to any woodland, as defined by the

TABLE 1 A comparison of the exploratory analysis of variables affecting dormouse presence in hedge and scrub habitats, where habitat factors are directly comparable.

Model variable	Hedge ANOVA <i>p</i> -value	Scrub ANOVA <i>p</i> -value
Abundance Index (subset)	0.229	0.001*
Dormouse travel distance (m)	0.785	0.888
Number of emergent trees	NA	0.658
Bramble (ordinal DAFOR)	0.060*	0.466
Hazel (ordinal DAFOR)	0.002*	0.853
Honeysuckle (ordinal DAFOR)	0.079*	0.717
Willow (ordinal DAFOR)	0.156	0.487
Shannon diversity index	0.050*	0.501
Distance to woodland (m)	0.058*	0.466

Note: Each variable has been tested individually in a model that also contains a random effect of site, and compared through ANOVA to a null model which only contains a random effect of site, to give the *p*-value displayed here. An asterisk indicates *p*-values below 0.1, which was used as the threshold for the initial selection of variables that were used in the joint model for hedge and scrub, respectively. A NA ANOVA *p*-value is due to a lack of degrees of freedom in the model for that variable. 'Ordinal DAFOR' refers to the abundance of a plant species using sequential categories (Dominant >75%, Abundant 51%–75%, Frequent 26%–50%, Occasional 11%–25%, Rare 1%–10%, plus Absent) and 'Abundance index' refers to the relative abundance of adult dormice at the nearest National Dormouse Monitoring Programme site.

National Forest Inventory 2020 (Anonymous, 2022). For hedges, we additionally considered the connecting habitat that a dormouse travelling outwards from the NDMP site would be going towards, either another woodland or more hedges. We used the tunnel-level data of the ranked vegetation species, which provided up to five species per tunnel position evenly distributed in the plot, to calculate plot-level Shannon diversity indices.

Finally, we included a measure of hazel dormouse abundance at the nearest NDMP site. We calculated an abundance index for each site using data from the NDMP surveys, where licensed volunteers count dormice in grids of nest boxes up to once a month from May until September. More information about the surveys can be found in the NDMP guidelines (PTES, 2019a). We used NDMP data from 1993 until 2021, including any site across the NDMP that had been surveyed for more than 2 years, and had found at least one dormouse. We used the approach initially applied by Goodwin et al. (2017) and updated by Scopes, Goodwin, et al. (2023), where counts of adult dormice were modelled with a Poisson error structure against year, site and month of survey, with an offset of number of boxes to control for survey effort. This gives an index for each site

TABLE 2 A comparison of the exploratory analysis of variables affecting dormouse detection in hedge and scrub habitats, where habitat factors are not directly comparable.

Habitat	Model variable	ANOVA <i>p</i> -value
Hedge	Number of intersections	0.013*
	Percentage gaps	0.013*
	Number of gaps >5m	0.044*
	Bank (Y/N)	0.075*
	Knuckle (Y/N)	0.112
	Height group (m)	0.141
	Width (m)	0.184
	Connection type (hedge/wood)	0.212
	Bank height (m)	0.273
	Number of connections	0.349
	Sycamore (ordinal DAFOR)	0.353
	Number of gates	0.488
	Structure group	0.500
	Length (m)	0.858
Scrub	Dominant mid-storey species	0.004*
	Management at edges (Y/N)	0.005*
	Land use percentage: woodland	0.117
	Land use percentage: route	0.119
	Dominant upper storey species	0.129
	Birch (ordinal DAFOR)	0.129
	Dominant ground species	0.191
	Management internally (Y/N)	0.222
	Land use percentage: pasture	0.322
	DME scale	0.367
	Height (m)	0.528
	Land use percentage: arable	0.621
	Number of paths >1 m	0.939
	Connection between shrubs (Y/N)	NA
	Land use percentage: scrub	NA

Note: Each variable has been tested individually in a model that also contains a random effect of site, and compared through ANOVA to a null model which only contains a random effect of site, to give the *p*-value displayed here. An asterisk indicates *p*-values below 0.1, which was used as the threshold for the initial selection of variables that were used in the joint model for hedge and scrub, respectively. An NA ANOVA *p*-value is due to a lack of degrees of freedom in the model for that variable. 'Bank present' refers to the presence of an earthen hedge bank, 'ordinal DAFOR' refers to the abundance of a plant species using sequential categories (Dominant >75%, Abundant 51%–75%, Frequent 26%–50%, Occasional 11%–25%, Rare 1%–10%, plus Absent), 'land use percentage' refers to the percentage of the perimeter of the scrub with different land uses and 'DME scale' refers to the ground coverage of the scrub (dominant, medium or encroaching).

indicating the number of dormice counted per unit of survey effort (per box) over the survey period 1993–2021. Not all the NDMP sites surveyed here had data for at least 2 years, so we used a subset for models utilising this data.

2.4 | Statistical analysis

All analyses were completed in R version 4.2.2 (R Core Team, 2022). We separately summarised variation in the presence of dormice and of other small mammals to compare their overall presence in hedges and scrub. To do so, we used a binomial generalised linear model (GLM) with the presence/absence of footprints as a binary response, and included habitat and distance to woodland as fixed effects, as scrub patches were on average closer to woodland than hedges. This is the only part of the analysis where hedge and scrub data were modelled together.

Next, and for each of the two habitats separately, we used two models, one at the level of the individual survey tunnel (tunnel-level model) and one at the hedge/scrub survey plot level (plot-level model) to explore how habitat factors at these two scales affect dormouse presence. For the tunnel-level model, within each plot, we modelled the presence/absence of dormice at each check as a binary response, using a binomial GLM with a logit link function. All models included fixed effects of the plot and the day of the year the check occurred, which was scaled so that the first survey date (20th June) was day zero. We then tested whether habitat data at the tunnel-level improved the fit of these models and significantly affected dormouse presence, by including each variable as a fixed effect. We only included the first rank dominant species. We compared model performances using the Akaike information criterion (AIC), looking for models with the lowest AIC, providing the AIC differed by more than two (Burnham & Anderson, 2002). When we had finalised the variables, we used *k*-fold cross validation to identify the best polynomial shape for the relationship between the day of the year and detection, with a *k* = 10 to avoid bias correction (Yates et al., 2023). This process gave a final, tunnel-level model for each habitat. To calculate a plot-level score of dormouse presence, we predicted the probability of dormouse presence for each plot when the other model variables (e.g. day of the year) were optimal for dormouse presence detection. Using the optimal conditions gave the most variation between plots, as detection rates were uniformly low across plots at intercept values (see Figure 2). These probabilities were the response data for the plot-level models.

For the next stage, for hedges and scrub separately, we used a quasi-binomial error structure to model the probabilities detailed above. To accommodate this error structure, and include random effects, we used a generalised linear mixed effect model (package *gam*, Hastie, 2023). Our study design, with 20 tunnels and at least 2 months of checks, gives >90% probability of detecting dormice for all habitat types (PTES, unpublished data). This means we have similar confidence in our presences and absences and did not weight the response variables. We first fitted individual models for each variable we collected, testing 23 individual habitat factors against dormouse presence in hedges, and 24 factors in scrub. All these plot-level models included a random effect of the NDMP site, controlling for un-surveyed aspects of habitat,

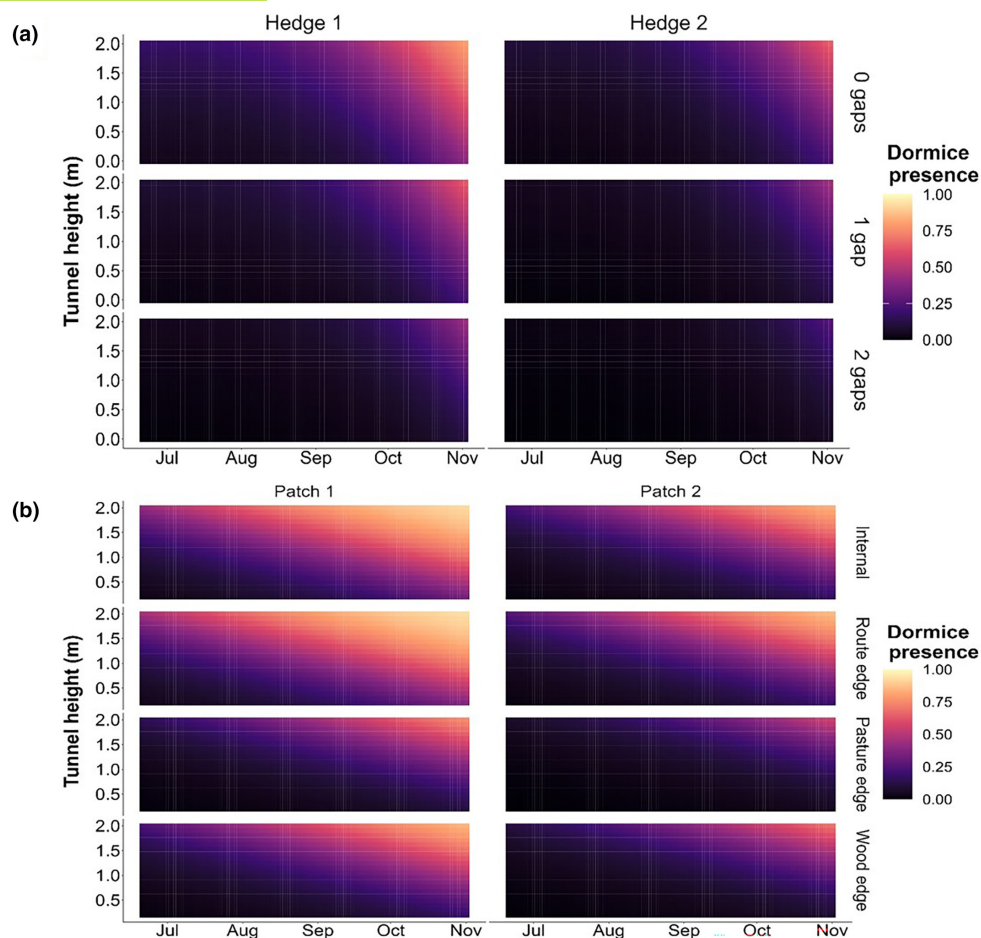


FIGURE 2 Dormouse presence at (a) two exemplar hedge plots and (b) two exemplar scrub plots. Figure 2a is the best model from the AIC selection process for the hedge tunnel-level model, and Figure 2b is the best model from the same selection process for the separate scrub tunnel-level model. For both figures, columns show two different plots (hedges or scrub patches) with differing frequencies of dormouse presence, and the colour of the squares indicates the frequency of dormouse presence. In plot a, the rows show the number of gaps, whilst in plot b rows show the different edge types.

location and local hazel dormouse population. Given that scrub patches were usually closer to woodland than hedges, we tested an interaction term between the effects of each variable and the distance to woodland; however, there were no significant interactions so these were not included. We assessed whether the variable had some significant effect through analysis of variance (ANOVA) comparison between the model and a null model including only the random effect of site, using a chi-squared test. As this was the first step in variable selection and was exploratory, we used a significance threshold of p -value of <0.1 . We then combined the variables that passed this threshold into two joint models, one for each habitat, to investigate whether significance of the factors was retained using a GLM summary (here p -value <0.05). The multivariate models included a random effect of site and a random effect of surveyor (volunteer or ERS). This provided a final model for each habitat, from which to draw inference. We present the results as odds ratios, where an odds ratio of one indicates equal odds of detecting a dormouse.

3 | RESULTS

3.1 | Footprint data

We completed 7560 individual tunnel checks in 38 hedges and 21 scrub patches, associated with 18 NDMP sites. All tunnels were checked on a minimum of four occasions (mean = 7.8), between 20th June and 3rd November 2022. 1266 checks were removed from the analysis as the tunnels were damaged or had fallen out of place. Of 3957 successful checks in hedges, hazel dormouse footprints were detected on 171 checks at 21 of 38 plots. Of 2337 successful checks in scrub, dormouse footprints were detected on 229 checks at 11 of 21 plots. The binomial model of all successful checks suggests there is a significant difference in detection of dormouse footprints between hedge and scrub habitat ($p < 0.0001$), with 4.5 (95% confidence interval: 3.2–5.8) detections per 100 tunnel checks in hedges and 9.3 (95% CI: 6.6–12.0) in scrub. For both habitats, the likelihood of detection decreased with increasing distance from woodland ($p = 0.001$).

Hazel dormouse nests were found at 20 tunnel checks (11.7% of checks with dormouse presences) in hedges and 11 checks (4.8% of checks with presences) in scrub.

Footprints of other small mammal species were frequently detected, with significantly greater frequency in hedges than in scrub ($p < 0.0001$). We found 1556 checks with footprints of other small mammals in hedges, or 38.9 (95% CI: 35.8–42.1) detections of footprints per 100 tunnel checks. In scrub, there were 778 checks that detected footprints of other small mammals or 34.2 (95% CI: 30.0–38.4) detections per 100 tunnel checks.

3.2 | Variation in hazel dormouse presence

3.2.1 | Tunnel-level factors

For hedges, detection of dormouse footprints was significantly greater in tunnels placed higher in the hedge and in hedges with fewer gaps (Table S1, Figure 2a). Tunnels placed higher in scrub had greater detection of dormouse footprints, as did tunnels placed in the interior of the

patch, or if they were on an edge, when that edge was next to a route (Table S1, Figure 2b). Though the relationships between check day and dormouse presence differed between habitats (Table S2), both showed increases across the season, peaking in late October (Figure 2). There was also significant variation between plots in both habitats (Table S3), which was analysed further in the plot-level models.

3.2.2 | Plot-level factors

In hedges, nine factors passed the initial screening threshold: the abundances of bramble (*Rubus fruticosus*), hazel (*Corylus avellana*) and honeysuckle (*Lonicera periclymenum*), the Shannon diversity index, the distance to woodland (Table 1), the number of intersections, the percentage gaps in the hedge, the number of gaps wider than 5 m, and the presence of an earthen hedge bank (Table 2). Combining these into the joint model, we found dormouse presence was significantly greater in hedges with high hazel and honeysuckle abundance, more intersections and without an earthen bank (Figure 3).

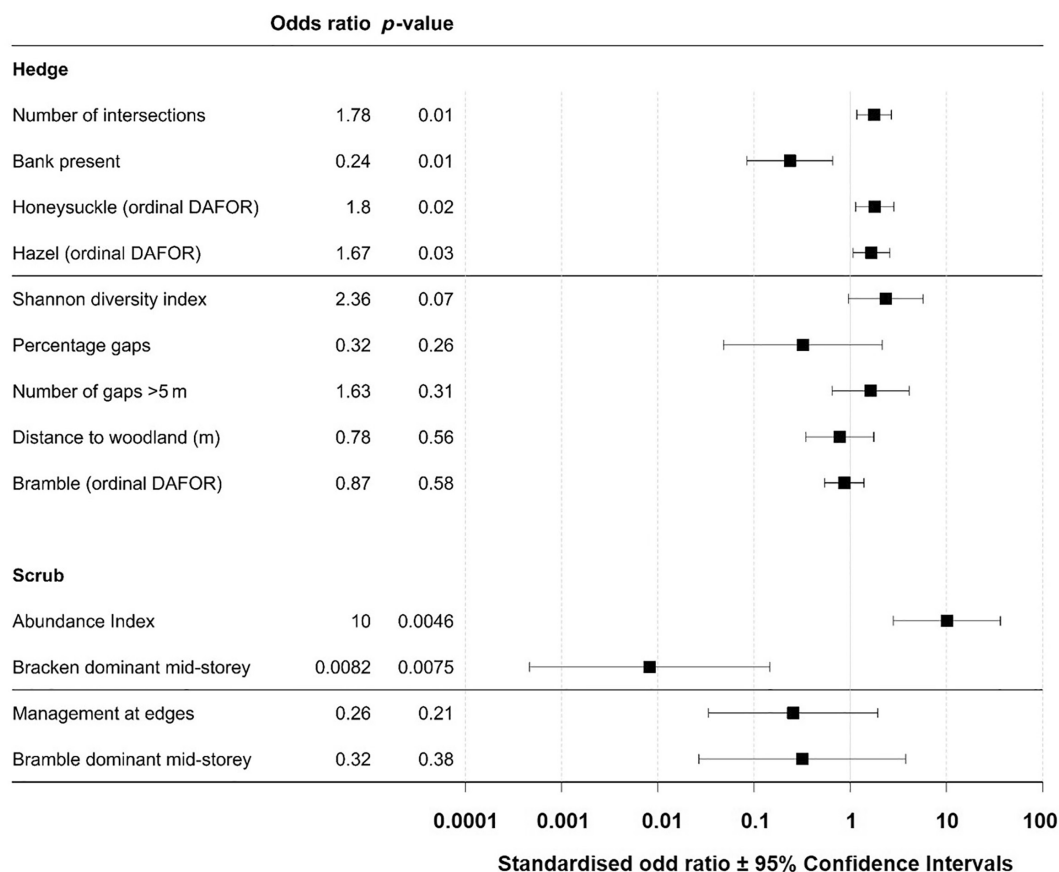


FIGURE 3 Relationships between habitat factors and dormouse presence in the joint models for hedges (top) and scrub (bottom). Standardised odds ratios (with 95% confidence intervals) and the p -value from the joint model are shown. Dominant mid-storey species (bracken and bramble shown here) are in comparison to gorse. An odds ratio of 1 indicates similar odds of dormouse detection. Odds ratios are displayed on a log scale. 'Bank present' refers to the presence of an earthen hedge bank, 'ordinal DAFOR' refers to the abundance of a plant species using sequential categories (Dominant >75%, Abundant 51%–75%, Frequent 26%–50%, Occasional 11%–25%, Rare 1%–10%, plus Absent) and 'Abundance index' refers to the relative abundance of adult dormice at the nearest National Dormouse Monitoring Programme site.

In scrub, only three factors passed the initial threshold; the NDMP site Abundance Index (Table 1), the dominant mid-storey species, and the presence of management along scrub edges (Table 2). In the joint model with these variables, we found dormouse presence was significantly greater near NDMP sites with a greater Abundance Index and significantly reduced in plots with a bracken (*Pteridium aquilinum*) dominated mid-storey (in comparison to a gorse dominated mid-storey, Figure 3).

4 | DISCUSSION

We undertook a targeted survey of the presence of hazel dormice in understudied hedge and scrub habitats in southwest England. We found more than double the frequency of dormouse presence in scrub habitats than in hedges, when controlling for distance to woodland. However, we did find more dormouse nests in hedges (11.7%) than in scrub (4.8%). Our study adds to the growing evidence that hazel dormice use and reside in these habitats, despite being generally viewed as sub-prime relative to broadleaf woodland.

In hedges, dormice were more frequently found, and so seemed to more frequently use, those with a greater abundance of hazel and honeysuckle, more intersections with other hedges and without an earthen hedge bank (Figure 3). Meanwhile, in scrub, dormice seem averse to areas with a bracken-dominant mid-storey, and were found more often in plots where the closest NDMP site had a greater population index (Figure 3).

The within-plot tunnel-level analysis suggests ways to refine future surveys using footprint tunnels (Figure 2). To maximise detection in either habitat, tunnels should be placed higher in the vegetation, up to 2m to allow surveyors to access them, and surveys should take place in September/October. In hedges, placing tunnels away from gaps will further increase detection, while in scrub, placing tunnels within the patch or along routes will be most effective.

Given there is less research on dormice in scrub than in hedges (Phillips et al., 2022), it is revealing that our study found scrub to be the more frequently used habitat. This suggests that scrub may be more important than previously considered, and indicates additional opportunities for habitat restoration. For example, dense native scrub in a conifer landscape in Sweden can support high densities of hazel dormice (up to 6.7 per hectare, Berg & Berg, 1999). In the UK, some experts were confident that scrub could sustain populations of dormice in the long-term, and that creating scrub would be a valuable conservation action (Phillips et al., 2022), which our surveys supports. Our study also agrees with the more extensive literature on hedges, including some evidence that hedges contribute to dormouse population viability at a landscape scale, not only by enabling connectivity, but also by hosting resident individuals (Schulz & Büchner, 2018). Hedges had a greater proportion of nests within tunnels than scrub, which might reflect better availability of natural nesting opportunities in scrub, such as dense bramble patches (Goodwin et al., 2018).

In scrub, dormice might avoid bracken-dominated patches as it shades out other plants (Pakeman & Marrs, 1992), reducing food availability, compared to gorse which, though also shading, could provide nectar for much of the year. Our results differ from studies in Sweden, where hazel dormice were more often detected in scrub with greater number of shrub species and greater cover of shrub (Berg, 1996; Berg & Berg, 1998), whilst we found no effect of analogous variables (diversity and DME scale, Tables 1 and 2). In this Swedish study (Berg & Berg, 1998), dormice were also associated with areas with greater cover of hazel, which the authors considered important food sources in that conifer-dominated landscape. Differences between our findings and those of Berg and Berg (1998) might reflect the studies' wider landscape contexts of commercial conifer forests, with our scrub adjacent to broadleaved woodland, which may offer greater resources. However, the landscape of our study and Berg (1996) are similar, with deciduous woodland fragmented by farmland. We also did not find dormice more often in bramble-dominated mid-storey, compared to gorse (Figure 3), despite bramble being a preferred nesting habitat and associated with population stability (Goodwin et al., 2018).

Greater abundances of dormice in the nearest NDMP site were associated with more frequent dormouse presence in scrub but not in hedges (Table 1). Scrub patches were also closer to woodland than the hedges surveyed, however, including distance to woodland as an interacting term with the other habitat variables did not contribute significantly to explained variance. One possible explanation is that scrub in this study might be predominantly used by resident hazel dormice, with their home ranges overlapping with woodland, whilst the more distant hedges are used by dispersing individuals.

Hazel nuts and honeysuckle provide a key resource for hazel dormice (Juškaitis, 2014), and are associated with greater breeding propensity and population abundance, respectively (Goodwin et al., 2018). Other research has suggested high hedge density, and therefore, high hedge connectivity, can support dormice populations in forest-poor landscapes (Ehlers, 2012; Schulz & Büchner, 2018), which is reflected in our findings. We also found that the presence of an earthen hedge bank decreased the probability of detecting dormice, which might be because tunnels had to be placed lower in hedges with banks, suggesting they would detect footprints less frequently (Figure 2). Dormice also appear to prefer wide hedgerows with a numerous native species and complex structure (Dondina et al., 2016), possibly requiring at least 12 woody species (Ehlers, 2012). Similarly, experts consider larger, fuller, more species-diverse hedges to be the most suitable for dormice (Phillips et al., 2022), which has been evidenced by surveys in England (Bright & MacPherson, 2002). Though we found some support, in the tunnel-level analysis, that dormice avoid gaps, we did not find support for changes in dormouse detection in relation to hedge-level species diversity, width, height or indications of severe management (the presence of a 'knuckle', vegetative scar tissue, indicating repeated trimming to the same point).

The differences between this study and the existing literature might be attributed to survey methods. Most of the previous

research use natural nests (Berg, 1996; Berg & Berg, 1998; Ramakers et al., 2014; Wolton, 2009) or nest tubes (Chanin & Woods, 2003; Dondina et al., 2016; Ehlers, 2012) to assess hazel dormouse presence, whilst we employed footprint tunnels which have been shown to be faster (Bullion et al., 2018; Mills et al., 2016) and more effective methods of detecting dormice (Melcore et al., 2020). Techniques relying on nests highlight habitats preferred for nesting locations rather than for foraging or dispersal. For example, Wolton (2009) found blackthorn (*Prunus spinosa*) was favoured for nest locations over hazel, likely due to its thick thorny vegetation providing structure and protection for nests. Our study may, therefore, capture additional uses of these habitats.

Our study only surveyed during one season, and so cannot investigate any changes in habitat use that result from annual changes in weather or dormouse population. Nevertheless, the main aim here was to compare detection in hedges and scrub, which experienced the same conditions within the survey year. The summer of 2022 was marked by a drought in southwest England (Environment Agency, 2022), which might have reduced blackberry fruiting, explaining the lack of effect in our analysis. The drought could also have dried the ink faster and reduced detection; however, the high frequency of other small mammal footprints suggests that the method worked as expected. Finally, though our study indicates how dormice are using hedges and scrub, there is some confounding between detection and habitat use. We have accounted for this with the multi-level analysis, with the tunnel-level models controlling for some of the survey variables that could affect detection, and by using a method that gives high detection probabilities. However, future studies combining multiple survey techniques over several seasons might deal more fully with these issues.

Overall, our study reveals hazel dormice frequently use both scrub and hedge habitats, indicating additional targets, beyond the conventional focus on 'prime' broadleaf woodland habitat, for management to increase populations on a landscape scale. Scrub in particular, where we detected the most dormice, could be an easy way of increasing valuable habitat, if marginal areas are left to succeed naturally to scrub (Phillips et al., 2022). Practitioners did not have management suggestions, beyond creation, for improving scrub for dormice (Phillips et al., 2022). However, our study indicates that bracken suppression, in favour of other native flowering and fruiting species, may be a management option to increase scrub suitability. This study also suggests establishing new hedges, with abundant hazel and honeysuckle, and improving management of existing ones to increase connectivity would be beneficial for dormice, measures that are well-supported by existing literature and practitioner experience. The high availability of hedges and scrub in UK landscapes indicates a key opportunity to increase available habitat for hazel dormice, rather than focusing on woodland alone. Such actions could help slow and maybe reverse their chronic decline.

AUTHOR CONTRIBUTIONS

The study was conceived by all authors. Data were collected and analysed by Eleanor R. Scopes, with input from Robbie A. McDonald

and Jonathan J. Bennie. The manuscript was initially written by Eleanor R. Scopes, with input from Robbie A. McDonald and Jonathan J. Bennie, and all authors commented on drafts and approved the manuscript for submission.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

PEER REVIEW

The peer review history for this article is available at <https://www.webofscience.com/api/gateway/wos/peer-review/10.1002/2688-8319.12329>.

DATA AVAILABILITY STATEMENT

The data and code for this analysis is available at the Zenodo data repository (Scopes, Bennie, et al., 2023).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Figure S1. Hedgerow cross-section illustration and description used to assign hedge structure categories (PTES, 2019).

Table S1. Model selection for variables to include in hedge and scrub tunnel-level models.

Table S2. Model selection for the shape of the relationship between check day and detection, in hedge and scrub tunnel-level models, based on *k*-fold cross validation (*k* = 10).

Table S3. Frequency of hazel dormouse detection for each plot in all hedges and scrub patches.

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