Received: 22 October 2020 | Revised: 11 February 2021 | Accepted: 8 March 2021

DOI: 10.1002/zoo.21603

RESEARCH ARTICLE

ZOOBIOLOGY WILEY

The effects of a zoo environment on free-living, native small mammal species

Emily Elwell[1] | **Christopher Leeson**[1,2] | **Stefano Vaglio**[1,3]

[1]Department of Biology, Chemistry and Forensic Science, University of Wolverhampton, Wolverhampton, UK

[2]Department of Conservation and Research, Dudley Zoological Gardens, Dudley, UK

[3]Department of Anthropology & Behaviour, Ecology and Evolution Research Centre, Durham University, Durham, UK

Correspondence
Emily Elwell, Department of Biology, Chemistry and Forensic Science, University of Wolverhampton, Wulfruna St, Wolverhampton WV1 1LY, UK.
Email: E.J.Elwell@wlv.ac.uk

Abstract

One of the main threats to native species conservation is urbanisation. It is causing changes to natural habitats and species composition. Urban green spaces have shown to have conservation value for native species by providing safe spaces in urban areas. They typically contain a variety of habitats and plant species which is correlated with greater abundance and diversity of small mammal species. Zoos are a vital resource for animal conservation and, in some instances, could be considered as an urban green space for native species conservation. Their unique environment provides free-living, native species an abundance of resources including food and shelter. This project involved the live trapping of free-living small mammal species (<40 g) between enclosures in Dudley Zoological Gardens to study the effects of the zoo environment. There were no significant differences found between the total number of captures and trap proximity to enclosures. There was a significant difference in total captures found between different enclosure trapping areas. Generalized linear mixed models were fitted to the data and there were significant relationships between abundance and both habitat type and enclosure species. Habitats associated with semi-natural woodland had the greatest diversity and total captures of small mammals. Total captures were lower in trapping areas that were associated with predatory species. Similar to research on green spaces, habitat was an important factor determining abundance, but predator enclosures were a factor unique to zoos. This study illustrates the potential of zoos as an urban green space and for the study of small mammals.

KEYWORDS

free-ranging species, live trapping, urban green spaces, urban wildlife, urbanisation

1 | INTRODUCTION

Urbanisation is one of the biggest threats to biodiversity and native species causing both habitat destruction and fragmentation (Encarnação & Becker, 2015; Klimant et al., 2015). Increasing populations means towns and cities are expanding to meet growing demand; consequently changing habitats and creating barriers to animal movements (Klimant et al., 2015). This is contributing to the continuing decrease of biodiversity across the world (MacGregor-Fors et al., 2016). A reduction in biodiversity could have many detrimental impacts on ecosystems. Predator–prey relationships could be disrupted leading to a potential reduction in food sources and more intense competition for resources both within and between species (MacGregor-Fors et al., 2016). Plant communities are at threat of becoming homogenised with more adaptable species dominating, again leading to a reduction in food sources and increased competition for other species (Ecke et al., 2017). In addition, barriers to movement and fragmented habitat can reduce gene flow between populations leading to a reduction in genetic diversity and even isolation of populations (Wilson et al., 2016).

To address the threat of urbanisation, it is essential that species conservation be integrated into urban areas and future developments (Villaseñor et al., 2016). Over recent years, there has been an increased emphasis placed on the value of urban green spaces as a tool for conservation (Łopucki et al., 2013; Young & Jarvis, 2001). Green spaces can provide diverse and suitable habitats as well as complex vegetation types, which a number of species may be able to exploit (Łopucki et al., 2013; Young & Jarvis, 2001). Urban green spaces can include public parks, residential gardens, arboretums, golf courses, cemeteries and zoos (Baker et al., 2003; MacGregor-Fors et al., 2016).

The majority of the zoos across the United Kingdom and the world are located near urban areas and contain native and free-living species, but there are very few studies that have looked into free-ranging species in zoos and little publicity about the zoo being a habitat for native species in itself (Harmon et al., 2005). Free-living species are defined as those that are found at the zoo but not actively kept in the zoo collection (Harmon et al., 2005). Many zoos in the United Kingdom are located in a variety of ecosystems that hold at-risk native UK species. Zoos may also breed native species for eventual release back into the wild. They play active roles in the conservation of species in local nature reserves and green spaces. Many zoos themselves are well-managed green spaces, and urban zoos in particular can provide a sanctuary for native wildlife in residential and industrial areas.

Furthermore, zoos play an important role in research, conservation and education, and studies on native wildlife within zoos offer new opportunities (Hambly & Marshall, 2014). One of their main aims is to educate the public about the natural world, both globally and locally, providing visitors with achievable goals to help preserve native species. Furthermore, zoos provide suitable habitats, vegetation, food sources and shelter that free-living animals are able to exploit (Baur, 2011; Harmon et al., 2005). Zoos, therefore, have a huge potential for native species conservation in urban areas.

Zoo grounds host many groups of free-living animal species, such as small mammals, mesomammals, birds and invertebrates (Baur, 2011; Harmon et al., 2005). Small mammals are very good study species because they are ubiquitous and play vital roles in many ecosystems with functions in seed dispersal, tree regeneration and vegetation composition (Ecke et al., 2017; McCleery et al., 2014; Stephans & Anderson, 2014). In the United Kingdom, small mammals are also important food sources for species such as the red fox (*Vulpes vulpes*), the common kestrel (*Falco tinnunculus*) and the barn owl (*Tyto alba*), again highlighting the importance of small mammals for the conservation and monitoring of ecosystems (Bond et al., 2004; Casula et al., 2017; Ecke et al., 2017).

Small mammals are typically either nocturnal or crepuscular and live trapping is the most widely used method to assess their diversity and population dynamics (Encarnação & Becker, 2015; Sakamoto et al., 2014). Small mammal species tend to have short life spans and their populations undergo rapid fluctuations in just short periods of time (van Benthem et al., 2017; Santoro et al., 2016; Sunyer et al., 2016). Small mammals are often able to adapt to a number of different habitat types, including urban areas (Wilson et al., 2016). However, some species, such as wood mice (*Apodemus sylvaticus*), are better able to adapt to human disturbances and so one species may typically dominate urban areas (Baker & Harris, 2007; Łopucki et al., 2013).

There are a number of factors that can affect the composition of small mammal populations in urban locations, such as habitat suitability, connectivity and predation (Dambros et al., 2015; Klimant et al., 2017). The risk of predation has also shown to be greater in urban areas due to the presence of mesocarnivore species that live in close proximity with humans, including higher densities of domestic cats (*Felis catus*) (Klimant et al., 2017; Roemer et al., 2009). Small mammals, thus, require certain habitat features to provide shelter from predators including shrubs, debris and holes to help increase their chances of survival (Dracup et al., 2015). In addition to this, a number of studies have looked at the effects of weather conditions on small mammal populations, but this is still unclear as results are often conflicting (e.g., Dambros et al., 2015; Vieira et al.,2014).

The overarching aim of this study was to complete a survey of free-ranging small mammal and mammalian mesocarnivore species found at Dudley Zoological Gardens (hereafter referred to as Dudley Zoo). In particular, we defined small mammals as rodents (Rodentia) and shrews (Eulipotyphla) weighing <40 g (Michel et al., 2007) and mesocarnivores as medium-sized mammals weighing <15 kg (Roemer et al., 2009). We specifically aimed to evaluate zoo factors that may affect small mammals including enclosure proximity, habitat type, associations with captive species and presence of free-ranging mesocarnivores. We predict that the abundance of small mammals will be greater further away from enclosure perimeters. This is because human disturbance has been shown to have a negative relationship with diversity and abundance of species and there is likely to be less disturbance further away from enclosures from both keepers and captive animals (Gryz et al., 2017). Our second prediction was that diversity and abundance will be greater in areas of woodland habitat. Studies have shown that diversity and abundance of small mammals increases in complex habitats with greater vegetation diversity (e.g., Gryz et al., 2017; Lagesse & Thondhlana, 2016; Nielsen et al., 2013). Our final prediction was that there will be a smaller abundance of small mammals near to enclosures housing predatory species and in areas with a larger presence of mesocarnvores. Predatory species tend to have a negative impact on the presence and number of small mammal species present in an area (Baker et al., 2003; Klimant et al., 2015).

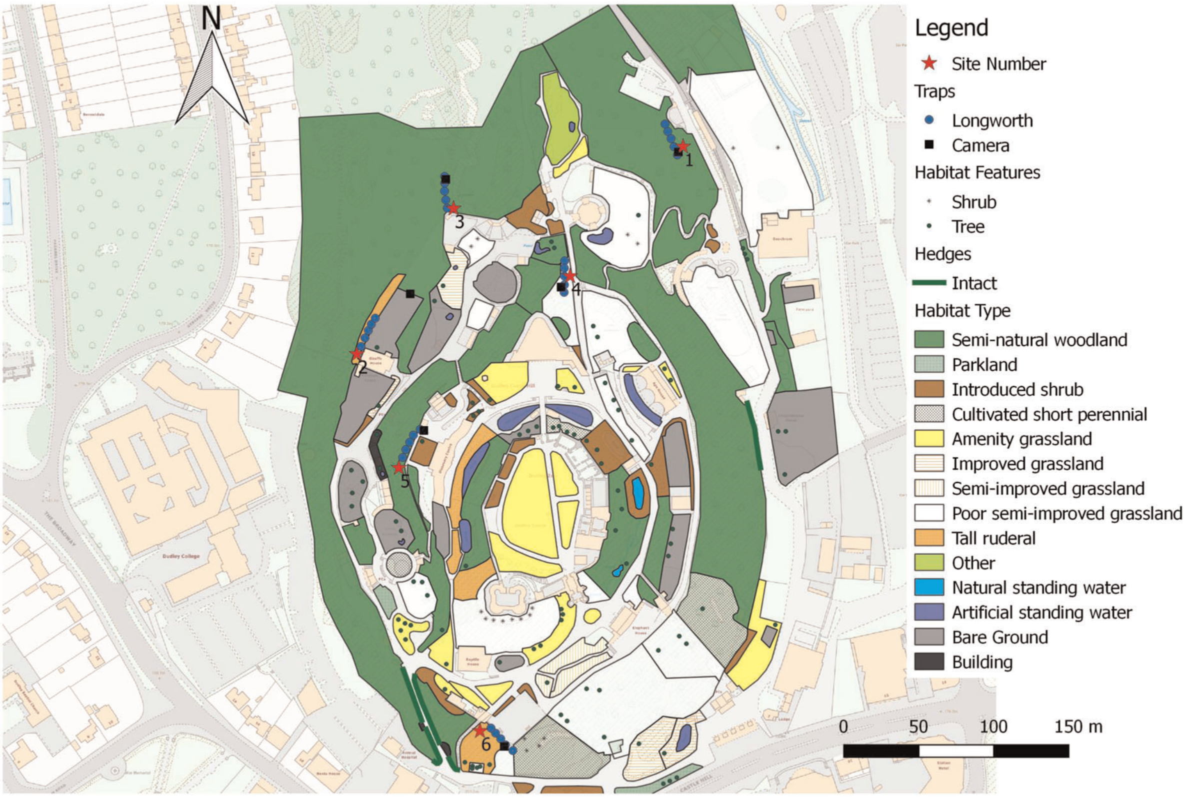

FIGURE 1 GIS map of Dudley Zoological Gardens showing habitat types and features, live trapping sites and transects across the zoo. Map created in QGIS (QGIS Development Team, 2017). Base map taken from Digimap (2017). GIS, Geographic Information System [Color figure can be viewed at wileyonlinelibrary.com]

2 | MATERIALS AND METHODS

2.1 | Site

This study was carried out at Dudley Zoo (52.5132°N, 2.0777°W), which is located in the urban town of Dudley in the West Midlands, United Kingdom. The zoo covers approximately 40 acres and contains a variety of habitat types such as unmanaged woodland, grassland and caverns. There is evidence for ancient woodland on the site, which is of particular interest. The site contains a number of different plant species including sycamore (*Acer pseudoplantanus*), ash (*Fraxinus* spp.), oak (*Quercus robur*), willow (*Salix* spp.) and dog's mercury (*Mercurialis perennis*).

A total of six enclosures were selected across the zoo as starting points for live trapping transects outside of the enclosures (Figure 1). These were selected to achieve as even a spread as possible across the zoo and included different habitat types and were all given a site number. The enclosures chosen were red squirrel (*Sciurus vulgaris*; Site 1), Rothschild giraffe (*Giraffa camelopardalis rothschildi*; Site 2), western grey kangaroo (*Macropus fuliginosus*; Site 3), Asiatic short-clawed otter (*Amblonyx cinereus*; Site 4), black-and-white-ruffed lemur (*Varecia variegate*; Site 5) and gelada baboon (*Theropithecus gelada*; Site 6). Sites 1, 2, 3 and 5 were located in semi-natural woodland, while Sites 4 and 6 were grassland.

2.2 | Ethics statement

This study followed the guidelines and standard procedures for live trapping of small mammals in the United Kingdom. This study was approved by the Life Science Ethics committee at the University of Wolverhampton (UK) and the Ethics committee at Dudley Zoological Gardens (UK).

2.3 | Trapping sessions

A total of 30 Longworth traps were used in the study; five for each of the trapping areas with 16 traps containing shrew holes and 14 without. These were distributed so that each trapping location contained traps both with and without shrew holes. The first trap for each location was placed as close to the perimeter of the enclosure as possible (defined as either the outside enclosure fence or indoor enclosure building) in suitable vegetation (designated as position 0 m). Traps were then placed every 5 m after for a total of 20 m outside of the enclosure moving away from the perimeter. The direction of the transects was chosen to avoid other enclosures and exposed areas with no vegetation. All traps were placed away from public areas and live trapping took place outside of public hours to omit visitor disturbance.

The traps were left open for an initial habituation period of 12 days before trapping sessions began. Hay and wood chippings were provided as a nest substrate and traps were covered with vegetation to keep them at a suitable temperature.

There were a total of 16 trapping sessions carried out over two trapping periods. The first period took place from May 29, 2017 to July 4, 2017, with the second period taking place from July 20, 2017 to August 11, 2017. Two trapping sessions were carried out per week.

Traps were set up in the evening at 20:00 h and baited with seed, castors, apple and carrot. The bedding was replaced where necessary. Traps were checked exactly 12 h later in the morning at 08:00 h and in the same order as they were set out to avoid any prolonged stress to individuals.

Individuals were sexed and their species recorded. Both tail length and body length were measured in centimeters, recorded to the nearest 1 mm. Individuals were weighed using a spring-loaded scale and weights were recorded to the nearest 1 g. Individuals were weighed inside a bag and the difference of the bag was taken away from this to provide the weight of each individual. Individuals were further classified as adults or juveniles based on weight, being classified as a juvenile if their weight was <16 g (Bellamy et al., 2000).

After successful capture, individuals were marked by taking a small hair clipping from their lower back to reveal the underfur (Barnett & Dutton, 1992). A second clipping was taken if an animal was recaptured to ensure marks lasted for the study period. A total of 56 individuals were marked during the study period. If an individual was caught with a clipping taken, it was recorded as a recapture.

Camera traps (Brand Crenova; model RD1000) were set along each transect to provide an overview of the diversity of larger species, such as mesocarnivores, present at the site. We also used camera trap data to assess the potential effects that other species, such as predators, may have on the populations of small mammals. Camera traps were set up at either the start (0 m) or end (20 m) of the transect. This was determined by whichever point gave the clearest overall view of the whole transect with the least obstructions and encompassed natural mammal runs. Camera traps were not available to be placed until June 26, 2017 for the remainder of the study.

The number of positive triggers ("hits") was recorded for foxes, domestic cats and badgers (*Meles meles*) and the hit rate at each location calculated. We applied a 15-min hit window (modified from Villette et al., 2016). Hits obtained within 15 min of each other which included the same species and number of individuals was recorded as a single hit. There was only one positive hit at Site 4 and no positive hits were recorded at Site 2, so these were omitted for subsequent analysis.

A habitat survey of the entire Dudley Zoo site was completed using Phase 1 Habitat Survey classifications (Joint Nature Conservation Committee (JNCC), 2010). The boundaries of each habitat were drawn and classified. Dominant and important plant species were recorded. The survey was carried out within the boundary of the zoo grounds, which are bordered by a town and woodland.

The maximum and minimum temperatures and total precipitation were obtained for trapping sessions from May 28, 2017 to August 4, 2017 from the Weather Underground (2017). Data were unavailable for the last two trapping sessions. Data were used from the nearest observation station from Dudley Zoo, which was located in Rowley Regis.

2.4 | Statistical analysis

The trapping effort of the study was calculated by multiplying the number of traps used by the total number of trapping sessions (Vieira et al., 2014). This was used to calculate the trapping success of the study period (the total number of animals caught divided by the trapping effort) as per previous studies (Lagesse & Thondhlana, 2016; Vieira et al., 2014).

The percentage of each species caught was calculated across the whole site and in each trapping location. Species richness, Shannon–Wiener Diversity Index, Simpson's Index of Diversity and species evenness were calculated for each location. Species richness was defined as the total number of species caught in each location (Lagesse & Thondhlana, 2016).

χ^2 analyses were used to compare the number of animals caught at each position in the transect at each individual trapping site. χ^2 analysis was also used to compare the total number of captures over the whole study period between all the sites.

Only data collected for wood mice were of sufficient sample size, with other species having less than 10 captures each, thus, only data on wood mice were used for further analysis. Population numbers were estimated for each trapping area using the Schnabel–Peterson method. Proportions of newly marked and recaptured individuals were calculated for each trapping session. χ^2 analysis was used to compare the ratio of males to females at each site. The mean weights of adult wood mice in each location were calculated and an ANOVA (analysis of variance) test was used to identify any differences.

A generalized linear mixed model (GLMM) was produced in SPSS (version 24) to examine the relationships between total animals caught, trap distance, habitat types, species in enclosure ("host species") and positive camera trap hits. Host species were classified according to their relationship to small mammals (i.e., predator or not). Twenty-nine trapping points were used for analysis. A Poisson distribution was used and the corrected Akaike information criterion (AIC_c) was used to determine the best models. The lowest AIC_c value was considered as the best model and differences between this and other models were calculated (ΔAIC).

The mean number of camera trap hits for each species was calculated for each trapping site. The relationship between mean hits and mean captures was tested using a non-parametric Spearman's rank correlation.

We analysed camera trap data using the software PRESENCE (V.13.6; Hines, 2006) by running simple single-season occupancy models (MacKenzie et al., 2002). We used habitat type, distance from human-used areas and precipitation as detection covariates. The models with the lowest AIC were selected as the best fit.

The relationships between temperature and precipitation and the percentage trapping success of each session were examined.

TABLE 1 Comparison of total captures (N), species richness (SR) and diversity between each trapping location

Trapping area	*N*	SR	*H′*	*E*	1−*D*
1	49	2	0.23	0.33	0.11
2	45	2	0.13	0.19	0.04
3	34	3	0.82	0.75	0.37
4	26	2	0.19	0.28	0.07
5	18	2	0.48	0.70	0.37
6	27	3	0.41	0.37	0.20

Note: Diversity comparisons included Shannon–Weiner Index (*H′*), species evenness (*E*) and Simpson's Index of Diversity (1−*D*).

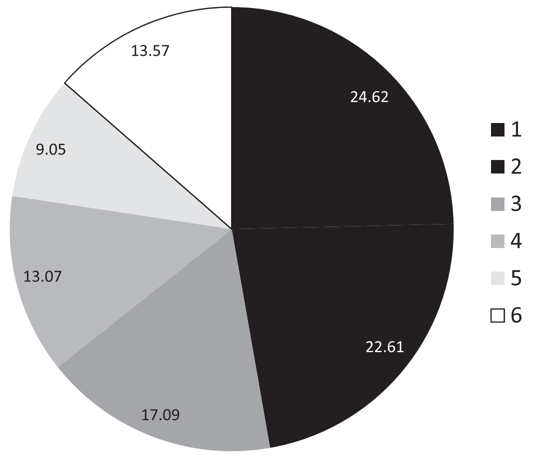

FIGURE 2 Percentage of total captures throughout the project period ($n = 198$) caught at each trapping site

The maximum and minimum temperature was defined as the mean temperatures of the day the traps were set and the day they were checked. This was also the case for total precipitation. The relationships were examined using non-parametric Spearman's rank correlations. All statistical tests were carried out in Excel and SPSS v24 and a significance level of $p < .05$ was applied.

3 | RESULTS

The trapping success over the project period was calculated to be 41.5%. Overall, there were a total of 198 captures, with 56 different individuals marked and 135 recaptures. There were five different species caught during the trapping sessions: wood mouse, house mouse (*Mus musculus*), field vole (*Microtus agrestis*), common shrew (*Sorex araneus*) and pygmy shrew (*Sorex minutus*). The majority of the total captures were of wood mice (177 captures; 89.4%) and this species was caught across all sites, while shrews accounted for only 4% of all captures. The greatest species richness was found at both Site 3 and Site 6 (SR = 3), while the greatest diversity of animals was caught at Site 3 and the lowest diversity was found at Site 2 (Table 1).

The majority of captures were recorded at Site 1 (24.6%) with the least number of captures occurring at Site 5 (9%) (Figure 2). Differences between the number of animals caught across trapping locations were significant ($\chi^2 = 21.4$; $p = .0007$). However, there were no significant differences found between proximity to the enclosure (transect position) and the number of animals caught at any of the individual sites ($p > .05$ for all sites).

The population of wood mice at each trapping location was estimated using the Schnabel method. The highest population estimate was found at Site 1 (10) with the lowest at both Site 3 and Site 4 (6). The proportion of newly marked individuals decreased during the first trapping period and there were three trapping sessions where only recaptured animals were caught (Figure 3). The proportion of newly marked animals began to increase again during the second trapping period. There were no significant differences found between the proportions of male and female wood mice found across all trapping locations ($p > .05$ for all sites).

The largest mean weight for adult wood mice was observed at Site 5 (26.8 g), while the lowest was found at Site 4 (21.7 g). There was variation across all sites and this was found to be significant ($p < .0001$).

3.1 | GLMMs

Based on the AIC_c the best fitting model for all examined relationships was the HS + PH model ($AIC_c = 140.49$) (Table 2). This was followed by the HS model ($AIC_c = 142.68$) and then both the HT and the HT + HS models ($AIC_c = 142.95$). Mean captures were estimated for the host species, habitat type and positive hit rate using their respective models. For the HS model, species classified as predators showed the lowest estimate for captures, while based on the HT model, semi-natural woodland habitat showed the greatest mean (9 captures). The PH model predicted that the mean number of small mammal captures will be higher where the rate of positive camera trap hits is lower.

3.2 | Free-ranging mesocarnivores

There were a total of 92 camera trap hits from foxes, 149 hits from badgers and 28 hits of cats recorded across the four camera trap locations. The greatest number of both badger and fox hits were recorded at Site 3 ($n = 88$ and $n = 55$, respectively), while the most hits for cats occurred at Site 5 ($n = 14$). Hits from all three species were recorded on camera at all sites. There was a negative correlation between the mean number of badger and fox hits and mean captures, but this was not significant ($r = −0.4$, $p = .75$). There was a strong negative correlation between mean cat hits and captures ($r = −0.8$, $p = .33$), but a linear regression fitted to the relationship showed no significance ($p = .19$).

The best model for detection probabilities for both foxes and cats was the null model (Table 3). In comparison, the best model for the detection probabilities of badgers was the distance to

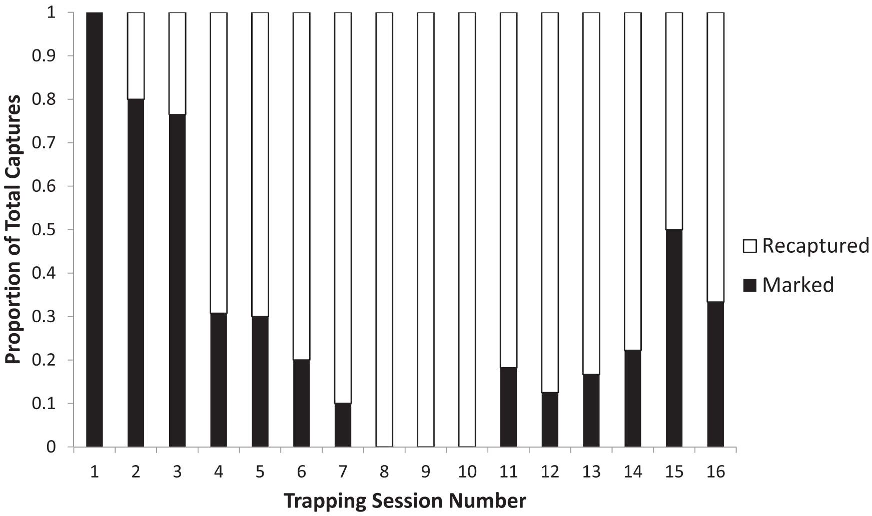

FIGURE 3 The proportion of newly marked and recaptured wood mice out of the total number of wood mice caught across 16 live trapping sessions

human-used areas. The detection probabilities for both foxes and badgers using the null models was 0.41 (±0.04*SE*), while the detection probability for cats was lower at 0.13 (±0.03*SE*).

3.3 | Effects of climate

There was a large variation of temperatures recorded during the study ranging from 8.6°C to 30.1°C, while daily precipitation ranged from 0 to 10.2 mm. Trapping success was negatively correlated with both maximum and minimum temperature ($r = -.23$ and $-.46$, respectively). There was no correlation found between the amount of precipitation and capture success ($r = .06$).

TABLE 2 GLMMs produced to examine the relationships between total animals caught with different fixed effects

Model name	AIC_c	ΔAIC
HS + PH	140.49	0.00
HS	142.68	2.19
HT	142.95	2.46
HT + HS	142.95	2.46
TD + HS	143.50	3.01
TD + HS + PH	143.64	3.15
TD + HT	145.44	4.95
TD + HT + HS	145.44	4.95
PH	145.47	4.98
TD	146.69	6.20
HT + PH	146.93	6.44
HT + HS + PH	146.93	6.44
TD + PH	148.04	7.55
TD + HT + PH	151.53	11.04
TD + HT + HS + PH	151.53	11.04

Note: The AIC_c value was used to determine the best models and ΔAIC was calculated to show the differences between the best model and other models. Acronyms used are as follows: TD (Trap distance), HT (Habitat type), HS (Host species) and PH (positive hit rate of camera trap). Data were used from 29 individual trapping points.

4 | DISCUSSION

Assessing the native biodiversity within a zoo's ground is important for several reasons. Firstly, it helps to focus educational material and public engagement on native species found within the zoo and their conservation. It is likely that many visitors will find the same species in their gardens and local parks, so by providing awareness, visitors

TABLE 3 Occupancy framework models for each mesocarnivore species from camera trap data at four sites across Dudley Zoo

Species name	Model name	AIC	ΔAIC	wi
Badger (*Meles meles*)	psi(.),p(distance)	166.94	0.00	0.59
	psi(.),p(habitat)	169.65	2.71	0.15
	psi(.),p(precipitation)	169.90	2.96	0.14
	psi(.),p(.)	170.19	3.25	0.12
Cat (*Felis catus*)	psi(.),p(.)	99.09	0.00	0.98
	psi(.),p(habitat)	107.22	8.13	0.02
	psi(.),p(precipitation)	121.22	21.94	0.00
	psi(.),p(distance)	144.51	45.42	0.00
Fox (*Vulpes vulpes*)	psi(.),p(.)	154.44	0.00	0.94
	psi(.),p(habitat)	160.51	6.07	0.05
	psi(.),p(precipitation)	163.62	9.18	0.01
	psi(.),p(distance)	173.29	18.85	0.00

Note: The AIC value was used to determine the best models and ΔAIC was calculated to show the differences between the best model and other models. wi is the AIC model weight. psi(.),p(.) is the null model. Other models include habitat type, distance to human-used areas and precipitation as detection covariates.

may be more likely to take actions to help preserve them. In addition to this, it is important for helping to inform management decisions. This could involve the establishment of best practice guidelines for the creation of new zoo exhibits. It could also help to inform management of areas on-site to establish new habitats and provide suitable features based on the needs of native species found within zoo grounds. Finally, it is important to understand what species are on-site to prevent the spread of any diseases between native and exotic species.

Overall, the trapping success of the project was high, over the 10% level at which Lagesse and Thondhlana (2016) consider trapping to be highly successful. The trapping success of this project thus illustrates the potential of zoos as a more controlled and important location to carry out studies of small mammal populations (e.g., population demographics and population fluctuations).

Wood mice made up the majority of successful captures which has been found in a number of small mammal trapping studies completed in urban environments (e.g., Casula et al., 2017; Klimant et al., 2015; Michel et al., 2007). There were only a total of three vole captures during this study, being found in two different locations. Voles prefer open, grassy habitats and the locations where they were trapped were associated with grassland (Ecke et al., 2017). One of the individuals caught was identified as an infant suggesting the presence of a breeding population (Bellamy et al., 2000).

Shrews were least commonly caught, which was also found by another study researching the diversity of small mammals in an urban location (Klimant et al., 2017). However, it is possible that the number of shrews caught in this study was underrepresented due to equipment limitations. Some of the Longworth traps used contained shrew holes and there were a number of anecdotal incidences to suggest that there were more shrew trappings. For example, scat was found inside the traps and the majority of food (in particular castors) had been chewed or eaten. This suggests shrews may have been located in more of the trapping areas and could be investigated further.

Site 3 had the highest diversity of species (three species) and was classified as semi-natural woodland. This was expected as a number of studies have shown a relationship between species diversity and habitat complexity (Gibson et al., 2004; Gryz et al., 2017; Nielsen et al., 2013). The areas of the zoo that contained semi-natural woodland had the greatest number of plant species within them, indicating increased complexity. In comparison, species diversity was lower at Site 1 despite being in a very similar habitat. Traps located in this area contained shrew holes, but evidence of shrews was present, which may account for the difference in species diversity. Furthermore, Site 2 showed the least diversity despite being located on the edge of a woodland habitat and representing a large proportion of total captures. The location was near a large area of bare ground with no vegetation cover, which could deter the movements of small mammals.

Live trapping may not necessarily provide the best overview of species composition for several reasons. Odours from animals using the traps, species/individual-specific behaviours (Flowerdew et al., 2004; Hammond & Anthony, 2006; McCleery et al., 2014) and learned behaviours (Graipel et al., 2014) may affect which individuals use the traps. In addition to this, only one animal may be caught in a trap and animals that use traps before setting may not be caught (McCleery et al., 2014). Alternative methods, such as camera-trapping and owl pellet analysis have been suggested and used in other studies (Heisler et al., 2015; McCleery et al., 2014). Passive techniques such as these may provide larger data sets across larger areas (Heisler et al., 2015). Camera trapping would allow for useful estimates of species occupancies across a site while accounting for imperfect detection (Burton et al., 2015). However, passive methods cannot provide valuable data that can be gained from live trappings, such as sex and weight, and some may not be possible in all locations (e.g., owl pellet collection). It may be important to consider using both live trapping and passive methods to complement each other to get a more accurate overview of small mammal populations.

Overall, the species composition present at Dudley Zoo seems to be typical of that of an urban area with a single species dominating (Dambros et al., 2015; Hlôška et al., 2016; Łopucki et al., 2013). Wood mice were the most common species present and are highly adaptable and often exploit human-dominated landscapes (Wilson et al., 2016).

The proximity to enclosures had no significant effects on the number of animals caught. Instead habitat types and enclosure species were shown to be more important to small mammal populations. There may be features present in enclosures, such as plant types and food availability which may also be important for small mammal species (Baker & Harris, 2007; Casula et al., 2017). Food availability was not tested during this study, however, this could impact on small mammal populations and zoos, in particular, may provide an abundance of suitable food sources (Harmon et al., 2005).

At the end of the data collection period, the proportion of newly caught individuals began to increase again. This is similar to patterns of small mammal population fluctuations found in other studies (e.g., Stephens & Anderson, 2014; Sunyer et al., 2016: Unnsteindottir et al., 2014). Breeding of small mammals typically begins in May, with the greatest increases in population numbers occurring in late summer to early autumn (Unnsteinsdottir et al., 2014). The mark and recapture data appears to follow this pattern, however, as the data collection ended before early autumn the population numbers at the zoo are likely to be higher than was estimated. It is important for studies to be carried out over a longer period of time to provide a more accurate representation of populations.

There was no significant bias to the sex of the animals caught in the traps, which indicates that there are breeding populations. This is in contrast to claims that traps provide a bias related to certain factors, including the sex of the animal (Torre et al., 2016). Instead sex ratios found in this study were similar to that of other small mammal population studies (Klimant et al., 2015, 2017; Łopucki & Mróz, 2016). A balanced proportion of sexes likely indicate that Dudley Zoo contains viable and established populations of small mammals (Klimant et al., 2015).

There was a significant difference between the mean weights of wood mice across the zoo. Weights of small mammal species can be used to infer age, with animals weighing less tending to be younger (Barros et al., 2015; Bellamy et al., 2000; Flowerdew et al., 2017). The lowest mean weight was recorded at Site 4 and the next lowest at Site 6. This suggests that the populations of animals may be younger in these areas. These trapping areas were the only locations in close proximity to predator species. This could indicate that there is a lower probability that animals will survive into older ages in these locations. Differences between average mass in populations are dependent upon the births and deaths within the population (van Benthem et al., 2017). Furthermore, older and more dominant individuals most likely have secured the most optimal territories away from predators, leaving these for younger or less dominant individuals.

There is a clear relationship between habitat types on small mammal abundance. The semi-natural woodland at Dudley Zoo had the highest abundance of small mammals and the majority was contiguous with few barriers to movement. These habitats also showed the greatest diversity of plant species. Other studies also found that habitat complexity is linked to abundance, richness and diversity of small mammals (e.g., Gibson et al., 2004; Gryz et al., 2017; Lagesse & Thondhlana, 2016). Increased vegetation cover was also found to increase abundance (Beckline & Yujun, 2014; Dracup et al., 2015; Stephens & Anderson, 2014). The semi-natural woodland at Dudley Zoo has a very dense understory dominated with dog's mercury providing good cover.

Host species was a very good predictor of the number of animal captures and the model predicted fewer animals would be caught near to enclosures of predatory species. The two best-fitting models both included host species as a fixed effect. Thus our findings support the final prediction that abundance is smaller near to predatory species. This is an interesting finding as this situation is unique to that of zoological collections and there are currently no studies concerning the effects of exotic and captive predators on native species. However, some studies have shown a negative relationship between the abundance of small mammals and native predator species (e.g., Baker et al., 2003; Baker & Harris, 2007; Klimant et al., 2017). However, it is important to consider that the habitat type by predatory species were grassland areas and were also more isolated, which could have contributed to the lower population numbers (Dambros et al., 2015; Gryz et al., 2017).

There were no significant relationships found between large mammal species and the mean number of captures despite all showing a negative correlation. Other studies have found significant effects on small mammals from cats in residential areas (Baker et al., 2003; Klimant et al., 2015). The presence of domestic cats is likely to be lower in zoos compared to other urban areas due to accessibility or distance from houses. This could suggest zoos provide areas of protection from high densities of cats in urban areas. However, the PH model predicted that mean captures would be lower at locations where hits from mesomammals are higher. Anecdotally, some of the traps were found to have been moved, broken and knocked over by larger animals, particularly near to the primate house, which could have affected the success of trapping in these areas.

Across the sites badgers were recorded most frequently on camera traps, followed by foxes and then cats. Detection rates for badgers increased with increasing distance from human used areas such as pathways. Site 3 was the furthest distance from human-used areas at the zoo and this also corresponded with the greatest camera trap hit rate. For both fox and cats the null models for detection were the best fitting which suggests the chosen covariates had very little effect on detection suggesting other factors were more important, such as behaviour. Although there were no hits at Site 4 and only one hit at Site 2, this does not necessarily mean that these species did not occupy these areas but were likely not detected during the study period (Burton et al., 2015). In addition to this, camera traps also provided a preliminary glimpse into other native and free-living species present at the zoo, such as, hedgehogs (*Erinaceus europaeus*), grey squirrels (*Sciurus carolinensis*) and several bird and bat species. This highlights that a plethora of biodiversity is found on zoo sites, which is important for both conservation and research.

This study has helped to show the potential of zoos for native species research and conservation. This study was only done in one zoo during one season, so it would be important to do this at other zoos over different seasons to compare results. As zoos present novel opportunities and challenges, these should also be considered for future studies. For example, the effects of supplementary feeding and visitors. This would provide more information into how the zoo environment may affect native small mammals.

5 | CONCLUSION

There was a variety of small mammal species present at Dudley Zoo and capture success was high, showing the value of zoos for small mammal studies. Proximity to animal enclosures was not a significant factor on its own with regard to number of captures. There were significantly more captures in woodland habitats, but species richness was similar across all habitats. There were fewer captures near enclosures containing predatory species.

ACKNOWLEDGEMENTS

We are grateful for the help, support and advice during the completion of the study from Dr. Christopher Young. We would like to thank the team at Dudley Zoo for their support and assistance with the project (especially David Beeston and Adam Wrench). We are also grateful for Richard Pearce, who provided support with equipment and invaluable advice for habitat surveys and GIS programs. We would also like to thank other colleagues from the Department of Animal Behaviour and Conservation at the University of Wolverhampton who provided constructive feedback. This study was supported by the Faculty of Science and Engineering, University of Wolverhampton.

CONFLICT OF INTERESTS

The author declare that there are no conflict of interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Stefano Vaglio http://orcid.org/0000-0003-0885-8573

REFERENCES

Baker, P. J., Ansell, R. J., Dodds, P. A. A., Webber, C. E., & Harris, S. (2003). Factors affecting the distribution of small mammals in an urban area. *Mammal Review*, *33*, 95–100.

Baker, P. J., & Harris, S. (2007). Urban mammals: What does the future hold? An analysis of the factors affecting patterns of use of residential gardens in Great Britain. *Mammal Review*, *37*, 297–15.

Barnett, A., & Dutton, J. (1992). *Expedition field techniques: Small mammals*. Expedition Advisory Centre.

Barros, C. S., Püttker, T., Pinotti, B. T., & Pardini, R. (2015). Determinants of capture–recapture success: An evaluation of trapping methods to estimate population and community parameters for Atlantic forest small mammals. *Zoologia*, *32*, 334–344.

Baur, B. (2011). Basel Zoo and its native biodiversity between the enclosures: A new strategy of cooperation with academic institutions. *International Zoo Yearbook*, *45*, 48–54.

Beckline, M., & Yujun, S. (2014). Assessing the effectiveness of urban nature reserves on biodivsersity conservation. *Applied Ecology and Environmental Sciences*, *2*, 130–134.

Bellamy, P. E., Shore, R. F., Ardeshir, D., Treweek, J. R., & Sparks, T. H. (2000). Road verges as habitat for small mammals in Britain. *Mammal Review*, *30*, 131–139.

Bond, G., Burnside, N. G., Metcalfe, D. J., Scott, D. M., & Blamire, J. (2004). The effects of land-use and landscape structure on barn owl (*Tyto alba*) breeding success in southern England, U.K. *Landscape Ecology*, *20*, 555–566.

Burton, A. C., Neilson, E., Moreira, D., Ladle, A., Steenweg, R., Fisher, J. T., Bayne, E., & Boutin, S. (2015). Wildlife camera trapping: A review and recommendations for linking surveys to ecological processes. *Journal of Applied Ecology*, *52*, 675–685.

Casula, P., Luiselli, L., Milana, G., & Amori, G. (2017). Habitat structure and disturbance affect small mammal populations in Mediterranean forests. *Basic and Applied Ecology*, *19*, 76–83.

Dambros, C. S., Cáceres, N. C., Magnus, L., & Gotelli, N. J. (2015). Effects of neutrality, geometric constraints, climate, and habitat quality on species richness and composition of Atlantic Forest small-mammals. *Global Ecology and Biogeography*, *24*, 1084–1093.

Digimap. (2017). *Ordnance Survey* [online]. https://digimap.edina.ac.uk/os/

Dracup, E. C., Keppie, D. M., & Forbes, G. J. (2015). Woodland mouse and vole response to increased structural diversity following midrotation commercial thinning in spruce plantations. *Canadian Journal of Forest Research*, *45*, 1121–1131.

Ecke, F., Angeler, D. G., Magnusson, M., Khalil, H., & Hörnfeldt, B. (2017). Dampening of population cycles in voles affects small mammal community structure, decreases diversity, and increases prevalence of zoonotic diseases. *Ecology and Evolution*, *7*, 5331–5342.

Encarnação, J. A., & Becker, N. I. (2015). Stealthy at the roadside: Connecting role of roadside hedges and copse for silvicolous, small mammal populations. *Journal for Nature Conservation*, *27*, 37–43.

Flowerdew, J. R., Amano, T., & Sutherland, W. J. (2017). Strong "bottom-up" influences on small mammal populations: State-space model analyses from long-term studies. *Ecology and Evolution*, *7*, 1699–1711.

Flowerdew, J. R., Shore, R. F., Poulton, S. M. C., & Sparks, T. H. (2004). Live trapping to monitor small mammals in Britain. *Mammal Review*, *34*, 31–50.

Gibson, L. A., Wilson, B. A., & Aberton, J. G. (2004). Landscape characteristics associated with species richness and occurrence of small native mammals inhabiting a coastal heathland: A spatial modelling approach. *Biological Conservation*, *120*, 75–89.

Graipel, M. E., Hernández, M. I. M., & Salvador, C. (2014). Evaluation of abundance indexes in open population studies: A comparison in populations of small mammals in southern Brazil. *Brazilian Journal of Biology*, *74*, 553–559.

Gryz, J., Lesiński, G., Krauze-Gryz, D., & Stolarz, P. (2017). Woodland reserves within an urban agglomeration as important refuges for small mammals. *Folia Forestalia Polonica*, *59*, 3–13.

Hambly, N., & Marshall, A. R. (2014). Zoo BAPs: Biodiversity action plans for conserving native wildlife in and around zoological gardens. *Journal of Zoo and Aquarium Research*, *2*, 18–21.

Hammond, E. L., & Anthony, R. G. (2006). Mark-recapture estimates of population parameters for selected species of small mammals. *Journal of Mammalogy*, *87*, 618–627.

Harmon, L. J., Baumon, K., McCloud, M., Parks, J., Howell, S., & Losos, J. B. (2005). What free-ranging animals do at the zoo: A study of the behaviour and habitat use of opossums (*Didelphis virginiana*) on the grounds of the St. Louis zoo. *Zoo Biology*, *24*, 197–213.

Heisler, L. M., Somers, C. M., & Poulin, R. G. (2015). Owl pellets: A more effective alternative to conventional trapping for broad-scale studies of small mammal communities. *Methods in Ecology and Evolution*, *7*, 96–103.

Hines, J. E. (2006). PRESENCE—Software to estimate patch occupancy and related parameters. *USGS-PWRC*. https://www.mbr-pwrc.usgs.gov/software/presence.html

Hlôška, L., Chovancová, B., Chovancová, G., & Fleischer, P. (2016). Influence of climatic factors on the population dynamics of small mammals (Rodentia, Soricomorpha) on the sites affected by windthrow in the High Tatra Mts. *Folia Oecologica*, *43*, 12–20.

Joint Nature Conservation Committee (JNCC). (2010). *Handbook for Phase 1 habitat survey—a technique for environmental audit*.

Klimant, P., Baláž, I., & Krumpálová, Z. (2015). Communities of small mammals (Soricomorpha, Rodentia) in urbanized environment. *Biologia*, *70*, 839–845.

Klimant, P., Klimantová, A., Baláž, I., Jakab, I., Tulis, F., Rybanský, L., Vadel, L., & Krumpálová, Z. (2017). Small mammals in an urban area: Habitat preferences and urban–rural gradient in Nitra city, Slovakia. *Polish Journal of Ecology*, *65*, 144–157.

Lagesse, J. V., & Thondhlana, G. (2016). The effect of land-use on small mammal diversity inside and outside the Great Fish River Nature Reserve, Eastern Cape, South Africa. *Journal of Arid Environments*, *130*, 76–83.

Łopucki, R., & Mróz, I. (2016). An assessment of non-volant terrestrial vertebrates response to wind farms—A study of small mammals. *Environmental Monitoring and Assessment*, *188*, 122.

Łopucki, R., Mróz, I., Berliński, L., & Burzych, M. (2013). Effects of urbanization on small-mammal communities and the population structure of synurbic species: An example of a medium-sized city. *Canadian Journal of Zoology*, *91*, 554–561.

MacGregor-Fors, I., Escobar, F., Rueda-Hernández, R., Avendaño-Reyes, S., Baena, M. L., Bandal, V. M., Chacón-Zapata, S., Guillén-Garcia, F., Lorea-Hernández, F., Montes de Oca, E., Montoya, L., Pineda, E., Ramírez-Restrepo, L., Rivera-García, E., & Utrera-Barrillas, E. (2016). City "Green" contributions: The roles of urban greenspaces as reservoirs for biodiversity. *Forests*, *7*, 146.

MacKenzie, D. I., Nichols, J. D., Lachman, G. N., Droege, G. B., Royle, J. A., & Langtimm, C. A. (2002). Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, *83*, 2248–2255.

McCleery, R. A., Zweig, C. L., Desa, M. A., Hunt, R., Kitchens, W. M., & Percival, H. F. (2014). A novel method for camera-trapping small mammals. *Wildlife Society Bulletin*, *38*(4), 887–891.

Michel, N., Burel, F., Legendre, P., & Butet, A. (2007). Role of habitat and landscape in structuring small mammal assemblages in hedgerow networks of contrasted farming landscapes in Brittany, France. *Landscape Ecology*, *22*, 1241–1253.

Nielsen, A. B., van den Bosch, M., Maruthaveeran, S., & van den Bosch, C. K. (2013). Species richness in urban parks and its drivers: A review of empirical evidence. *Urban Ecosystems*, *17*, 305–327.

QGIS Development Team. (2017). QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org

Roemer, G. W., Gompper, M. E., & Valkenburgh, B. V. (2009). The ecological role of the Mammalian Mesocarnivore. *BioScience*, *59*, 165–173.

Sakamoto, S. H., Suzuki, S. N., Koshimoto, C., Okubo, Y., Eto, T., & Suzuki, R. O. (2014). Trap distance affects the efficiency and robustness in monitoring the abundance and composition of forest-floor rodents. *Journal of Forest Research*, *20*, 151–159.

Santoro, S., Sanchez-Suarez, C., Rouco, C., Palomo, L. J., Fernández, M. C., Kufner, M. B., & Moreno, S. (2016). Long-term data from a small mammal community reveal loss of diversity and potential effects of local climate change. *Current Zoology*, *63*(5), 515–523.

Stephens, R. B., & Anderson, E. M. (2014). Habitat associations and assemblages of small mammals in natural plant communities of Wisconsin. *Journal of Mammalogy*, *95*, 404–420.

Sunyer, P., Muñoz, A., Mazerolle, M. J., Bonal, R., & Espelta, J. M. (2016). Wood mouse population dynamics: Interplay among seed abundance seasonality, shrub cover and wild boar interference. *Mammalian Biology*, *81*, 372–379.

Torre, I., Freixas, L., Arrizabalaga, A., & Díaz, M. (2016). The efficiency of two widely used commercial live-traps to develop monitoring protocols for small mammal biodiversity. *Ecological Indicators*, *66*, 481–487.

Unnsteinsdottir, E. R., Hersteinsson, P., Jonasson, J. P., & McAdam, B. J. (2014). Using Bayesian growth models to reconstruct small-mammal populations during low-trapping periods. *Journal of Zoology*, *292*, 206–211.

van Benthem, K. J., Froy, H., Coulson, T., Getz, L. L., Oli, M. K., & Ozgul, A. (2017). Trait-demography relationships underlying small mammal population fluctuations. *Journal of Animal Ecology*, *86*(2), 348–358. http://dx.doi.org/10.1111/1365-2656.12627

Vieira, A. L. M., Pires, A. S., Nunes-Freitas, A. F., Oliveira, N. M., Resende, A. S., & Campello, E. F. C. (2014). Efficiency of small mammal trapping in an Atlantic Forest fragmented landscape: the effects of trap type and position, seasonality and habitat. *Brazilian Journal of Biology*, *74*(3), 538–544. http://dx.doi.org/10.1590/bjb.2014.0075

Villaseñor, N. R., Tulloch, A. I. T., Driscoll, D. A., Gibbons, P., & Lindenmayer, D. B. (2016). Compact development minimizes the impacts of urban growth on native mammals. *Journal of Applied Ecology*, *53*, 794–804.

Villette, P., Krebs, C. J., Jung, T. S., & Boonstra, R. (2016). Can camera trapping provide accurate estimates of small mammal (*Myodes rutilus* and *Peromyscus maniculatus*) density in the boreal forest? *Journal of Mammology*, *97*, 32–40.

Weather Underground. (2017). Rowley Regis, United Kingdom [online]. https://www.wunderground.com/

Wilson, A., Fenton, B., Malloch, G., Boag, B., Hubbard, S., & Begg, G. (2016). Urbanisation versus agriculture: A comparison of local genetic diversity and gene flow between wood mouse *Apodemus sylvaticus* populations in human-modified landscapes. *Ecography*, *39*, 87–97.

Young, C. H., & Jarvis, P. J. (2001). Assessing the structural heterogeneity of urban areas: An example from the Black Country. *Urban Ecosystems*, *5*, 49–69.

How to cite this article: Elwell, E., Leeson, C., & Vaglio, S. (2021). The effects of a zoo environment on free-living, native small mammal species. *Zoo Biology*, 1–10. https://doi.org/10.1002/zoo.21603