Biodiversity in urban gardens: assessing the accuracy of citizen science data on garden hedgehogs

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Abstract

Urban gardens provide a rich habitat for species that are declining in rural areas. However, collecting data in gardens can be logistically-challenging, time-consuming and intrusive to residents. This study examines the potential of citizen scientists to record hedgehog sightings and collect habitat data within their own gardens using an online questionnaire. Focussing on a charismatic species meant that the number of responses was high (516 responses were obtained in 6 weeks, with a ~ 50:50% split between gardens with and without hedgehog sightings). While many factors commonly thought to influence hedgehog presence (e.g. compost heaps) were present in many hedgehog-frequented gardens, they were not discriminatory as they were also found in gardens where hedgehogs were not seen. Respondents were most likely to have seen hedgehogs in their garden if they had also seen hedgehogs elsewhere in their neighbourhood. However, primary fieldwork using hedgehog 'footprint tunnels' showed that hedgehogs were found to be just as prevalent in gardens in which hedgehogs had previously been reported as gardens where they had not been reported. Combining these results indicates that hedgehogs may be more common in urban and semi-urban gardens than previously believed, and that casual volunteer records of hedgehogs may be influenced more by the observer than by habitat preferences of the animal. When verified, volunteer records can provide useful information, but care is needed in interpreting these data.

Keywords

Hedgehog, Garden, Urban Biodiversity, Mammal, Citizen Science

Introduction

It is estimated that 87% of homes in the UK have access to a garden and that the total area covered by UK gardens is in excess of 400,000 ha (Davies et al., 2009). Gardens are thus an important resource for wildlife and are frequented by many taxa including birds, mammals, reptiles, amphibians and insects (e.g. Ryall and Hatherell 2003; Gaston et al. 2005; Davies et al. 2009). There is growing evidence that species that are suffering declines in the wider countryside can be found in significant numbers in gardens, for example, the common frog (*Rana temporaria*), the song thrush (*Turdus philomelos*) and the hedgehog (*Erinaceus europaeus*) (e.g. Gregory and Baillie 1998; Mason 2000; Gaston et al. 2005). Gardens may also act as wildlife corridors between larger areas (Ryall and Hatherell 2003) and, in this way, maybe important in a landscape context as well as in their own right.

A large network of gardens is difficult to survey: conducting professional fieldwork is generally not practical because of access restrictions (Toms and Newson 2006) and such an approach would likely be prohibitively expensive and time consuming. For this reason, volunteer surveys are being used increasingly to collect large amounts of biodiversity and habitat data over large spatial scales at a relatively low cost (e.g. Toms and Newson 2006; Baker and Harris 2007). Garden owners can be recruited to participate in simple surveys to collect data on the species that frequent their gardens, as well as the habitat features that their garden supports (e.g. Gaston et al. 2005; Newson et al. 2005; Toms and Newson 2006; Davies et al. 2009; Stafford et al. 2010). These large-scale "citizen science" surveys using data collected by members of the public can provide meaningful ecological data on distribution and species-habitat associations, and, if conducted on a regular basis, also allow species to be monitored over time (Silvertown 2009). Indeed, Cannon et al. (2005) used a citizen science survey run by the British Trust for Ornithology (BTO) to monitor trends in the use of gardens by birds and secured weekly bird records from 18,300 gardens over eight years.

Citizen science is a rapidly evolving field of research. Initially it was defined as a method of scientific data collection by untrained personnel (Irwin, 1995), but the definition has expanded to include many elements of public engagement with science; from data collection through to truly collaborative science (extreme citizen science) involving planning surveys or experiments and analysis of results (Haklay, 2013). Higher levels of participant involvement put citizens on equal footing with scientists, and may result in more accurate data and more advanced projects (Shirk et al., 2012; Haklay, 2013). However, currently the vast majority of citizen science projects, especially in biodiversity and ecology studies, rely on citizens collecting and submitting data only (reviewed

by Catlin-Groves, 2012). As such, for the purposes of this study, we define citizen scientists as any participant willing to provide data on hedgehogs and features of their garden.

Citizen science surveys rely on securing the interest and motivation of participants, and this may be why most of the hugely popular surveys involve easily recognisable and charismatic vertebrates such as birds, mammals and amphibians. In the UK, the hedgehog is regarded with affection and as a beneficial garden visitor (Morris 1985; Young et al. 2006; Baker and Harris 2007; Dowding et al. 2010). It is considered to be an ideal study species for citizen science because it is readily identifiable and not especially wary of people (Morris 1985; Young et al. 2006; Baker and Harris 2007; Dowding et al. 2010), and encounters with hedgehogs are usually memorable (Hof and Bright 2009). The hedgehog is also of interest to many members of the public because it is reported to be declining in the UK and is a priority species nationally and in many local areas under the Biodiversity Action Plan framework (Hof and Bright 2009; Gaglio et al. 2010). Its decline is thought to be caused by a combination of factors including the loss of suitable habitat such as hedgerows and uncultivated field margins, a high level of mortality on roads, predation and competition by badgers, and high concentrations of pesticides that diminish invertebrate food supplies (Ward et al. 1997; Wilson et al. 1999; Huijser and Bergers 2000; Young et al. 2006). However, urban areas, notably playing fields and gardens, are important habitats for hedgehogs. This is suggested to be because they offer shelter from predation by badgers as well as a range of habitat features suitable for foraging and nesting (Rondinini and Doncaster 2002; Morris 2006; Hubert et al. 2011).

Citizen science hedgehog surveys are already underway. For example, in the UK, Royal Holloway University of London together with two large conservation charities, the People's Trust for Endangered Species (PTES) and the British Hedgehog Preservation Society (BHPS) are undertaking a nationwide study named "HogWatch", which aims to map hedgehog sightings in gardens and the wider countryside (PTES and BHPS 2007). The PTES "Living with Mammals" survey has also provided valuable data on the presence of hedgehogs (among other species), and habitat features associated with their presence in urban areas (Hof and Bright 2009). However, citizen science data are not usually verified because this would not be logistically feasible on a nationwide level (Hof and Bright 2009).

Citizen science is often criticised because methods used to collect data may lack the rigour of conventional scientific studies (Irwin 1995), resulting in errors and bias. These issues may still occur when species are easy to identify, as in the case of the hedgehog. Delaney et al. (2008) found that volunteers were able to provide accurate data for easily detected organisms, whereas Fitzpatrick et al. (2009) and

Sewell et al. (2010) found differences between volunteer and professional data for species that were difficult to detect. Recorded hedgehog sightings should be reliable, for reasons discussed above. However, because of the hedgehog's current decline (Hof and Bright 2009; Gaglio et al. 2010), it is especially important that data collected by volunteers are as accurate as possible, and this should include reliable absence data.

This study has two aims: (1) to assess types of data on urban gardens that can be collected by citizen scientists (including details on potential ecological habitats and presence and absence of a charismatic species – the European hedgehog) and to compare data from citizen scientists to those collected by a researcher; (2) to identify if these data can be used to determine the important features of urban gardens for attracting hedgehogs.

Methods

Overview

This study examines what can be learned about habitat selection in hedgehogs in gardens using citizen science data, and tests the reliability of those data. An online survey was conducted in order to determine whether certain garden features were associated with hedgehog sightings in gardens around the county of Gloucestershire (UK). The accuracy of the hedgehog presence and absence data was verified during visits to a subset of 47 gardens, where hedgehog footprint tunnels were used to provide objective evidence of the presence of hedgehogs in these gardens. Footprint tunnel data were compared to hedgehog sightings (or lack of sightings) as recorded by garden owners during the previous year to determine whether a lack of sightings reflected a true absence of hedgehogs in a particular garden, or whether these were actually likely to be false absences. To ascertain whether citizen scientists recorded data for their gardens in a significantly different way to a professional scientist, a single researcher (RLW) visited each study garden and completed a survey of garden features using the same method as used by each participant.

Questionnaire design and citizen science data

A questionnaire was developed, targeted at members of the public, and was widely advertised in local press, two wildlife charities websites' (Gloucestershire Wildlife Trust and Help a Hedgehog Hospital) and newsletters, as well as word of mouth via e-mail and social media (Facebook and Twitter). The questionnaire was disseminated in November and December 2011, during the time when hedgehogs would be hibernating.

Before the web link to the questionnaire was activated, 40 paper copies were distributed at a local hedgehog charity event (the event was held in a town centre in Gloucestershire and there were similar amounts of completions from people who had seen hedgehogs and not seen hedgehogs in their garden as in the remainder of the survey with 22 'no sightings' and 18 'sightings' of hedgehogs, see results).

Upon returning the questionnaires, respondents were asked whether they thought the questions were clear and the length of the questionnaire was acceptable. This was thought to be important because several studies highlight the positive effect of shorter questionnaires on response rates (Jepson *et al.*, 2005; Nakash *et al.,* 2006; Galesic and Bosnjak, 2009; Rolstad *et al*., 2011), and the importance of keeping the questions themselves short and clear (Holbrook *et al.*, 2006; Lietz, 2010). As the questionnaire was approved by participants, it remained unchanged before release online and the 40 responses were included in the final results.

The online survey method was chosen because of the increasing popularity and advantages of internet-based surveys over traditional mail survey methods, notably, the reduction in research costs and ease of survey administration (Kwak and Radler, 2002). Because of the negative relationship between questionnaire length and response rates, the questionnaire used in this study was constructed in 3 sections, each on a separate page with a progress bar at the bottom of each page so that respondents were not deterred by a list of 21 questions. The rationale behind this is that if respondents know how much progress they have made, they will be more likely to complete the questionnaire (Yan *et al.*, 2011). When designing the survey, none of the questions were made compulsory (i.e. if a respondent did not answer a particular question, they could still complete the rest of the survey).

The questions used in the survey were selected based on a literature search of publications concerning hedgehog habitat preferences (Table 1). There were two optional questions at the end of the survey asking for the postcode and e-mail address of the respondent. The postcode was sought with the aim of mapping hedgehog sightings, and the e-mail address was provided if the respondent wished to participate in additional fieldwork in their garden. A copy of the questionnaire is available as supplementary material for this paper.

All responses were standardised using a numerical key for each answer. Where appropriate, response variables were classed as ordinal (i.e. a response of 'frequently' would have a higher value than 'occasionally'); where no meaningful ordinal scale was possible (i.e. when only a yes/no or present/absent response was available), variables were categorical. Answers were divided into variables

based on whether the answer was single or multiple choice. For binary variables such as "have you seen any hedgehogs", only one answer was possible – yes (1) or no (0), so this represented one variable in the analysis. For multiple choice questions such as "do you have a pet that uses your garden", there were seven possible options that were not mutually exclusive, so these were treated as seven separate variables in the analysis with each type of pet being treated as either absent (0) or present (1). A separate column recorded an absence of any pet. When large numbers of respondents answered "other" with similar responses, these were reclassified into separate variables, resulting in the creation of the categories "wooded area", "shrubs" and "wild area" for the question concerning main ground type, the categories "road", "grassland", "parkland" and "public green space" added to the question concerning garden boundaries and "neighbour's cat" added to the question concerning pets.

Statistical analysis of questionnaire citizen science data

To determine whether gardens with and without hedgehog sightings could be distinguished based on the variables recorded in the questionnaire, Discriminant Function Analyses (DFA) were run, taking into account *a priori* probabilities for the different group sizes (gardens with sightings n = 245 or 47%; gardens with no sightings n = 271 or 53%; note that 53% *a priori* probability stems from the dataset in which 53% of people had not seen a hedgehog in their garden: therefore, in theory, 53% of gardens could be correctly classified by chance alone). The classification power of each DFA was ascertained using a jackknife cross-validation procedure, such that each model was repeatedly calculated with the omission of a different single case, which was then classified (Shaw 2003).

Initially, all variables were all entered into the analysis. Following this, a stepwise DFA was run in order to distinguish the most important explanatory variables associated with the sighting of hedgehogs in gardens, using the Wilks Lambda method. Variables were entered on the basis of $\alpha < 0.05$ and removed when $\alpha > 0.10$ (Field 2009). In the stepwise model, all independent variables were included in the candidate list for possible entry into the model.

Data verification

47 individuals who indicated they would be willing to partake in further research on their questionnaire response volunteered to participate in a data verification stage of the study. These included respondents who had reported hedgehog sightings in their garden (n = 23 henceforth referred to as 'yes' gardens) and who had reported no hedgehog sightings (n = 24 referred to as 'no' gardens) during the previous year (2011). This was representative of the 47:53% split between 'yes' and 'no' gardens observed in the initial questionnaire dataset.

Gardens were located within the main urban and suburban areas around Cheltenham (centred at 51.89 N, 2.08 W), Stroud (centred at 51.74 N, 2.22 W), and Gloucester (centred at 51.84 N, 2.24 W). Consistent use of only urban and suburban gardens as opposed to rural regions reduced the potential effect of a higher winter mortality rate in rural areas (Kristiansson 1990; Hubert et al., 2011), and also allowed for further evaluation of urban hedgehog frequency. Predation by badgers is also more intense in rural areas, resulting in higher densities of hedgehogs in urban and suburban areas (Doncaster et al. 2001; Hof and Bright 2009; Hubert et al. 2011). Excluding rural populations thereby helped to reduce these confounding factors.

During visits to these 47 gardens, one author (RLW) undertook a survey of the garden and the features therein, using the same questionnaire that had been completed previously by the residents. This was designed to test whether the citizen science data differed significantly from that collected by a single professional scientist. It should be noted that both surveys were somewhat subjective, and neither the professional scientist survey nor the citizen science survey can be considered 'accurate'; neither should it be assumed that one is "better" than the other. The surveys were undertaken using a blind protocol so that the citizen science data were not consulted during professional survey. All questions involving sightings of other species, presence of pets and use of pesticides were left out for the purpose of this verification exercise.

An indirect evidence survey was then carried out using a hedgehog footprint tunnel method that had been trialled and recommended by the UK Mammal Society. The tunnels were assembled following Mammal Society instructions (Mammal Society 2012) and consisted of a triangular plastic tunnel containing a tracking plate with sections of A4 sized paper and ink (black powdered paint mixed with vegetable oil), with bait (a hotdog sausage) placed in the centre of the tunnel to attract hedgehogs (Figure 1a). When hedgehogs moved through the tunnel, over the inkpad, they left footprints on the paper. The survey took place in the first three weeks of June 2012 to reduce temporal and seasonal effects possible in prolonged surveys.

One tunnel was set up by the lead author (RWL) in each garden along boundary lines such as walls, fences or flower borders, and preferentially concealed in vegetation or beside garden sheds, following the protocol of the Mammal Society (Figure 1b). Tunnels were flush with the ground and were secured with tent pegs. All equipment (spare ink, sponges, gloves and bait) and comprehensive written instructions were provided to the volunteers.

Tunnels were baited every evening before dusk and the paper and leftover bait removed in the mornings to avoid visits by non-target diurnal species. The survey lasted for five consecutive nights

in each garden; a period sufficient to detect hedgehogs in an area, according to Mammal Society recommendations (Mammal Society 2012). Hedgehog presence or absence, as well as for presence of other species was recorded daily.

In order to verify that the sample size used was sufficiently large, a power analysis for a Mann Whitney U test was performed (as per Lehmann 1975) using standard deviations taken from a hedgehog tunnel study by Huijser and Bergers (2000). Results of the power analysis showed that using 23 tunnels in 'yes' gardens and 24 tunnels in 'no' gardens would have allowed the detection of a mean difference of 1.5 hedgehog visits with a power of 0.89 (with $\alpha = 0.05$), if sampled for five nights. As such, a sample size of 47 gardens was deemed to be large enough for the current survey.

Footprint tunnel data analysis

After the data were collected, an *a posteriori* power analysis (in addition to the *a priori* power analysis above) was performed in order to confirm that the sample size was large enough to detect significant differences between 'yes' and 'no' gardens (see Results). To examine whether there was a association between footprint data and the original questionnaire data (as there should be if questionnaire data were accurate), a chi-squared 2*2 test for association was performed to relate gardens that had no hedgehog visits during the five nights of tunnel data collection (0) and gardens that had at least one visit (1) relative to whether the garden had originally had hedgehogs reported as being present ('yes' or 'no' gardens, respectively). Following this analysis of hedgehog prevalence, a non-parametric Mann-Whitney U test was performed (as data were positively skewed) in order to determine whether there was a significant difference in the frequency of visits (hedgehog abundance) to 'yes' and 'no' gardens.

A Spearman's rank correlation was used to determine whether there was a relationship between the number of hedgehog visits in each garden and the visits of other species in the same garden during the survey (all nights pooled). To further investigate the relationship between cats and small mammals, data were examined on a nightly basis in all gardens to determine the percentage of trapping nights in which both cats and small mammals visited the same tunnel.

Results

Responses to the online questionnaire

In total, 516 questionnaires were completed over 6 weeks: 53% of respondents reported not seeing a hedgehog in their garden in 2011 and 47% reported seeing one. Despite being targeted at Gloucestershire residents only 73.4% of respondents lived in Gloucestershire, 15% lived elsewhere in the UK and Ireland and 11.6% did not enter their postcode. Responses were obtained from all areas of Gloucestershire, but were clustered around the three main urban areas of Gloucester, Cheltenham and Stroud (Figure 2).

DFA results

When all independent variables (i.e. variables generated for each question detailed in Table 1 except the first) were entered into a full model with hedgehog sightings as the binary dependent variable generated using responses to the first question in Table 1, an average of 80.2% of cases were correctly classified (86.5% of gardens with sightings were correctly classified, and 74.5% gardens with no sightings were correctly classified). This is substantially higher than the a priori probability of 53% (the percentage of gardens which had reported not seeing hedgehogs, see methods).

In the stepwise model, four variables were found to be significant discriminators of garden hedgehog sightings, together explaining 77.3 % of correctly classified cases: live hedgehogs seen in the neighbourhood (+ve relationship), feeding hedgehogs (+ve relationship), decking as a main ground type (-ve relationship), and no hedgehogs seen in the neighbourhood (-ve relationship) (Table 2; Figure 3). Note, since dead hedgehogs could be seen in the neighbourhood, seeing no hedgehogs is independent of seeing live hedgehogs. Seeing a live hedgehog in the neighbourhood was the single most important variable, explaining 75.4 % of the cases that were correctly classified. The other three variables, although significant, explained a small percentage of the correctly classified cases (Table 2).

In all models, classification accuracy was very evenly distributed between categories, such that the accuracy of correctly classifying gardens with hedgehogs correctly was almost equal to the accuracy of correctly classifying gardens without hedgehogs (see Table 2).

Garden feature data accuracy

Objective features were the most accurately recorded: the type of house, adjacent road, bordering habitats and the presence or absence of a vegetable patch matched professional data in over 90% of cases. The level of enclosure of a garden (i.e. partial or complete), the type of boundary surrounding the garden and the presence of a compost heap or bin matched professional data in 70-80% of cases. There was a difference of 27% between citizen scientists and our assessment of whether a

garden was wildlife friendly or not. Most of the discrepancies between the volunteer and our data occurred when recording the major ground types and the presence of wildlife friendly features, in particular, unkempt areas (50% of cases).

Hedgehog footprint tunnel analysis

Performing an *a posteriori* power analysis with actual data (as opposed to estimates taken from a similar study) showed that a mean difference of 0.90 visits over five nights (i.e. less than one night) could have been detected with a power of 0.86 using the obtained standard deviation of 0.99 for 'yes' gardens and a standard deviation of 1.01 for 'no' gardens, justifying the sample size used.

There was a relatively low number of hedgehog visits overall (n = 29 occasions with n = 14 for "yes" gardens and n = 15 in "no" gardens), and these equated to 12% of 235 trapping nights (47 gardens * 5 nights in each garden). Hedgehogs visited 38% of "no" gardens and 35% of "yes" gardens and, when hedgehogs visited, they did so for an average of 1.7 nights (min = 1, max = 4, out of a possible 5 nights). Analysis of when hedgehogs visited tunnels showed that the majority visited on the second night (with a cumulative percentage of 53% of the total number of visited gardens being visited by this time). By the fifth night, only one additional tunnel recorded hedgehogs – or 6% of the total number found in the survey, hence five nights were sufficient to capture tunnel usage (although transient hedgehogs may not be found without a much longer trapping period).

The chi-squared test for association showed that there was no significant association between the presence of hedgehogs in gardens and whether the owners had reported seeing hedgehogs or not in the previous year ($\chi^2 = 0.06$, df = 1, p = 0.81), suggesting that there was no association between these survey methods. There was also no significant difference between the number of hedgehog visits in 'yes' and 'no' gardens (Mann-Whitney U test: U = 271.50, $n_1 = 24$, $n_2 = 23$, p = 0.91) (Figure 3), such that the frequency of visits did not differ between "yes" and "no" gardens.

There was a significant negative correlation between visits to the tunnels by cats and small mammals on a per-garden basis (Spearman's rank test: $r_s = - 0.39$, N = 47, $p < 0.01$), but no significant relationship between hedgehog and cat visits ($r_s = - 0.10$, N = 47, p = 0.50) or hedgehog and small mammal visits ($r_s = 0.11$, N = 47, p = 0.47). Cats visited tunnels on 26% percent of trapping nights (total number of trapping nights: 47 gardens * 5 nights = 235), and small mammals visited tunnels on 29% of nights. Both cats and small mammals visited the same tunnel on the same night in 4% of nights.

Discussion

The results of this study show that: 1) citizen scientists who have seen hedgehogs elsewhere in their neighbourhood are also much more likely to see hedgehogs in their gardens and those not seeing hedgehogs in the neighbourhood are less likely to see them in their gardens; 2) citizen scientists can describe the key features of their gardens, especially if these are not subjective; and 3) independent verification of hedgehog presence indicates that many gardens do have hedgehogs, even if they have not been sighted previously by the garden's owners. The potential implications of these findings are twofold. Firstly, hedgehogs are likely utilising urban and semi-urban gardens far more than is realised, and secondly, that the accuracy of 'casual' citizen science records of hedgehog sightings will depend more on the person than the actual presence of the species, although citizen scientists may be able to provide good habitat or other environmental data.

Real urban hedgehog populations

Given that hedgehogs are easy to identify, and given the assumption that volunteers completing the survey accurately reported their sightings of hedgehogs, the initial survey results confirm previous research indicating the importance of gardens as habitats for urban and semi-urban hedgehogs (Baker and Harris 2007; Dowding et al. 2010). Especially in urban areas, spatial analysis of the sightings indicated that hedgehogs were spread throughout these urban areas, rather than concentrated in only a few areas. Nightly ranges of hedgehog movement outside the breeding season are typically a few hundred metres, but hedgehogs have been known to travel up to 9.9 km (Ward et al. 1997; Doncaster et al. 2001). As the average garden size in the UK is 190 m^2 (Davies et al. 2009), it is highly likely that hedgehogs can travel between several gardens in a single night, and that the key determining factor on whether a hedgehog can use a garden as a habitat is related to the ability to access the garden.

The importance of urban gardens for hedgehogs is further supported by the results of the footprint tunnel verification survey. Tunnels were visited roughly equally by hedgehogs in gardens where hedgehogs had previously been seen as in gardens where they had not previously been seen. In addition, the detection rate of hedgehogs, even in gardens they were known to have previously visited, was low, logically meaning that hedgehogs may be present in far more gardens where they had not been seen by the citizen scientists than were detected in the footprint tunnel survey. This is likely to mean that hedgehogs may in fact visit or use a very high proportion of gardens, certainly far higher than casual (i.e. based on chance encounters) reporting rates by garden owners might indicate.

Winter mortality may have affected the results of the footprint tunnel survey, especially if hedgehogs had died in gardens between when they had previously been seen in 2011 (the questionnaire period) and the footprint survey in 2012. However, the winter of 2011-2012 was much milder than the 3 previous winters (MetOffice, 2012) so it is probable that many hedgehogs survived hibernation, especially due to the survey being undertaken in urban and suburban areas, where winter mortality is low (Kristiansson, 1990; Hubert *et al*., 2011).

One possible factor which might mean a lower number of gardens are inhabited by hedgehogs, as compared to the discussion above, is that respondents in this survey may have been biased towards wildlife-friendly practices in their gardens. It is reasonable to assume that predominantly only people with an interest in wildlife completed the questionnaire and 86% of respondents said that they tried to make their garden wildlife-friendly. Gaston et al. (2005) state that surveys revolving around "appeals for information" that are advertised in the media (magazines, newspapers, television, radio) can be highly non-random in their coverage, for example, in terms of the demographic of volunteers taking the questionnaire.

'Casual' recordings

Clearly, relying only on citizen scientist reported 'casual' recordings is unreliable for a nocturnal species such as a hedgehog. Detectability of hedgehogs by garden owners is likely to vary from garden to garden depending on the size of the garden, the amount of vegetation that could conceal a hedgehog, and perhaps more importantly, the lifestyle of the garden owner who may be more likely to see a hedgehog if they are in their garden when hedgehogs are active (i.e. mainly at night and occasionally at dawn or dusk – Reeve 1994). A further possible reason for unreliability in casual records is the overall awareness or sensitivity of the participants to nature in general, or hedgehogs in particular. In this study, people who had seen hedgehogs elsewhere in their neighbourhood were also most likely to report hedgehogs in their garden, perhaps indicating that they were more regularly outside at night, and hence more likely to see nocturnal wildlife, or were more in tune and aware of nature and thus likely to recognise or look for hedgehogs. Feeding of hedgehogs was also correlated with presence of hedgehogs, again indicating that awareness of hedgehogs may lead to the development of nature friendly behaviours, and enhanced accuracy of results.

The idea of a 'nature deficit disorder' has become common in recent years, with many adults and children not demonstrating the same level of interaction with their environment as in the past (Louv, 2010; Sandry, 2013) . As such, it may be that not only are participants less likely to spend time in gardens, but might be unaware of the signs of hedgehogs (e.g. faeces or even noises in the

hedgerows) and therefore less likely to notice them or feed them. Recruiting 'nature aware' people for studies such as these may promote accuracy in data collection; however, such approaches may also limit the number of participants in the study.

Failing to allow for the variation in detectability generates unreliable data, especially with respect to false negatives (MacKenzie et al. 2002; Schmidt 2003; Sewell et al. 2010). However, casual recordings from many individuals should be able to produce accurate distribution maps of species presence on a broader spatial scale (Stafford et *al.* 2013).

Because of the lack of certainty in terms of presence of hedgehogs in a given garden, it is difficult to draw conclusions about what makes favourable hedgehog habitats within a garden from the results of the questionnaire. For example, while decking was extracted as a significant variable from the questionnaire data, it did not add much to the classification power of the results. Really, the survey served only to provide useful information about the behaviour of citizen scientists and their ability to record nocturnal wildlife, rather than behaviours of habitat preferences of hedgehogs themselves. However, volunteers are able to provide useful and accurate information about their gardens for explaining the presence or absence of species such as hedgehogs. It is the accurate quantification of the dependent variable which is not always possible. These results have important implications for further garden surveys, especially if diurnal species are considered, or if training to promote awareness of more elusive species is given. Citizen scientists can also be prepared to undertake more intensive surveys than just 'casual' recordings, and these can provide useful information in terms of conservation (although participation in more involved citizen science activities than simply submitting online forms does result in a sharp decrease in participation). In this study, footprints from small mammals and cats recorded over five nights indicated that neither appeared to have competitive or tropic relationships with hedgehogs in urban gardens, although such results should be considered very preliminary.

The study has indicated some important issues regarding urban biodiversity, and monitoring of this. For example, it has demonstrated that, at least in Gloucestershire, there is a widespread use of gardens by hedgehogs. It also demonstrates some limitations of casual recordings by volunteers, but that also, many 'citizens' are willing to be part of citizen science schemes. In terms of conservation, involvement with citizen science has benefits beyond data collection, and may increase awareness of urban biodiversity and a greater understanding of cultural and behavioural practices on urban biodiversity (Field et al. 2010). The results are important for the majority of existing citizen science projects, which generally use citizen scientists to collect data (Hakley's Level 1 classification, Hakley,

2013), but also provide further evidence that citizen science data collection can be improved with further engagement of volunteers beyond simple 'ecological sensors'.

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References

Baker PJ, and 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. Mam Rev 37: 297-315

Catlin-Groves C (2012) The citizen science landscape: from volunteers to citizen sensors and beyond, Int J Zool 2012: 349630

Davies ZG, Fuller RA, Loram A, Irvine KN, Sims V, Gaston KJ (2009) A national scale inventory of resource provision for biodiversity within domestic gardens, Biol Cons 142: 761-771

Delaney DG, Sperling CD, Adams CS, Leung B (2008) Marine invasive species: validation of citizen science and implications for national monitoring networks. Biol Invasions 10: 117-128

Doncaster CP, Rondinini C, Johnson PCD (2001) Field test for environmental correlates of dispersal in hedgehogs *Erinaceus europaeus*, *J Anim Ecol* 70: 33-46

Dowding CV, Harris S, Poulton S, Baker PJ (2010) Nocturnal ranging behaviour of urban hedgehogs, *Erinaceus europaeus*, in relation to risk and reward. *AnimBeh* 80: 13-21

Field A (2009) Discovering statistics using SPSS. Sage, London

Field D, Voss P, Kuczenski T, Hammer R, Radeloff V (2010) Reaffirming social landscape analysis in landscape ecology: a conceptual framework *Soc Nat Res* 16: 349-361

Fitzpatrick MC, Preisser EL, Ellisonm AM, Elkinton JS (2009) Observer bias and the detection of low-density populations, Ecol Applications 19: 1673-1679

Gaglio G, Allen S, Bowden L, Bryant M, Morgan ER (2010) Parasites of European hedgehogs (*Erinaceus europaeus*) in Britain: epidemiological study and coprological test evaluation, Euro J Wildlife Res 56: 839-844

Galesic M, Bosnjak M (2009) Effects of questionnaire length on participation and indicators of response quality in a web survey. Public Opinion Quart 73: 349-360

Gaston KJ, Warren PH, Thompson K, Smith RM (2005) Urban domestic gardens (IV) The extent of the resource and its associated features. Biodiv Cons 14: 3327-3349

Gregory RD, Baillie SR (1998) Large-scale habitat use of some declining British birds. J App Ecol 35: 785–799

Haklay M (2013) Citizen Science and Volunteered Geographic Information – overview and typology of participation. In: Sui DZ, Elwood S, Goodchild MF (eds) Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice. Springer, Berlin, pp 105-122

Hof AR, Bright PW (2009) The value of green-spaces in built-up areas for western hedgehogs. Lutra 52: 69-82

Hof AR, Bright PM (2011) Factors affecting hedgehog presence on farmland as assessed by a questionnaire survey. Acta Theriologica 57: 79-88

Holbrook A, Cho YI, Johnson T (2006) The impact of question and respondent characteristics on comprehension and mapping difficulties. Public Opinion Quart 70: 565–595

Hubert P, Julliard R, Biagianti S, Poulle ML (2011) Ecological factors driving the higher hedgehog (*Erinaceus europeaus*) density in an urban area compared to the adjacent rural area. Landscape Urban Plan 103: 34-43

Huijser MP, Bergers PJM (2000) The effect of roads and traffic on hedgehog (*Erinaceus europaeus*) populations. Biol Cons 95:111-116

Irwin A (1995) Citizen science: a study of people, expertise and sustainable development. Routledge, London

Jepson C, Asch DA, Hershey JC Ubel PA (2005) In a mailed physician survey, questionnaire length had a threshold effect on response rate. J Clin Epidem 58: 103-105

Kristiansson H (1990) Population variables and causes of mortality in a hedgehog (*Erinaceus europaeus*) population in southern Sweden. J Zool 220: 391–404

Kwak N, Radler B (2002) A comparison between mail and web surveys: response pattern, respondent profile and data quality. J Official Stat 18: 257-273

Lehmann E L (1975) Nonparametrics: Statistical methods based on ranks, Holden-Day, San Francisco

Lietz P (2010) Research into questionnaire design: a summary of the literature. Int J Mark Res 52: 249-272

Louv R (2008) Last child in the woods: Saving our children from nature-deficit disorder. Algonquin Books, New York.

MacKenzie DI, Nichols JD, Lachman GB, Droege S, Royle JA, Langtim CA (2002) Estimating site occupancy rates when detection probabilities are less than one. Ecology 83: 2248-2255

Mammal Society (2012) National hedgehog volunteer survey information pack. Mammal Society, Southampton.

Mason CF (2000) Thrushes now largely restricted to the built environment in eastern England. Diversity Distrib 6: 189-194

MetOffice (2012) UK winter temperatures 2011-2012 [online] available at: <http://www.metoffice.gov.uk/climate/uk/2012/winter.html> (accessed 22nd August 2012)

Morris PA (1985) The effects of supplementary feeding on movements of hedgehogs (*Erinaceus europaeus*). Mam Rev 15: 23-33

Morris PA (2006) The New Hedgehog Book. Whittet Books Ltd, Stowmarket

Nakash RA, Hutton JL, Jørstad-Stein EC, Gates S, Lamb SE (2006) Maximising response to postal questionnaires – A systematic review of randomised trials in health research. BMC Med Res Method, 6: 5

Newson SE, Woodburn RJW, Noble DG, Baillie SR, Gregory RD (2005) Evaluating the breeding bird survey for producing national population size and density estimates. Bird Stud 52: 42-54

Reeve NJ (1994) Hedgehogs. T. & A.D. Poyser Ltd, London

Rondinini C., Doncaster CP (2002) Roads as barriers to movement for hedgehogs. Func Ecol 16: 504-509

Rolstad S, Adler J, Ryden A (2011) Response burden and questionnaire length: is shorter better? A review and meta-analysis. Value in Health 14: 1101-1108

Ryall C, Hatherell P (2003) A survey of strategies adopted by UK Wildlife Trusts. Environmentalist 23: 81–87

Sandry N (2013) Nature deficit disorder. Educating Young Children: Learning and Teaching in the Early Childhood Years 19: 32

Schmidt BR (2003) Count data, detection probabilities and the demography, dynamics, distribution and decline of amphibians. Comptes Rendus Biologies 326: S119-S124

Sewell D, Beebee TJC, Griffiths RA (2010) Optimising biodiversity assessments by volunteers: the application of occupancy modelling to large-scale amphibian surveys. Biol Cons 143: 2102-2110

Shaw P (2003) Multivariate statistics for the environmental sciences. Hodder Arnold, London

Shirk JL, Ballard HL, Wilderman CC, Phillips T, Wiggins A, Jordan R, McCallie E, Minarchek M, Lewenstein BV, Krasny ME, Bonney R (2012) Public participation in scientific research: a framework for deliberate design. Ecol Soc 17: 29

Silvertown J (2009) A new dawn for citizen science. Trends Ecol Evol 24: 467–471

Stafford R, Hart AG, Collins L, Kirkhope CK, Williams RL, Rees SG, Lloyd JR, Goodenough AE (2010) Eu-social science: the role of internet social networks in the collection of bee biodiversity data. PLoS ONE 5: e14381

Stafford R, Hart AG, Goodenough AE (2013) A visual method to identify significant latitudinal changes in species' distributions. Ecol Inform 15: 74-84

Toms MP, Newson SP (2006) Volunteer surveys as a means of inferring trends in garden mammal populations. Mam Rev 36: 309-317

Ward JF, MacDonald DW, Doncaster CP (1997) Responses of foraging hedgehogs to badger odour, Anim Beh 53: 709-720

Wilson JD, Morris AJ, Arroyo BE, Clark SC, Bradbury RB (1999) A review of the abundance and diversity of invertebrate and plant foods of granivorous birds in northern Europe in relation to agricultural change. Agri Ecosyst Environ 75: 13-30

Yan T, Conrad FG, Tourangeau R, Couper MP (2011) Should I stay or should I go: the effects of progress feedback, promised task duration, and length of questionnaire on completing web surveys. Int J Pub Opinion Res 23: 131-147

Young RP, Davison J, Trewby ID, Wilson GJ, Delahay RJ, Doncaster CP (2006) Abundance of hedgehogs (*Erinaceus europaeus*) in relation to the density and distribution of badgers (*Meles meles*). J Zool 269: 349-356

Table 1) Details of questions asked and possible responses. Note: Responses marked with * were not given as an option in the questionnaire but were reclassified as separate variables in the analysis because several people cited them as "other". All questions other than the first question were used as potential explanatory (entered into the stepwise DFA) variables to predict the answer to "Have you seen a hedgehog in your garden in the past year (2011)?"

Question	Possible responses
Have you seen a hedgehog in your garden in the past year (2011)?	Yes/no
What is the MAIN ground type in your garden? (you can tick several if you think they are of equal size)	Lawn Gravel Paving Decking Flower beds Vegetable patch or cultivated area Other (please specify) Wooded area* Shrubs* Wild area*
Is your garden enclosed or not?	Yes - completely enclosed (no gaps in walls/fences and I keep the gate closed: hedgehogs probably can't get in to my garden) Yes - partially enclosed (some gaps and/or the gate is left open: hedgehogs could get in to my garden) Not enclosed (no walls, fences or hedges at all)
If yes, what is the boundary made of? (Tick all that apply)	Wooden fence Wire fence Wall Hedge
Do you see foxes or badgers in your garden?	Foxes - Frequently, occasionally, rarely, never Badgers - Frequently, occasionally, rarely, never
Do you have a vegetable patch?	Yes/no
Do you use pesticides?	Yes – natural or organic Yes – artificial No
Do you have a compost heap/bin	Yes – open compost heap Yes – compost bin

Question	Possible responses
	Yes but I don't use it No
Have you seen a hedgehog in your neighbourhood in the past year? (Tick all that apply)	Yes – alive Yes – dead No
Do you live in a…	Completely rural area (no houses nearby) Hamlet (few houses nearby) Village Town City
What does your garden border? (Tick all that apply)	Other gardens Farmland Woodland Scrub (unmanaged land) Other (please specify) Road* Grassland* Parkland* Public green space*
What type of house do you live in?	Terraced house Semi-detached house Detached house Flat with communal gardens
What type of road do you live on?	A-road B-road Single track road Residential area
Do you try to make your garden wildlife friendly?	Yes/no
Some features are particularly beneficial for wildlife. Do you have... (Tick all that apply)	A pond An unkempt area (e.g. long grass, weeds, piles of leaves...) Bird feeders/bird nestboxes A log pile Other (please specify)
Do you try to attract hedgehogs by	Yes – regularly Yes – occasionally

Question	Possible responses
putting food out?	No
Do you have a pet that uses your garden? (Tick all that apply)	A dog A cat A rabbit or guinea pig Poultry I don't have a pet that uses my garden Other (please specify) Neighbour's cat*

Table 2: Stepwise DFA results for classifying the accuracy with which gardens could be classified as having (or not having) hedgehogs using specific independent variables. It should be noted that for each model, the overall classification accuracy is not a simple average of the classification accuracy of gardens with/without hedgehogs due to an unequal sample size (see methods).

Model	Correctly classified	Wrongly classified	Variables in model
Model 1:			1. Live hedgehogs seen in neighbourhood (positive relationship)
Gardens with hedgehogs	78.6%	21.4%	
Gardens without hedghogs	74.0%	26.0%	
Overall	75.4%	24.6%	
Model 2:			1. Live hedgehogs seen in neighbourhood (positive relationship) 2. Feeding hedgehogs in garden (positive relationship)
Gardens with hedgehogs	78.4%	21.6%	
Gardens without hedghogs	73.7%	26.3%	
Overall	75.6%	24.4%	
Model 3:			1. Live hedgehogs seen in neighbourhood (positive relationship) 2. Feeding hedgehogs in garden (positive relationship) 3. Decking (negative relationship)
Gardens with hedgehogs	76.3%	23.7%	
Gardens without hedghogs	76.2%	23.8%	
Overall	76.3%	23.7%	
Model 4:			1. Live hedgehogs seen in neighbourhood (positive relationship) 2. Feeding hedgehogs in garden (positive relationship) 3. Decking (negative relationship) 4. No hedgehogs seen in neighbourhood (negative relationship)
Gardens with hedgehogs	77.2%	22.8%	
Gardens without hedghogs	77.3%	22.7%	
Overall	77.3%	22.7%	

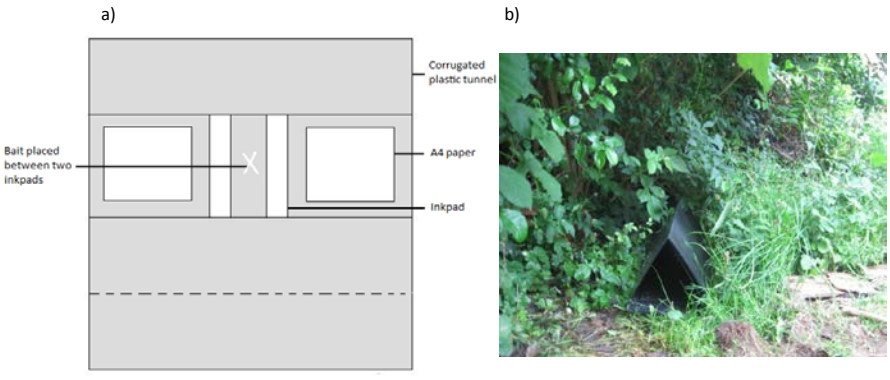

Figure 1. Hedgehog footprint tunnels (a) Diagram of a hedgehog footprint tunnel (paper, inkpads and bait were located on the floor of the tunnel, which folded into a triangular shape with panels overlapping on one side). (b) Photograph of an assembled tunnel in a garden.

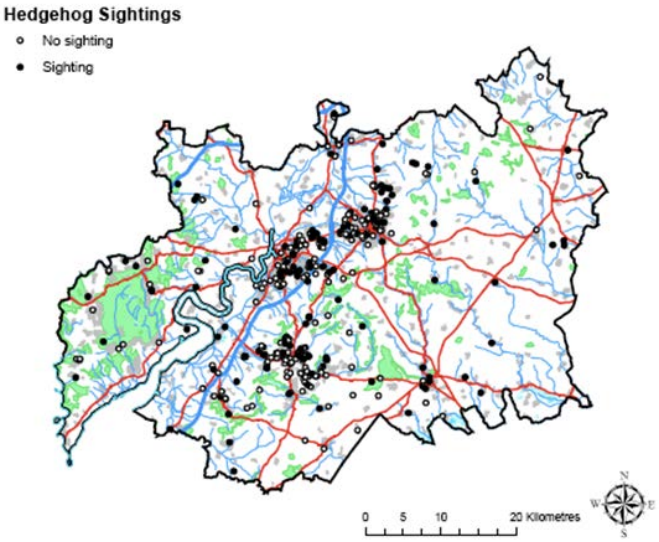

Figure 2. Map of hedgehog sightings around the county of Gloucestershire, showing clusters of respondents in the densely populated urban areas around Cheltenham, Gloucester and Stroud. © Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.

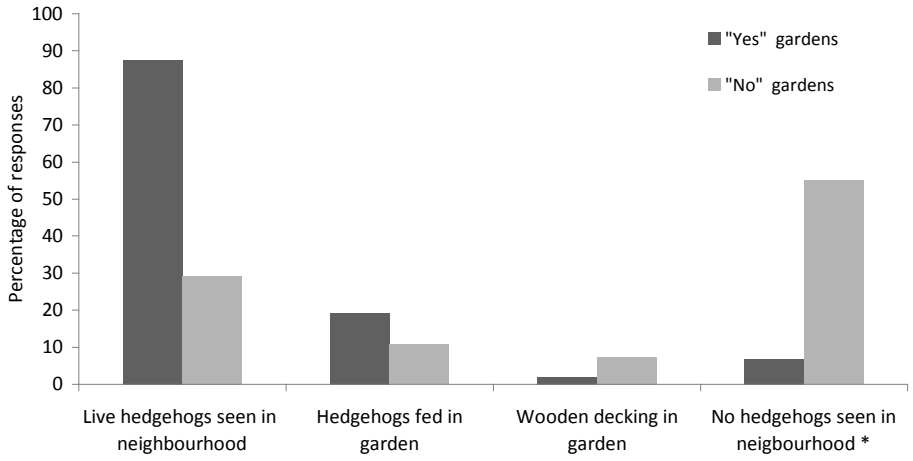

Figure 3) Percentage of recorded hedgehog sightings in gardens according to the 4 most important variables in the stepwise DFA. Note that the question “have you seen a hedgehog in your neighbourhood?” could have multiple answers and therefore corresponded to 3 separate variables in the analysis: live hedgehogs, dead hedgehogs and no hedgehogs. *Respondents who had not seen any live or dead hedgehogs in their neighbourhood.

Supplementary material. The questionnaire given to volunteers to assess if they had seen hedgehogs and to identify features of their gardens

A little about your garden…

These answers will tell me which garden features hedgehogs prefer.

1) **Have you seen a hedgehog in your garden in the past year (2011)?**
   - ☐ Yes
   - ☐ No

2) **If yes, how often?**
   - ☐ Frequently (more than once a month)
   - ☐ Occasionally (less than once a month, but more than 3 times in the last year)
   - ☐ Rarely (less than 3 times in the last year)

3) **What is the MAIN ground type in your garden? (You can tick several if you think they are of equal size)**
   - ☐ Lawn
   - ☐ Gravel
   - ☐ Paving
   - ☐ Decking
   - ☐ Flower beds
   - ☐ Vegetable patch or cultivated area

   Other (please specify): _____

4) **Is your garden enclosed or partially enclosed?**
   - ☐ Yes – completely enclosed (no gaps in walls/fences and I keep the gate closed: hedgehogs probably can't get in to my garden)
   - ☐ Yes – partially enclosed (some gaps and/or the gate is left open: hedgehogs could get in to my garden)
   - ☐ Not enclosed (no walls, fences or hedges at all)

5) **If enclosed, what is the boundary made of? (Tick all that apply)**
   - ☐ Wooden fence
   - ☐ Wire fence
   - ☐ Wall
   - ☐ Hedge

6) **Do you see foxes or badgers in your garden?**

   Foxes: ☐ Frequently ☐ Occasionally ☐ Rarely ☐ Never

   Badgers: ☐ Frequently ☐ Occasionally ☐ Rarely ☐ Never

7) **Do you have a vegetable patch?**
- ☐ Yes
- ☐ No

8) **Do you use pesticides? (Tick all that apply)**
- ☐ Yes – natural or organic
- ☐ Yes – artificial
- ☐ No

9) **Do you have a compost heap/bin?**
- ☐ Yes – compost heap
- ☐ Yes – compost bin
- ☐ Yes but I don't use it
- ☐ No

A little about where you live…

This section will help me find out how hedgehogs are doing in the area.

10) **Have you seen a hedgehog in your neighbourhood in the past year? (Tick all that apply)**
- ☐ Yes – alive
- ☐ Yes – dead
- ☐ No

11) **Do you live in a…?**
- ☐ Completely rural area (no houses nearby)
- ☐ Hamlet (few houses nearby)
- ☐ Village
- ☐ Town
- ☐ City

12) **What does your garden border? (Tick all that apply)**
- ☐ Other gardens
- ☐ Farmland
- ☐ Woodland
- ☐ Scrub (unmanaged land)

Other, please specify _____

13) **What type of house do you live in?**
- ☐ Terraced house
- ☐ Semi-detached
- ☐ Detached
- ☐ Flat with communal garden

14) **What type of road do you live on?**
- ☐ A-road
- ☐ B-road

☐ Single track road
☐ Residential area

15) **Optional: What is your postcode?** The purpose of this is to create a map of hedgehog sightings. (It will not be disclosed to any third party, will be kept anonymous and will not be kept on file following entry in a database.)
Postcode: _____

A little about you…

This short final section will help me find out whether there is anything else that may be attracting or deterring hedgehogs from your garden.

16) **Do you try to make your garden wildlife friendly?**
☐ Yes
☐ No

17) **Some features are particularly beneficial for wildlife. Do you have... (Tick all that apply)**
☐ Pond
☐ Unkempt area
☐ Bird feeders
☐ Log pile
Other (please specify): _____

18) **Do you try to attract hedgehogs by putting food out?**
☐ Yes – regularly
☐ Yes – occasionally
☐ No

19) **Do you have a pet that goes in your garden? (Tick all that apply)**
☐ Dog
☐ Cat
☐ Rabbit
☐ Poultry
☐ I don't have a pet that goes in my garden
Other (please specify): _____

Optional: Would you like to be involved in a hedgehog survey in your garden in Spring 2012?
This survey will involve setting up a hedgehog track tube to see whether hedgehogs use your garden. If hedgehogs walk through it, they leave footprints. If you have children, they will be thrilled to see what wanders about in their garden at night!

If you are interested, please provide your e-mail address below and I will give you more information. You are not committed to anything and can withdraw your interest at any stage. Your contact details will not be disclosed to any third party.

E-mail address: _____