The importance and effectiveness of volunteer-collected data in ecology and conservation

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Abstract

Volunteers have been collecting ecological data for centuries. However, volunteer-collected data are frequently challenged because they lack the precision and rigour of scientific studies. This thesis evaluates the advantages of volunteer-collected data and the importance of such data for the study of ecology and conservation, and considers methods to verify data to avoid or reduce inaccuracies. Different case studies aimed to answer questions relating to species' ecology, habitat selection, and behaviour. Charismatic mammals were selected in order to increase volunteer participation (Water voles *Arvicola terrestris*; dormice *Muscardinus avellanarius*; North American otters *Lontra canadensis*; hedgehogs *Erinaceus europaeus*). Simple, rapid data collection methods were used so that volunteers and citizen scientists could easily follow instructions.

The findings show that simple methods such as scales and estimates can be an effective way of studying water vole habitat associations; however, inter-observer variability was highly problematic when volunteers collected data based on subjective estimations. A volunteer-collected long-term dataset on dormouse nestbox occupancy provided excellent information on habitat selection despite some irregularities when the data were recorded. Untrained citizen scientists could not record activity budgets for captive otters despite simple instructions, whereas citizen scientists were able to record habitat variables within their gardens, but false absences were found to be an issue when they recorded hedgehog sightings.

Overall, this thesis suggests that volunteer-collected data can provide useful insights into various aspects of ecology, for example, for studying distributions and species-habitat interactions. Encouraging volunteers to collect ecological data has additional benefits such as increasing the health and wellbeing of participants, and it also raises public awareness of conservation issues. Recommendations on how to increase participation rates while minimising sources of error and bias are given.

I declare that the work in this thesis was carried out in accordance with the regulations of the University of Gloucestershire and is original except where indicated by specific reference in the text. The help and advice of those who have had direct involvement with this thesis is acknowledged. No part of the thesis has been submitted as part of any other academic award. The thesis has not been presented to any other education institution in the United Kingdom or overseas. Any work that has been published prior to submission can be found as appendices. Any views expressed in the thesis are those of the author and in no way represent those of the University.

Signed ……………………………………………. Date ………………………………

For Mum, Dad and Andrew

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Acknowledgements

First and foremost I would like to thank my Dad for letting me drain his bank account in order to do this PhD. You didn't want kids *or* pets, remember? I successfully brought home over 30 pets over the years, and then wrote this book about animals to make you proud ☺ Thank you for letting me pursue my passion.

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Chapter 1: Introduction

1.1) An overview of volunteer projects

1.1.1) Small-scale volunteer projects: a dedicated team

Members of the public have recorded their observations of the natural world for centuries, including plant and animal distribution and phenology, water quality, weather data, and astronomical phenomena (Miller-Rushing *et al*., 2012). For example, amateur birdwatchers have been collecting data for the British Trust for Ornithology (BTO) since it was founded in 1932 (Greenwood, 2007), and volunteers from local communities in Spain have been collecting plant and bird records since the 1940s (Gordo and Sanz, 2006; 2009).

Organisations invest considerable amounts of time and effort into a close partnership with their volunteers, training them so that they can collect high quality data. While some schemes require intensive training and licences in order to survey protected species such as birds and bats (a full list of species that require such licences in England is maintained by Natural England, 2012a), others simply harness the enthusiasm and commitment of their volunteers and provide a small amount of training and guidance in order to obtain suitable data (Figure 1.1). Training can take place either at a specialised workshop provided by the organisation (e.g. Newman *et al*., 2003; Mammal Society, 2012a; BTO, 2012a), or through detailed written instructions or online tutorial (e.g. PTES, 2011; Bat Conservation Trust, 2012a). In long term monitoring programmes where surveys are conducted in groups, volunteers who have been participating for longer often supervise and train new volunteers. For example, volunteers participating in monthly dormouse (*Muscardinus avellanarius*) nestbox surveys are supervised by more experienced, licensed volunteers. Additionally, many wildlife organisations (e.g. BTO schemes – Greenwood, 2007; National Dormouse Monitoring Programme - PTES, 2011) continually input valuable data collected by their local volunteers into nationwide databases such as the National Biodiversity Network (NBN), which allows large-scale trends such as changes in the distribution or abundance of species to be examined (NBN, 2012a).

1.1.2) Large-scale "citizen science" projects: strength in numbers

An increasingly popular way of collecting vast quantities of data rapidly and with minimal effort is to crowd-source interested members of the public. This type of data collection has been named "citizen science" (Irwin, 1995), and is defined as the participation of non-scientists in data collection for scientific investigations (Trumbull *et al*., 2000). Citizen science projects range from submitting photographs or casual sightings of a species, to participating in short and simple surveys in readily accessible locations such as gardens or parks (Figure 1.1). Citizen scientists help to monitor a broad range of taxa (e.g. plants, fungi, earthworms, insects, crabs, fish, mammals, amphibians and reptiles – Dickinson *et al*., 2010). Successful large-scale citizen science projects have helped map the spread of disease and invasive species as well as monitoring range shifts and phenological changes associated with the pressures of climate change or changing land use: detailed examples can be found in many comprehensive literature reviews (e.g. Silvertown, 2009; Dickinson *et al*., 2010; Conrad and Hilchey, 2011; Wiggins and Crowston, 2011; Catlin-Groves, 2012a). Data collected by members of the public have resulted in some of the largest long-term ecological datasets; some have been conducted for over a century. One of the earliest examples is the yearly Christmas Bird Count that was launched by the American Audubon Society in 1900 (Silvertown, 2009). This tradition of contributing ecological records also exists in the UK, and increasing numbers of members of the public are participating in nationwide surveys such as the Royal Society for the Protection of Birds' Big Garden Birdwatch (BGB), which had 600,000 participants in 2012 (RSPB, 2012a) and the Big Butterfly Count, which had over 25,500 participants in 2012 (Butterfly Conservation, 2012).

It should be noted that the terms "volunteer" and "citizen scientist" are often used interchangeably in the literature, and it is likely that some dedicated volunteers might also contribute records to large-scale citizen science projects that are of interest to them. Additionally, even within the same project, participants may be a combination of casual citizen scientists and dedicated, highly skilled, regular volunteers. A good example of this is the BTO's Nest Record Scheme, in which the level of skill and time commitment varies considerably among participants, from dedicated "expert" birdwatchers rigourously searching for nests within the wider countryside, to members of the public submitting casual records for a bird nestbox in their garden (BTO, 2012b; Table 1.1). Not all citizen science projects are unstructured (e.g. the majority of BTO surveys). To simplify the terms used throughout this thesis, volunteers are distinguished from citizen scientists in that they are amateur naturalists who have undergone at least a small amount of training before participating in a project, and they generally submit data regularly over a longer period of time. As a result, they have a higher level of commitment and skill than the typical citizen scientists studied in this thesis, undertaking regular surveys rather than, or in addition to, submitting casual sightings or participating in simple one-off surveys.

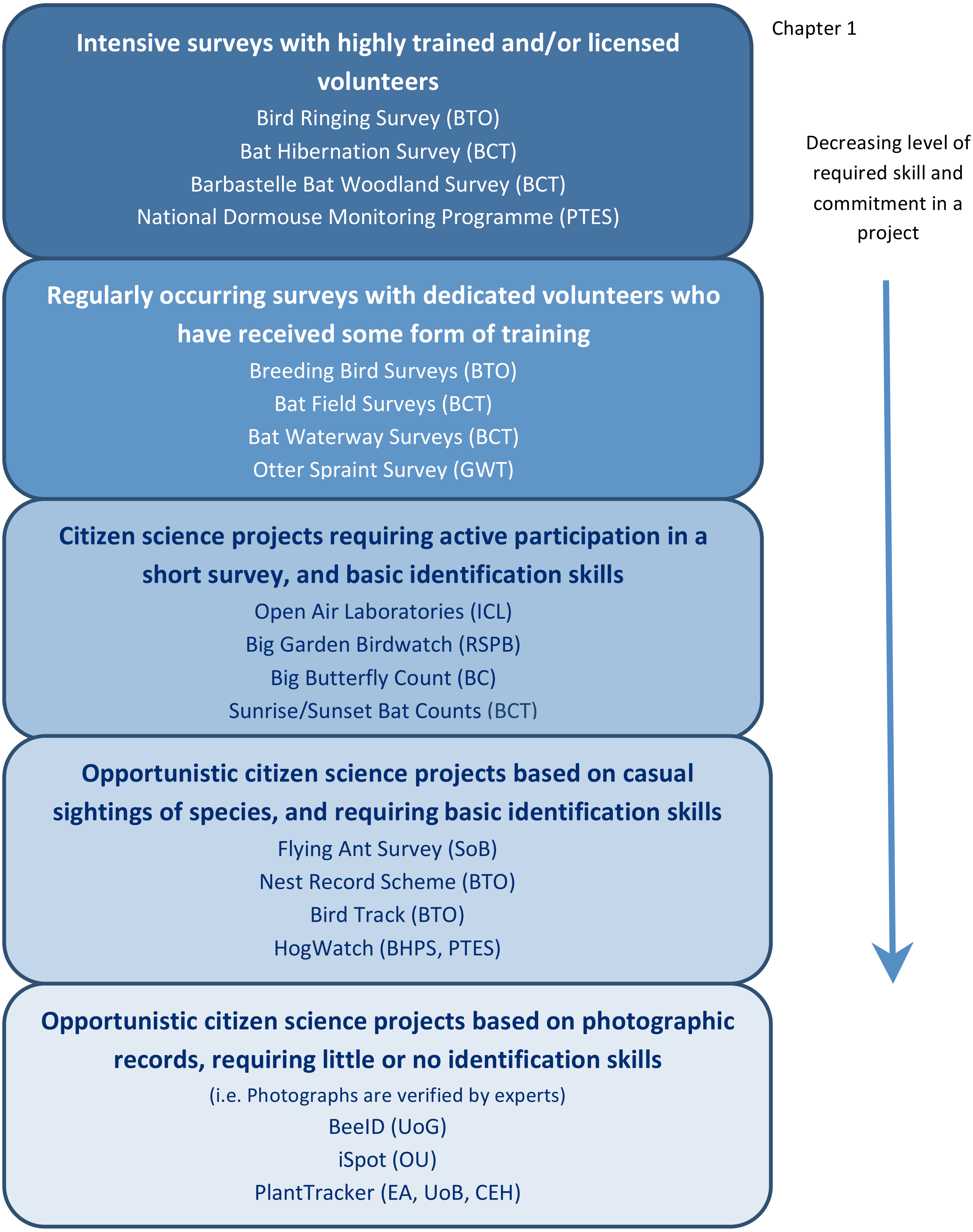


Figure 1.1 – Conceptual illustration of the scale of volunteering according to level of skill and commitment required in various projects (BTO British Trust for Ornithology; BCT Bat Conservation Trust; PTES People's Trust for Endangered Species; GWT Gloucestershire Wildlife Trust; ICL Imperial College London; RSPB Royal Society for the Protection of Birds; BC Butterfly Conservation; SoB Society of Biology; BHPS British Hedgehog Preservation Society; UoG University of Gloucestershire; OU Open University; EA Environment Agency; UoB University of Bristol; CEH Centre for Ecology and Hydrology)

Table 1.1 – Examples of BTO core surveys, classified according to the level of skill and commitment required to participate

Project name	Type of data collected	Training/skill level required	Commitment level
Nest Record Scheme	Usually casual records of nests and number of eggs in them; although records also submitted by dedicated nestbox or nest monitoring schemes	Some identification skills (nests and eggs): often highly variable between volunteers	Records during breeding season
Bird Track	Birdwatching records submitted online (presence/absence)	Fairly good bird identification skills	Casual records at any time of the year
Garden Nesting Survey	Very simple information on birds breeding in gardens	Some identification skills (nests and eggs)	Weekly during breeding season
Garden Birdwatch	Records of birds in gardens	Ability to identify common birds by sight	Weekly throughout the year
Heronries Census	Counts of occupied nests at heron colonies each year (egret nests also recorded)	Ability to identify these two species by sight	Yearly
Breeding Bird Survey (BBS)	Organised survey – Records of birds seen and heard in randomly selected transects (simple habitat data also recorded)	Ability to identify birds by sight, song and call	3 visits (1 to assess habitat and 2 visits during breeding season)
Waterway BBS	Same as BBS but along a watercourse	Ability to identify birds by sight, song and call	3 visits during breeding season
Wetland Bird Survey	Counting the number of birds of each species at a wetland site	Ability to recognise all species of waterbird at selected site. For larger sites, ability to be able to estimate numbers accurately	Monthly (Sept – March)
Ringing Scheme	Marking birds with numbered metal rings	Requires a specific permit to ring independently using mist nets to catch birds	Training for a permit requires, on average, 18 months until suitable skills acquired

1.2) The attributes of volunteer-collected data

1.2.1) Financial, temporal and spatial benefits

In both large and small-scale programmes, one of the biggest advantages to using volunteers or citizen scientists to collect data is that they can greatly reduce the financial cost of research, as monitoring by scientists can be time-consuming and expensive (Crick *et al*., 2003; Schmeller *et al*., 2009; Finn *et al*., 2010; Stafford *et al.*, 2010). The worldwide Convention of Biological Diversity (CBD) relies heavily on volunteers to collect data on the abundance and distribution of species as part of a goal to halt biodiversity loss. France relies solely on volunteers to collect data for CBD and it is estimated that if the volunteers no longer took part, public funding worth between €678,523 and €4,415,251 per year would have to be invested to hire professionals to carry out the work (Levrel *et al.*, 2010). Overall, the EuMon biodiversity monitoring project reported 395 volunteer schemes across Europe in 2007, and these involved more than 46,000 volunteers devoting over 148,000 person-days per year to biodiversity monitoring activities, which represented an estimated annual value of €4 million (Schmeller *et al*., 2009). Ecotourism is a different example of financial support generated by volunteers whereby a financial contribution is made by volunteers in order to participate in biodiversity monitoring projects, helping to fund conservation research as well as providing free labour and collecting data. Growing numbers of fee-paying volunteers are leaving the UK each year to work on global conservation projects (Lorimer, 2010).

Using volunteers to collect data can also shorten the length of time between data collection, publication of results and implementation of management strategies. Danielsen *et al.* (2010) found that involving local volunteers in environmental monitoring schemes increased the speed of decision-making before tackling environmental challenges. The typical turnaround between scientist-collected data and management responses in this study was 3-9 years, whereas volunteer-collected data led to a change in environmental management practices in under a year. Additionally, using large numbers of people to collect data over a short length of time reduces the amount of seasonality in data collection, which is crucial when investigating seasonal or temporal effects such as the effects of climate change on phenology. For example, Davis and Howard (2005; 2009) used citizen science data to examine the autumn migration and spring recolonisation rates of monarch butterflies (*Danaus plexippus*).

Citizen science is thought to be effective at finding rare organisms or for monitoring species in decline (Losey *et al*., 2007; Dickinson *et al*., 2010). This is because having a large workforce spread over a large geographical area can increase the rates of detection in comparison to lone researchers, despite these individuals having greater expert knowledge (Lukyanenko *et al*., 2011). In recent times, this has been facilitated by the development of smartphone technology with the possibility of GPS and data upload, which means that records can be logged instantly and accurately (Aanensen *et al*., 2009; Catlin-Groves, 2012b). Additionally, volunteers and citizen scientists can collect data on private land (e.g. gardens) that would be very difficult or impossible to survey conventionally with professionals due to access restrictions (Carter *et al.,* 2004; Toms and Newson, 2006; Baker and Harris, 2007).

These benefits are not limited to large-scale citizen science projects, as small teams of volunteers can also overcome spatial constraints by collecting ecological data that are fed in to large-scale national databases. A particular benefit of using dedicated volunteers to collect data is that these individuals are often willing to travel considerable distances to specific target sites to collect data (Weston *et al*., 2003), and this ensures that appropriate sampling procedures can be followed. Examples of this include the BTO Breeding Bird Surveys, which are regular surveys carried out by volunteers at designated sites (BTO, 2012b), teams of dormouse monitors participating in the National Dormouse Monitoring Programme in local woodlands (PTES, 2011), and Bat Conservation Trust volunteers travelling to lakes and lochs to survey Nathusius' pipistrelles *Pipistrellus nathusii* (Bat Conservation Trust, 2012b).

1.2.2) Contributions to science

The contributions of volunteer-collected data and citizen science data to research are undeniable; a recent literature search resulted in the location of over 300 peer-reviewed publications resulted from citizen science data and the trend has been increasing rapidly in the past few years (Catlin-Groves, 2012a). Even within single projects, there can be multiple publications investigating different topics using the same dataset (e.g. the Audubon Society's Christmas Bird Count: Root, 1988; Repasky, 1991; Canterbury, 2002; Link *et al*., 2008). Similarly, since the BTO's Nest Record Scheme was founded in 1939, over 250 scientific publications have used data collected through this scheme, analysing various aspects of basic bird breeding biology and performance, population dynamics, and causes of population declines in the UK (Crick *et al*., 2003). Several studies show that volunteer-collected data can be as accurate as data recorded by scientists (e.g. Foster-Smith and Evans, 2003; Schmeller *et al.*, 2009; Finn et al., 2010; Newman *et al*., 2003; Kremen *et al.*, 2011). For example, from 1,342,633 bird records in "Project FeederWatch", only 0.02% (378) were questioned due to uncertainty, and out of these, 54% (158) were rapidly confirmed and 16% (45) were corrected, leaving only 30% (88)

that had to be removed from the dataset due to the impossibility of confirming these (Dickinson *et al.*, 2010). Within very large datasets, small numbers of errors or "noise" would have little or no effect on the overall results because statistical power is a function of sample size (Catlin-Groves, 2012a).

However, even in small-scale projects using groups of volunteers, reliable data can be produced if the projects are carefully devised and managed. Finn *et al*. (2010) found that the visual estimation of percentage seagrass cover by community-based volunteers in Moreton Bay, Australia, was highly correlated with that of scientists and could therefore be used as a reliable source of baseline information about seagrass in the area. Foster-Smith and Evans (2003) found that volunteers were capable of performing straightforward tasks, such as learning to identify species, recording their occurrence and measuring the length of gastropods. They found that while volunteers made some recording errors during the fieldwork, experienced scientists also made similar errors. Similarly, Kremen *et al.* (2011) found that volunteers were able to record and classify insects visiting flowers at the resolution of orders or super families, and that volunteer and professional data reflected similar trends in abundance and species richness, as well as similarities and differences between sites. Clearly, in some contexts, volunteer-collected data can have as much value as data collected by professionals if projects are carefully managed.

1.2.3) The wider benefits of volunteering: public engagement, education, health and wellbeing

Many volunteer and citizen science projects incorporate an element of public education, striving to encourage participants to learn about the organisms they are observing and the process by which scientific investigations are conducted (Foster-Smith and Evans 2003; Cohn, 2008; Bonney *et al*., 2009). As such, they also have the potential to increase public engagement and awareness of conservation issues (Cannon *et al*., 2005; Schmeller *et al*., 2009), and this, in turn, has delivered opportunities for arguments in favour of greater species and habitat protection (Simmonds, 2000; Greenwood, 2007). Weston *et al*. (2003) reported that most of their volunteers were employed or in education but were also members of conservation or natural history groups. This indicates a key interest in conservation, and indeed, this was their main reason for volunteering; most volunteers also considered habitat conservation of primary importance. Newman *et al*. (2003) found that at least 30% of their volunteers joined conservation organisations as a result of volunteering on their mammal research project.

The benefits of volunteering are not limited to promoting scientific research and improving conservation practices. Indeed, the act of volunteering may also have a therapeutic effect on the participants, and has the potential to provide a shared purpose for people (Fraser *et al.*, 2009; O'Brien *et al.*, 2011). Meaningful interactions with the natural world have the potential to enhance human well-being (Miller, 2005), and individuals often reported that volunteering gave them a sense of wellbeing and fulfilment (Newman *et al*., 2003). Koss *et al.* (2009) found that the prime motivation for participation in a volunteer programme was to assist with scientific research, followed closely by wanting to work close to nature. This indicates that there are wider benefits to encouraging people to volunteer to collect ecological data, and these should be an important consideration when recruiting volunteers and maintaining participation.

1.3) The limitations of volunteer-collected data

1.3.1) Observer error: misidentification and false absences

While citizen science or volunteer-collected data are highly useful, they are also often questioned by scientists because methods used to collect them may lack the rigour of conventional scientific studies (Irwin, 1995; Catlin-Groves, 2012a). This can lead to errors, inconsistency and bias. In some instances, surveys by professionals may be more reliable (e.g. Croxton *et al*., 2006). One of the most serious errors is the misidentification of species (e.g. deer droppings and badger latrines – Newman *et al*., 2003; amphibian calls - Genet and Sargent, 2003; visual identification of amphibians – de Solla *et al*., 2005; invasive species – Fitzpatrick *et al*., 2009), and this can result in false positives, whereby species have been erroneously recorded as present (Fitzpatrick *et al*., 2009). Misidentification may occur either directly through observation, or indirectly through photographs. Stafford *et al.* (2010) found that identification of bees was not possible from all photographs taken by citizen scientists, even when passed on to bee experts, especially when photographs excluded lower abdomen detail, and these records had to be omitted.

False absences are another source of error in volunteer-collected data. These occur when species are recorded as absent when they are, in fact, present (Hof, 2009; Stafford *et al*., 2010; Sewell *et al.* 2010; Kremen *et al*., 2011; Bois *et al*., 2011) and this limits the quality of the data, especially when attempting to map species' distributions (Brotons *et al*., 2004). Sewell *et al.* (2010) found that when volunteers carried out simple presence-absence surveys as part of the National Amphibian and Reptile Recording Scheme (NARRS), there were significant issues over false absences and subsequent data interpretation. Similarly, Kremen *et al.* (2011) found that volunteers missed half of the bee groups recorded by professional scientists at the same sites. However, false absences are difficult to verify because proof of absence is relatively difficult to obtain (Sewell *et al*., 2010). This is why absence data are often overlooked in citizen science projects that rely on members of the public submitting observations of a particular species (presence-only data) rather than using rigorous scientific sampling methods to record absence as well as presence, which can lead to bias (Pearce and Boyce, 2006).

1.3.2) Inconsistencies within datasets and incomplete records

Inconsistencies are common in both volunteer- and citizen scientist-collected data. For example, in the National Dormouse Monitoring Programme, in which records vary greatly in quality and quantity between sites across the UK (S. Sharafi, PTES, pers. comm.). In addition, Crick *et al*. (2003) state that the information recorded on Nest Record Cards (NRCs) through the BTO's NRS is generally incomplete. For example, nests are often found after the first egg has been laid (such that the lay date is unknown), volunteers may cease to visit nests before the young have fledged, and nest visits are often relatively infrequent. As a result, nesting success has to be estimated with special techniques due to a lack of information on individual NRCs, and some records have to be omitted because of uncertainty (Crick *et al*., 2003). Note that incomplete data can also occur in professional studies, for example, due to a species' detectability.

1.3.3) Geographical and temporal bias

Geographical and temporal bias may also influence volunteer-collected data (Bonter and Cooper, 2012); this is perhaps most apparent in large-scale citizen science data that are collected in an *ad hoc* manner rather than following a carefully designed survey. As mentioned previously, organisations can ask their dedicated volunteers to travel to specific sites and to follow a particular sampling regime, whereas citizen science data are usually opportunistic (i.e. asking members of the public to collect data while they happen to be in a particular area). This often results in citizen science data being clustered around urbanised areas (e.g. PTES and BHPS, 2007). Cooper *et al*. (2012) caution that that observations by citizen scientists may be biased towards the detection of birds at bird feeders. Sparks *et al.* (2008) found that volunteer recorders were biased towards recording bird arrival dates at weekends rather than on weekdays ("the weekend effect"), and this could affect the accuracy of phenological records and the detection of changes and responses to temperature. Bloomfield and Solandt (2006) state that the number of casual reports of surface sightings of basking sharks in the UK, and thus the accuracy of the data, depended on the number of potential observers present in an area. Furthermore, public participation was dependent on weather conditions, public holidays, dedicated surveys and the level of promotion of the scheme. Bias may also be increased due to variable levels of interest in the species. However, even if volunteers are recording a subset of what would be recorded by more experienced professionals, as long as their recording effort and the detectability of the species is consistent over time then temporal trends may still be revealed. These need to be disentangled from trends that could be an artefact of using non-systematically collected data that is subject to unequal sampling effort over time.

1.3.4) Inter-observer variability

The very nature of collecting data using a large number of individuals raises the issue of inter-observer variability. To become more widely accepted as a valuable research tool, citizen-science projects must find ways to ensure that data gathered by large numbers of people with varying levels of expertise are of consistently high quality (Bonter and Cooper, 2012). Many studies have examined this issue across a wide range of topics (e.g. animal biometric measurements – Goodenough *et al.*, 2010; 2012; plant species abundance – Simpson, 1940; habitat research – Sykes *et al.*, 1983; Gotfryd and Hansell, 1985; Block *et al*. 1987). Recently, there is a growing focus on the importance of inter-observer variability among volunteers and citizen scientists (e.g. Fitzpatrick *et al.*, 2009). Indeed, Foster-Smith and Evans (2003) reported that volunteer assessments of abundance for some species surveyed were inconsistent and some individuals interpreted scale in different ways. This was due to (1) a lack of field experience in the volunteers; (2) inadequate guidelines on the use of the abundance scale; and (3) insufficient training before field surveys commenced (Foster-Smith and Evans, 2003). However, it may be possible to take inconsistencies into account to allow population trends to be detected. Indeed, using models to test the effect of experience on individuals' ability to record data with the BTO's Breeding Bird Survey data showed that there was no consistent first-time observer-experience effect across species, and the authors concluded that including observer experience in population models is unlikely to improve population estimates (Eglington *et al.*, 2010). It is clear that, while some effects of inter-observer variability may be reduced by careful training and modelling, the issue is made increasingly difficult to quantify because of the interaction of a range of different socio-economic factors such as age and education, which may also influence an individual's ability to collect data (e.g. Newman *et al.*, 2003; Dickinson *et al.*, 2010). Furthermore, people from socio-economically deprived areas are under-represented in recording schemes at both national and local levels, and measures should be taken to facilitate participation because of the positive impact that this can have on the participants' wellbeing (Hobbs and White, 2012).

1.4) The importance and difficulty of verifying volunteer-collected data

The important attributes of citizen science and volunteer-collected data outlined above make it very worthwhile to invest a considerable amount of time and effort in studying the limitations and constraints of such data so that these can be allowed for in analysis, reduced at source or even, ideally, eliminated. Indeed, in order for volunteer-collected and citizen science data, and the results of studies using these data to be more widely accepted by scientists, it is crucial that they are verified to assess their reliability (Catlin-Groves, 2012a). Recently, some organisations have been developing mechanisms to verify citizen science data with the help of experts, for example by telephone interview or by requesting photographic evidence (e.g. Vliegenthart and Bekker, 2012) or by weighting data according to their reliability (e.g. NBN, 2012a). However, these processes are only possible where there are 'gatekeepers' to filter the information, and this may not be possible on a global scale (Catlin-Groves, 2012a), or where time and funding are lacking.

Preliminary data 'cleaning' or 'scrubbing' may help to remove obvious outliers (Rahm and Hai Do, 2000), and this can be facilitated using automatic filtering with specialist software (e.g. Bonter and Cooper, 2012). Statistical modelling may help to circumvent issues with large citizen science datasets, for example, by modelling presence-only data to predict species distributions because of a lack of absence data (e.g. Zaniewski *et al*., 2002; Brotons *et al*., 2004; Pearce and Boyce, 2006; VanDerWal *et al*., 2009). Other methods are also being developed in order to overcome geographical bias, for example, with the use of smartphone GPS software that allows records to be verified (e.g. Aanensen *et al*., 2009; Catlin-Groves, 2012b). Observer effects can also be allowed for statistically, for example through use of random factors in mixed models (Zuur *et al*., 2009). It should be noted that the difficulty of verifying data is not solely applicable to large-scale citizen science projects; even in small-scale volunteer projects where it should theoretically be easier to verify data, it remains rare for volunteer work to be reported in the 'Methods' sections of publications, and even rarer for its effectiveness to be calibrated or validated (Newman *et al*., 2003). Furthermore, scientific research using professional data also encounters similar issues (such as inter-observer variability - Goodenough *et al*., 2010; 2012), such that lessons learnt from volunteer-collected data may have even wider relevance in the scientific community.

1.5) Research outline

1.5.1) Aims and scope

The research undertaken in this thesis investigates some of the important attributes and limitations of citizen science and volunteer-collected data described above, with a focus on the importance of verifying those data and the methods used to collect them, as well as using the data to uncover new findings about the study species. Topics covered aimed to assess: (1) the use of simple methods to collect habitat data, (2) problems of, and potential solutions to inter-observer variability in ecological studies, (3) long-term volunteer datasets, (4) the feasibility of using citizen scientists to collect behavioural data, (5) the accuracy of citizen science data, (6) the potential of harnessing social media to collect citizen science data and (7) the issue of false absences in a species that is difficult to detect due to its nocturnal and secretive habits.

This thesis relied on high volunteer participation rates in order to collect a sufficient quantity of data for analysis, so it was important to choose species that would appeal to members of the public. Charismatic or flagship species are often used to promote wider biodiversity conservation (Kontoleon and Swanson, 2003). Science communication is heavily biased towards mammals (Barua, 2011) and mammals are the most popular class in zoos (Moss and Esson, 2010). For these reasons, four charismatic mammal species of conservation concern were selected for the case studies in this thesis (water voles *Arvicola amphibius*; dormice *Muscardinus avellanarius*; North American river otters *Lontra canadensis*; hedgehogs *Erinaceus europaeus*). It is probable that charismatic species are over-represented in citizen science studies, but this issue is beyond the scope of this thesis.

1.5.2) Thesis structure

The research involves a series of case studies, and is structured according to the level of skill and commitment required of the participants in each project (Figure 1.2).

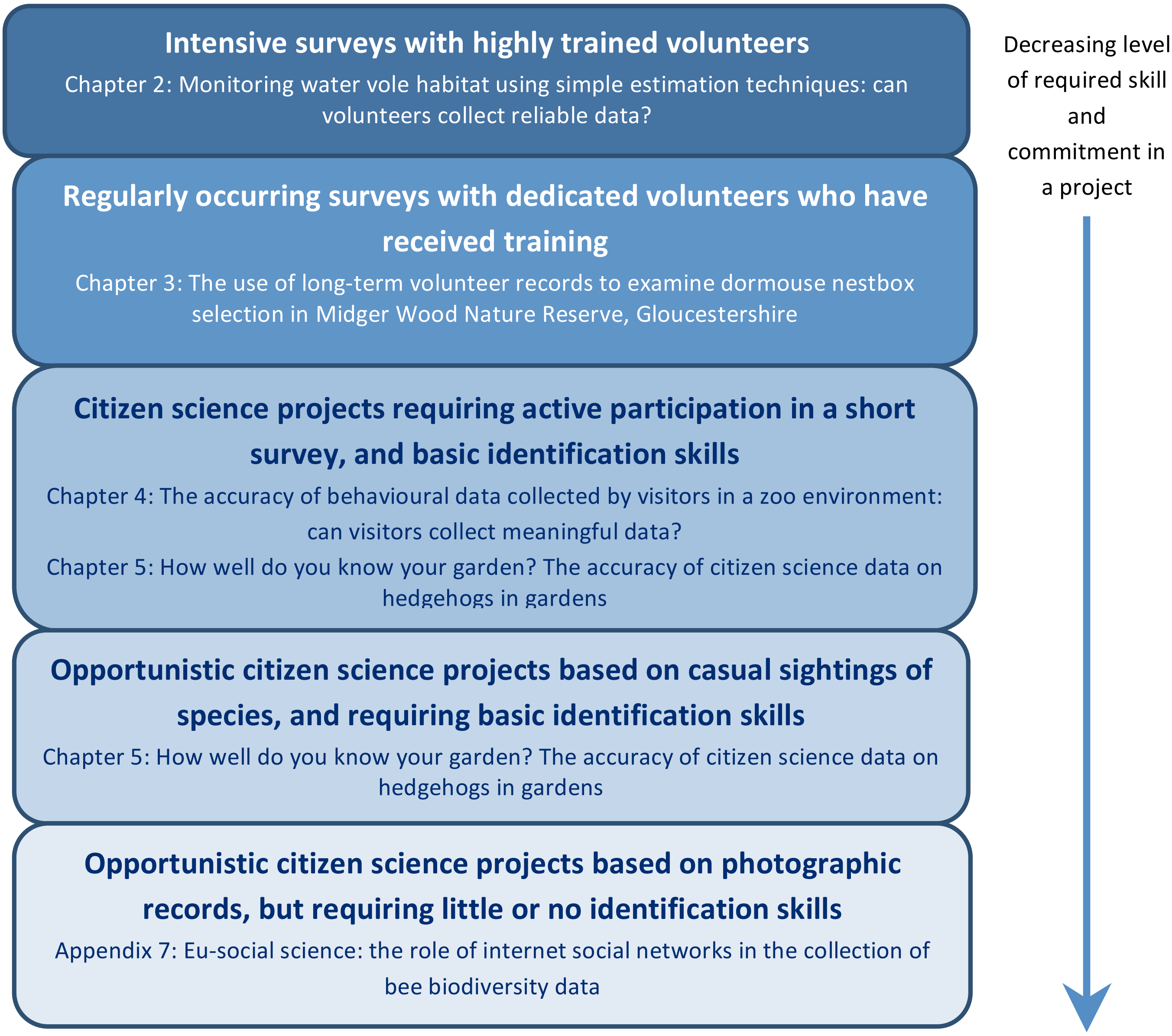


Figure 1.2 – Conceptual illustration of the scale of volunteering according to level of skill and commitment required for the projects in this thesis

This thesis is divided into seven chapters, which are outlined below:

Chapter 1 (this chapter) has provided an overview of the different scales of volunteer and citizen science projects, along with their attributes and limitations.

Chapter 2 investigates the effectiveness of using simple scales and ocular estimates to assess water vole *Arvicola amphibius* habitat, then explores whether inter-observer variability would present an issue if such methods were used by a group of volunteers.

Chapter 3 assesses the usefulness of a long-term volunteer dataset to examine dormouse *Muscardinus avellanarius* nestbox selection and discusses some of the strengths and weaknesses of using such datasets.

Chapter 4 assesses the accuracy of citizen scientist-collected behavioural data by asking visitors at a wetland centre to record the behaviour of a group of captive North American river otters *Lontra canadensis*. Various factors that could have influenced their ability to collect data (e.g. age, previous experience, personal interests) are also examined.

Chapter 5 examines citizen science data on hedgehogs *Erinaceus europaeus* in gardens using an online questionnaire. It investigates hedgehog habitat associations and aims to verify the accuracy of presence/absence data.

Chapter 6 provides a summary of the findings made throughout this thesis and offers avenues to explore in the future.

Appendix 1 contains the instructions given to students as part of Chapter 2
Appendix 2 contains the publication resulting from Chapter 3:
Williams, R.L., Goodenough, A.E., Hart, A.G., and Stafford, R. (2013) Using long-term volunteer records to examine dormouse (*Muscardinus avellanarius*) nestbox selection, *PLoS One*, 8, e69986
Appendix 3 contains the publication resulting from Chapter 4:
Williams, R.L., Porter, S.K., Hart, A.G., Goodenough, A.E. (2012) The accuracy of behavioural data collected by visitors in a zoo environment – Can visitors collect meaningful data? *International Journal of Zoology*, Article ID 724835
Appendix 4 contains the questionnaire handed out to visitors as part of Chapter 4
Appendix 5 contains the segmentation questionnaire handed out to visitors as part of Chapter 4
Appendix 6 contains the hedgehog footprint tunnel instructions part of Chapter 5
Appendix 7 consists of the publication resulting from previous research on citizen science, and that is relevant to this thesis:
Stafford, R., Hart, A.G., Collins, L., Kirkhope, C.K., **Williams, R.L**., Rees, S.G., Lloyd, J.R. and Goodenough, A.E. (2010) Eu-social science: the role of internet social networks in the collection of bee biodiversity data, *PLoS One*, 5, e14381

Chapter 2: Monitoring water vole habitat using simple estimation techniques: can volunteers collect reliable data?

Abstract

Volunteers present numerous benefits for conservation organisations, often collecting vast quantities of data and alleviating financial restrictions. However, in most studies, volunteers collect little or no habitat data while recording species presence or abundance. Knowledge of habitat requirements is crucial for devising effective conservation strategies, especially for declining species such as the water vole (*Arvicola amphibius*). In this study, river habitat data were collected by an experienced professional using ordinal scales and visual estimates at sites where water voles were known to be either present or absent. Several features correlated with water vole presence, including plant species associated with food and cover (e.g. meadowsweet, willowherb, grasses) and deep, fast flowing water. These findings reflect associations found in other studies using precise measurements, and, using a subset of habitat variables, sites could be classified as supporting or not supporting water voles with 87% accuracy. Encouraging volunteers to collect simple habitat data in this way should be beneficial. However, when estimates made by a group of students (acting as proxy volunteers) were compared to data collected simultaneously by a professional, inter-observer variability was high and mean student estimates varied from the professional's estimates. The implications of these findings are discussed along with recommendations for reducing inter-observer variability.

Water vole habitat in Gloucestershire

2.1) Introduction

Volunteers often generate vast quantities of data that are useful for monitoring large-scale changes in numbers and distributions of species (e.g. National Dormouse Monitoring Programme, NDMP, run by the People's Trust for Endangered Species, PTES, and Big Garden Birdwatch, BGB, run by the Royal Society for the Protection of Birds, RSPB). Indeed, Dickinson *et al.* (2010) quantify data collected by volunteers as "indispensable" for the study of macroecology (relationships between organisms and their environment over broad spatial scales). Although some volunteer-based projects such as the Breeding Bird Survey (BBS) do generate environmental data, most data usually comprise basic assessments such as recording the type of habitat by assigning it to a predefined category (e.g. Crick, 1992). Instructions for these tasks, such as "please complete as much detail as you feel able" (BTO, 2012c), highlight the limitation imposed by the varying ability of the volunteers to record habitat data. During the NDMP survey in Gloucestershire, UK (See Chapter 3), volunteers recorded very little habitat data alongside monthly dormouse nestbox records and these data were very irregular despite PTES requesting information about the surrounding habitat at five-year intervals (S. Sharafi, PTES, pers. comm.). This meant that potential insights into dormouse habitat requirements and the effectiveness of habitat-based conservation and management strategies were limited at this site (pers. obs.). If volunteers could collect habitat data at an appropriate level of detail while they conduct routine surveys, this may prove useful for monitoring changes in habitats and species-habitat interactions over time.

Subjective estimations based upon scales such as DAFOR (Dominant, Abundant, Frequent, Occasional and Rare) or numerical ranks are widely employed in ecological studies, for example, to determine vegetation coverage (Hope-Simpson, 1940; Hatton *et al.*, 1986; Avila, 2002; McCrea, 2004; Agea *et al*., 2007; Affre *et al*., 2009) and to standardise results between surveys. One practical benefit of using such scales is that sites can be surveyed rapidly, which is beneficial when trying to minimise the amount of seasonal change during a survey, as well as providing logistical and financial benefits (McCrea *et al*., 2004). Additionally, these simple scales might be appropriate for volunteer data collection as they reduce the need for training and specialist equipment (Foster-Smith and Evans, 2003; Helm and Mead, 2004; Brightsmith *et al.*, 2008). Simple scales do not require expert botanical knowledge (Crick, 1992) and protocols that are too rigid, demanding or labour intensive have been shown to decrease volunteer participation (Dickinson *et al*., 2010). However, one of the most contentious issues with volunteer-collected data is their reliability, and, as such, collecting data using subjective estimates rather than objective measurements might create further problems for the reliability of the data.

Habitat selection is likely undertaken by the majority of species (e.g. dormice *Muscardinus avellanarius* - Morris, 1991; prairie voles *Microtus ochrogaster* - Solomon *et al*., 2005; harvest mice *Micromys minutus* - Kuroe *et al*., 2007; hole-nesting birds - Goodenough *et al*., 2009; great bustards *Otis tarda* - Magana *et al*., 2010). Knowledge of species-habitat interactions is of utmost importance from an applied perspective, for example, in assessing the effects of human activity on various species and for devising effective conservation strategies (Crick, 1992). However, collecting such data can be time consuming and expensive (Schmeller *et al*., 2009; Stafford *et al*., 2010). This is especially true for riparian mammals such as otters (*Lutra lutra*) and water voles (*Arvicola amphibius*), where populations are widely dispersed and their habitat is often only accessible by boat (Rushton *et al*., 2000; Tansley, 2009; Melis *et al*., 2011). Water voles have been in decline in the UK since 1900 and their decline has been accelerating in recent times, resulting in extirpations in some areas (Barreto and MacDonald, 2000; Carter and Bright, 2003; Moorhouse, 2004) (see Box 2.1). Reasons for the decline include loss and fragmentation of suitable habitat leaving water vole populations highly vulnerable to the impact of depredation by invasive American mink (*Neovison vison*) (MacDonald and Strachan, 1999; Carter and Bright, 2003). Knowledge of habitat requirements is therefore essential for safeguarding water voles and for conducting successful reintroductions (Moorhouse, 2004). Conservation organisations such as Gloucestershire Wildlife Trust (GWT) train volunteers to record water vole field signs in order to monitor the distribution and abundance of the species in the county of Gloucestershire; however, these volunteers do not collect habitat data simultaneously (J. Field, GWT, pers. comm.).

In this study, water vole habitat relationships will be examined using estimates of variables recorded by an experienced professional (the author, RLW) to determine whether any associations agree with previous research that has used actual measurements, in order to test the validity of using estimates. The effect of inter-observer variability will then be studied by comparing estimates taken by a group of biology students who have received basic training against data collected simultaneously by RLW in order to establish whether simple methods can be replicated to provide accurate and reliable data.

Box 2.1) Water voles *Arvicola amphibius* (Information synthesised from: Arkive, 2012; NBN, 2012b; JNCC, 2012; PTES, 2012 – for illustration credits see page 161)

Kingdom: Animalia	Phylum: Chordata	Class: Mammalia
Order: Rodentia	Family: Muridae	Genus: *Arvicola*

Physical description Body 140-220 mm; tail 95-140 mm; weight 150-300 g (largest British vole). Water voles have chestnut brown fur, a blunt muzzle, and small black eyes. Their ears are rounded and almost hidden in their fur and their tail is dark and slightly furry. Entrances to burrows can often be identified by a 'lawn' of cropped grass around the hole; territorial latrines can be found close by during the breeding season.

Water vole

Behaviour Mainly diurnal. In winter, a female, her daughters and unrelated males share a communal nest, but they do not hibernate.

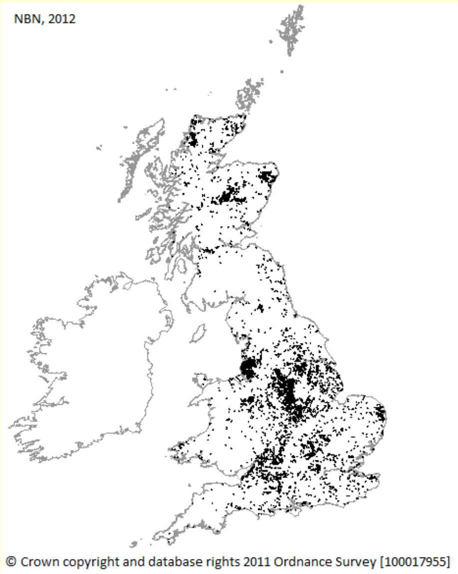
Breeding Young reach sexual maturity after their first winter. Breeding season is April – September, and water voles produce one to five litters per year. Litters usually contain three to seven pups.

Diet Consume up to 80% of their bodyweight each day feeding on grasses, sedges, rushes, watercress, roots, tree bark and fruit.

Habitat Generally restricted to lowland areas beside water. They live in complex burrow systems, and are found on densely vegetated or grassy banks along slow moving rivers, ditches, lakes, ponds, fens, swamps and marshland.

Predators and threats Owls, stoats, herons, pike and cats predate water voles; but the most serious predatory threat is the American mink *Neovison vison*, thought to be responsible for several local extirpations of water voles. Habitat loss and fragmentation, riverbank modification, drainage and flood defence works, pollution of waterways and poisoning by rodenticides also affect water voles.

Distribution Widely distributed throughout Europe from Eastern Siberia to the UK. They are found throughout England, Wales and Scotland but not in Ireland, and they are absent from most islands except Anglesey and the Isle of Wight (see below).



Status and conservation efforts IUCN Red List: Least Concern. Protected under: Wildlife and Countryside Act 1981. UK Biodiversity Action Plan priority species. In the UK, numbers are thought to have declined by 88% and water voles have disappeared from 94% of sites where they were previously found.

Public involvement Most famous of the British voles - portrayed in Kenneth Grahame's Wind in the Willows as “Ratty”. There are currently no known citizen science surveys involving water voles although wildlife organisations do recruit volunteers to survey riverbanks for signs of water vole activity.

2.2) Methods

2.2.1) Data collection

2.2.1.1) Water vole records

Data on the presence and absence of water voles on watercourses in Gloucestershire, UK, were obtained from the Gloucestershire Wildlife Trust (GWT). These data had been collected during detailed surveys conducted yearly between 2009 and 2011 by a professional ecologist who was assisted by a group of trained volunteers. These volunteers underwent a formal training day to enable them to identify indirect signs of water vole presence (latrines, footprints and food remains), and were accompanied by the professional ecologist until they felt confident enough to work on their own and the professional was satisfied with their ability to carry out the work to a suitable standard, ensuring that the data collected were reliable (J. Field, GWT, pers. comm.). The surveys were conducted on main rivers, ordinary watercourses (smaller than main rivers – Environment Agency, 2012), drainage ditches and wetland sites. However, because of pronounced differences between linear watercourses and two-dimensional wetlands (Moorhouse, 2004), wetlands were excluded from the current study. Drainage ditches were also excluded because they were too difficult and/or dangerous to access to collect habitat data.

GWT divided watercourses into stretches measuring an average of 387 m (range 100-810 m) based on local landmarks, and recorded water vole signs as present, absent or inconclusive. Stretches where water vole signs had been recorded as inconclusive were excluded from the current study because it was impossible to ascertain whether water voles were actually present at these stretches. These exclusions left 21 stretches that had indirect evidence of water vole presence. However, some of these were inaccessible so the final number of stretches was 10 (termed WV stretches). These were located on the River Cam, the Wickster's Brook (a tributary of the River Cam), the Ozleworth Brook and Dyer's Brook (two tributaries of the Little Avon River) as well as on some smaller tributaries of these watercourses (See Figure 2.1). Water voles are on the Gloucestershire Biodiversity Action Plan (BAP) and these rivers are thought to be particularly important to the population (Gloucestershire Biodiversity Partnership, 2012).

Figure 2.1) Map of Gloucestershire showing the watercourses used in this study (River Cam, Wickster's Brook, Ozleworth Brook and Dyer's Brook). Modified and adapted after Environment Agency (2009) "Severn tidal tributaries catchment flood management plan – Summary report December 2009" Contains Environment Agency information © Environment Agency and database right

2.2.1.2) Riverbank surveys

Table 2.1) Methods for data collection (DAFOR scale*: Dominant >75% cover, Abundant ~ 50% cover, Frequent ~ 25% cover, Occasional ~ 10% cover and Rare ~ 5% cover, as per Avila *et al.*, 2002)

	Keys/details on data collection
DAFOR trees and saplings	DAFOR scale*
DAFOR shrub layer	As above. Shrubs were any woody vegetation that could not be walked through
DAFOR field layer	As above. Field layer was defined as non-woody vegetation, at knee-height or above, that could be walked through
DAFOR herb layer	As above. Herb layer was defined as non-woody vegetation that could be walked on (i.e. ankle-height or below)
DAFOR submerged plants	As above. Plants fully underwater or floating on surface
DAFOR emergent plants	As above. Plants growing out of the water
DAFOR rushes (Juncacae)	As above
DAFOR sedges (Cyperaceae)	As above
DAFOR reeds and grasses (Poales)	As above
DAFOR herbaceous plants	As above (herbaceous = any non-woody plants)
DAFOR nettles (Urtica spp.)	As above
DAFOR yellow flag iris (*Iris pseudacorus*)	As above
DAFOR willowherb (Epilobium spp.)	As above
DAFOR meadowsweet (*Filipendula ulmaria*)	As above
DAFOR Himalayan balsam (*Impatiens glandulifera*)	As above
DAFOR duckweed (Lemnoideae)	As above
Canopy overhang	Estimated according to the amount of likely shade over the riverbank on a scale of 0 – 5 with 0 = none and 5 = very heavily shaded
Bank angle	Estimated based on 0 – 4 scale with 0 = flat, 1 = approx. 23 degrees, 2 = approx. 45°, 3 = approx. 68° and 4 = 90° (vertical)
Water depth	Estimated based on 0 – 3 scale with 0 = no water, 1 = shallow (ankle deep), 2 = medium (between ankle and knee) and 3 = deep (above knee deep)
Flow	Estimated based on 0 – 3 scale with 0 = no water or stagnant, 1 = slow (hard to tell if water is moving), 2 = medium (water moving quite noticeably), 3 = fast (ripples visible). This was based on observation of detritus etc. in the current
Path	Presence (1) or absence (0) of path within 20m of riverbank
Road	As above
Fence	As above

The 10 WV stretches were paired with 10 stretches that had no indirect evidence of water vole presence (non-WV stretches). Pairs were as close as possible to one another and on the same watercourse or a tributary up to a maximum distance of 1.6 km (this followed the "nearest neighbours" principle as per Lawton and Woodroffe, 1991). Water voles are heavily reliant on connectivity between sites (Moorhouse, 2004), and this distance is justified by previous research where water voles were studied over a 1.6 km stretch of river, indicating that WV can travel that distance (Woodall, 1993). The purpose for this pairing was to ensure that there were water voles in the vicinity of non-WV stretches, and that aspects of the habitat of the non-WV stretches were preventing occupation by water voles, rather than these areas being outside of the species' current range, despite having potentially suitable habitat.

To account for habitat variability within a stretch, each stretch was divided into five mutually exclusive, randomly selected sites (selected at random distances within the limits of the predetermined length of each stretch). Each site was 5 m long and covered the width of the riverbank, from the top of the bank to the water's edge. Habitat data were collected at 100 sites in total (20 stretches * 5 sites within each stretch), according to simple pre-defined scales or presence/absence of certain features (Table 1.1). Simple scales such as DAFOR (Dominant, Abundant, Frequent, Occasional or Rare) have been used in previous studies as a suitable means of rapidly assessing cover of different plant species (Avila, 2002; McCrea, 2004; Agea *et al*., 2007; Affre *et al*., 2009). Although habitat data collection occurred two years after the water vole survey began, GWT confirmed that water voles were still present at the same sites through continual monitoring (J. Field, GWT, pers. comm.).

2.2.1.3) Verification of inter-observer variability

A 15-minute training session was given to a group of 39 first year undergraduate biology students next to the River Wye, Monmouthshire, UK (note: this was in a different area to that used for the main water vole study but was potentially suitable water vole habitat, however no conclusions can be drawn about the presence or absence of water voles based on the data collected at this site). Students were instructed on how to use estimates to survey features of a riverbank with the aim of assessing water vole habitat suitability. An example site was set up (5 m long and covering the width of the riverbank, from the top of the bank to the water's edge) so that the methods could be demonstrated. Detailed handouts were given to all students with descriptions of each variable to estimate along with illustrations and photographs to aid the identification of key species, as appropriate (see Appendix 1). All variables were estimated without the use of any equipment, such that the methods were identical to those described above (see Methods). Students were told to record the data individually without discussing or sharing them so that inter-observer variability could be measured. Students then collected data at 10 sites randomly marked out along a 200 m stretch of river. An experienced professional (RLW) collected data simultaneously at the same sites for comparison, producing a baseline value for each variable at each site (these values are henceforth referred to as the "actual" data).

2.2.2) Data analysis

2.2.2.1) Riverbank data

A nested MANOVA was run using the Wilks-Lambda method to determine whether differences occurred between the overall habitat at WV and non-WV sites, and at a larger scale, to determine whether differences occurred between WV and non-WV stretches. Prior to the test, all data were linearly transformed to a proportional scale between 0 and 1:

DAFOR scale	0 – 5 Scale	0 – 4 Scale	0 – 3 scale	Present/Absent
Absent = 0	0 = 0	0 = 0	0 = 0	Absent = 0
Rare = 0.2	1 = 0.2	1 = 0.25	1 =0.33	Present = 1
Occasional = 0.4	2 = 0.4	2 = 0.5	2 = 0.66	
Frequent = 0.6	3 = 0.6	3 = 0.75	3 = 1	
Abundant = 0.8	4 = 0.8	4 = 1		
Dominant = 1	5 = 1			

Data were then arcsine transformed before analysis. A series of nested ANOVAs were then run as post-hoc tests to determine which specific variables differed between stretches with WV and non-WV classifications, as recommended by Crawley (2005).

Finally, discriminant function analysis (DFA) was used to determine the proportion of sites that could be correctly classified using the measured variables. The DFA was run using the Wilks' Lambda method, and the classification power of the DFA was ascertained using a jackknife cross-validation procedure, such that the model was repeatedly calculated with the omission of a different single case, which was then classified (Shaw, 2003). In this way, power was tested for each data point by a model that was not created using that data point. This procedure was used as the comparatively small sample size precluded the use of the preferred split-sample validation process (McGarigal *et al*., 2000). However, the minimum required case to variable ratio of 3:1 was exceeded (as recommended by Tabachnick and Fidell, 1989). Variables were entered on the basis of $p < 0.05$ and removed when $p > 0.10$ (Field, 2009). The DFA was then run using a full (forwards and backwards) stepwise procedure to determine the most important variables in the classification.

2.2.2.2) Inter-observer variability data

Means and confidence intervals were calculated for each variable at each site using data from all 39 students and were compared to actual values measured by RLW. A separate repeated measures ANOVA was then run for each of the variables at each site, examining differences between students (n = 39).

2.3) Results

2.3.1) Water vole habitat assessment

The nested MANOVA showed highly significant differences between overall habitat of riverbank in the presence or absence of water voles, and between stretches within this classification (Table 2.2). Following the MANOVA, ANOVA tests on each factor demonstrated significant differences (defined *a priori* as $p < 0.050$; but in reality, $p < 0.002$ for all significant factors, which greatly reduced the risk of a type 1 error) between 14 variables at WV and non-WV stretches (Figure 2.2). DFA showed that, on the basis of the measured factors, a site could be classified correctly as a WV or non-WV site with 80% accuracy. Using the stepwise model reduction approach (with both forwards and backwards stepwise procedure), 87% of sites were found to be correctly classified using seven of the estimated variables (Table 2.3).

Table 2.2) Results of nested MANOVA used to examine differences in overall habitat of riverbank in the presence or absence of water voles (Classification = WV or non WV)

	d.f.	Wilks' lamdba	Approx. F	Num d.f.	Den d.f.	p-value
Classification	1	0.1	19.1	23	58.0	p < 0.001
Stretch (Classification)	18	0.0	6.1	414	888.7	p < 0.001
Residuals	80					

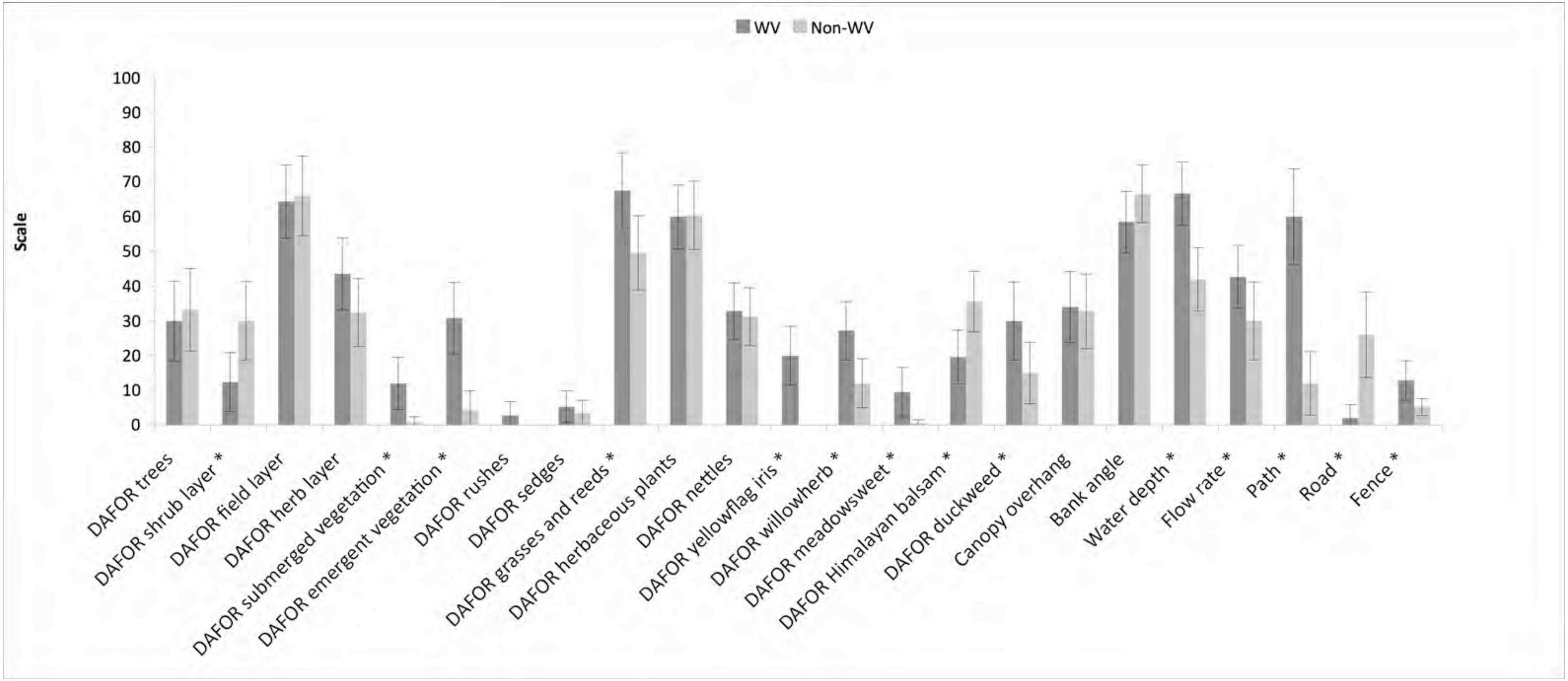


Figure 2.2) Mean and 95% confidence intervals for each variable, showing differences between WV and non-WV classifications. Significant differences between water vole and non water vole classifications, as determined with the nested ANOVA are indicated by * (in all cases p < 0.002). All data were linearly transformed to a scale between 0 and 100 so that they could be represented graphically (e.g. for presence absence, 0 = absent/100 = present, for DAFOR, absent = 0, Rare = 20, Occasional = 40, Frequent = 60, Abundant = 80, Dominant = 100).

Table 2.3) Results of Discriminant Function Analysis showing the percentage of sites correctly classified, and the most important habitat variables

Model	Correctly classified	Wilks' Lambda	Association with water voles
DAFOR emergent vegetation	71%		Positive
DAFOR emergent vegetation	79%	0.75	Positive
Path		0.74	Positive
DAFOR emergent vegetation	81%	0.62	Positive
Path		0.65	Positive
Road		0.58	Negative
DAFOR emergent vegetation	80%	0.59	Positive
Path		0.53	Positive
Road		0.54	Negative
DAFOR Himalayan balsam		0.50	Negative
DAFOR emergent vegetation	80%	0.56	Positive
Path		0.52	Positive
Road		0.51	Negative
DAFOR Himalayan balsam		0.49	Negative
DAFOR yellow flag iris		0.45	Positive
DAFOR emergent vegetation	83%	0.53	Positive
Path		0.49	Positive
Road		0.46	Negative
DAFOR Himalayan balsam		0.45	Negative
DAFOR yellow flag iris		0.42	Positive
DAFOR meadowsweet		0.42	Positive
DAFOR emergent vegetation	87%	0.52	Positive
Path		0.46	Positive
Road		0.43	Negative
DAFOR Himalayan balsam		0.42	Negative
DAFOR yellow flag iris		0.40	Positive
DAFOR meadowsweet		0.40	Positive
Flow rate		0.39	Positive (fast flow)

2.3.2) Verification of inter-observer variability

Student data varied greatly compared to the actual value measured by RLW (Table 2.4). Students were relatively poor at estimating 5 variables in particular (< 37% of sites where student-estimated value matched the actual value). They underestimated canopy cover (at 80% of sites) and field layer (60%), and overestimated trees (60%), herb layer (60%) and grasses (20%), although the actual value for grass occurred within student-estimated mean 95% confidence intervals at 60% of sites. The typical standard deviation between different student estimates was in the region of one. Given that 95% of a population will fall within two standard deviations of the mean, and the range of these samples fell between zero and five, this indicates that there is considerable variability between students.

Table 2.4) Data collected by students varied greatly compared to actual data (as collected by an experienced professional). Note that some counter-intuitive differences between the final two columns were due to several students recording highly different values from the rest of the students, thus changing the overall mean even when most students values matched actual estimates.

Variable measured	Mean SD for all students across all sites	% occasions where student-estimated value matches actual value	% sites where actual value occurs within student-estimated mean 95% confidence limits
Canopy cover	0.95	32	10
Bank Angle	0.71	42	20
Depth of river	0.74	46	30
Flow rate	0.58	59	40
Trees	1.02	37	0
Shrubs	1.26	32	10
Field Layer	1.26	25	10
Herb Layer	1.30	27	10
Submerged vegetation	0.71	78	10
Emergent vegetation	0.94	47	20
Rushes	1.08	51	0
Sedges	1.23	68	0
Grasses	1.51	24	60
Nettles	1.15	35	40
Yellowflag iris	0.27	97	90
Willowherb	0.79	71	20
Meadowsweet	0.85	58	0
Himalayan balsam	0.45	91	70
Japanese knotweed	0.36	94	90

The repeated measures ANOVA (Table 2.5) showed that there were significant differences between individual students for almost all variables except submerged vegetation, yellowflag iris, Japanese knotweed and Himalayan balsam.

Table 2.5) Results of the repeated measures ANOVA for each of the variables, between students (n=39). Significant values ($p < 0.05$)* are in bold

	Students		
Variable	F	df	p
Canopy cover	**2.93**	**5.66**	**0.02***
Bank Angle	**5.03**	**7.32**	**<0.01***
Depth of river	**5.54**	**2.77**	**0.02***
Flow rate	**5.3**	**6.61**	**<0.01***
Trees	**3.54**	**5.68**	**<0.01***
Shrubs	**3.77**	**6.23**	**0.03***
Field Layer	**3.12**	**6.97**	**0.07***
Herb Layer	**5.37**	**4.71**	**<0.01***
Submerged vegetation	3.83	4.35	0.10
Emergent vegetation	**6.58**	**5.06**	**<0.01***
Rushes	**5.99**	**5.72**	**<0.01***
Sedges	**15.31**	**3.75**	**<0.01***
Grasses	**9.31**	**4.99**	**<0.01***
Nettles	**4.51**	**5.65**	**<0.01***
Yellowflag iris	1.68	1.86	0.22
Willowherb	**3.91**	**3.18**	**0.02***
Meadowsweet	**5.30**	**5.43**	**<0.01***
Himalayan balsam	2.87	3.60	0.45
Japanese knotweed	2.80	4.15	0.40

Yellowflag iris, willowherb, meadowsweet, Himalayan balsam and Japanese knotweed were absent from every site on the River Wye. The vast majority of students correctly recorded the absence of yellowflag iris (97%, from all students at all sites), Himalayan balsam (91%) and Japanese knotweed (94%), and at most of the sites, the actual value for each variable fell within the student-estimated 95% confidence limits for the variable at that site. In the case of willowherb (correctly recorded by 71% of students), the actual value only fell within the student-estimated mean 95% confidence intervals at 20% of the sites, and in the case of meadowsweet (correctly recorded by 58% of students), the actual value never fell within the student-estimated mean 95% confidence intervals. These noticeable differences between the percentage of occasions where student-estimated values matched the actual value, and the percentage of sites where the actual value occurred within the student-estimated mean 95% confidence intervals, were due to occasional students recording highly different values to the majority, thus increasing or decreasing the mean.

2.4) Discussion

2.4.1) Water vole habitat selection

Water voles were positively correlated with the abundance of grasses and reeds, meadowsweet, willowherb, yellow flag iris and emergent and submerged plants in this study. Reasons for this may be that all of these plants are important food sources and provide cover from predators. Other research has shown similar results, with water voles being associated with emergent vegetation, reeds, short grasses, nettles and tussock sedges (Lawton and Woodroffe, 1991 ; Woodall, 1993; Moorhouse, 2004). Water voles were negatively correlated with dense shrub layer and Himalayan balsam, probably due to these dominating the plant community and excluding food sources such as grass and herbaceous plants (Provan *et al*., 2007). Note that Japanese knotweed, another invasive species, was not found at the study sites but is thought to have a negative influence on water voles for the same reason as Himalayan balsam (Woodall, 1993). Deep, fast flowing water was positively associated with water voles in this study, in agreement with other studies: flow intensity and depth influenced water vole population numbers and dynamics (Muzyka *et al*., 2010), and Woodall (1993) also found that water voles preferred deeper water, perhaps because it allowed them to escape predation by diving and swimming away. However, this may not prevent depredation by American mink, as mink are skilful swimmers and divers and can hunt in both aquatic and terrestrial environments (Williams, 1983; Craik, 1995; Macpherson and Bright, 2010; Heyn *et al*., 2011). Mink are known to be present in the area surrounding the sites used in this study, however, management is ongoing and 30 mink have been culled since 2007 (Field, unpubl. data).

Human structures also affected water voles: water voles were postively correlated with the presence of paths and fences along watercourses. Because of a suspected negative impact of livestock on watervoles (Lawton and Woodroffe, 1991), fences have been erected as a preventative measure to stop the erosion and overgrazing of riverbanks caused by livestock in adjacent fields (Field, 2010). It is therefore possible that the positive correlation with fences in this study is due to these fences being erected in areas where water vole populations were known to be present (and therefore, sites near fences were not actively chosen by water voles). One speculation to explain the positive correlation with paths may be that human activity could deter mink from sites near paths, allowing water vole populations to establish themselves without this intense predatory threat. Indeed, in a neigbouring area along the Gloucester-Sharpness canal, a healthy water vole population is thriving despite a high level of human activity from pedestrians, cyclists and boat traffic (J. Field, GWT, pers. comm.). Canals and urban rivers were also inhabited by water voles in other studies (Moorhouse, 2004; Strachan, 2004), with one study reporting that a canal site had double the water vole population density than wetlands (Moorhouse, 2004), which have less human traffic. However, mink are nocturnal (Wellman and Haynes, 2009; Zschille *et al.,* 2010), so whether they would be affected by diurnal human activity could be questionned. It is not known why water voles were negatively correlated with roads in this study, as another study has demonstrated that they can be found along busy trunk roads and motorways (Strachan, 2004). This suggests that either distance to road was correlated with another, non-measured variable, or, more likely, that the effect of roads on water voles is site specific.

2.4.2) Inter-observer variabilty

Inter-observer variability was found to be an issue when several individuals collected data. Variability between individuals indicates that data collected in this way must be treated with caution, although some individuals did appear to be more accurate than others. Reasons for this, for example, previous practical experience, ability and sampling effort, were not measured in this study although they may have been important. For example, Hope-Simpson (1940) reported that “extra-careful” vs. “ordinary” sampling caused a 50% increase in the length of species lists in grassland. Demographic factors such as age and education, which have been found to influence volunteer data collection in other studies (e.g. Dickinson *et al*., 2010), were not applicable in this study as the participants were of similar ages and educational backgrounds.

Variables for which estimates were especially subjective e.g. canopy, field layer and herb layer cover, were, perhaps not surprisingly, the most variable among individuals. In the future, it would be interesting to compare the influence of subjectivity between a group of professionals and a group of volunteers to see whether it is volunteer-specific or the result of having more than one observer. Estimating canopy cover may have presented a greater challenge due to the lack of shade over the riverbank while the data were being collected. In the handout, field layer was described as vegetation that could be walked though as opposed to herb layer that could be walked on; however, these descriptions could have been interpreted differently among individuals despite examples being given for each (ferns, long grass, nettles for field layer, and short grass and small plants for herb layer). Tree cover was highly variable between individuals, and this may be because individuals interpreted the DAFOR scale differently e.g. some may have considered the number of trees rather than the instructed percentage cover, with individuals ranking one tree as rare even if it was covering a large percentage of the bank (as found in Agea *et al.*, 2007). The cover of grass, which is easily identifiable, was also highly variable among individuals despite the actual value occurring within student-estimated mean 95% confidence intervals at 60% of sites. In this case, the mean value for all students represented the actual cover of grass more accurately than examining the percentage occurrence of individual values. Even if taking a mean value from a large number of individuals does increase data accuracy in some occasions, it would not be practical for wildlife charities to ask a large group of volunteers to estimate the same variables across a large number of sites.

The majority of individuals accurately recorded the absence of charismatic and easily identifiable species such as yellowflag iris, Japanese knotweed and Himalayan balsam, although it should be noted that these species were absent from all sites, so the actual percentage cover was technically not estimated. However, it is encouraging that individuals were generally able to record the absence of invasive non-native species (Japanese knotweed and Himalayan balsam) as this could be useful in volunteer surveys of these species. Errors caused by the misidentification of similar species may also contribute to inter-observer variability and inaccuracy (Hope-Simpson, 1940). Errors did occur in this study, with individuals recording the presence of various species which were in fact absent. Again, this was highly variable between individuals and some correctly identified more species than others. Reflecting the trends found in this study, Sykes *et al.* (1983), Block *et al.* (1987) and Brandon (2003) found that the degree of variability among recorders fluctuated according to the variable or species being measured. Brandon (2003) found that species within the elm (*Ulmus*) and oak (*Quercus*) genera presented greater difficulty to volunteers identifying them as part of a woodland vegetation survey.

Even when volunteers can correctly identify species, the variability of ocular estimates presents an issue. Hatton *et al.* (1986) asked students to estimate the percentage cover of two-dimensional artificial images in laboratory conditions and found that extremes of cover may be estimated with less error than intermediate cover levels (variability between participants peaked at approximately 55% cover). They concluded that classes of vegetation cover should reflect these error rates, and recommend the Bailey and Poulton scale with 7 classes of percentage cover: 0-1, 1-5, 5-25, 25-50, 50-75, 75-95, and 95-100. However, increasing the number of categories to increase the accuracy of measurements means that there is more scope for error, i.e. choosing the wrong category, if volunteers were to use such a scale.

Although the DAFOR scale is widely used, it is often not standardised between separate studies, and while this may not compromise the overall results of each study, it may become a problem if DAFOR estimates vary between observers within the same study (Hope-Simpson, 1940). For example, in Agea *et al.* (2007): R = 1-20, O = 21-40, F = 41-60, A = 60-80 and D > 80, categories referred to the observed number of individuals of a particular species. In other studies, DAFOR represented the estimated percentage cover (as in this study), with Affre *et al.* (2009) using the following scale: R < 5%, O = 5-25%, F = 25-50%, A = 60-80% and D > 80%. One potential issue with their scale is that percentages overlap, and this could cause confusion: an estimate of around 25% could fall into either occasional or frequent. Even when using DAFOR as a measurement of percentage cover, designated categories can vary from study to study: e.g. In Avila *et al*. (2002), R = 5%, O = 10%, F = 25%, A = 50% and D > 75%. Note that 50% represents frequent in Affre *et al.* (2009) whereas the same percentage represents abundant in Avila *et al.* (2002). These differences underline the importance of using clearly defined scales when briefing participants during volunteer surveys. For example, the BBS habitat survey contains 3 vegetation categories: "dense, moderate and sparse" (BTO, 2012c). Although these are simple to understand, these descriptions may be highly subjective and are not explained in terms of the percentage cover they represent. Estimates could vary as a result, not only between different individuals, but also according to the type of habitat being measured e.g. dense shrub layer in scrubland may be different to dense shrub layer in woodland, leading to issues if different variables were compared across different types of habitat.

Assessing the reliability of ocular estimates in volunteer surveys is of utmost importance because many different volunteers usually contribute data for an individual survey. Indeed, the organisers of the Breeding Bird Survey report that habitat should be ideally surveyed by the same person over the years, although in reality there is some changeover of volunteers (BTO, 2012d). This changeover in volunteers is likely to vary according to the type of survey and the length of time it is running for. The NDMP in Gloucestershire had at least 3 core volunteers participating in most monthly nestbox surveys over 18 years, but most of the other volunteers participated sporadically or for a fixed length of time before leaving altogether. Volunteer numbers were also thought to vary in other NDMP sites over the country (see Chapter 3).

2.5) Conclusion and recommendations

The simple estimation methods used by a single professional in this study produced data that mirrored differences found in other water vole habitat studies using exact measurements. This indicates that estimates are a valid method to measure water vole habitat preferences. Indeed, Hope-Simpson (1940) states that simple methods are effective as part of a descriptive survey that does not require a high standard of accuracy. However, several studies have concluded that inter-observer variability can be problematic in habitat research (e.g. Sykes *et al*., 1983; Gotfryd and Hansell, 1985; Block *et al*. 1987) and this was also true in the current study. However, it should also be noted that inter-observer variability is not limited to estimates; it can also be an issue when precise measurements are taken with the aid of specialist equipment (e.g. callipers, spring balances, digital image software) (e.g. Goodenough *et al*., 2010; 2012).

Potential benefits of using volunteer estimates in habitat research should not be completely overlooked. These include the financial and temporal benefits provided by volunteers and the lack of necessity for technical equipment (only a tape measure and a plant identification field guide were required in this study). Using estimates in this riverbank survey did not require access to the water's edge, thus reducing health and safety risks to volunteers, and these considerations are of paramount importance to organisations that recruit volunteers (K. Lloyd and J. Field, GWT, pers. comm.). With these considerations in mind, it would be useful to conduct further research into ways in which to maximise volunteer estimate accuracy, by determining an optimal length of training for volunteers, by examining the effectiveness of different types of training (i.e. in a classroom setting or in the field), or by supervising volunteers while they practise their skills in the field until they can collect reliable data (as done by GWT to train volunteers to survey indirect water vole signs). Further investigation could also determine whether inter-observer variability would actually affect the distinction between sites that support water voles and sites that do not, or if variability was consistent within observers, but such studies should obviously be treated with care. Therefore, the overall recommendation would be further volunteer training to reduce variability.

Chapter 3: The use of long-term volunteer records to examine dormouse nestbox selection in Midger Wood Nature Reserve, Gloucestershire

Abstract

Within ecology, there are unanswered questions about species-habitat interactions, which could potentially be resolved by a pragmatic analysis of a long-term volunteer-collected dataset. Here, 18 years of volunteer-collected data from a UK dormouse nestbox monitoring programme were analysed to determine the influence of habitat variables on nestbox choice by common dormice (*Muscardinus avellanarius*). A range of habitat variables in a coppiced woodland in Gloucestershire, UK, were measured and analysed in relation to dormouse nestbox occupancy records (by dormice, other small mammals, and birds) collected by volunteers. While some characteristics of the woodland had changed over 18 years, simple transformation of the data and interpretation of the results indicated that the dataset was informative. Using stepwise regressions, multiple environmental and ecological factors were found to determine nestbox selection. Distance from the edge of the wood was the most influential (this did not change over 18 years), with nestboxes in the woodland interior being selected preferentially. There was a significant negative relationship with the presence of ferns (indicative of damp shady conditions). The presence of oak (a long-lived species), and the clumped structural complexity of the canopy were also important factors in the final model. There was no evidence of competition between dormice and birds or other mammals. The results provide greater understanding of artificial dormouse nest-site requirements and indicate that, in terms of habitat selection, long-term volunteer-collected datasets contribute usefully to understanding the requirements of species with an important conservation status.

Torpid dormouse during a nestbox survey

This chapter has been published with very minor amendments (See Appendix 2:
Williams, R.L., Goodenough, A.E., Hart, A.G., and Stafford, R. (2013) Using long-term volunteer records to examine dormouse (*Muscardinus avellanarius*) nestbox selection, *PLoS One*, 8 (6), e67986

3.1) Introduction

Many animals, both invertebrate and vertebrate, build nests (e.g. stingless bees *Trigona spinipes* – Dos Santos *et al*., 2012; grass-cutting ants *Atta vollenweideri* – Cosarinski and Roses, 2012; chimpanzees *Pan troglodytes* – Koops *et al*., 2012; great tits *Parus major* – Kilgas *et al*., 2012). Selecting a suitable nest-site is important as it provides shelter from predators or adverse weather conditions, and increases fitness and survival of young (Morris, 1991; Magana *et al*., 2010; Cudworth and Koprowski, 2011). Species create nests for different reasons (breeding, roosting, hibernation, group living etc.). Most nest-building birds, for example, invest considerable time and energy choosing their nest-site because certain sites greatly influence reproductive success (Goodenough *et al*., 2008 and references therein) and the same is true for large mammals (e.g. badgers *Meles meles* – Kaneko *et al*., 2010), and for many small mammal species (e.g. Morris, 1991; Solomon *et al*., 2005; Kuroe *et al*., 2007). Knowledge of nest-site requirements is essential for the conservation of rare or specialist species (Bright and Morris 1990; Cudworth and Koprowski, 2011), especially where nest-site availability limits population sizes, as has been observed in a variety of arboreal mammals (e.g. grey mouse lemurs *Microcebus murinus* – Lutermann *et al.,* 2010; northern flying squirrels *Glaucomys sabrinus* – Carey *et al*., 1997; greater gliders *Petauroides volans* – Smith *et al*., 2007; common dormice *Muscardinus avellanarius* – Wolton, 2009).

In the UK, a lack of appropriate woodland management and habitat fragmentation has resulted in the reduction of suitable habitat for dormice, at the edge of their range, leading to extirpations (Bright *et al*., 1994). As a result, and despite legal protection, dormouse distribution has reduced by more than half since the 19^{th} century, and the species is now of conservation concern in the UK (Harris and Yalden, 2008). Dormouse nesting ecology is difficult to study because dormice are cryptic, nocturnal and arboreal; their natural nests are difficult to locate as they are usually concealed in thick foliage or in tree cavities, and may be as high as 15 m in the canopy (Bright and Morris, 1992; Bright *et al*., 1994) (see Box 3.1). This makes studies relying on natural nest-sites logistically challenging, or even misleading, because of the high risk of not finding nests (Bright and Morris, 1991). Nestbox occupation data provide an opportunity to estimate relative abundance and distribution of dormice with minimal labour (Juškaitis, 2000). Dormice are found in nestboxes from mid-May to October, and are known to use them across their range, thereby allowing the comparison of findings across similar studies (Juškaitis, 1997).

Box 3.1) Dormice *Muscardinus avellanarius* (Information synthesised from: Arkive, 2012; NBN, 2012b; JNCC, 2012; PTES, 2012 – For illustration credits see page 161)

Kingdom: Animalia	Phylum: Chordata	Class: Mammalia
Order: Rodentia	Family: Gliridae	Genus: *Muscardinus*

Physical description Body 60-90 mm; tail 55-80 mm; weight: 15-30 g. Common dormice have golden fur on their back with a pale, cream-coloured underside. They have large black eyes and a long furry tail, distinguishing them from other species of mouse.

Dormouse

Behaviour Nocturnal and arboreal. They build nests of woven honeysuckle bark, grass and fresh leaves in dense understory, in the tree canopy, in tree cavities or in manmade nestboxes. Dormice spend a large proportion of their lives sleeping and often enter a state of torpor during the day. In winter, dormice hibernate for up to 7 months in nests close to or on the forest floor.

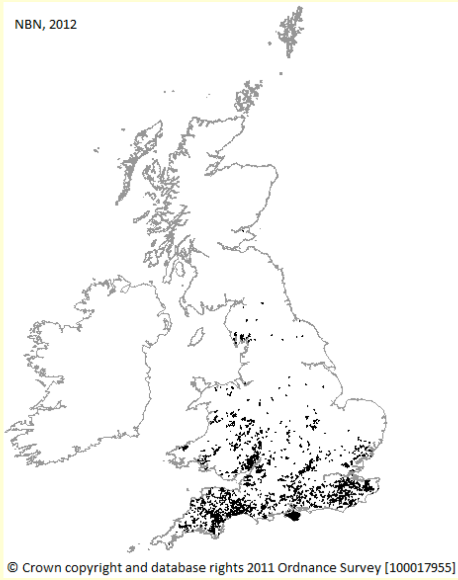
Breeding Sexually mature at one year old. Breeding season is May – September. Dormice produce between two and seven young and can raise two litters a year. Young dormice stay with their mother until they are approximately 10 weeks old.

Diet Flowers, honeysuckle, pollen, fruits, nuts, caterpillars, aphids, and other small insects.

Habitat Deciduous woodland (especially hazel coppice), thick shrub and overgrown hedgerows (i.e. not intensively managed).

Predators & threats Owls, weasels and cats predate dormice, but their main threat is habitat loss and fragmentation, making them vulnerable to extirpations. Climate change may also have an effect on dormice.

Distribution Found across Europe as far east as the Ural Mountains and south to the Mediterranean. In the UK, their range is largely restricted to the South of England and Wales (see below).



Status and conservation efforts IUCN Red List: Least Concern in Europe but Vulnerable in the UK. Protected under: Bern Convention; European Habitats Species Directive; UK Biodiversity Action Plan priority species. Natural England has also included dormice in their Species Recovery Programme (SRP).

Public involvement Several awareness campaigns and surveys are run by the People's Trust for Endangered Species (PTES): the National Dormouse Monitoring Programme (nestbox monitoring), and the "Great Nut Hunt", in which members of the public are encouraged to search their local woods for signs of nibbled hazel nut shells.

Nestboxes also benefit dormouse conservation. Bright and Morris (1991) conducted a radio-tracking survey and found that artificial nestboxes were by far the most frequently used nest-sites compared to natural nests. They argued that, where nestboxes are present, almost the whole population would use them, and providing nestboxes appeared to double the number of dormice present in an area. Some cavity-nesting bird species such as blue and great tits are known to use artificial nestboxes almost exclusively when they are available, and numerous studies have benefited from the study of these species in nestboxes (Minot and Perrins, 1986). As dormice also readily breed in nestboxes (Morris *et al*., 1990), this also allows the study of their breeding ecology. Both male and female dormice use nestboxes, and they can be found either singly or in groups of two or more (e.g. male-female breeding pairs, groups of juveniles, mothers with litters) and this fluctuates depending on the time of year. Dormice can have several litters per year, although exact numbers of litters and young per litter differ across their range (Juškaitis, 1997) (note that two litters per year were commonly found in some nestboxes at the present study site; one in early summer and one in the autumn). Any findings that relate habitat features to nestbox preference or breeding success in nestboxes could therefore easily be used in an applied sense (e.g. changing nestbox location) and may have more immediate conservation implications than findings relating to habitat features in natural nest-sites (because these cannot be moved), although factors influencing the selection of natural and artificial sites may not be identical.

There is a growing interest in long-term volunteer-collected datasets in ecology (Brewer, 2002; Evans *et al*., 2005) because volunteer-run programmes provide large quantities of data at minimal cost (Newman *et al*., 2003; McCaffrey, 2005). Deploying a team of volunteers can also save substantial amounts of time compared to using professional ecologists (Newman *et al*., 2003). In the UK, many conservation organisations rely heavily on volunteers to collect data (e.g. the British Trust for Ornithology BTO, the Royal Society for the Protection of Birds RSPB, the People's Trust for Endangered Species PTES, the Mammal Society, the Marine Conservation Society, the Wildlife Trusts and the Bat Conservation Trust), however, volunteer-collected data are often questioned because they lack the rigour and precision of scientific studies (e.g. Irwin, 1995).

The dormouse is a popular and charismatic species in the UK. Currently, over 1,000 volunteers participate in the National Dormouse Monitoring Programme (NDMP) run jointly by the PTES and Natural England. These volunteers have been submitting records since 1988, and in 2011, there were 305 sites involved in the scheme (with some annual variation – S. Sharafi, PTES, pers. comm.). Volunteers are required to check nestboxes at a site at least twice a year (May/June and Sept/Oct) to monitor evidence of dormouse occupation. The records are analysed by the PTES to estimate national trends in dormouse numbers and distribution.

Understanding breeding dormouse population nestbox requirements is crucial if nestboxes are to be maximally effective for conservation. Using long-term (18-year) volunteer-collected data collected as part of the NDMP, this study: (1) tests whether dormice actively choose (rather than randomly occupy) nestboxes; (2) examines some of the biotic and abiotic factors responsible for this selection; and (3) provides recommendations on using large volunteer datasets, discussing the attributes and limitations such datasets present.

3.2) Methods

3.2.1) Site Description

This study was undertaken at Midger Wood Nature Reserve (51° 36' 15.8", 2° 17' 26.9"), a 9 ha site in Gloucestershire, UK, managed by the Gloucestershire Wildlife Trust. The site is an ancient semi-natural coppiced woodland, dominated by ash (*Fraxinus excelsior*) with some Pedunculate oak (*Quercus robur*) and beech (*Fagus sylvatica*), with an understory of hazel (*Corylus avellana*), hawthorn (*Crataegus monogyna*), and holly (*Illex aquifolium*) (Bracewell, 2009).

3.2.2) Data Collection

The presence of dormice, other small mammals (combining records for woodmice *Apodemus sylvaticus*, yellow-necked mice *Apodemus flavicollis,* and shrews *Sorex* spp.), and birds (mainly blue tits *Cyanistes caeruleus* and great tits *Parus major*) was recorded monthly from April to November in 97 wooden dormouse nestboxes between 1994 and 2011 inclusive (no other species were found, and there was no indication of grey squirrels *Sciurus carolinensis* entering the nestboxes to compete with, or depredate, dormice). Nestboxes were located at chest height, and were distributed along transects across the hazel coppice coupes of the wood, such that they were at least 20 m apart, in accordance with NDMP guidelines (PTES and Natural England, 2012) (note that the number and location of the nestboxes remained the same over the 18 year period). Although the nestboxes were situated substantially lower than the potential height of natural nest-sites for logistical reasons (following NDMP guidelines), there is no evidence to suggest that this makes them less attractive to dormice than higher natural nest-sites (see Bright and Morris, 1991). Additionally, Sara *et al*. (2003) found no significant difference between nestboxes placed at 1.5 m, 3 m and 5 m above ground. Nestbox monitoring was undertaken by volunteers for Gloucestershire Wildlife Trust (GWT), who manage the site. New volunteers were trained by long-term volunteers who accompanied them until they had enough experience to qualify for a dormouse handling licence (a legal requirement in the UK (Natural England, 2008). Nestboxes measured 140x140 mm at the base, had a slanted roof with a mid-point height of 160 mm and a rear entrance hole of 30 mm in diameter, and were fixed to trees at chest height. Volunteer-collected data included presence or absence of nests and the number of individuals found in the nestbox during the survey. Volunteers did not search for natural nest-sites, since 1) this is not a requirement of the National Dormouse Monitoring Programme; and 2) there would have been considerable difficulty locating natural nests (Bright *et al*., 1994; Bright and Morris, 1992). Summary data can be requested from the Gloucestershire Centre for Environmental Records (GCER). Dormouse occupation of nestboxes was relatively low, with an average of 7.3 % of nestboxes occupied in any given year (S.D. = 3.3, minimum 2%, maximum 13%).

Volunteers removed nests and cleaned nestboxes at the end of winter each year unless the nestbox contained a dry, intact dormouse nest, as the volunteers hoped that this may encourage dormice to re-use the nestbox in the following year. Since dormouse nests were sometimes left over successive years, this variable could not be assured to be independent between years, and certainly not between monthly surveys. Furthermore, historic records showed that dormice were occasionally absent from nestboxes even when recently-made nests were found during a survey. As such, the presence of individuals in a nestbox at any point during the year was used as a dependent variable, since this removed the confounding results of nests being present between successive recordings, but also accounted for the lower likelihood of sightings of individuals compared to nests (this variable is termed dormouse occupancy).

The percentage of occupancy for each nestbox was calculated over the 18-year period (e.g. 9 years of occupancy = 50% occupancy). It was hypothesised that leaving nests in nestboxes over successive years may have an influence on dormouse nestbox selection, alongside habitat variables surrounding the nestbox. To remove this effect, dormouse nestbox selection was also examined by treating dormouse nests as a binary variable (whereby nestboxes that had contained a nest at any time over the 18-year period were given a value of 1, and those which had never contained a nest were given a value of 0 – see below).

Local habitat variables were recorded in December 2009 when dormice were hibernating (note: these habitat variables were recorded by the author, RLW, not the volunteers, such that there was no scope for inter-observer variability). The number of trees and shrubs, and the plant species present, were recorded during a five-minute search within a 10 m radius of each nestbox to give an indication of the overall complexity and species diversity. Percentage ground cover was not calculated as cover varied greatly throughout the year. Data were collected during winter to better assess structural complexity related to tree branches. This provided a more meaningful value for this study than if foliage was dense, because dormice travel on branches, not leaves. Bird and small mammal nestbox data were obtained from the historic volunteer records (Table 3.1). Bird and small mammal nests were always removed from one year to another (bird nests were removed soon after young had fledged from the nest), and individuals were rarely found in a nest during the surveys. Consequently, nests were thought to be a more reliable indicator of bird or small mammal presence in a given year, so this variable was used in all analyses, instead of occupancy (as described for dormice in the previous section).

Table 3.1 – Variables measured at each nestbox

Measurement	Units and Further Information
Small mammal and bird nests	Percentage of occasions when nests were found in each box over 18 years
Circumference of the nestbox tree	As above (cm, measured at the height of the nestbox)
Distance of the nestbox from ground*	(m)
Angle of the nestbox floor*	Degrees from horizontal
Accessibility	Number of branches directly touching the nestbox
Distance from the edge of the woods	(m)
Distance from the nearest footpath	(m)
Distance from the stream (Kilcott Brook)	(m)
Number of trees in a 10 m radius	Trees were defined as plants taller than chest-height
Number of shrubs in a 10 m radius	Shrubs were defined as plants below chest-height
Woodland management regime*	Age of the coppice coupe in which the nestbox was situated (Obtained from the Gloucestershire Wildlife Trust)
Canopy cover	(%)
Canopy clumpiness	Index of dispersion value indicating the aggregation of the canopy
Mean structural complexity	(%) mean taken from two photos (see Methods for details)
Structural complexity clumpiness	Index of dispersion value indicating the aggregation

Measurement	Units and Further Information
	of the shrub layer
Moss (Bryophyta)	Presence or absence in 10 m radius (1 = present; 0 = absent)
Ash (*Fraxinus excelsior*)	As above
Bramble (*Rubus fruticosus* agg.)	As above
Pedunculate oak (*Quercus robur*)	As above
Honeysuckle (*Lonicera periclymenum*)	As above
Ferns (Pteridophyta)	As above
Dog's mercury (*Mercurialis perennis*)	As above
Holly (*Ilex aquifolium*)	As above
Hawthorn (*Crataegus monogyna*)	As above
Hart's-tongue ferns (*Asplenium scolopendrium*)	As above
Ivy (*Hedera helix*)	As above
Grasses (Poeace)	As above
Sycamore (*Acer pseudoplatanus*)	As above
Crab apple (*Malus sylvestris*)	As above
Other vegetation	As above

Footnotes for Table 3.1: Hazel (a dominant species in the wood) was excluded as it was always found within 10 m of every nestbox. Other vegetation refers to plants growing from the ground. For details of canopy cover, clumpiness and structural complexity parameters, see Methods. *Angle of the nestbox floor and distance of the nestbox from the ground were not included in the analysis because these varied when nestboxes were handled during dormouse monitoring surveys and would not, therefore, be consistent over time. Woodland management regime was also disregarded because several coppicing dates could not be determined.

To record canopy complexity and structural complexity of the surrounding shrub layer, three photographs were taken at each nestbox, one vertically upward and two horizontally at nestbox height (these standard images were taken using a Canon IXUS 860 IS compact digital camera rather than hemispherical images taken with a fish-eye lens, so picture distortion did not need to be accounted for (Goodenough and Goodenough, 2012). The shrub layer photographs, one behind and one in front of the nestbox, were taken against a white sheet for contrast. Vegetation density and complexity were calculated using CanopyDigi (Goodenough and Goodenough, 2012). This digital image analysis provided an objective quantification of vegetation cover and an index of dispersion value to assess vegetation aggregation and identify significant gaps (high values = clumping with gaps; low values = more uniform vegetation – (Fowler *et al.,* 1998). Shrub layer structural complexity was calculated using the mean of the two photographs, creating a mean percentage cover and mean index of dispersion.

3.2.3) Statistical methods

To test whether actual nestbox occupation data showed significant departures from a random distribution, as expected if nestboxes were actively chosen but not if they were randomly selected, the frequency of dormouse occupation in each nestbox over the 18 years was compared to a hypothetical Poisson distribution. This was done using a Kolmogorov-Smirnov test (as per Gooenough *et al*., 2009).

All percentage variables were converted to proportions and arcsine transformed. Given that the circumference of trees would have increased over the study period, values in this variable were ranked (1 = smallest circumference) rather than using absolute values. The age of coppice, angle of nestbox floor and height of nestbox were not included in the analysis because coppice dates were not known for all sections of the wood, and the height and angle of the nestbox would have changed during the monthly surveys as the volunteers monitored the contents of the nestboxes.

A stepwise regression was used to determine which independent variables were predictors of dormouse nestbox selection, using both forward and backward procedures (the default for the 'step' command in the R statistical software package) and Akaike's Information Criterion (AIC) as a method of model reduction. This allows the optimal (sub)set of predictors to be identified and maximum parsimony to be achieved. This analysis used the percentage of dormouse occupancy over the 18-year period as the dependent variable. Standardised residuals of the final regression were normally distributed, as verified by a Lilliefors test for normality ($D = 0.08$, $p = 0.12$) (as per Thode, 2002).

To remove any bias that could have arisen from dormice reselecting nestboxes in which nests remained from one year to another, a stepwise binary logistic regression was run (1 = nestbox containing a nest sometime during the 18-year period; 0 = never occupied by dormice). Note that the number of nestboxes each year remained the same ($n = 97$). The independent variables of small mammal nests and bird nests were still percentages (as above) because these nests were always cleared out from year to year, thus removing any confounding effects. The logistic regression was more robust to the assumptions of the data than the use of percentage occupancy over 18 years. This conversion to simple presence or absence of a nest in the entire 18-year period also lost valuable information on the preference of nestboxes, i.e. a box occupied once in 18 years was given the same value as a box occupied in most years. Given that the aim was to understand factors influencing nestbox selection, this detail of preference was useful. Similar results from both analyses would strengthen the evidence that significant factors were of biological importance.

To further investigate the relationship between bird nests and dormouse occupancy within years (this was found to be significant in the first stepwise model – see Results), a Spearman's Rank correlation was run comparing the percentage of dormouse occupancy and bird nests for all nestboxes together over each individual year. Finally, possible competitive effects between dormice and birds were examined between individual nestboxes, in each individual year. The percentage of cases where dormouse and bird nests were found (along with percentage of cases where only bird nests, only dormouse nests, or neither of these, were found) were compared against expected values calculated by the equation:

$$p(D|B) = p(B|D) = B * D \quad ,$$

where the probability of dormice being found when bird nests were present is equal to the probability of bird nests being found when dormice were present at any point during the year (i.e. when no facilitation or competition is occurring), and B is the average percentage of bird nests found in all nestboxes over all years, and D is the average percentage of dormice found in all nestboxes over all years. Differences between expected and observed values were tested with a chi-squared test.

3.3) Results

Occupation of nestboxes was relatively low, with an average of 7.3 % of nestboxes occupied in any given year (S.D. = 3.3, minimum 2%, maximum 13%). Occupation of nestboxes was not random ($Z = 5.07$, $n = 97$, $p < 0.01$), indicating active nestbox selection. The final stepwise-reduced model was highly significant ($F_{8, 88} = 5.68$, $p < 0.01$) and the suite of habitat variables entered explained 28% of variability in dormouse occupancy (adjusted $r^2 = 0.28$) (Table 3.2). It is important to note that the stepwise approach creates a best-fit model of numerous predictor variables in a multivariate framework, balancing model explanatory power and parsimony. Overall, this model is highly significant, and all explanatory variables in the model are important in achieving the overall significance and r^2 value, and warrant further discussion. Not all explanatory variables are independently significant in this final model (Table 3.2) since many of these are important in association with other variables (i.e. there is no simple univariate relationship). The most important factor determining occupancy was the distance from the wood edge. This was a positive correlation, indicating that dormice preferred nestboxes towards the centre of the wood. There was a negative relationship between occupancy and the circumference of the nestbox tree; smaller trees were associated more strongly with nestbox use than larger trees. There was also a negative relationship with the presence of ferns. Presence of oak and canopy clumpiness, as well as the number of trees and the presence of hawthorn were also important factors in the final best-fit model.

Table 3.2) Variables found to be important for dormouse nestbox selection, as determined by a stepwise regression. Significance codes: '***' p < 0.001 '**' p < 0.01 '*' p < 0.05 '.' p < 0.1

	df	Estimate	Standard error	p-value
Hawthorn	1	-0.063	0.042	p = 0.14
Number of trees	1	0.004	0.002	p = 0.11
Oak	1	0.072	0.041	p = 0.08 .
Canopy clumpiness	1	0.001	0.001	p = 0.07 .
Ferns	1	-0.096	0.048	p = 0.05*
Birds	1	0.224	0.096	p = 0.02*
Circumference of the tree	1	-0.002	0.001	p < 0.01**
Distance from edge of wood	1	0.002	0.000	p < 0.01***

The stepwise regression also showed that there was a positive relationship between dormouse occupancy and bird nests (Table 3.2), indicating that nestboxes were selected on the basis of similar variables. When bird nests and dormouse occupancy were further examined for all nestboxes within years, a relatively strong significant negative correlation was found (r_s = -0.56; n = 18; p = 0.016), implying potential competition or mutual exclusion on a yearly basis (Figure 3.1). Comparison of the observed percentage of occupation of each nestbox in a given year by birds, dormice or both showed no significant difference to calculated expected values where dormouse and bird occupation were calculated independently of one another (χ^2 = 0.01; df = 3; p > 0.99), although this test might have low power because of the comparative rarity of both dormice and birds in the nestboxes. Hence, there was no evidence of competition between birds and dormice at this site.

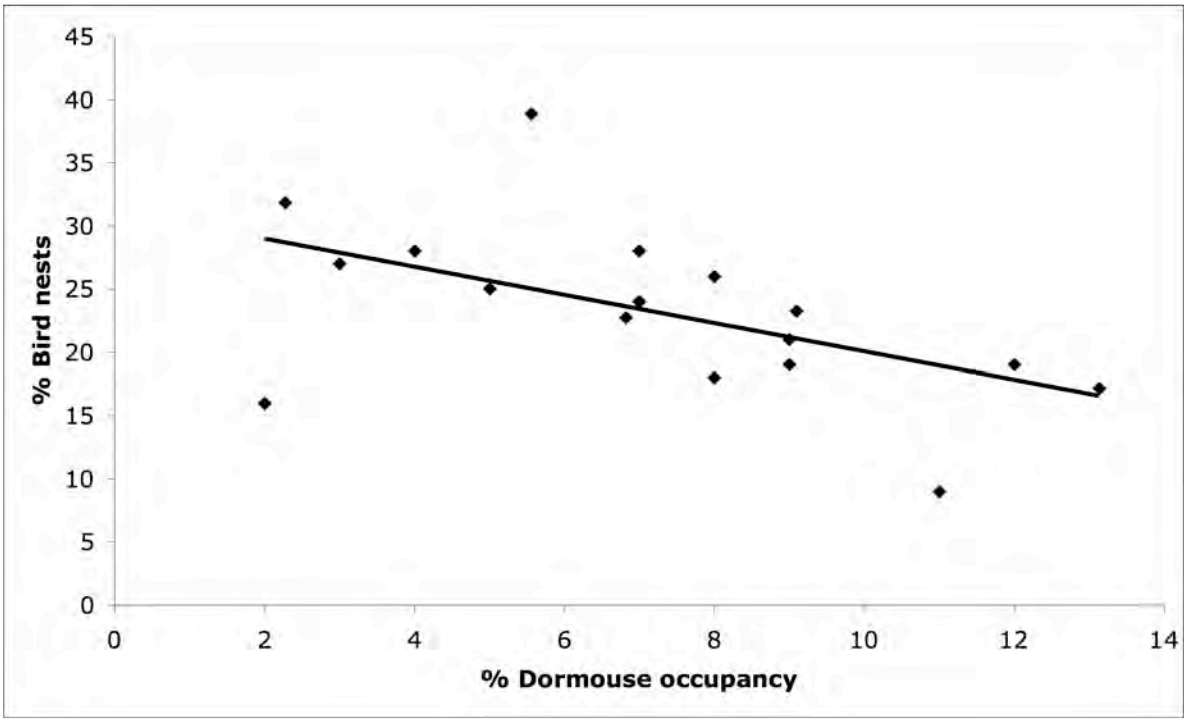


Figure 3.1) Relationship between percentage of nestboxes containing bird nests and percentage dormouse occupancy of nestboxes between 1994 and 2011

In the stepwise binary logistic regression, five factors were found to be significant and these explained 28% of dormouse nestbox selection in total (estimated $r^2 = 0.28$, Wald = 0.83, $p < 0.01$). Distance from the edge of the wood remained the most significant explanatory variable ($p < 0.01$), followed by canopy clumpiness ($p = 0.03$). Ferns, honeysuckle and sycamore were also important in the final best-fit model (Table 3.3).

Table 3.3) Variables found to be important for dormouse nestbox selection, as determined by a binary stepwise logistic regression. Significance codes: '**' p < 0.01 '*' p < 0.05 '.' p < 0.1

	df	Estimate	Standard error	p-value
Honeysuckle	1	0.673	0.478	p = 0.16
Ferns	1	-1.043	0.578	p = 0.07 .
Sycamore	1	-16.900	1379.000	p = 0.10
Canopy clumpiness	1	0.019	0.009	p = 0.03 *
Distance from edge of wood	1	0.016	0.006	p < 0.01**

3.4) Discussion

This study demonstrates three main points. Firstly, dormice actively select nestboxes, a point often overlooked or impossible to test in habitat selection studies (e.g. Goodenough *et al*., 2009; Higby *et al*., 2012). Secondly, a suite of habitat factors can explain a considerable degree of this nestbox selection, which could inform the placement of nestboxes for the purpose of dormouse research and conservation. Thirdly, volunteers can collect useful data on dormouse nestbox occupation.

Several of the factors included as candidate variables in the model influenced dormouse nestbox selection, together explaining 28% of variability in occupancy. The most influential factor was the distance from the edge of the wood, which may be due to edge effects (such as increased predation or competition (Batáry and Báldi, 2004), although some nestboxes were occupied despite being close to the wood edge and the presence of potential dormouse predators was not recorded in this study (for example, corvid birds are potential predators of dormice in edge habitats – see (Andren, 1992). As Midger Wood is a small wood (9 ha), it is not possible to determine at what point distance to the edge of the wood would cease to be important, for example, in a much larger wood. Additionally, the shape of the woodland might affect the importance of the distance to edge variable on dormouse nestbox selection, since this affects the edge:interior ratio. The influence of edge effects on nest-site selection has been studied mainly in avian populations (Paton, 1994) and there are currently no studies on its effect on dormice, although edge effect influences in smaller woods have been proposed (Juškaitis, 2003). Contradictory results show that dormice readily occupied nest tubes on the fringe of dense scrub in Dorset (S. Eden, pers. comm.), possibly because these were less favoured by competing small mammals (note: nest tubes consist of a length of corrugated plastic tubing and square in section containing a sliding wooden tray (Chanin and Woods, 2003). There may be very different selection pressures influencing populations across different habitats.

Since dormice selected nestboxes on thinner trees in this study, it may be that larger trees supported more natural nest-sites such as cavities or dense foliage in the canopy. There is much contention as to whether dormice prefer to use nestboxes or natural nest-sites and factors vary greatly in different habitats. In young woodlands, hedgerows and scrub, dormice may favour unenclosed natural nest-sites (e.g. woven into bramble) over tree hollows or artificial nest-sites (Juškaitis and Remeisis, 2007; Wolton, 2009), although in diverse, low-growing woodlands, radio-tracked dormice preferred nestboxes to natural nest-sites (Bright and Morris, 1991). In coppice-with-standards woodland, radio-tracked dormice spent the majority of time either in nestboxes (34% of dormouse tracking days) or in natural tree hollows (41%) and far less time in natural nests in bramble (8%) (Bright and Morris, 1992). Juškaitis (1997) found that dormouse nestbox occupation was negatively, but weakly, correlated with tree crown density; the positive relationship with canopy clumpiness found in this study might be due to similar reasons, as gaps in the canopy would mean fewer arboreal routes, which may cause dormice to descend to nestboxes. High canopy clumpiness meant that there were areas of dense cover but also large gaps that let through direct sunlight, which would benefit the plant species that dormice use for food and nest material. It is still unclear how selection for natural nest-sites interacts with nestbox selection mechanisms, and this would be an interesting area for further investigation. Note that studies into natural nest-sites in woodland are facilitated by radio-tracking, and this is unlikely to be feasible using NDMP volunteers due to the legislation surrounding fitting radio-tracking devices to dormice, and the prohibitive costs involved. Nestboxes therefore remain a more practical way of studying dormice with the help of volunteers.

The presence of certain plant species influenced dormouse nestbox selection: dormice were positively correlated with oak and honeysuckle, and negatively correlated with ferns, sycamore and hawthorn. Food sources influence nestbox selection, as dormice rarely travel further than 100 m from their nests but require a diversity of food sources to ensure that food is available continuously throughout the active season (Bright and Morris, 1990; 1991). Honeysuckle and oak are important food sources (Richards *et al.,* 1984; Bright and Morris, 1990; Harris and Yalden, 2004; Juškaitis, 2007), with honeysuckle also forming an important component of dormouse nests in Midger Wood (Bracewell, 2009). It is therefore unsurprising that these plant species are important explanatory variables in the final models. The presence of ferns is characteristic of dark and damp areas (Page, 1997), which may be avoided by dormice. The negative relationship with sycamore is unlikely to be biologically meaningful as this species was only present near three nestboxes (these never contained dormice, and this is the reason for its statistical inclusion in the stepwise regression).

The lack of competition between dormice and other nestbox inhabitants was of particular interest in this study because competition for nestboxes occurs in other studies (e.g. Juškaitis, 1997; Eden, 2009). Although the lack of competition between birds and dormice agreed with the findings of Morris *et al.* (1990), years in which dormice occupied more nestboxes generally coincided with years in which birds occupied fewer nestboxes, implying that larger scale effects such as population fluctuations might influence nestbox occupancy. The amount of volunteer-collected data available on birds and dormice might provide an opportunity to investigate this relationship further.

The remaining variability in this study might be explained by chance, variables that were not measured as part of this study (e.g. climate, predators, parasites, pathogens etc), or by dormouse learning and previous experience. Indeed, Marsh and Morris (2000) found that nestboxes favoured by dormice in one year tended to be reselected by them in the following year; however, since individuals were not individually marked for identification at the study site, it was not possible to investigate this. Furthermore, since the study only investigated one small woodland in the UK, it is possible that the results may be site and size specific, and further exploration would be needed to elucidate the generality of the results. The temporal span of the dataset was 18 years, and some of the explanatory factors may have changed over this time despite consistent management by GWT. The influence of parasites and predators on dormouse nestbox selection would be an interesting topic for future study, but as this would require annual records of the relevant variables, it was not possible to examine this here using a historical dataset.

Using volunteer-collected data has both advantages and disadvantages. Alongside the usual benefits of saving time and money compared to recruiting professionals (e.g. Newman *et al.*, 2003; McCaffrey, 2005), a key advantage of this volunteer-collected dataset was its longevity; this can also be an important attribute of useful volunteer-collected data (Devictor, 2010). Additionally, volunteers surveyed the nestboxes monthly from April to November, the highest recommended number of nestbox checks in a year (PTES, 2012). As a result of this, the dataset was large (>30,000 data points: 97 nestboxes * 6 months * 18 years * 3 species – dormice, small mammals and birds), which reduced the chance of a type II error.

Volunteer-collected data also has indirect benefits. For example, volunteers also monitored any issues at the site (e.g. fallen trees across footpaths) and reported these back to GWT, thus facilitating the overall management of the site. Most of the regular volunteers at Midger Wood were members of GWT, providing financial support through their memberships and therefore contributing to the cost of managing the site as well as collecting data. Newman *et al*. (2003) found that at least 30% of their volunteers joined conservation organisations after they had volunteered on their project. Meaningful interactions with the natural world also have the potential to enhance human wellbeing and quality of life (Miller, 2005; Goswami, 2007) and volunteers who participated in mammal surveying projects gained fulfilment and knowledge (Newman *et al*., 2003). When asked, volunteers at Midger Wood stated that they gained enjoyment from monitoring the nestboxes and some had been participating in dormouse surveys at the site for 18 years.

The volunteer dataset did, however, present some analytical challenges. Although nestbox occupancy data were collected regularly and followed the majority of NDMP guidelines, volunteers did not collect any habitat data, despite habitat data being requested at 5-year intervals for the NDMP. These habitat data would have proved extremely useful in the present study. Habitat characteristics were measured by the author at the end of an 18-year period, and some of these would have changed during this time. A careful analysis and a consideration of variables that may have changed resulted in useful trends being identified. Although instructions to volunteers were straightforward and recording forms were simple and easy to fill in, some nestbox records were difficult to interpret and, if they could not be confirmed, they had to be discarded from the dataset (<5% of the records). There was a certain degree of variability in the records that made computerising the dataset time-consuming (e.g. a record of "*DORMOUSE*" was described as an unoccupied dormouse nest at the bottom of the recording form, not the presence of a dormouse as suggested). Exact records (i.e. how nestbox contents were recorded on the form) were variable between different people despite using the same data recording forms, and this issue increased with the fluctuating number of volunteers.

3.5) Conclusions and recommendations

This study has developed work by previous researchers and has furthered understanding of dormouse nestbox selection. It indicates that dormice select nestboxes based on a combination of factors. While views on the importance of nestboxes for dormouse conservation differ, many, but not all of the results of this study are likely to be relevant for natural nest selection too. Large scale features, such as distance to the edge of the wood, or combinations of plant species in the nearby vicinity are likely to apply equally to natural nests and nestboxes. Some localised factors may differ, as nestboxes provide shelter that may be absent on thin trees with low structural complexity, which would prevent dormice from building natural nests on these trees. Nevertheless, these results are important in informing conservation management decisions where nestboxes are used, and, in combination with other studies, in understanding the broad principles of dormouse habitat selection in any woodland.

Monitoring dormice using volunteers can provide an adequate quantity of analysable data, and useful information can be extracted from data that might usually be considered less reliable compared to rigourous scientific data, as shown in other studies (e.g. Crick *et al*., 2003; Devictor *et al*., 2010). Volunteer schemes with large historical datasets are irreplaceable and invaluable as they can produce important ecological information and can help identify important sites and management strategies (Crick *et al*., 2003; McCaffrey, 2005). NDMP records vary greatly in quantity and quality between sites and years (S. Sharafi, PTES, pers. comm.), so it would be useful to determine the reasons behind this variation in order to uncover ways in which to reduce it, thus improving the national database. Volunteers should be informed of the importance of completing forms consistently and of collecting regular habitat data, and guidance on this matter should be given to the leaders of monitoring groups. Volunteer schemes would undoubtedly benefit from scientific input to improve data collection, thereby facilitating scientific study of those data and allowing the results to be of maximum usefulness for applied ecology and conservation.

Chapter 4: The accuracy of behavioural data collected by visitors in a zoo environment: can visitors collect meaningful data?

Abstract

Volunteer data collection can be valuable for research. However, the accuracy of such data is often a cause for concern. If clear, simple methods are used, volunteers can monitor species presence and abundance in a similar manner to professionals, but it is unknown whether volunteers could collect accurate data on animal behaviour. In this study, visitors at a Wetlands Centre were asked to record behavioural data for a group of captive North American river otters *Lontra canadensis* by means of a short questionnaire. They were also asked to provide information about themselves to determine whether various factors would influence their ability to collect data. Using a novel analysis technique based on Principle Components Analysis, behavioural data collected by visitors were compared to baseline activity budget data collected by a trained biologist to determine whether visitor data were accurate. Although the response rate was high, visitors were unable to collect accurate data. The principal reason was that visitors exceeded the observation time stated in the instructions, rather than being unable to record behaviours accurately. It is proposed that automated recording stations, such as touchscreen displays, might prevent this as well as other potential problems, such as temporal autocorrelation of data, and may result in accurate data collection by visiting members of the public.

North American river otters at Slimbridge WWT

This chapter has been published with very minor amendments (See Appendix 3):
Williams, R.L., Porter, S.K., Hart, A.G., and Goodenough, A.E. (2012) The accuracy of behavioural data collected by visitors in a zoo environment: can visitors collect meaningful data? *International Journal of Zoology*, Article ID 724835

4.1) Introduction

Animal behaviour data are important across the field of biological sciences, from evolution and population biology to ethology in captive or domesticated animals. However, collecting these data is time consuming. Given that the duration of data collection for behavioural studies can range from several weeks (Md-D-Zian *et al*., 2008; Rees, 2009) to several years (Berger *et al*., 1999), funding professional researchers can be prohibitively expensive (Schmeller *et al*., 2009; Stafford *et al*., 2010), especially for zoological parks and wildlife organisations. However, animal behaviour is of considerable interest to the general public (or at least a subset of the public with environmental and zoological interests), and many people spend considerable amounts of time observing animals as a hobby (e.g., watching pets, wild birds, or animals in zoos). Professionals could use this interest to recruit volunteers to record animal behaviour.

There are many advantages of using volunteers to collect data. Volunteers can collect data at little or no financial cost to the organisation running the project (Schmeller *et al*., 2009; Finn *et al*., 2010; Stafford *et al*., 2010); indeed large numbers of untrained members of the public have been collecting biodiversity data for wildlife organisations for several decades. For example, in 2011, over 600,000 members of the public took part in the Royal Society for the Protection of Birds' "Big Garden Birdwatch" (RSPB, 2011). Several studies have shown that volunteer-collected data on, for example, species identification and quantifying abundance, can be as accurate as basic biodiversity data recorded by scientists (Foster-Smith and Evans 2003; Schmeller *et al.*, 2009; Finn *et al.*, 2010; Kremen *et al.*, 2011), especially when projects offer basic training and are closely supervised by scientists. Moreover, several methods have been developed to enhance the accuracy of volunteer-run surveys, either in terms of the methods used to collect the data or in subsequent analysis (Darwall and Dulvy, 1996; Engel and Voshell, 2002; Newman *et al*., 2003; Henry *et al*., 2008; Schmeller *et al.*, 2009; Szabo *et al.*, 2010). Collection of behavioural data, however, is subject to a certain degree of subjective interpretation and may be more complex to record than counting or identifying species. It is not known whether the quality of volunteer-collected behavioural data would be sufficient to calculate accurate activity budgets or to test behavioural ecology hypotheses.

Monitoring animal behaviour is particularly important in zoos because of the importance of animal welfare (Hill and Broom, 2009; Claxton, 2011). Zoos may encourage their zookeepers to participate in research (Reed, 2006) but data collection often cannot be a priority amongst the zookeepers' daily husbandry activities (Margulis and Westhus, 2008). Research activities can be supplemented with undergraduate and postgraduate students under the supervision of lecturers and scientists, at no financial cost for the zoos involved (Bristol Conservation and Science Foundation, 2008; Colchester Zoo, 2012), but while this provides useful and reliable data, it relies on the availability of students and on University course content.

An alternative approach could be to use zoo visitors to collect data on a voluntary basis. The benefits of asking zoo visitors to collect data while they visit could be numerous. Zoos are popular attractions worldwide, attracting more than 700 million people each year (Gusset and Dick, 2011), so there is no shortage of potential volunteers. Many visitors have a keen interest in animals and wildlife conservation (Broad, 1996; Ballantyne *et al.*, 2007), and this could be a strong incentive to participate in research that may benefit the animals they are observing. Furthermore, behavioural data could be collected almost continuously throughout the day as and when visitors pass the animal enclosures. This should create a database from which daily activity budgets can be calculated. Finally, interactive activities create more positive experiences for visitors when compared to passive exhibit viewing (Anderson *et al.*, 2003), so an activity such as this could make the zoo more attractive to its visitors.

While some research suggests that zookeepers' casual observations throughout the day provide a good indication of the overall activity budgets of the animals (Margulis and Westhus, 2008; Canino and Powell, 2010; Collins *et al.*, 2011), and keepers are generally well acquainted with individual animals and their behaviours, they may not be acquainted with recording behaviour in a scientific and rigorous manner. It also seems reasonable to assume that the vast majority of visitor-based "volunteers" would have no prior experience of collecting behavioural data and it would be logistically difficult, or impossible, to train and/or supervise them while they collect data. However, if visitors are able to collect accurate data on captive animals, there is a potential for volunteer projects to collect behavioural data on wild animals, especially where there are large concentrations of people and animals, such as in nature reserves or game parks. The aim of this study is to determine whether visitors can collect accurate data on the behaviour of a small group of captive North American river otters (see Box 4.1). Visitor data were compared to data collected by a trained biologist.

Box 4.1) North American river otters *Lontra canadensis* (Information synthesised from: Arkive, 2012 – for illustration credits, see page 161)

Kingdom: Animalia	Phylum: Chordata	Class: Mammalia
Order: Carnivora	Family: Mustelidae	Genus: *Lontra*

Physical description Body 1.5 m; weight: 5-14 kg. Long, streamlined body, short powerful limbs, fully-webbed paws and a long tapering tail. Fur is generally brown or black with paler greyish-brown to silver fur on the underside, but there is considerable regional variation in this species' appearance, with numerous recognised subspecies.

North American river otters

Behaviour Mainly nocturnal, but often seen during the day in winter. The social structure of the North American river otter is extremely variable, with some animals being solitary, whilst others live in family units. There is considerable overlap in individual home ranges, and although this otter is non-territorial, scent-marking with faeces, urine and scent glands is an important form of communication.

Breeding Breeding takes place once a year around late winter and spring. Gestation lasts 60 – 63 days but there may be a period of delayed implantation for up to 8 months following copulation. A litter of up to 5 cubs are born. Cubs will normally remain with their mother for 10 months or more.

Diet Mainly slow-moving fish, amphibians and crustaceans, but also birds, reptiles, molluscs, small mammals and fruit.

Habitat A wide variety of habitats from rivers, creeks and streams, to coastal waters, swamps and lakes.

Predators & threats Alligators, American crocodiles, killer whales, bobcats, cougars, coyotes, dogs and wolves. Current threats also include trapping by man (20,000-30,000 otters per year), habitat loss and pollution, notably oil spills in coastal areas.

Distribution Occur through much of Canada and the United States, from the Atlantic to the Pacific coast, and from the Gulf of Mexico up to northern Alaska (see below).

Status and conservation efforts Protected under CITES. By the 20th century, the North American river otter had been extirpated from large parts of its range. Reintroduction projects have been critical to the re-establishment of otter populations in many parts of the United States, especially in the interior.

Public involvement Black (2009) runs an ongoing citizen science survey in northern California where members of the public can submit their otter sightings.

4.2) Methods

4.2.1) Study site

The study was conducted at the Wildfowl and Wetlands Trust (WWT) centre at Slimbridge, Gloucestershire, UK (OS grid reference SO722047). A group of three female captive North American river otters (*Lontra canadensis*) were selected for the study because of their popularity with visitors and the fact that this species demonstrated a rich suite of behaviours during the daily opening hours of the centre (pers. obs.). It was important that visitors could see the otters in order to record their behaviour, and the layout of the otter enclosure facilitated this. Large panels of clear glass around the enclosure allowed visitors to view the otters easily from the walkway that spanned the front of the enclosure (Figure 4.1). There was also a small indoor sleeping chamber in which visitors could see the otters through small glass windows in a walkthrough tunnel. Otters could access all parts of the enclosure at any time of the day, and no parts of the enclosure were closed during routine cleaning of the exhibit.

Figure 4.1) Otter enclosure at Slimbridge WWT, photograph taken from the front of the enclosure and showing the visitors' viewpoint

4.2.2) Ethogram data

4.2.2.1) Ethogram construction and scientific data collection

To determine whether visitors could record data that would accurately represent the otters' behaviour, reliable baseline data were required for comparison. A biologist with experience in collecting behavioural data (RLW) created an ethogram as per Martin and Bateson (2007) to record the otters' behaviour based on prior observations in a pilot study. Behaviour categories were adapted from a behavioural study done by Anderson *et al.* (2003) on a similar species (Asian small-clawed otters *Aonyx cinerea*). Behaviours were grouped into simple, easily definable, categories to ensure that members of the public should be able to recognise them in the latter part of the study (Table 4.1).

Table 4.1) Ethogram used by a trained biologist to record simple otter behaviours

Behaviour	Comments and additional information
Inside	"Inside" is not a behaviour, but it was necessary to record this so that the period of time that the otters spent inside was included in the activity budget (it was speculated that visitors may under-record otters when they were inside – see discussion).
Swimming	In water, not interacting with other otters and/or showing signs of play*.
Eating	This occurred mainly during twice-daily public demonstrations.
Playing	Any playful interaction with another otter (such as chasing, play fighting) or playing alone (diving/rolling in the water, playing with an object)*.
Walking or running	As stated.
Grooming	Self-grooming or mutual grooming (if mutual grooming occurred, all otters involved were recorded as grooming).
Rolling	Rolling on land.
Sitting or lying down	Inactive animal (included pausing for a few seconds but also sleeping outside).
Fighting	This was never recorded with the ethogram, though the otters did display aggressive behaviour over food on one occasion (outside a recording period), so it is possible that visitors could have recorded this.
Other	Any behaviour not mentioned above e.g. sprainting, climbing a tree, drinking.
Out of view	If an otter was not observable at any point during a sampling interval such that its behaviour could not be recorded (i.e. under the pedestrian walkway or hidden in vegetation).

* See discussion for comments about the differentiation of swimming and playing.

The study took place over seven days during the opening hours of the park (10 am until 5 pm). Each hour was divided into six 10 minute periods and the otters' behaviour was recorded during two randomly selected 10 minute periods each hour (Stamp Dawkins, 2007). An instantaneous scan sampling method (Lehner, 1996; Stamp Dawkins, 2007; Martin and Bateson, 2007) was used to record the behaviour of each of the three otters systematically every 10 s during the recording periods. As is normal in behavioural studies, this method involved recording the occurrence of behaviour at 10-second intervals. Behaviour categories were mutually exclusive: only one behaviour was ticked at each interval. This was the shortest interval in which data could be recorded by watching each otter consecutively. By using this sampling technique for each of the otters, the problem of missing out individual behaviours was minimised and an overall activity budget for all three otters could also be calculated. Subtle differences in size and coat colouration were used to distinguish each otter to calculate individual activity budgets. If an individual otter was out of view at any time during the recording period, it was noted as such. In total, 16.5 h of data were collected for each otter, with a data point collected from each otter simultaneously, giving 1,980 ethogram observations per otter (6 recordings per min, i.e. one every 10 s, * minutes of observation per h * h in total). This sample size is comparable to those used in studies of a similar nature (Margulis and Westhus, 2007; Stafford *et al.*, 2012).

4.2.2.2) Inter-observer variability

To examine the potential for inter-observer variability in the collection of behavioural data, a second biologist (herein referred to as CK), with the same level of experience as RLW, collected ethogram data over one day, during exactly the same recording periods (14 * 10 min). The paired data were then compared.

4.2.3) Questionnaires

4.2.3.1) Otter behaviour questionnaire

The ethogram was simplified to a multiple-choice questionnaire to determine whether visitors could collect accurate data on otter behaviour (See Appendix 4). The instructions on the questionnaire were as clear, concise, and self-explanatory as possible, as recommended by previous studies (Darwall and Dulvy, 1996; Newman *et al.*, 2003; Foster-Smith and Evans, 2003; Sewell *et al.*, 2010; Finn *et al.*, 2010). Visitors had to fill in basic information (e.g., write the time down, answer "yes" or "no" if they could see otters inside and/or outside), and tick the behaviours they saw when the otters were outside (i.e., not in the sleeping chamber) during a 30 s period. This method was adapted from the one-zero sampling method in that all behaviours which were observed within the interval were ticked once (1) and those that were not observed were not ticked (0). It is recognised that the two datasets differed not only in who had collected the data (biologist or visitors) but how the data had been collected (ethogram instantaneous scan sampling or questionnaire extended one-zero sampling, respectively). The differences in data collection methods were undertaken for good reason: one-zero sampling was the easiest type of sampling for visitors (and thus the most likely to be reliable) whereas instantaneous scan sampling is a more robust method for generating data for activity budgets. Therefore, although it could be argued that different methods will give different results, the study aimed to determine whether visitor-collected data (at its simplest) could be compared to maximally robust and reliable data, validating the approach taken.

The layout of the questionnaire was an important consideration (Oppenheim, 1992). Colour photographs were used to illustrate each of the behaviours with the exception of “other”, which was represented by a question mark with space underneath for visitors to write down what they had seen. Visitors were not asked to distinguish between individual otters, because identifying them reliably would have been very difficult given the short recording period and subtlety of the physical differences between otters. Consequently, they were requested to record all of the behaviours they observed, regardless of which individual otter was performing the behaviour. The “out of view” category from the ethogram was not included in the questionnaire because visitors did not know how many otters were in the enclosure. If they could not see any of the otters, they should have answered “no” to the questions asking whether they could see any otters inside or outside.

Visitors were asked how long they spent at the otter enclosure overall to determine whether this was related to the number of behaviours recorded, and because this could be a potential indication that visitors might be spending longer than the requested 30 s recording data. Visitors were asked some anonymous personal information questions (e.g., their age group, whether they had volunteered before, whether they were a member of a wildlife organisation) to determine whether any of these factors influenced their ability to record accurate data. Finally, visitors were required to indicate how many people had helped them fill in the questionnaire.

The study took place over eight consecutive days, for seven hours each day. Visitor data were collected for a day more than the ethogram data because of logistical issues when undertaking both activities was not possible. However, analysis of daily otter activity budgets after the data were collected showed that this did not affect the results. The study was advertised using A3-sized posters at the entrance of the centre and near the otter enclosure, and was promoted by the mammal keeper during the twice daily otter feeding demonstrations (11.30 am and 3.30 pm). Visitors approaching the otter enclosure were asked whether they would be willing to fill in a questionnaire as part of a research project on otter behaviour (as such, data could be collected simultaneously by different people). No other details were given unless visitors asked questions, as the aim of the study was to determine whether visitors could collect data without supervision. In order to compare ethogram- and questionnaire-derived data, both were collected on the same days (in order to ensure consistent activity levels of the otters—Anderson *et al*. (2003)). The study was carried out on four days before the school holidays and on four days during the school holidays. This allowed a comparison between uptake of the questionnaire during quiet and busy periods at the centre, as well as increasing the range of different visitors filling in the questionnaire (e.g. more families during school holidays).

4.2.3.2) Visitor Segmentation Questionnaire

The WWT developed a questionnaire as part of a survey to learn more about their visitors, and this was used as a complementary tool in this study (Hargreaves McIntyre, 2011 – see Appendix 5). This questionnaire (named the visitor segmentation questionnaire) was stapled behind the otter behaviour questionnaire, but was optional so that length of the two combined questionnaires did not deter visitors from participating. It consisted of a list of questions with the instruction “tick the statement that best describes you”. The questions concerned topics such as motivations for visiting the centre, personal interests and affinity for nature, and preferences for various animals at the centre. Analysis of the results determined which “segment” a visitor belonged to (Table 4.2) and, subsequently, allowed examination to test whether different segments of visitors could record otter behaviour more effectively than others.

Table 4.2) Segmentation Pen Portraits – Modified and adapted from WWT visitor segmentation report (Hargreaves McIntyre, 2011)

Visitor Segment	Description and comments
Learn together families	They believe in life-long learning for their family. Accessing the outside plays an important role in their leisure time, and they are generally open to all forms of nature, rather than visiting specifically to see birds.
Fun time families	Doing something that entertains and satisfies their children is the main priority in their day out. If their children learn something along the way then this is an added bonus.
Social naturalists	Their interest in nature is broad; it is not about acquiring detailed knowledge on specific species, but more about simply enjoying any kind of wildlife.
Interested naturalists	Interested naturalists are not active birdwatchers, but visit to improve their knowledge and learn new things, driven by a broad interest in the natural world.
Interested birders	For interested birders, trips in the outside are a significant part of their life and the majority are active birdwatchers. Whilst they are mainly looking to develop their interests, their interest in birds is often tied into other hobbies such as walking, photography and painting.
Social birders	Social birders are seeking to spend quality time with other people in natural surroundings where they are guaranteed to see interesting birds.
Expert birders	Expert birders are applied birdwatchers who tend to take their hobby relatively seriously. This segment has the most knowledge about the WWT's wider conservation activities.
Sensualists	Experiencing the outside is essential to sensualists' lives, to them, it is food for the soul and is a space in which they can relax and experience nature's beauty.
Social day-outers	Wildlife and the outside are not of prime interest to them; their main focus is to spend quality time with others in a nice environment.

4.2.4) Data processing and analysis

4.2.4.1) Uncorrected and corrected data

When data were entered into a spreadsheet, two copies were made: an uncorrected version with data exactly as they were recorded by visitors and a corrected version, whereby any mistakes visitors had made that were noticed by RLW were rectified when possible or omitted from the dataset if the whole questionnaire was unusable (c. 10% of the questionnaires were affected). Mistakes that resulted in exclusion from the corrected dataset included writing the wrong time (pers. obs.), not answering all of the questions, and ticking all of the boxes haphazardly (such questionnaires were usually filled in by young children—pers. obs.). Questionnaires that could be rectified were those in which visitors had interpreted a behaviour as "other" when it could be reclassified as one of the categories listed, for example, "kissing" or "licking" = grooming; "going through tunnel" = playing, and so forth. These datasets are henceforth referred to as uncorrected visitor data and corrected visitor data.

4.2.4.2) Calculating activity budgets

Ethogram data and questionnaire data were converted into activity budgets to indicate the percentage occurrence of specific behaviours as per Stafford *et al*. (2012). An activity budget was calculated for each individual otter and for the whole group (using ethogram data), as well as for the group of otters using visitor data (using corrected and uncorrected data). In addition to the full questionnaire datasets, various subsets were extracted for separate analysis, for example, for each visitor segment and from adapted or standardised datasets (see below).

4.2.4.3) Adaptation of the visitor datasets and extraction of subsets

In addition to the full activity budgets mentioned above, activity budgets were also calculated with the behaviours playing and swimming combined into one category because these behaviours often overlapped. This was similar to the adaptations of Margulis and Westhus (2007) where "swim" and "stereotypic swim" were combined to allow the comparison of keeper-collected data and scientist data on brown bear (*Ursus arctos*) behaviour.

There was a disparity in the number of visitors at different times of day, which could have led to an under-representation of inside in the mornings when there were fewer questionnaires completed (because there were fewer visitors in the centre) and an overrepresentation of eating when many questionnaires were filled in during the otter demonstrations. To reduce the effect of pseudoreplication and temporal autocorrelation (visitors recording the same behaviours at the same time) that may result from this, an average activity budget was calculated over each half hour period taking into account the number of questionnaires answered in each period. Given the varying length of time that visitors took to complete the questionnaires, it was not logistically possible to calculate an average from the questionnaires over a shorter time interval than 30 min, and in some cases, autocorrelation between questionnaires was likely. The effects of this possible autocorrelation are discussed below.

Separate activity budgets were also calculated from subsets of questionnaires extracted from the complete dataset. These were based on the personal information questions at the end of the behaviour questionnaire. Activity budgets were calculated based on the removal of all questionnaires that had been filled in by a child aged 10 or under from the initial dataset (because children may have difficulty giving accurate answers – Borgers *et al.*, 2003), as well as separate subsets for the visitors who had prior experience volunteering and for those who had none, and for visitors who were members of a wildlife organisation and for those who were not.

4.2.4.4) PCA and analytical framework

To compare the ethogram activity budgets with the activity budgets calculated for the visitor datasets and subsets, bootstrapped Principal Components Analysis (PCA) was conducted in the R statistical package (R Development Core Team, 2011), following methods in Stafford *et al*. (2012). Rather than plotting each activity budget on a two-dimensional scatterplot (as in conventional PCA), this approach involved plotting the mean value of calculated principal components in three dimensions with the radius of the resulting sphere, or "bubble", indicating the confidence radius. Plots were constructed using the RGL library and rgl.sphere function for R (Adler and Murdoch, 2008). Each bubble represented the overall activity budget, with the centre representing the mean of the first three principal components and the radius representing the 95% confidence interval (as is standard in bootstrapping analyses – see Stafford *et al.* (2013)). Statistical inferences were made on the basis that overlapping bubbles signify no significant difference between the activity budgets represented by the bubbles while no overlap indicates significant differences in the activity budgets ($\alpha = 0.05$). In order for the plot to be reliable, the cumulative proportion of the variance explained by the first three principle components (i.e., those used to create the plots) needs to be greater than 0.95 (Stafford *et al*., 2012); in this study, all values exceeded 0.95.

A chi-square test for association was performed to test whether the number of behaviours recorded related to the length of time spent at the otter enclosure. The corrected visitor data were used to calculate the number of behaviours recorded, and any questionnaires where the question regarding time spent at the enclosure was left blank were excluded. The number of behaviours recorded was combined into five categories for the chi-square test (0, 1-2, 3-4, 5-6, and 7-8) and time periods were classed as less than 2 mins, 2–5 mins, 6–10 mins, and over 10 mins (note that this is categorical data, not continuous data, so a chi-squared test is justified). It is worth noting that, although visitors could have recorded up to 10 behaviours, this did not occur (one visitor did record 9 behaviours, but this was excluded from the analysis because the visitor was a young child and data accuracy was questionable).

4.2.5) Simulations to test accuracy of visitor-collected data

The selection of the time period in which the visitors were asked to collect data was based on the concept that a 30 s period would capture more data than a single instantaneous scan, yet would not be likely to result in all behaviours being observed; hence an estimate of frequency of behaviours could be obtained using this method. Given that preliminary observations indicated that visitors vastly exceeded this time period (see below), a computer simulation was developed to determine if the 30 s sampling period would produce comparable data to ethogram recordings given assumptions that incorrect identification of behaviour and temporal autocorrelation of the data did not exist (i.e., data were collected perfectly, except for the time of recording). The simulation was constructed using R (R Development Core Team, 2011). The simulation was parameterised according to the relative probability of the behaviours, as collected from ethogram recordings, making the assumption that the ethogram data collected in this study were an accurate representation of the otters' activity budget (see Results, Figure 4.2).

The simulation produced a random score between 1 and 100, which corresponded to a particular behaviour based on the proportion of its occurrence (see results for details, but otters were seen swimming 11% of the time, so a score between 1 and 11 would correspond to the behaviour "swimming"). After this initial score had been set, the simulation ran with a timestep of the simulation of 5 s. At each timestep, the score was modified by adding or subtracting a second, randomly generated number (between 3 and −3 from a uniform distribution), from the current score. This new score then indicated the behaviour of the otter at the next timestep. In practise, this meant that successive time steps normally resulted in the same behaviours being recorded, which corresponded to observations on behaviour (i.e., behavioural inertia is more likely than behavioural change).

To parameterise this alteration (named the "change by" variable), results from the ethogram recordings were used. Results indicated that the otters performed on average 3.6 behaviours in a 10 min period. Therefore, the "change by" variable was systematically changed, and for each value, 100,000 individual 10 min periods were simulated (with sampling every two 5 s timesteps—equating to the 10 s recording periods that were used in this study) to produce a number of behaviours as close as possible to 3.6. The "change by" variable of 6 (i.e., between −3 and 3) produced the most accurate representation, producing an average of 3.5 behaviours over 10 min. (when the "change by" variable was 7 (±3.5), the model produced an average number of behaviours of 3.8, and when 5 (±2.5) produced an average of 3.2 behaviours).

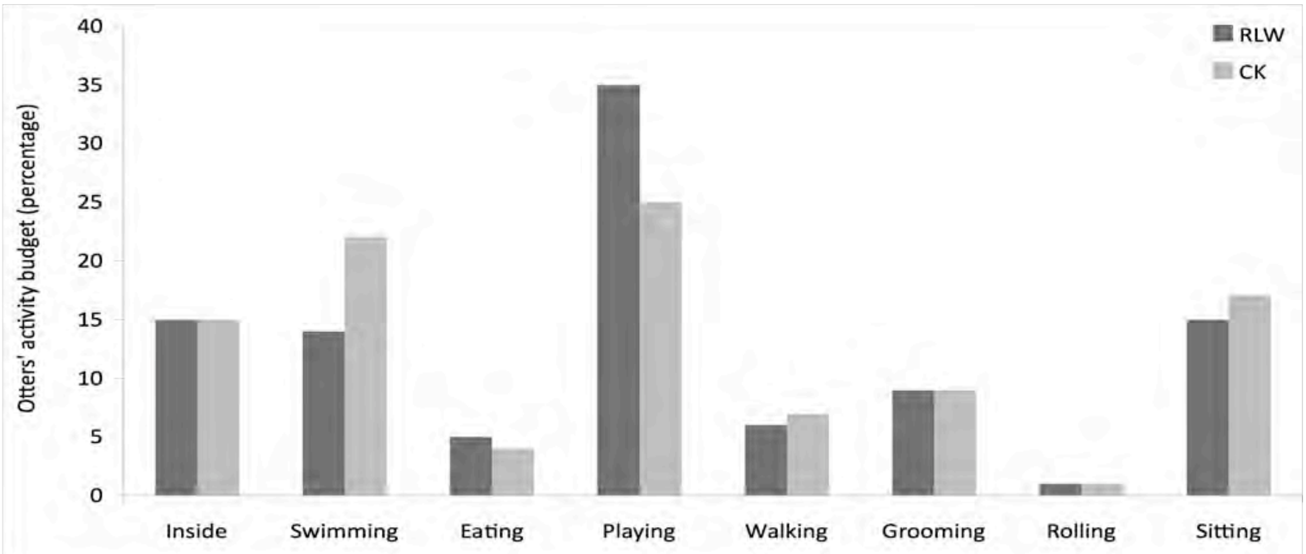
Next, data that represented 30 s of sampling by visitors were simulated. Although these simulated data were free from confounds such as temporal autocorrelation and misidentification of behaviours, they would give an accurate indication of whether the 30 s recording period would have allowed visitors to collect accurate data on the otters' activity budget. As such, 574 visitor responses were simulated (the same number collected in the study). Simulated and real visitor-collected data were compared in terms of the number of behaviours recorded in a questionnaire to examine the average length of time that visitors may have recorded data for. The 30 s simulated visitor data were also compared to ethogram data and real visitor data using modified PCA or "bubble" analysis, to determine whether recording behaviour for 30 s would result in significant differences to either of these recording methods.

4.3) Results

4.3.1) Inter-observer variability

The activity budgets collected by the two biologists were very similar except for the categories of playing (35% for RLW and 25% for CK) and swimming (14% for RLW and 22% for CK). Because playing and swimming were sometimes difficult to differentiate (playing often occurred in water), the differences between the two activity budgets were less apparent when these categories were combined as a single category (Figures 4.2(a) and 4.2(b)). There was no significant difference between activity budgets collected by the two biologists. However, when playing and swimming were combined, the bubbles overlapped more, indicating greater similarity (Figures 4.3(a) and 4.3(b)). Figure 4.3(c) shows the relationship between the data for each individual, and the average taken for both individuals. Note: because this relies on percentage occurrence of each behaviour, the confidence intervals of the combined category are largely the same size as for each individual observer.

a



b

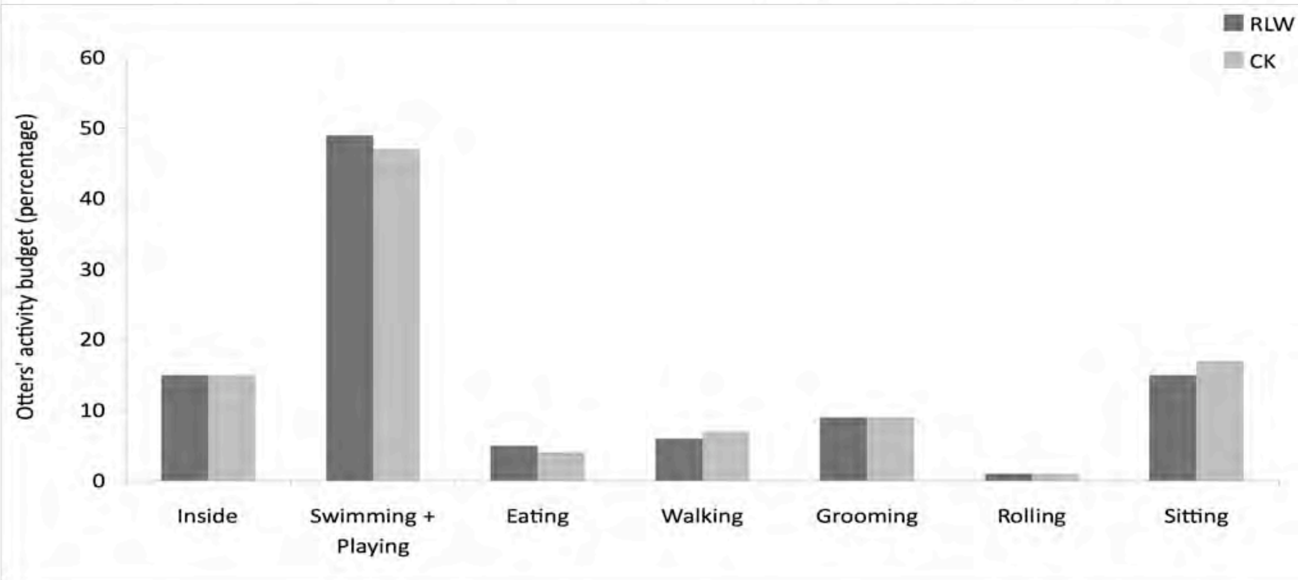


Figure 4.2 (a) Comparison of otters' activity budgets calculated from ethogram data collected by two biologists (RLW and CK) over one day. Note: categories 'fighting' and 'other' are not displayed on the graph because neither occurred n that day. (b) As above, with swimming and playing combined as one category.

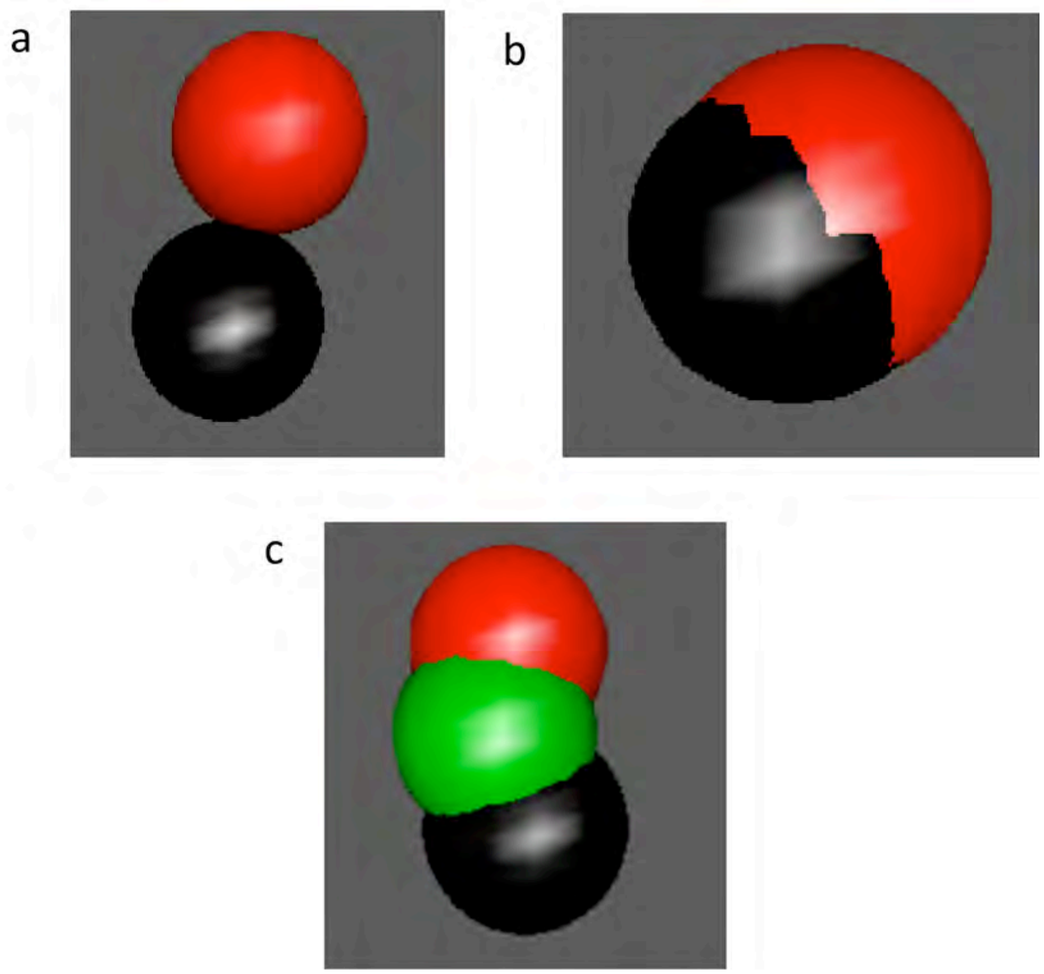


Figure 4.3) (a) Results of bootstrapped PCA examining differences between ethogram data collected by two biologists for the group of otters over one day. Black = RLW, red = CK. Cumulative proportion of variance explained by first 3 principal components > 0.999. (b) as above but with playing and swimming combined. (c) Results of bootstapped PCA showing the relationship between ethogram data for professionals as individuals and combined (i.e. as an average). Black = RLW, Red = CK, Green = average of RLW and CK.

4.3.2) Uptake of questionnaires and potential errors

In total, 574 questionnaires were collected during the study. A very low number of visitors declined to fill in the questionnaire when they were asked (estimated at <5%), and the main reason given for this was that they did not have time. Of the questionnaires collected, 39.2% were collected outside of school holidays and 60.8% during the school holidays, reflecting the increase in visitor numbers in the centre. Some visitors left various questions unanswered in the otter behaviour questionnaire (Table 4.3). The segmentation questionnaire was completed by 62.4% of visitors who had filled in the otter behaviour questionnaire, but of these, 5.6% could not be used because visitors had not followed the instructions and had ticked more than one answer, meaning that they could not be classified into a visitor segment.

While the questionnaires were being filled in, personal observations indicated that visitors were watching the otters for longer than 30 s. This was reflected in the responses to the question concerning the length of time visitors had spent at the enclosure. A chi-square test showed that the length of time a visitor spent at the enclosure affected the number of behaviours recorded (χ^2 = 41-7, df = 12 , p < 0.001). This was because visitors who stayed at the otter enclosure for shorter lengths of time recorded significantly fewer behaviours than those who stayed at the enclosure for longer (mean number of behaviours recorded when they stayed for: less than 2 mins = 2.14; 2–5 mins = 2.34; 6–10 mins = 2.93, over 10 mins = 3.33).

Table 4.3) Percentage of questions not answered in the otter behaviour questionnaire

Question	Questionnaires where this was left unanswered
What time is it?	0.2%
Approximately how long will you have spent at the otter enclosure in total today?	5.7%
Are you, or someone who helped fill in this questionnaire a member of any wildlife charities?	8.3%
Have you or anyone who helped fill in this questionnaire volunteered or done something to help any wildlife charities? (e.g. habitat improvement, wildlife surveys, helped at events, raised money...)	11.6%
What age are you / the people who helped fill in this questionnaire? Write down the number of people in each age group.	9.9%

4.3.3) Comparing ethogram activity budgets with activity budgets calculated from visitor data

The otters' activity budget calculated using ethogram data consisted mainly of time spent inside (28%), followed by playing (21%) (Figure 4.4). "Other" behaviours (e.g., sprainting, drinking, climbing…), and rolling amounted to the smallest proportion of the activity budget (2%). Fighting is not represented in the ethogram activity budget, but visitors did record fighting (1%), and it was observed during the study (outside of the randomly allocated observation periods). Compared to the ethogram data, visitors underrecorded sitting, time spent inside and playing and overrecorded all of the other behaviours, with the exception of “other” in the corrected visitor data, which was identical to the ethogram data. The most noticeable differences between ethogram and visitor data lie between time spent inside (28% for ethogram data and 11% for visitor data) and swimming (10% for ethogram data and 25% for visitor data).

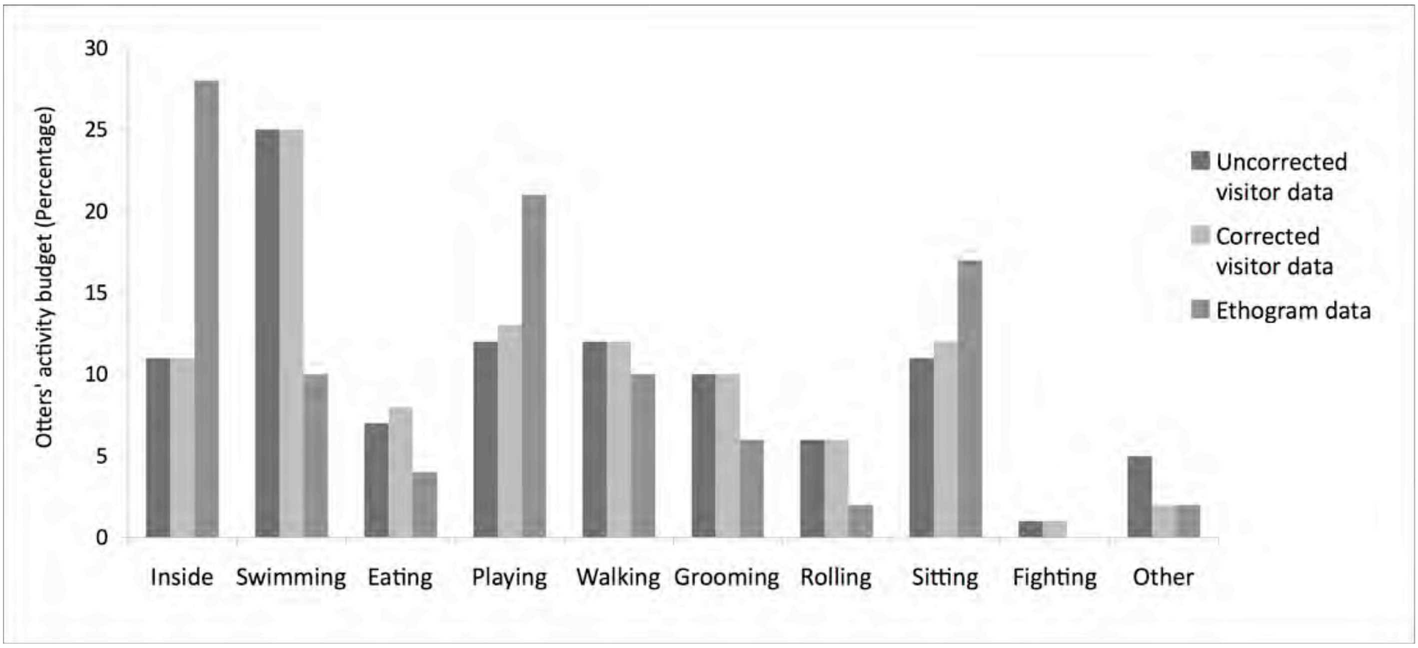


Figure 4.4) Differences in otters’ activity budgets calculated using corrected and uncorrected visitor data and ethogram data.

There were significant differences between ethogram data and visitor data, but there were no significant differences between uncorrected visitor data and corrected visitor data (Figure 4.5). Additionally, there were no significant differences between each individual otter and the average taken for the group, so to simplify subsequent analyses, only corrected visitor data and ethogram data for the group of otters were used. Significant differences also occurred between ethogram data and data collected by different visitor segments, but there were no significant differences between the behavioural data recorded by different types of visitor (as quantified using the visitor segments used in the analysis: learn together families, fun time families, sensualists, social naturalists and expert birders, note: other segments could not be used because of small sample sizes) (Figure 4.6).

There was a significant difference between ethogram data and visitor data, but no significant difference between corrected visitor data before and after questionnaires filled in by children were excluded from the dataset. There was no significant difference between visitors who had prior experience volunteering, or were a member of a wildlife organisation and those who were not. All visitor datasets were still significantly different to the ethogram dataset (Figures 4.7(a) and 4.7(b)). There were still significant differences between ethogram and visitor data when playing and swimming were combined in the activity budgets and when visitor data was reclassified taking into account time periods in which the data had been collected (Figures 4.7(c) and 4.7(d)).

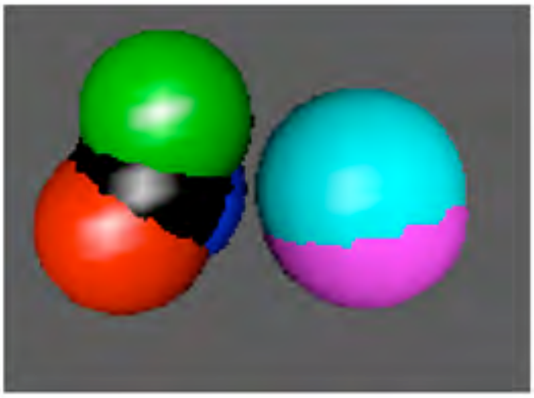


Figure 4.5) Results of bootstrapped PCA examining differences between ethogram and visitor data. Black = ethogram data for group of otters, red = ethogram data for otter 1, green = ethogram data for otter 2, dark blue = ethogram data for otter 3, light blue = corrected visitor data, pink = uncorrected visitor data. Cumulative proportion of variance explained by first 3 principal components = 0.995.

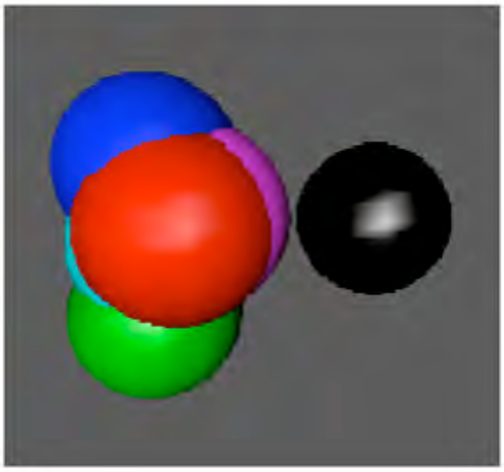


Figure 4.6) Results of bootstrapped PCA examining differences between ethogram data and different visitor segments. Black = ethogram data for group of otters, red = fun time families, green = sensualists, dark blue = social naturalists, light blue = expert birders, pink = learn together families. No other visitor segments were included, since in total they contained < 20 responses. Pairwise comparisons between social naturalists and sensualists also indicated no significant differences occurred between these categories. Cumulative proportion of variance explained by first 3 principal components = 0.997.

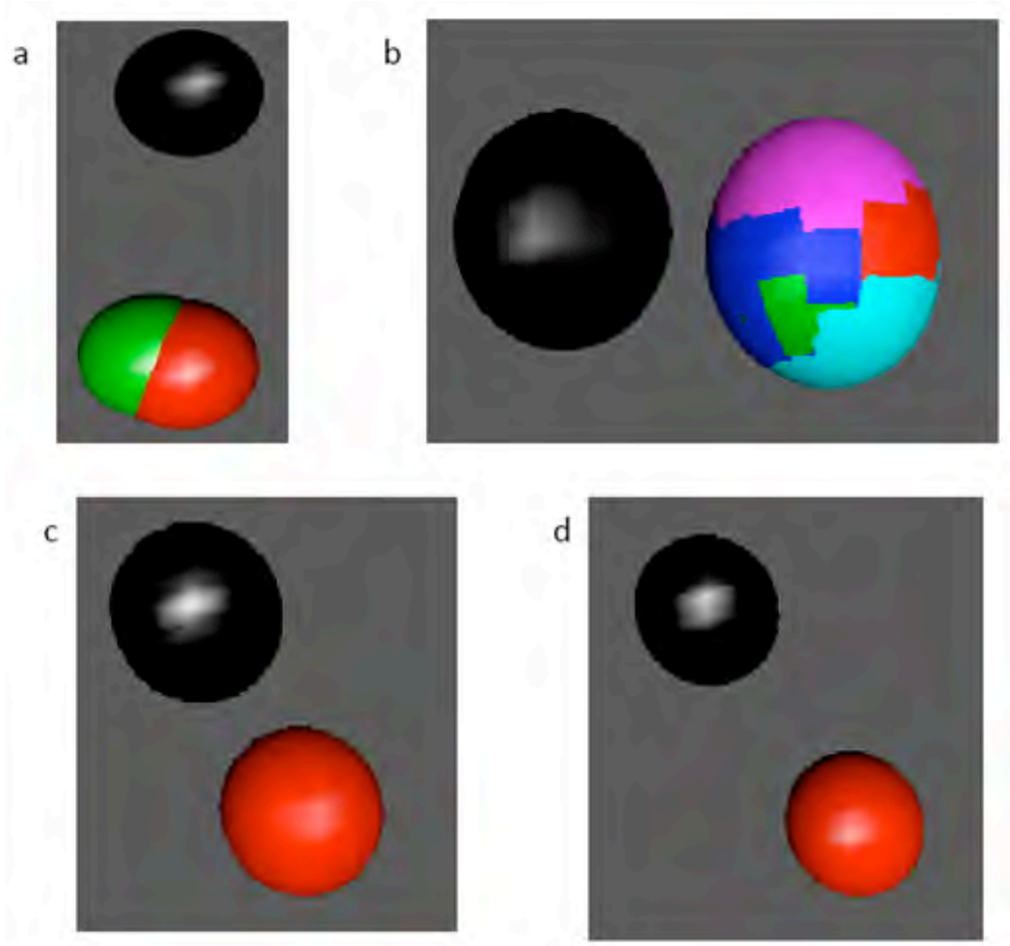


Figure 4.7) (a) Results of bootstrapped PCA examining differences between ethogram data, corrected visitor data and corrected visitor data when all questionnaires filled in by children were removed from the dataset. Black = ethogram data for group of otters, red = children's questionnaires removed from corrected visitor data, green = corrected visitor data. Cumulative proportion of variance explained by first 3 principal components > 0.999. (b) as above but examining visitor segments. Black = ethogram data for group of otters, red = corrected visitor data, green = visitors who had previous experience volunteering, dark blue = visitors who did not have prior experience volunteering, light blue = visitors who were members of a wildlife organisation, pink = visitors who were not members of a wildlife organisation. Cumulative proportion of variance explained by first 3 principal components = 0.995. (c) as above but examining ethogram data for group of otters and corrected visitor data when playing and swimming were combined. Black = ethogram data for group of otters, red = corrected visitor data. Cumulative proportion of variance explained by first 3 principal components > 0.999. (d) as above but examining ethogram data and visitor data with standardised time periods. Black = ethogram data for group of otters, red = corrected visitor data. Cumulative proportion of variance explained by first 3 principal components = 0.987.

4.3.4) Simulation of test accuracy of visitor data collection methods

The average number of behaviours recorded by visitors in the study was 2.9, whereas the average number of behaviours recorded in the simulation running for 30 s was 1.4. Changing the length of time that visitors took to record behaviours in the simulation indicated that visitors may have watched the otters for up to 8 min, instead of following the instructions and recording behaviour for 30 s. Comparing the overall behaviour of all three otters combined using bootstrapped PCA demonstrated that there was no significant difference in overall behaviour when observations took place for 30 s (from simulated data) and the real ethogram data, but when compared with the longer 8 min observation period or the visitor collected data, significant differences to the ethogram data occurred (Figure 4.8).

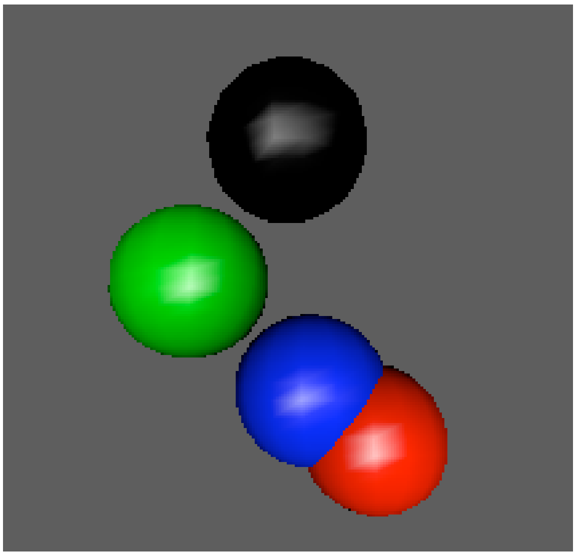


Figure 4.8) Results of bootstrapped PCA examining differences between real data and simulated data. Black = real visitor data, red = real ethogram data, green = simulated visitor data where data were collected for 8 min, blue = simulated visitor data where data were collected for 30 s. Cumulative proportion of variance explained by first 3 principal components = 99.8.

4.4) Discussion

4.4.1) Visitors cannot accurately collect behavioural data

The ethogram method used to determine otter activity budgets was repeatable between trained biologists, and this suggests that it is a reliable way of determining activity budgets. However, visitors were unable to collect activity budget data regardless of which visitor segment they were in, their age, prior experience volunteering or whether they were a member of a wildlife organisation. This did not differ when behaviours that overlapped (playing and swimming) were combined in the analysis, nor when much of the potential pseudoreplication caused by varying numbers of visitors throughout the day was removed. It may seem intuitive that an “expert birder” with experience of collecting scientific data on birds may be more likely to collect accurate data than a “fun time family” that is on a recreational trip, but this was not the case in this study.

4.4.2) Where did they go wrong?

4.4.2.1) Ignoring the instructions

One of the most important instructions on the questionnaire was the length of time required to observe the otters for. This length of time was chosen because it was thought to be short enough not to deter visitors from participating and would allow the recording data as and when visitors walked past the enclosure. Ease of data collection and reliability were both a key aspect of this study because visitors were assumed to be untrained. Therefore, 30 s was considered to be a reasonable length of time for visitors to scan the otter enclosure and be able to identify behaviours while imposing a time limit so that all visitors should spend approximately the same length of time recording data. Results of the simulation model of visitors undertaking 30 s sampling periods when filling in questionnaires showed that this length of time should have resulted in the accurate representation of the otters’ activity budgets.

Despite the instruction to watch for 30 s being underlined and in bold font, most visitors did not follow this and recorded data for much longer than 30 s (pers. obs.). When visitors stayed longer at the otter enclosure, they ticked significantly more behaviours. This is probably one of the main reasons why their activity budgets were incorrect. In some cases, visitors admitted watching for longer. One visitor ticked rolling and wrote “when arrived,” indicating that they felt this was an interesting behaviour and that they should record it, even though it was not in their 30 s recording period. Another visitor wrote “the otters came out at 10.36,” which also indicates that they watched for longer than 30 s but may have thought that adding extra detail would benefit the study. At the end of one questionnaire that had been filled in by a parent and child (where all but one of the boxes had been ticked), the parent wrote, “hence saw all of the above because watched for a long time.” Another visitor wrote that they “saw the otters outdoors earlier" so had filled their questionnaire in for a previous time (based on their memory of what they saw the otters do) as well as the present (when the otters were indoors), thus confounding their results. Some visitors demonstrated attention to detail by adding detailed notes on their questionnaires. However, these details are often impossible to analyse unless they can be reclassified, and this process can be time consuming (pers. obs.). It seems that attention to detail and enthusiasm, while generally considered key attributes for volunteering, can hinder the quality of behavioural data collected.

4.4.2.2) Making mistakes and adding extra details

Occasionally, visitors admitted errors on their questionnaires, despite understanding the instructions. One visitor ticked rolling but wrote “in water” next to the box despite the fact that the behaviour was entitled “rolling—e.g. on soil or rocks”, another ticked sitting but specified that the otters were indoors. However, only the obvious mistakes could be removed from the corrected dataset, and it is highly likely that some mistakes remained undetected (i.e. if visitors wrongly interpreted behaviours or deliberately ticked boxes even though they had not seen a particular behaviour). It was impossible to measure this. Furthermore, the question “What age are you/the people who helped fill in this questionnaire? Write down the number of people in each age group” could not be analysed because visitors misunderstood the question. Most visitors wrote down the number of people in their group, regardless of whether or not they had helped fill in the questionnaire.

The fact that visitors underrecorded sitting and time spent inside may be because these could be ignored if they appeared less interesting for visitors than more active behaviours. Sitting generally occurred for short periods of time (with otters pausing for a few seconds), in which case visitors could have missed this. The underrecording of time spent inside may have been caused by visitors missing otters inside if some of the otters were outside. If this was the case, visitors often observed the otters that were outside and did not check the sleeping chamber (pers. obs.). Another contributing factor could be that otters spent more time inside during quiet times when there were no visitors around to record this (early morning and late afternoon). The underrecording of playing is probably correlated with the overrecording of swimming; it is likely that some visitors confused the two behaviours and ticked swimming instead of playing when otters were playing in the water (Figures 4.2(a) and 4.2(b)). Playing may have been difficult for some visitors to interpret. Indeed, most “other” behaviours that were reclassified in the corrected dataset were reclassified as playing. However, removing mistakes and omissions and grouping behaviours did not change the overall results. This suggests that misidentification of behaviours by visitors was not the prime reason for the differences between ethogram and visitor activity budgets.

4.4.2.3) Item nonresponse

Item nonresponse, in which a questionnaire is returned with one or more questions unanswered, can have an impact on results of a survey but these impacts are difficult to measure (Ferber, 1966; Durand *et al.*, 1983; Denscombe, 2009). There could be various reasons why some visitors left questions blank (Table 4.3). For example, the visitor who missed out the question asking for the time may not have been able to find out what the time was as they did fill in all of the other questions. Boredom or rushing to finish the questionnaire may have been reasons why 1.6% of visitors filled in the time and ticked behaviours but did not answer any other questions that appeared later in the questionnaire (Kraut *et al.*, 1975). It is also possible that some of the visitors who did not answer questions on the second page did not realise they were there, despite the staple and instruction “please turn over” in bold and underlined at the bottom of the first page: some visitors only realised this when another visitor pointed it out to them (pers. obs.). Another possibility is that visitors may not have wanted to fill in the questionnaire but felt obliged to do so out of politeness and as a result, may have rushed through the questions, missing some out.

This lack of attention to detail could be caused by the fact that the questionnaire was *impromptu*: visitors were on a day out not expecting to have to concentrate on a task. They may also have been distracted by the surrounding environment (e.g. by their children or by other visitors). Slightly more visitors avoided answering the question about volunteering than the question about being a member of a wildlife organisation or charity (Table 4.3). This may be because the membership question can be more easily interpreted, as membership to the WWT is well advertised throughout the centre and 57% of all visitors to the centre during the study were members of WWT. The volunteering question may confuse those who are unfamiliar with the idea of volunteering; one visitor said that she considered visiting the centre as volunteering (pers. comm.).

4.4.2.4) Temporal autocorrelation of the data

Questionnaires were handed to visitors as and when they arrived at the otter enclosure. As such, it is highly likely that some of the otters’ behaviours were simultaneously recorded by many visitors, especially at busy times such as during the feeding demonstrations. While it would have been possible to hand out only one questionnaire at a time, such an approach would reduce the uptake of the questionnaire, and also would have a negative influence on visitor experience, with visitors either waiting a long time to participate or feeling left out if they could not participate. In a zoo environment, it would be very difficult to fully control the spread of questionnaires over time because of the irregular flow of visitors, not only at different times of day (e.g. when the centre first opens or when visitors are hurrying to leave before the closing time), but also in adverse weather conditions when visitors would be less likely to want to fill in a questionnaire. Additionally, there were often more visitors at the enclosure when the otters were active, with large crowds often attracting passersby because the formation of a crowd could indicate that the otters were doing something interesting or unusual (pers. obs.). In this study, the averaging of data over 30 min periods helped reduce autocorrelation effects due to the effects mentioned previously, but would not completely eliminate them if there was a difference in recorder effort within a 30 min period.

However, the effects of temporal autocorrelation on the results of this study appear minimal. Firstly, “standardised” data (where an average activity budget was calculated over each 30 min period taking into account the number of questionnaires answered) and “unstandardised” data both differed significantly from ethogram data. Secondly, when data were simulated (and autocorrelation effects were eliminated) results corresponding to visitors collecting data for a long period of time (8 min) were highly significantly different from ethogram recordings. Hence, it appears that it was the length of time in which visitors recorded behaviour that was the largest source of error, rather than potential errors inherent to the sampling design used. Nevertheless, methods to eliminate temporal autocorrelation and enhance the visitor experience are given in Section 4.5.

4.4.3) A success: the high questionnaire uptake rate

The questionnaire uptake rate may not have been so high if the questionnaires had not been handed out in person (e.g. Dillman, 1975). Indeed, very few visitors were observed picking up a questionnaire themselves when the questionnaires were laid out on a wall next to the otter enclosure, despite posters advertising the study. In this situation, children were more curious than adults, often picking up questionnaires and filling them in of their own accord. Curiosity is a strong motivational force in children (Peterson and Lowery, 1968; Jenkins, 1969; Chak, 2007) and it is often believed that curiosity decreases with age (Chak, 2007), which may explain why fewer adults picked questionnaires up. Distributing questionnaires in the manner described in this study could cause logistical problems for zoos (for financial and temporal reasons). However, it may be possible that handing questionnaires upon entry to the park along with a quick explanation or instruction leaflet could be a suitable method to increase participation, similar to the method described in Dillman (1975).

Uptake rate may be less high when animals are out of view or in an indoor area. As discussed previously, otters were less popular with visitors when they were inside, visitors walked past and/or did not see the point of filling in the questionnaire until it was explained that it was important to find out how much time the otters were spending inside. This has been discussed in previous studies. Indeed, Altman (1998) and Anderson *et al.* (2003) found that zoo visitors paid more attention to an animal's behaviour when the animals were most active compared to when they were less active or inactive. Jackson (1994) and Johnston (1998) found that visitors spent less time in front of enclosures where animals were inactive. Additionally, mammals are the most popular class in zoos (Moss and Esson, 2010), and larger animals may be preferred by visitors over smaller animals (Ward *et al*., 2008). It is possible that a behavioural study would not prove as popular with visitors if it involved less appealing classes or species. Indeed, Hoff and Maple (2005) found that some visitors deliberately avoided going to reptile exhibits.

4.5) Conclusions and recommendations

A visitor who had completed the questionnaire made the following comment: "you could tell us more about the otters than we could tell you". This statement underlies the concept of volunteer data collection: a scientist's work can be more reliable than that of a volunteer, as was the case in this study. However, it is the large number of volunteers that can make them a powerful tool for research. Although the method in this study did not allow visitors to record accurate activity budgets, it did have some success. The high uptake rate suggests that getting visitors to collect data on active and entertaining animals can be successful. Public engagement and distributing the questionnaires by hand also undoubtedly had a major influence on the uptake rate.

Several improvements could be made in future research. When asking volunteers to collect behavioural data, it is important that behaviours are simple enough that volunteers can distinguish them without confusion. Clear instructions are needed when designing questionnaires, but in situations where a time limit is necessary, it is important to try to facilitate this to ensure that methods are followed as closely as possible, perhaps by providing a clock in front of the enclosure. A time limit could also be imposed with the use of technology, for example, through multimedia or interactive video screens, which have previously been used in zoos and aquaria to convey information to visitors (e.g. Semani *et al*., 2002; Hlavacs *et al*., 2005; Lindemann-Mathies and Kamer, 2006). This type of technology has also been used by the National Marine Aquarium in Plymouth, UK to allow visitors to collect data on fish in an exhibit (pers. obs). Visitors could also collect data with the use of smart phone technology as this has already been used for other types of volunteer data collection (Aanensen *et al*., 2009). Technology such as this may also reduce the number of questions that are unanswered by imposing a response, or could be used to eliminate any temporal autocorrelation of responses by either only having a single display, or by accurately recording the time of the response, so replication in time can be removed.

Overall, many of the aims of volunteering were completed in this study as visitors were keen to participate, enjoyed observing the otters, gave positive feedback, and wanted to know more about the study. Visitors were generally able to recognise different behaviours and recorded a rare behaviour that the scan sampling method did not detect (Martin and Bateson, 2007). They were also often eager to provide detailed notes on their observations. The "*ad libitum*" behaviour sampling method may be more suited to volunteers as it would remove the need for a restrictive time limit and would allow volunteers to record behaviours as they wished. This technique is commonly used in preliminary studies or to record rare but important events (Martin and Bateson, 2007). However, data collected in this manner would be difficult to analyse and could not be used to calculate activity budgets. New data collection techniques need to be tested if volunteers are to be used to collect behavioural data effectively.

Chapter 5: How well do you know your garden? The accuracy of citizen science data on hedgehogs in gardens

Abstract

Gardens provide a rich habitat for species that are declining in rural areas. However, collecting data in gardens can be 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 were important in 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. Fieldwork using 'footprint tunnels' showed that approximately equal numbers of hedgehogs were found in gardens in which hedgehogs had previously been seen as gardens where they had not been seen. Overall, the results indicate that casual volunteer records of hedgehogs may be influenced more by the observer than by habitat preferences of the animal, and care needs to be taken when using casual records in future citizen science wildlife surveys.

Hedgehog

This chapter was presented at a conference symposium entitled "Applying citizen science generated species occurrence data in ecology and conservation research":

Williams, R.L. (2012) Simple citizen science habitat assessment; can we correlate garden condition with hedgehog presence? Proceedings of the 3rd European Congress of Conservation Biology, Glasgow, UK

5.1) 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 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; Humphreys *et al*., 2011). 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).

A large network of gardens is difficult to survey: conducting professional fieldwork is not practical because of access restrictions (Carter *et al.,* 2004; Toms and Newson, 2006) and such an approach would be prohibitively expensive. For this reason, volunteer surveys are being used increasingly to collect large amounts of biodiversity and habitat data across large areas 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; Humphreys *et al.,* 2011). 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 garden surveys are very popular with members of the public. The Royal Society for the Protection of Birds' (RSPB) "Big Garden Birdwatch", for example, recruited nearly 600,000 volunteers in 2012 to record birds in gardens and public areas, making it the world's largest bird survey (RSPB, 2012a). The RSPB has also recently launched a similar survey named "Make your Nature Count". This survey requires participants to answer questions about their garden and to record visiting birds and various species such as badgers (*Meles meles*), slow worms (*Anguis fragilis*), hedgehogs, moles (*Talpa europea*), squirrels (*Sciurus vulgaris* and *S. carolinensis*) and deer (*Capreolus capreolus* and *Muntiacus muntjak*). This more recent survey had around 50,000 respondents in 2011 (RSPB, 2012b). Even surveys that previously targeted a single taxon are expanding due to the popularity of citizen science, and are beginning to collect data across other taxa. For example, the BTO's Garden BirdWatch is now investigating changes in mammal populations (Toms and Newson, 2006).

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) (see Box 5.1). The hedgehog is also of interest to many members of the public because it is reported to be declining in the UK and is now listed on the Biodiversity Action Plan (Hof and Bright, 2009; Gaglio *et al.,* 2010; Wembridge, 2011). 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 preferred habitats of 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).

Box 5.1) Hedgehogs *Erinaceus europeus* (Information synthesised from: Arkive, 2012; NBN, 2012b; JNCC, 2012; PTES, 2012 – For illustration credits, see page 161)

Kingdom: Animalia	Phylum: Chordata	Class: Mammalia
Order: Eulipotyphla	Family: Erinaceidae	Genus: *Erinaceus*

Physical description Body 150-300 mm; tail 10-20 mm; weight up to 2 kg. Hedgehogs are one of the UK's most instantly recognisable native mammals as they are the only British mammal to possess spines.

Hedgehog

Behaviour Nocturnal and can travel up to 1-2 km in a night to forage. They are known for their habit of rolling into a tight ball when threatened. Hedgehogs hibernate in winter in a nest made of leaves, typically under sheds or log piles and emerge around March or April.

Breeding Breed between April – September; there may be 2 litters per year. Gestation lasts four and half weeks, after which females give birth to 4-5 young in a nest made of grass and leaves. Young become independent at two months old.

Diet Worms, slugs, caterpillars and many other invertebrates as well as frogs, berries and eggs and chicks of ground-nesting birds.

Predators & threats Foxes and dogs may occasionally kill hedgehogs, but badgers are their main predatory threat. Other threats include agricultural changes, pesticide use, the loss of hedgerows and grassland, drowning in garden ponds, falling into cattle grids, road deaths, poisoning by garden chemicals and deaths caused by mowers.

Habitat Overgrown hedgerows, woodland edges and rough pasture, farmland, parks and gardens.

Distribution Hedgehogs are found across western Europe. In Britain, they are widely distributed, and have been introduced to several islands (see below).

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Status and conservation efforts IUCN Red List: Least Concern (L). Protected under: Bern Convention; UK Wildlife and Countryside Act. UK Biodiversity Action Plan priority species. In the UK, hedgehogs are common on a national basis but may be vulnerable in some areas (especially rural areas). They are thought to have experienced a 20% decline in numbers over 4 years (2001-5).

Public involvement PTES and the British Hedgehog Preservation Society run several surveys involving members of the public: HogWatch (reporting sightings), Hedgehog Street (raising awareness of hedgehogs in gardens), and two general surveys that encompass hedgehogs and other mammals: Mammals on Roads and Living with Mammals.

Citizen science hedgehog surveys are already underway. 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 (Carter *et al*., 2004; 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). Unreliable data undermine the credibility and findings of such studies.

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. It is reasonable to assume that methods resulting in the collection of suitable quantities of data for common or diurnal species may not be as effective for studying uncommon, elusive or nocturnal species because of issues with detectability. In support of this, 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; Wembridge, 2011), it is especially important that data collected by volunteers are as accurate as possible, and this should include reliable absence data.

Absence data may be overlooked in many citizen science projects because they do not require volunteers to record absence as well as presence. The lack of absence records limits the quality of the data, especially when attempting to map species' distributions (Brotons *et al*., 2004). Another issue is the reliability of absence data in surveys where it is recorded because proof of absence is difficult to obtain: false absences may occur when the "absence" is due to a lack of sightings rather than true absence (Hof, 2009; Sewell *et al*., 2010; Bois *et al*., 2011). The true effect of false absences in citizen science projects is only recently being examined (e.g. Sewell *et al*., 2010) and it is often largely ignored in nationwide citizen science projects (e.g. Hof, 2009).

At present, this is the first attempt to examine false absences in a study using casual citizen science records of hedgehogs.

This study examines what can be learned about habitat selection in hedgehogs in gardens using citizen science data, and then 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 habitat data was verified during visits to a subsection of 47 gardens, and hedgehog footprint tunnels were used to detect the presence or absence of hedgehogs in these gardens. Footprint tunnel data were compared to hedgehog sightings (or a 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 in fact false absences.

5.2) Methods

5.2.1) Questionnaire design and data collection

In order to examine the distribution and habitat preferences of hedgehogs in gardens around Gloucestershire, an online survey was created on the website Survey Monkey (www.surveymonkey.com). Before the web link to the questionnaire was activated, 40 paper copies were distributed at a local hedgehog charity event. 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 and the responses collected were added to the database.

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 (Bogen, 1996), 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 first section, entitled "A little about your garden" established whether the respondent had seen hedgehogs in their garden in 2011 and identified the physical features of their garden. The second section "A little about where you live" ascertained whether hedgehogs had also been seen in the respondent's neighbourhood, as well as some landscape features that were adjacent to their garden. The final section "A little about you" established whether the respondent tried to make their garden wildlife friendly and whether they had pets. The questions used in the survey were selected based on a literature search of publications concerning hedgehog habitat preferences (Table 5.1).

Table 5.1) 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".

Question	Possible responses
Have you seen a hedgehog in your garden in the past year (2011)?	Yes/no
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)
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*

Question	Possible responses
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 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*

Question	Possible responses
	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 putting food out?	Yes – regularly Yes – occasionally 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*

The rationale behind the questions relating to habitat features was linked to knowledge of hedgehog ecology. However, the question relating to people seeing hedgehogs in their neighbourhood served the purpose of attempting to find out either whether people were not seeing hedgehogs in their garden even though they were present in the area, or whether hedgehogs were patchily distributed (i.e. people were not seeing them in their gardens because they were absent from the area). The three possible answers (live, dead or no hedgehogs in the neighbourhood) make sense from a citizen science perspective rather than a biological perspective: biologically, dead or alive indicates that the species is present, however, volunteers might have seen dead hedgehogs in the neighbourhood during the day but not seen hedgehogs in their garden because they never go outside at night so are unlikely to see a live hedgehog. Alternatively, they might see live hedgehogs in their neighbourhood as well as in their garden because they go outside in the evening or pay more attention to nocturnal wildlife. It was important to investigate such patterns and distinguish between live and dead hedgehogs in the neighbourhood as trends might also infer information about the volunteers' likelihood of seeing hedgehogs. Similarly, asking volunteers if they fed hedgehogs could indicate that the volunteers were actively looking out for hedgehogs in their garden and might therefore be more likely to notice them (see Discussion).

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.

The questionnaire was targeted at members of the public and was advertised in local press (a newspaper and two radio stations), two wildlife charities' websites and newsletters (Gloucestershire Wildlife Trust and Help a Hedgehog Hospital), word of mouth at two charity events related to hedgehogs and via e-mail and social media (Facebook and Twitter). It also received attention from the producers of a national television nature program, BBC AutumnWatch, and was advertised on their blog (AutumnWatch, 2011). Although a small number of paper copies of the questionnaire were left in a shop and a veterinary surgery, these only resulted in ≈ 20 responses; the vast majority of the responses were collected online.

5.2.2) Questionnaire data standardisation

All responses were standardised using a numerical key for each answer. Where appropriate, meaningful response variables were classed as ordinal (i.e. a response of 'frequently' would have a higher value than 'occasionally'), and where no meaningful ordinal scale could be obtained (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 (you could have several different pets), 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 pets. 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.

5.2.4) Questionnaire statistical analysis

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 prior probabilities for the different group sizes (gardens with sightings $n = 245$; gardens with no sightings $n = 271$). 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 forcefully 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 $p < 0.05$ and removed when $p > 0.10$ (Field, 2009). In the stepwise model, all independent variables were included in the candidate list for possible entry into the model.

5.2.5) Data verification

130 respondents of the initial 516 who answered the questionnaire expressed an interest in taking part in further fieldwork in their gardens. These individuals were contacted by e-mail with additional information, and 47 individuals subsequently volunteered to participate. 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, Stroud, and Gloucester. Consistent use of urban and suburban gardens reduced the potential effect of a higher winter mortality rate in rural areas (Kristiansson, 1990; Hubert *et al*., 2011). Depredation 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, a professional biologist (the author, RLW) completed the same questionnaire to determine whether the volunteer habitat data were accurate (all questions were answered on the basis of observed physical garden features, so any questions involving sightings of other species, presence of pets and use of pesticides were left out for the purpose of this verification exercise).

A 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, 2012b) 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 5.1a). 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.

Tunnels were set up by the professional biologist 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 5.1b). 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 (see Appendix 6). A practical demonstration on baiting the tunnels was given so that volunteers could ask questions if needed, although clarifications were rarely required.

Volunteers were instructed to bait the tunnel every evening before dusk and to remove the paper and leftover bait 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, 2012b). In order to determine on which nights a hedgehog visited, tracking paper was dated. If hedgehogs visited during the night, this was recorded as 1, and if they did not, this was recorded as 0. Visits of other species (i.e. domestic cats *Felis catus*, and small mammals) were identified and recorded separately.

The number of volunteers willing to participate was the limiting factor for the sample size in this study. However, in another study, Huijser and Bergers (2000) used a smaller sample of 15 footprint tunnels near roads and in control areas (total n = 30) to estimate hedgehog density using the frequency of visits to footprint tunnels. Although the current study was not investigating density (merely presence or absence), 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 the study by Huijser and Bergers (of 1.8). 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 ($\alpha = 0.05$). As such, a sample size of 47 gardens was deemed to be large enough to conduct the current survey.

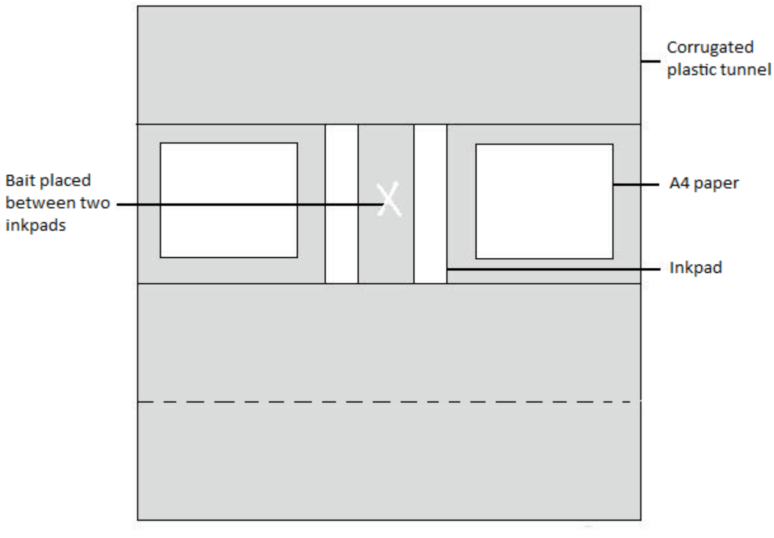

Figure 5.1a - Diagram of a hedgehog footprint tunnel (paper, inkpads and bait were located on the floor of the tunnel, which folded into a triangular shape with panels overlapping on one side)

Figure 5.1b – Photograph of an assembled tunnel in a garden

5.2.6) Footprint tunnel data analysis

After the data were collected, a post-hoc power analysis was performed in order to confirm that the sample size was large enough to detect significant differences between 'yes' and 'no' gardens (see Results). A chi-squared 2*2 test for association was performed on the dataset using binary values of 0 representing gardens that had no hedgehog visits during the five nights and 1 representing gardens that had one or more visits. Following this, a non-parametric Mann-Whitney U test was performed (data were positively skewed) in order to determine whether there was a significant difference in the frequency of visits to 'yes' and 'no' gardens. To remove the confounding effect of annual variation (caused by original questionnaire data being collected the previous year), data were also analysed in the same way on the basis of people seeing hedgehogs in the year when the footprint tunnels were used.

A Spearman's rank test was used to determine whether there was a relationship between the number of hedgehog visits and the visits of other species overall during the survey. To further investigate the relationship between cats and small mammals (found to be significant as a result of the Spearman's rank test – see Results), 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.

5.3) Results

5.3.1) 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. 73.4% of respondents lived in Gloucestershire, 15% lived elsewhere in the UK (including one respondent in Ireland) and 11.6% did not enter their postcode (Figure 5.2). Responses were obtained from every postcode district in Gloucestershire, but were clustered around the 3 main urban areas of Gloucester, Cheltenham and Stroud. Websites were the most effective means of advertising the survey, followed by e-mail (Figure 5.3).

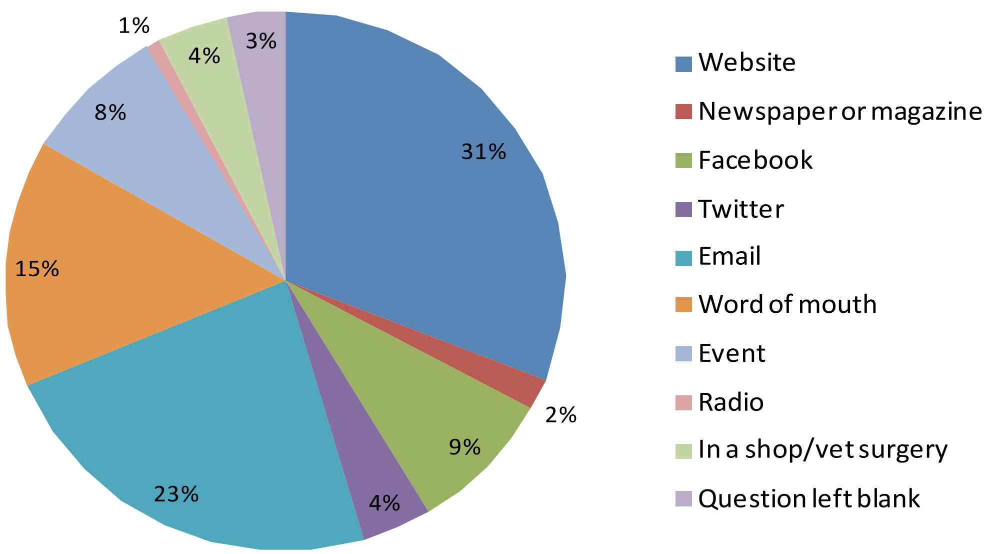

Figure 5.3) Methods by which respondents became aware of the survey. In total, 97% of respondents answered this question.

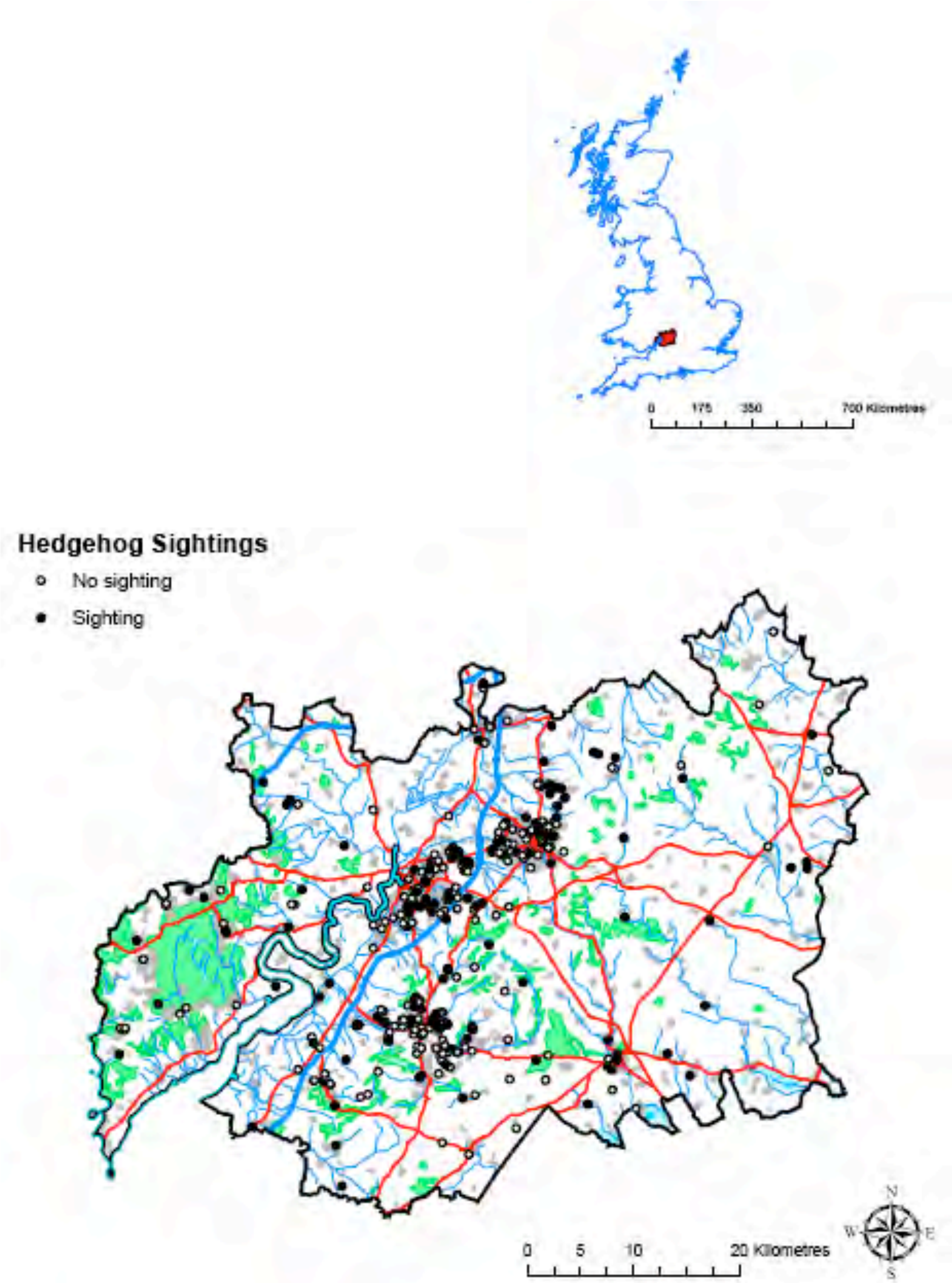

Figure 5.2) Map of hedgehog sightings around the county of Gloucestershire, showing clusters of respondents in the densely populated urban areas around Cheltenham, Gloucester and Stroud. © Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.

5.3.2) DFA results

5.3.2.1) Full model: all independent variables forcefully entered

When all independent variables were entered into the model using hedgehog sightings (present vs. absent) as the binary dependent variable, an average of 77.2% of cases were correctly classified (80.1% of gardens with sightings were correctly classified, and 74.7% gardens with no sightings were correctly classified). This is substantially higher than the prior probability of 53% (note that 53% prior 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). This improvement from random classification is highly significant (MANOVA: Wilks' Lambda = 0.514, $p < 0.001$).

5.3.2.2) Stepwise model: all independent variables entered as candidate variables for selection

In the stepwise model, four variables were found to be significant discriminators of hedgehog sightings, together explaining 80.2% of correctly classified cases: live hedgehogs seen in the neighbourhood (+), feeding hedgehogs (+), decking as a main ground type (-), and no hedgehogs seen in the neighbourhood (-) (Figure 5.4). This classification model showed a highly significant improvement from random classification (MANOVA: Wilks' Lambda = 0.587, $p < 0.001$). Seeing a live hedgehog in the neighbourhood was the single most important variable, explaining 79.6% of the cases that were correctly classified. The other three variables, although significant, explained a negligible percentage of the correctly classified cases (Table 5.2).

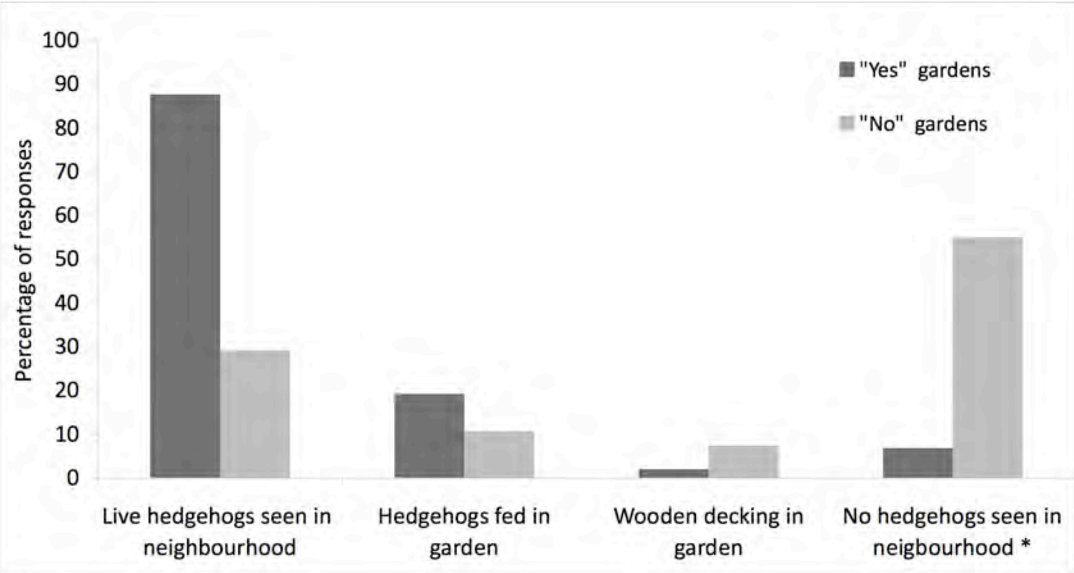

Figure 5.4) Percentage of recorded hedgehog sightings in gardens according to the 4 most important variables in the stepwise DFA. Note that the question "have you seen a hedgehog in your neighbourhood?" could have multiple answers and therefore corresponded to 3 separate variables in the analysis: live hedgehogs, dead hedgehogs and no hedgehogs. *Respondents who had not seen any live or dead hedgehogs in their neighbourhood.

Table 5.2) Stepwise DFA results for the most important explanatory variables. Wilks' Lambda values indicate the decreasing values of this test statistic as model complexity increases from a single variable to four explanatory variables.

Model	Correctly classified	Wilks' Lambda	Association with hedgehogs
Live hedgehogs seen in neighbourhood	79.6%	0.651	Positive
Live hedgehogs seen in neighbourhood Feeding hedgehogs in garden	79.6%	0.610	Positive Positive
Live hedgehogs seen in neighbourhood Feeding hedgehogs in garden Decking	80%	0.598	Positive Positive Negative
Live hedgehogs seen in neighbourhood Feeding hedgehogs in garden Decking No hedgehogs seen in neighbourhood	80.2%	0.587	Positive Positive Negative Negative

5.3.2.5) Volunteers record habitat data more accurately for objective variables than subjective variables

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

5.3.2.6) Hedgehog footprint tunnel analysis

Performing a post-hoc 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 a 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). There was only one new detection of hedgehogs on the fifth night – or 6% of the total number found in the survey.

The chi-squared test for association showed that there was no significant relationship 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 relationship 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 5.5), such that the frequency of visits did not differ between "yes" and "no" gardens. When data were analysed using sightings in the same year (as opposed to sightings reported in the questionnaire), there was no significant difference between gardens where hedgehogs had been seen in the same year, and those where they had not (Mann-Whitney U test $U = 123$, $n_1 = 10$, $n_2 = 37$, $p = 0.06$).

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.

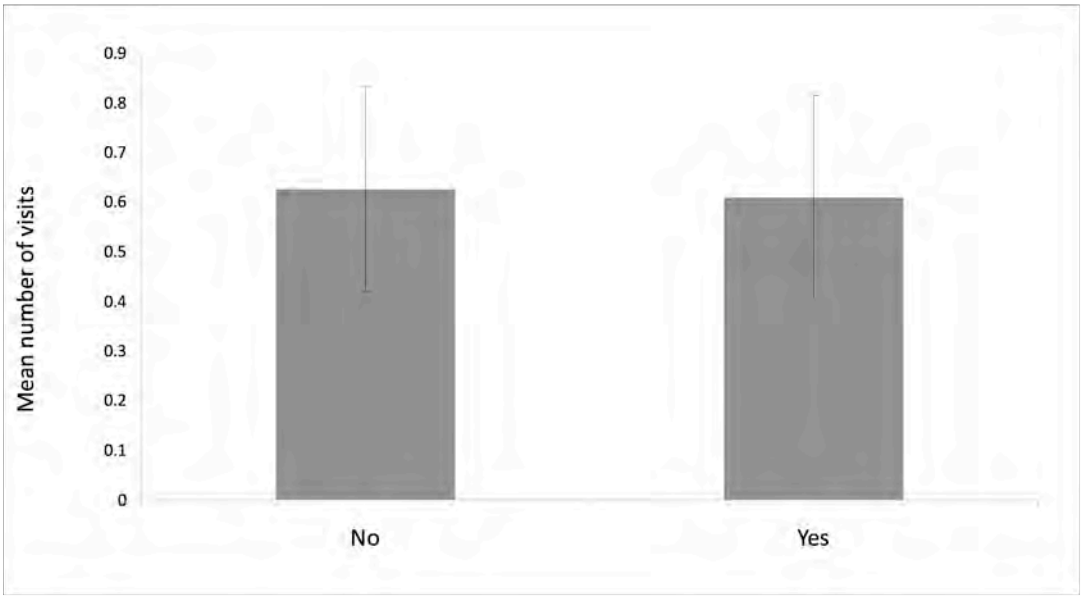

Figure 5.5 – Mean number of hedgehog visits at 'yes' and 'no' gardens ± standard error (n = 23 for 'yes' gardens and n = 24 for 'no' gardens)

5.4) Discussion

5.4.1) Using online surveys: practical benefits and limitations

5.4.1.1) Financial benefits

Online surveys are used across many fields, for example, in marketing research (e.g. Craig and Douglas, 2001; Ilieva *et al*., 2002), in the health sector (e.g. Jepson *et al*., 2005; Nakash *et al*., 2006), and, increasingly, in the field of ecology and conservation (White *et al*., 2005). Online surveys facilitate the collection of ecological data across large spatial scales, often covering a whole country (Table 5.3). This allows researchers to gain information about the distribution of particular species, as well as other important ecological information. The online survey used in this study received a high number of responses, although it is impossible to determine how many people heard about the questionnaire but decided not to complete it. Its success was probably due to the methods used to promote it and the fact that it was online, rather than mail-based. Online surveys may result in the collection of more responses than traditional mailed questionnaires that heavily rely on participants making an effort to complete and return them (Kaplowitz *et al*., 2004; Evans and Mathur, 2005).

Table 5.3) Examples of online biodiversity recording schemes using data that have been collected and entered by citizen scientists

Organisation(s) involved	Name of scheme	Description and aims
BirdWatch Ireland (in partnership with BTO, RSPB and SOC)	Bird Track	To map the migration movements and distribution of birds throughout Britain and Ireland using data entered by volunteer birdwatchers
Stafford *et al.* (independent researchers)	Bee ID	To map the distribution of bee species across the UK using geo-tagged photographs uploaded by volunteers to a photo-sharing website, Flickr
Butterfly Conservation	Moths Count – Migrant Watch	To map the arrival, spread and departure of migrant insects online using volunteer records
Butterfly Conservation	Big Butterfly Count	To map the distribution of butterflies in the UK by asking members of the public to record the number of species they observe during a 15 min period during the summer and submitting their records online
Open Air Laboratories (OPAL)	Various surveys	To encourage volunteers to collect data on soil, air and water quality, the distribution of invertebrates and hedge biodiversity in the UK
Natural History Museum, as part of the Decade on Biodiversity	Urban Cherry Tree Survey	To encourage members of the public to locate, identify and count cherry trees in streets, parks and gardens across the UK (by creating an interactive map)
British Hedgehog Preservation Society and the People's Trust for Endangered Species	HogWatch	To map the distribution of hedgehogs throughout the UK using casual sightings submitted by members of the public

Hof and Bright (2011) sent paper questionnaires to 4,000 farmers to assess the distribution of hedgehogs and habitat features that they were associated with, and 26% of these were returned. One considerable drawback of printing and posting surveys to such large numbers of people is the incurred cost. It is estimated that posting 4,000 questionnaires would have cost the researchers at least £1,440 (based on the price of second class stamps for a standard letter at the time the research was undertaken – Royal Mail, 2011). The online survey used in the current study allowed the questionnaire to be sent to many people at no cost, as well as having the practical benefit of receiving data in an electronic format, ready to analyse (Kaplowitz *et al.,* 2004). Such features are attractive feature for researchers and wildlife conservation organisations with limited funds.

5.4.1.2) Sources of bias

Although the questionnaire was targeted at residents of Gloucestershire, it was completed by members of the public living as far away as Ireland. This demonstrates that the questionnaire could have been successful on a national level if advertised on a wider scale (however, for the purpose of verification, it was important to focus the study on a smaller scale). While efforts were made to include people that did not have access to the internet by offering hard copies at various locations, it was not possible to ensure that data were collected from a random sample of gardens. There were clusters of responses around the 3 largest towns in Gloucestershire: Gloucester, Cheltenham and Stroud (Figure 5.2). This is likely to be because of the larger numbers of inhabitants in towns, a pattern that has also been observed in the nationwide hedgehog survey “HogWatch” (PTES and BHPS, 2007). Additionally, respondents often sent the questionnaire to their neighbours and friends, resulting in snowball sampling (e.g. Black, 1999; Baltar and Brunet, 2012), which is not a biologically representative way of sampling. This may be another reason for the clusters of responses. This could have implications for the even distribution of the questionnaire, despite the fact that responses were obtained from every postcode district in Gloucestershire.

The respondents in this survey may have been biased towards wildlife-friendly practices in their gardens, and it is reasonable to assume that only people with an interest in wildlife completed the questionnaire: 86% of respondents said that they tried to make their garden wildlife-friendly and one of those who answered negatively tried to justify this by detailing that it was because their garden was very small, perhaps feeling that their garden was somewhat inferior to a wildlife-friendly garden. This is an issue frequently encountered in citizen science projects. From a telephone survey of inhabitants of Sheffield (UK), it was estimated that 14.4% of dwellings with gardens had ponds, 26% had nest-boxes and 29%

had compost heaps (Gaston *et al*., 2005). The number of dwellings with "wildlife-friendly" features in this randomly selected sample was much lower than in this study, indicating that the sample in this study may not be representative of an entire cross-section of the community. 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. Indeed, such surveys rely on exposure to the appropriate medium, willingness to respond to such appeals for information, and are unlikely to be independent of people's interests and activities in relation to wildlife, gardening and conservation. Additionally, the BTO's Garden BirdWatch involved participants who were likely to have "bird-friendly" gardens, which may have reduced the variation in garden habitat across the sample (Chamberlain *et al*., 2004). The authors suggest that an assessment of the representativeness of survey sites is required to increase the knowledge of habitat associations of garden birds; the same is likely to be true for citizen science hedgehog surveys.

5.4.1.3) Item nonresponse and potential errors

There will always been a certain degree of subjectivity in questionnaires that may influence the results but this is very difficult to eliminate (see Results). Some people answered that they did not try to make their garden wildlife friendly, yet they reported various wildlife friendly features in the following question e.g. pond, bird feeders, unkempt areas. By choosing not to make questions compulsory, there was also a risk of item nonresponse (when a respondent fails to answer questions that they are supposed to respond to – Kwak and Radler, 2002). However, this was relatively low in the current study as only 20% of questionnaires had at least one missing value (excluding the two optional questions asking for the respondent's postcode/e-mail address). A low level of item nonresponse is an indicator of a high quality survey (Kwak and Radler, 2002). Having some unanswered questions, where the rest of the data are still usable, is arguably better than lowering the completion rate by deterring respondents with error messages that appear if they leave a question blank.

While the inclusion of "other" as an open response can provide an opportunity to learn more about a respondent's garden, it was sometimes used to add comments that were unrelated to the question (this occurred on 19 occasions). Most of these were, in some way, related to hedgehogs, for example, reporting hedgehog faeces, the exact location of a hedgehog sighting, the length of time since hedgehogs were last seen, or accusing neighbours for deterring or harming hedgehogs. However, some responses were not related to the subject matter. In the question concerning pets in gardens, one respondent answered that “a Chris” frequented their garden, one reported that they had frogs and toads in their garden and another reported that foxes had killed some of their pet chickens and rabbits. Some opinionated comments were typed in capital letters, perhaps to make them stand out from other responses (e.g. one respondent condemning their neighbour’s use of pesticides). Responding to questions with sarcasm or humour suggests that the respondent is not taking the survey seriously, and because of this, it may be necessary to remove their answers from the results. Equally, expressing anger denotes that respondents have a very strong opinion on the subject matter and might have biased answers. However, such answers are inevitable when allowing respondents to add further details, and while some may be useful and can be reclassified, those that are not can hinder the formatting and analysis of results. When results are to be analysed quantitatively, it is recommended that “other” should only be given as an option if additional responses are required, (i.e. if collecting data on a wide range of features where it may not be possible to anticipate all possible answers) rather than as general practice.

5.4.2) Biological significance of questionnaire results

In this study, the single most important explanatory factor for hedgehogs being seen in a garden was whether or not live hedgehogs had also been seen in the neighbourhood. This is logical when hedgehog home ranges are considered. These vary widely between individuals, sexes, populations and habitats (Ward *et al.*, 1997). Nightly ranges 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 travel between several gardens in a single night, making it relatively easy for people to see them in their neighbourhood as well as their garden. If hedgehogs were not seen in a garden or in the surrounding neighbourhood, this may indicate that they were either absent from the area altogether or that the respondent did not observe a hedgehog even though hedgehogs were present, and this could be for a number of reasons (see below).

Other significant factors were minor in comparison to live hedgehogs being seen in the neighbourhood. A highly significant positive relationship between hedgehog sightings and people who feed hedgehogs in their gardens is logical. If food is put out specifically for hedgehogs, then this is likely to be because the respondent has already seen a hedgehog in their garden or because they have been deliberately watching out for hedgehogs when they put food out and are more likely to notice them. There have been similar conclusions in another study where hedgehogs were positively correlated with manmade hedgehog nestboxes and feeders. The authors suggest that it is likely that hedgehog nestboxes were placed in gardens after hedgehogs had been seen there, so it cannot be concluded that a hedgehog nestbox will attract hedgehogs to gardens (Hof and Bright, 2009). Similar caution should be taken with the findings of the current study, however, it is interesting to note that 11% of respondents who reported that they had not seen a hedgehog in their garden said they put food out for hedgehogs, and a third of these put food out on a regular basis. The reason for this is unclear but illustrates that the variables measured in this study are not perfect correlates. It is possible that some respondents assumed that hedgehogs were eating the food, but the food was, in fact, consumed by other opportunistic carnivores such as domestic cats, foxes or badgers.

Questionnaire data showed that hedgehog sightings were negatively associated with decking, but this should be treated with caution in the light of the verification of volunteer-collected data (see below). Wooden decking is an increasingly popular garden surface, and it may cover large areas of a garden (Martin, 2008). Decking sales were worth more than £120m a year in 2005, and this was predicted to grow to £400m within four years, as a result of a trend for what retailers describe as “the new lawn” (Nicholson-Lord, 2005). There has been no research on the effect of decking on hedgehogs, however, this open surface lacks dense vegetation cover required by hedgehogs for shelter and nest sites (Morris, 2006) and hedgehogs have been found to avoid open areas in several studies (Riber, 2006; Doncaster *et al.*, 2011). Although decking attracts slugs and snails, an important food source for hedgehogs, it lacks the rich diversity of soil-dwelling invertebrates such as earthworms and beetles that hedgehogs also forage for. Decking might deter hedgehogs by being difficult to access if it was raised above the ground. Conversely, raised decking may create an open space underneath it in which hedgehogs could nest; in this case, even if hedgehogs were present in the garden, they may go undetected if hidden under the decking, resulting in a false absence.

5.4.3) Accuracy of volunteer-collected data

5.4.3.1) Verification of habitat data

Habitat data collected by volunteers were deemed to be broadly accurate, although some features did differ from data collected by a professional biologist in the same gardens. Although it is not possible to perform a direct statistical comparison because of the nature of the data, it does give an indication of the variability between volunteer-collected data and data collected by a professional.

After discussion with the volunteers, it became apparent that discrepancies between their data and professional data were due to the professional not always detecting some features when they were present rather than these being wrongly recorded by the volunteers (e.g. a wire fence hidden within a hedge, a compost bin recorded instead of a compost heap). The difference between volunteers and the professional assessing whether a garden was wildlife friendly or not was unsurprising due to the subjective nature of this variable (and indeed, it may be that volunteers overestimated this variable because of a fondness for wildlife and a sense of responsibility for protecting it in their garden).

Although there were differences in the major ground types recorded, this was never due to respondents wrongly recording features that were in fact absent. Instead, differences lay in whether the ground type was deemed to be "major" (i.e. of equal size). According to the professional, unkempt areas were defined as being specifically created for wildlife and subsequently left "unmanaged", but this definition seemed to vary greatly among respondents (pers. obs.).

5.4.3.2) Do hedgehog sightings reflect hedgehog presence and absence in gardens?

There was no relationship between the frequency of hedgehog visits, as recorded by hedgehog footprint tunnels, and previous sightings, as reported by volunteers. Post-hoc power analysis using the standard deviations from the current dataset showed that the sample size would have allowed the detection of a mean difference of less than one night between "yes" and "no" gardens, indicating that the lack of relationship was not due to the sample size being too small. A significant negative correlation between small mammal and cat visits was found, indicating that the sample size was indeed large enough to detect differences.

This study highlights the importance of testing the effect of false absences because hedgehogs were sometimes present in gardens in which they had not been seen in the previous year. Overall, it is felt that this is a positive finding with regard to hedgehog conservation as it indicates that a lack of sightings does not necessarily indicate an absence of hedgehogs.

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). Indeed, hedgehogs had never been seen in the garden that was visited most frequently during the survey (4 out of 5 nights) despite the participant's keen interest in wildlife and the large amount of time they spent gardening. Landscape and temporal changes in the detectability of different species affected recordings in other studies (e.g. hedgehogs – Hof, 2009; amphibians – Sewell *et al*., 2010), so assumptions about the state of the hedgehog population in non-garden habitats in the UK cannot be made from this 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).

Several factors could have resulted in hedgehogs not being detected in gardens in which they had been seen during the previous year. Firstly, hedgehogs may have not visited those gardens during the five night study period despite this being recommended as an adequate length of time by the Mammal Society and being longer than the three nights used in a similar study (Huijser and Bergers, 2000). Secondly, winter mortality may have affected the results despite efforts to reduce this effect: hedgehogs may have died between a reported sighting in 2011 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 (see Methods).

Another issue is that footprint tunnels do not always detect hedgehogs even when they are present. This was reported by two volunteers (from "yes" gardens) who saw hedgehogs in their garden during the footprint survey but the hedgehogs did not enter the tunnels; one was reported to be unwell so may not have been actively foraging, and the other was said to be foraging under a bird feeder (and was frequently seen doing so before the survey), so may not have sought out the bait in the tunnel. The bait in question (tinned hotdog sausages) was occasionally left untouched or only partially consumed after hedgehog visits; several volunteers suggested that a different type of bait might be more appealing to hedgehogs. Tinned meat-based pet food has successfully been used in another hedgehog footprint tunnel survey (Huijser and Bergers, 2000), although it was avoided in the current study because it was thought that it would attract too many domestic cats.

One of the most important prerequisites of citizen science and volunteer projects is that they should be rigorous enough to collect data of sufficient quality while being user-friendly enough so as not to deter participants. Sewell *et al*. (2010) found that four volunteer visits to each site using four separate methods were required to be able to record the absence of a species with 90% confidence. This level of investment in a project requires volunteers with a particularly keen interest in the species and a high level of motivation, and this is not found across all volunteer projects (and especially citizen science projects such as those in Chapter 4). Indeed, Sewell *et al*. (2010) also state that asking volunteers to record the temperature of the air and water at the time of the survey deterred volunteers. This highlights the importance of making volunteer surveys simple, easy and enjoyable in order to increase participation rates. Simplicity is also the reason why many citizen science surveys use casual records (observations without effort) rather than effort-based monitoring (see Sullivan *et al.*, 2009). Casual records collected during a year formed the basis of the PTES' nationwide hedgehog survey 'HogWatch' (Hof 2009), and this provides a justification for the methods used in the current study. Effort-based surveys may be more useful to science but could potentially reduce the number of participants in a survey; however, a large number of participants is desirable to get an idea of the presence or absence of a species in a particular area (Sullivan *et al*., 2009).

Participants reported that they had enjoyed taking part in the hedgehog footprint tunnel survey, and this was reflected in the quality of the data collected: all 47 participants correctly followed instructions for the full length of the survey (5 nights).

5.5) Conclusions and recommendations

This study highlights some of the well-known strengths of citizen science: a considerable amount of data can be collected in a short period of time with little effort and little or no financial cost. At present, it is also the first attempt to verify the accuracy of citizen science data on garden features, and has proved that such data are generally reliable. This adds credibility to other surveys that use questionnaires to record data on gardens. However, care must be still taken when analysing citizen science data because of potential biases and errors such as false absences. Garden owners sometimes did not detect hedgehogs even when they were present: errors such as this may cause issues when trying to examine hedgehog habitat preferences or distribution. Additionally, casual volunteer records of hedgehogs may be influenced more by the observer than by habitat preferences of the animal, and care needs to be taken when using such records. These findings are highly relevant considerations for the design of future questionnaire-based wildlife surveys, even though questionnaire structure may vary from study to study.

It may be beneficial to prepare citizen scientists for a survey in advance so that they can actively search for hedgehogs in their garden at a particular time, as is the case in the Big Garden Birdwatch, the Big Butterfly Count, and Living with Mammals, but this may still not fully remove the issue of false absences because casual (i.e. non-amateur) citizen scientists may be less likely to conduct a survey in the middle of the night. Theoretically, people who reported that they had not seen hedgehogs could have been just as likely to search for hedgehogs in their gardens than those who had seen hedgehogs, i.e. the tendency to search for hedgehogs could be correlated with the tendency to respond to the questionnaire (because of an interest in hedgehogs). However, to counteract the issue of casual records not taking into account observer effort (i.e. some participants search for hedgehogs more frequently or more rigorously than others), it could be useful to have an measurement of effort in the form of an extra question in future studies: “do you actively look for this species?” or “how often do you search for this species?”. If this were done, a weighting system could then be used to account for the increased likelihood of seeing a hedgehog as observer effort increases.

Nevertheless, it is felt that citizen science could still provide useful insights into the habitat requirements of garden-dwelling species such as hedgehogs, and in turn, this may have practical implications for hedgehog conservation. In urban environments, citizen science adds a new dimension to ecological monitoring, providing complementary data on human attributes such as participants’ residential habitat management e.g. pesticide use or wildlife-friendly features, and this may increase understanding of cultural and behavioural practices on ecological response variables (Field *et al*., 2010).

Chapter 6: General Discussion

6.1) Summary of research

The aims of this thesis were to evaluate some of the attributes and limitations of citizen science and volunteer-collected data, with a focus on the importance of verifying those data, and determining their contribution to scientific knowledge. Each chapter investigated a different aspect of citizen science or volunteer-collected data according to the level of commitment and skill required of the participants, as set out in Chapter 1. Each chapter also identified a different type of data collected by volunteers (habitat, species presence behaviour etc.) While simple methods were an effective way of studying water vole habitat associations, inter-observer variability was highly problematic when volunteers collected data using methods that relied on subjective estimations (Chapter 2). With careful analysis, volunteer-collected long-term datasets can provide excellent information on trends of dormouse nestbox selection despite some irregularities when the data were recorded (Chapter 3). However, untrained citizen scientists could not accurately record otter activity budgets, even when simple instructions were given (Chapter 4). Citizen scientists were generally able to record habitat variables accurately within their gardens; however, they were more likely to over-estimate subjective variables, such as the "wildlife friendliness" of their garden. While hedgehog sightings were thought to be a reliable indicator of hedgehog presence, the issue of false absences became apparent when using sightings and indirect signs to record the absence of hedgehogs (Chapter 5). For a summary of findings and recommendations, see Table 6.1.

Table 6.1) Main advantages and disadvantages of citizen science and volunteer-collected data

Method	Example purposes	Advantages	Disadvantages	Recommendations
Simple scales and estimates to assess habitat (Chapter 2)	Studying habitat selection Advising habitat management	Simple scales and estimates can reflect similar trends found by accurate measurements, and reduce time and effort required to collect data	Lack of training meant that inter-observer variability was high	With further training, scales and estimates may be used by skilled volunteers
Long-term monitoring (Chapter 3)	Monitoring population trends Studying habitat selection	Provides useful data where professional scientific data are lacking Can result in important findings about species' ecology	Hypotheses have to be adapted to the data already collected Errors and bias are difficult to verify	Long-term datasets should continue to be highly valued for research as long as data are analysed in an appropriate manner
Questionnaires to record animal activity budgets (Chapter 4)	Studying animal behaviour (in captivity or in the wild)	Untrained people can identify simple behaviours Educational value	Untrained individuals may not recognise the importance of following methods	Without improvement, these data may not be useful to research, but could be used as an educational exercise for school children
Crowdsourcing to record casual sightings of species (Chapter 5)	Mapping species' distributions Studying population trends	Effective and easy way of mapping the distribution (presence only) of easily recognisable species	Geographical bias – not a randomised sampling method (resulting in clusters of sightings in populated areas and false absences)	Could be complemented by other surveys using more controlled sampling (e.g. asking citizen scientists to search for a species at a given time, in a given area)
Using indirect signs as an indicator of species presence/absence (Chapter 5)	Mapping species' distributions Studying population trends	Most effective way to study elusive, nocturnal species Can be used to confirm presence	May result in false absences	Trained volunteers can record indirect signs, but should be encouraged to participate more regularly

6.2) The importance of clear instructions

A preliminary consideration when examining the accuracy of volunteer-collected data is whether or not the volunteers have followed the instructions. As with any scientific research, asking volunteers the right questions to the right people is vital so that the initial hypothesis can be answered with confidence. In order for this to happen, it is important to prepare clear and concise instructions that are adapted to the ability of the volunteer (Darwall and Dulvy, 1996; Newman *et al*., 2003; Foster-Smith and Evans, 2003; Sewell *et al*., 2010; Finn *et al.*, 2010). However, if volunteers do not follow instructions and answer the questions correctly, then no conclusion can be drawn, regardless of what the results show (see below).

6.2.1) Volunteers can follow instructions

The aim of this thesis was not to test whether volunteers followed instructions, however, in many cases, evidence suggests that they did. For example, most students attempted to follow the instructions to collect riverbank habitat data to the best of their ability because the exercise formed part of a field course (Chapter 2). No explicit instructions could have been given to volunteers collecting dormouse nestbox occupancy data because data collection began 18 years prior to this study (Chapter 3). However, it was still possible to draw conclusions about the volunteers' ability to follow instructions as volunteers should have followed guidelines and advice set out by the People's Trust for Endangered Species as part of the National Dormouse Monitoring Programme to ensure consistency between all of the sites participating in this programme (e.g. regular monitoring of the nestboxes, recording the same variables). The volunteers at Midger Wood did follow these guidelines, submitting fairly consistent data to the NDMP each year. Volunteers in Chapter 5 followed written instructions for the hedgehog tunnel survey as they baited the tunnels each night and collected the paper as required.

In surveys relying on questionnaires to collect data, it is crucial that respondents answer questions truthfully. In this thesis, respondents were probably honest because they were interested in the subject matter (although there were discrepancies between the correctness of factual, objective answers and opinion-based or subjective answers – see below). Personal questions, for example, whether an individual had volunteered previously (Chapter 4) or whether they had seen a hedgehog in the previous year (Chapter 5), must be assumed to be correct as there is no way of verifying such facts without challenging each respondent. This would have been logistically impossible, and any attempt to do this may have annoyed the respondents. It was clear that citizen scientists correctly answered simple questions about their garden, and there is no reason to assume that volunteers and citizen scientists would deliberately falsify answers to factual questions (Chapter 5).

One solution that could help ensure that instructions are followed is to train, and ideally, supervise volunteers while they collect data. Highly trained volunteers were only permitted to collect data on the presence and absence of water voles once a professional was satisfied with the quality and accuracy of their work (Chapter 2). Supervising volunteers while they collect data is only logistically possible with small numbers of volunteers (not large numbers of citizen scientists). This would be a very time-consuming way to ensure accurate data collection, and in many ways, it would defeat the purpose of recruiting volunteers. Throughout this thesis, the decision was made to provide minimal supervision to volunteers and citizen scientists while they were collecting data in order to be able to fully assess the accuracy of their data.

6.2.2) Occasions when instructions may be misinterpreted or ignored

Instructions must be simple and rapid enough for volunteers not to lose interest in a study (e.g. Sewell *et al*., 2010). This may be especially relevant to citizen science projects that rely on capturing the attention of members of the public, rather than the “captive audience” of volunteers who conduct regular surveys for wildlife organisations and might be more likely to invest time and effort into those surveys. However, even when utmost care has been given to preparing questions and instructions, some volunteers and citizen scientists may fail to follow them or even ignore them altogether (e.g. Stafford *et al*., 2010 – see Appendix 7; Chapter 4). Some discrepancies between student estimates in Chapter 2 may have been due to different interpretations of the instructions concerning the DAFOR method (e.g. confusing direct counts of the number of individuals of a species as used by Agea *et al.* (2007) and the percentage ground cover of a species, as used by Affre *et al.* (2009) and Avila *et al*. (2002)). Additionally, some students may have shared data with their colleagues despite explicit verbal instructions not to do this. It is unclear whether these students were not listening to the instructions or whether they deliberately ignored them.

While the highly motivated volunteers at Midger Wood (Chapter 3) did follow the NDMP guidelines, they did not collect any of required habitat data at the site. In rare occasions, surveys were not completed every month during a given year (this was due to circumstances beyond the control of the volunteers). However, frequent irregularities at other NDMP sites were reported, with some failing to submit data for an entire year or withdrawing their participation altogether (S. Sharafi, PTES, pers. comm.). Similar irregularities were found in long-term monitoring schemes involving other species (e.g. British Trust for Ornithology bird surveys – Crick *et al*., 2003; Bat Conservation Trust surveys – Barlow, 2012).

In some situations, good intentions and a large amount of enthusiasm for a project may paradoxically increase bias and error, rather than resulting in more accurate data. This occurred, to a varying degree, in most chapters of this thesis. Visitors may have disregarded the instructions to record otter behaviour for 30 s because they were over-enthusiastic, and this resulted in highly significant differences between their data and the otters' true activity budget. A small minority explicitly stated that they had watched the otters for longer than 30 s, thus openly admitting that they had not followed the instructions (Chapter 4). Furthermore, a participant in the hedgehog footprint tunnel survey reported adding a different type of bait to her tunnel because she believed that the bait stated in the instructions was not attracting hedgehogs (Chapter 5). Some volunteers and citizen scientists added extra detail that was not directly relevant to the survey or questionnaire they were completing, and this meant that it was time-consuming to extract the relevant data from the record (see Section 6.5.2). As such, it may be important to educate volunteers and citizen scientists about the importance of following instructions because not doing so can have consequences on the quality of the data.

6.3) The accuracy and usefulness of volunteer-collected data

6.3.1) Volunteer-collected data can be accurate and useful

This thesis has demonstrated that accurate data *can* be collected by volunteers and citizen scientists, when projects are carefully designed and managed. Skilled volunteers successfully collected data on indirect water vole signs to a professional standard in (Chapter 2). Volunteers and citizen scientists can accurately record the presence of easily recognisable, charismatic species such as the dormouse (Chapter 3) and the hedgehog (Chapter 5); this has also been found in other studies using both trained volunteers (e.g. Foster-Smith and Evans, 2003; Newman *et al*., 2003; Finn *et al*., 2010) or citizen scientists (e.g. Schmeller *et al*., 2009; Dickinson *et al*., 2010).

Data collected by volunteers and citizen scientists can provide useful insights into various aspects of ecology, for example, for studying distributions and species-habitat interactions. Long-term datasets such as the dormouse monitoring dataset are an excellent example of how volunteer-collected data can be used when professional scientific data are lacking (Chapter 3). Important findings were made about dormouse nestbox selection from these data, despite the fact that they were not “perfect” in a scientific sense. Imperfections and noise within datasets can be taken into account during analysis. For example, when collecting habitat data, it was possible to rank tree circumferences in order to account for an increase in actual measurements over the years. A biologically meaningful relationship between dormouse occupancy and tree circumference was found, despite not using accurate measurements.

Simplicity is an important feature in volunteer programmes, but it is not necessarily a hindrance: using simple scales, as opposed to accurate measurements, reflected associations between water voles and their habitat that were similar to those found in studies using accurate measurements (Chapter 2). If adequate training is provided, there is no reason to assume that skilled volunteers would not be able to collect useful habitat data using scales and estimates. For example, Finn *et al*. (2010) found that the visual estimation of percentage seagrass cover by trained volunteers in Moreton Bay, Australia, was highly correlated with that of scientists and could be used as reliable baseline data. However, there may be issues when inexperienced volunteers use scales to estimate cover (see below).

6.3.2) Errors and bias can influence data quality if not dealt with appropriately

There are some occasions when using citizen scientists to collect data might not be suitable. As previously discussed, citizen scientists did not record activity budgets so their data could not have been used to study otter behaviour (Chapter 4), however, a more highly trained volunteer may be able to collect accurate data. In other studies, data may still be used if sufficient care is taken to ensure that errors and bias are accounted for. Some of the sources of bias and error discussed in Chapter 1 were found to be important in this thesis. Although citizen science crowdsourcing projects may result in data being collected at a suitable spatial scale (e.g. Appendix 7), geographical bias can also occur, for example, when sightings of a particular species are clustered around urban areas (e.g. Chapter 5). This could have consequences when drawing conclusions about the distribution of a species. Geographical bias has also been found in other studies (e.g. basking sharks –

Bloomfield and Solandt, 2006; hedgehogs – PTES and BHPS, 2007; flying ants – Catlin-Groves, 2012b).

It is also important to consider the detectability of the study species, especially when using citizen science data to study nocturnal species. For example, citizen science may not be an effective way of studying hedgehogs in rural (non-garden) areas because most people would not spend time outside in these areas at night. Complimentary methods should be used in this situation, and encouraging citizen scientists or volunteers to visit specific locations to collect data may reduce issues of detectability, false absence and geographical bias, for example, by conducting systematic surveys (e.g. the monthly dormouse nestbox surveys in Chapter 3) rather than relying on casual or previous sightings of a species (as in Chapter 5). However, even with these biases, it may be possible to determine changes in population density over time, if the assumption of equal spatial bias is met at each time period.

The issue of inter-observer variability was encountered to a varying degree in each chapter. Even though the dormouse nestbox data was deemed to be reliable, there were small differences between the records of individual volunteers, despite them using identical recording forms (Chapter 3). Similarly, visitors collecting data on otter behaviour invested varying amounts of effort into completing the questionnaires (i.e. some did not answer all of the questions) (Chapter 4). Chapter 2 specifically focussed on the issue of inter-observer variability and concluded that scales and estimates were too subjective for inexperienced volunteers to be able to collect accurate data using them. This has significant implications for national surveys that require volunteers to record habitat data. The very nature of volunteer and citizen science data – recruiting groups of people to collect data – immediately implies that inter-observer variability could be an issue. There may be ways to reduce this, for example, by asking simple "binary" yes/no questions (e.g. in Chapter 5), even though this may restrict the data that can be obtained (i.e. presence/absence of a particular habitat feature, rather than the percentage cover of that feature). However, it is important to note that inter-observer variability is not a weakness specific to volunteer-collected data, as it is also common in scientific studies when data are collected by more than one observer (e.g. Goodenough *et al*., 2010; 2012). Assuming it is possible to identify individual volunteers, it may also be possible to account for systematic (i.e. consistent over or under recording of a variable), by including the term 'volunteer' as a random effect in a mixed regression model (e.g. Zuur et al., 2007). However, many citizen science type crowdsourcing applications do not require identification of individuals, and it is best to try to reduce interobservaer availability in the data collection methods, rather than apply statistical corrections.

6.4) Other considerations when recruiting volunteers and citizen scientists

6.4.1) Motivation for volunteering

The wetlands centre visitors (Chapter 4) differed to the volunteers and citizen scientists in the other chapters in the sense that they participated in the studies because they were recruited in person, and therefore might have found it harder to refuse (i.e. they participated out of kindness and politeness). The biology students did not actively volunteer to participate in the water vole fieldwork as it was part of their course; instead, they acted as proxy volunteers (Chapter 2). However, it was clear that both volunteers and citizen scientists shared a common interest in wildlife.

Motivation is clearly an important consideration when recruiting volunteers or citizen scientists. Although it was not specifically measured during this thesis, motivation was the primary reason for volunteer involvement in the various studies. Volunteers stated that their main reasons for regularly monitoring dormouse nestboxes included: wanting to see a rare species, an enjoyment of being outside, and a desire to experience the natural world with like-minded people (Chapter 3). Citizen scientists showed an obvious interest in hedgehogs and other garden wildlife when they completed the questionnaire on hedgehogs in their garden (Chapter 5). Similar motivations are reflected in other volunteer- or citizen science-based studies. For example, Campbell and Smith (2006) directly measured the values (or motivations) of volunteers on a sea turtle conservation project in Costa Rica, and all but one volunteer identified with conservation and scientific (learning driven) values. Similarly, Butterfly Conservation published several statements from citizen scientists who had participated in their Big Butterfly Count survey, many of whom showed an enjoyment of nature, and expressed concern over the status of butterflies (Butterfly Conservation, 2012).

6.4.2) Educational benefits of recruiting volunteers and citizen scientists to collect data

There are clear educational benefits to volunteering and collecting citizen science data (Catlin-Groves, 2012a; Chapter 1), and education was an important outcome of the research despite not being a particular focus of this thesis. Although students could not collect accurate habitat data using scales (Chapter 2), this exercise was used as a teaching session to introduce riverbank survey methods and the notion of inter-observer variability. Similarly, collecting basic behavioural data on captive animals may have educational benefits, for example, if methods were taught to visiting school children or students (Chapter 4). In turn, this may have positive outcomes, such as inspiring young people to become interested in nature (see below). After volunteering for the hedgehog tunnel survey, many participants gave unsolicited positive feedback about the project, reflecting their enthusiasm:

"We are really happy that we are getting visits from hedgehogs and the kids now want to make their own tunnel"

"Let me know if there is anything more I can do to help. Several friends were interested and are willing to take part in the survey if you need more results from this area"

Others stated that they would make hedgehog-friendly improvements to their gardens, such as making gaps in fences or providing hedgehog food. This is a key strength of citizen science, one that can be readily harnessed to raise awareness of conservation issues and to increase participation in citizen science projects (see Section 6.5.2).

6.5) Conclusions and recommendations

6.5.1) How to improve data quality and accuracy

Improving data quality and accuracy is of utmost importance because of the growing role of volunteers and citizen scientists in ecological data collection, especially if it is to be accepted as a reliable method to collect data. There are several ways in which this could be achieved (Figure 6.1). First and foremost, individuals and organisations should invest in training, both for small groups of volunteers, and for citizen science projects that require any amount of biological knowledge (such as those requiring species identification). Indeed, several conservation organisations are developing online and field-based training material (Table 6.2).

Online material has the advantage of being accessible to a wider audience compared to in-person training and, aside from the initial cost of designing the material, it should be relatively inexpensive. The BirdID bird census project in Norway has launched online tutorials and a web-based test (www.birdid.no) for volunteers to learn and practise their bird identification skills before participating in surveys. Volunteers receive study credits for university courses, certificates and prizes (t-shirts) for successfully completing identification tests. Preliminary results have shown that there is a correlation between volunteers' test results and their field identification skills (Husby, 2012). Although this is encouraging, providing such rewards is likely to be expensive.

Where resources are available, organisations would benefit from making their training materials as widely accessible as possible by reducing or subsidising the cost of workshops and by developing free online resources or smartphone applications. This may be achieved through educational grants or partnerships with large organisations or businesses (for example, the “Plan A” partnership between the major British retailer Marks and Spencer with Butterfly Conservation and the Marine Conservation Society – Marks and Spencer, 2012).

The long-term benefits of receiving large quantities of high quality data should outweigh the initial financial investment, and these resources would appeal to a wider audience and could even increase the organisation’s membership rates. Indeed, Newman *et al*. (2003) found that 30% of volunteers joined conservation organisations after having participated in mammal-identification workshops. Furthermore, when groups of volunteers undertake surveys, it is often the case that experienced volunteers transfer their knowledge to new volunteers at no additional cost to the organisation running the surveys (see Chapter 3).

Once the data are collected, they must be filtered or “scrubbed” to remove any unusable data, outliers, and any obvious errors (Catlin-Groves, 2012a). All data were manually checked before analysis during this thesis, as this is highly important when verifying data. Specialised software may facilitate this process within very large databases. For example, the Dutch biodiversity data warehouse 'National Database Flora and Fauna' (NDFF) contains over 50 million records, and data can be submitted by anyone. To validate data, the system comprises data entry portals, a basic archive and a validation service, whereby experts confirm or reject any records that have been “flagged” by the system (Vliegenthart and Bekker, 2012).

Data should be analysed using appropriate statistical methods according to the type of data collected. New statistical methods are currently being developed in order to counter some of the issues of citizen science data. For example, Bayesian statistical analysis can assign different priors as levels of confidence for the accuracy of the data (Brooks, 2003) in order to overcome bias and errors, such as incorrect identification or wrongly mapped locations that are outside of a species’ normal range. Bayesian approaches also allow citizen science or volunteer-collected data to be used alongside predictions, such as those generated from ecological niche models, to help improve knowledge of species distributions (Reute, 2012).

However, it has been demonstrated that, in some cases, the use of Bayesian techniques can result in decreases in data accuracy (Stafford and Lloyd, 2011). Depending on the research question asked, it is also possible to use robust techniques that to analyse presence only data, for example, by determining changes in species distribution patterns through a bootstrapped 'centre of gravity' approach. This method can be effective in areas where as few as 10% of possible locations have been surveyed, even if there is considerable spatial bias in the sampling (Stafford, 2012; Stafford *et al*., 2013). However, these methods are all problem-specific, and still currently being developed or validated.

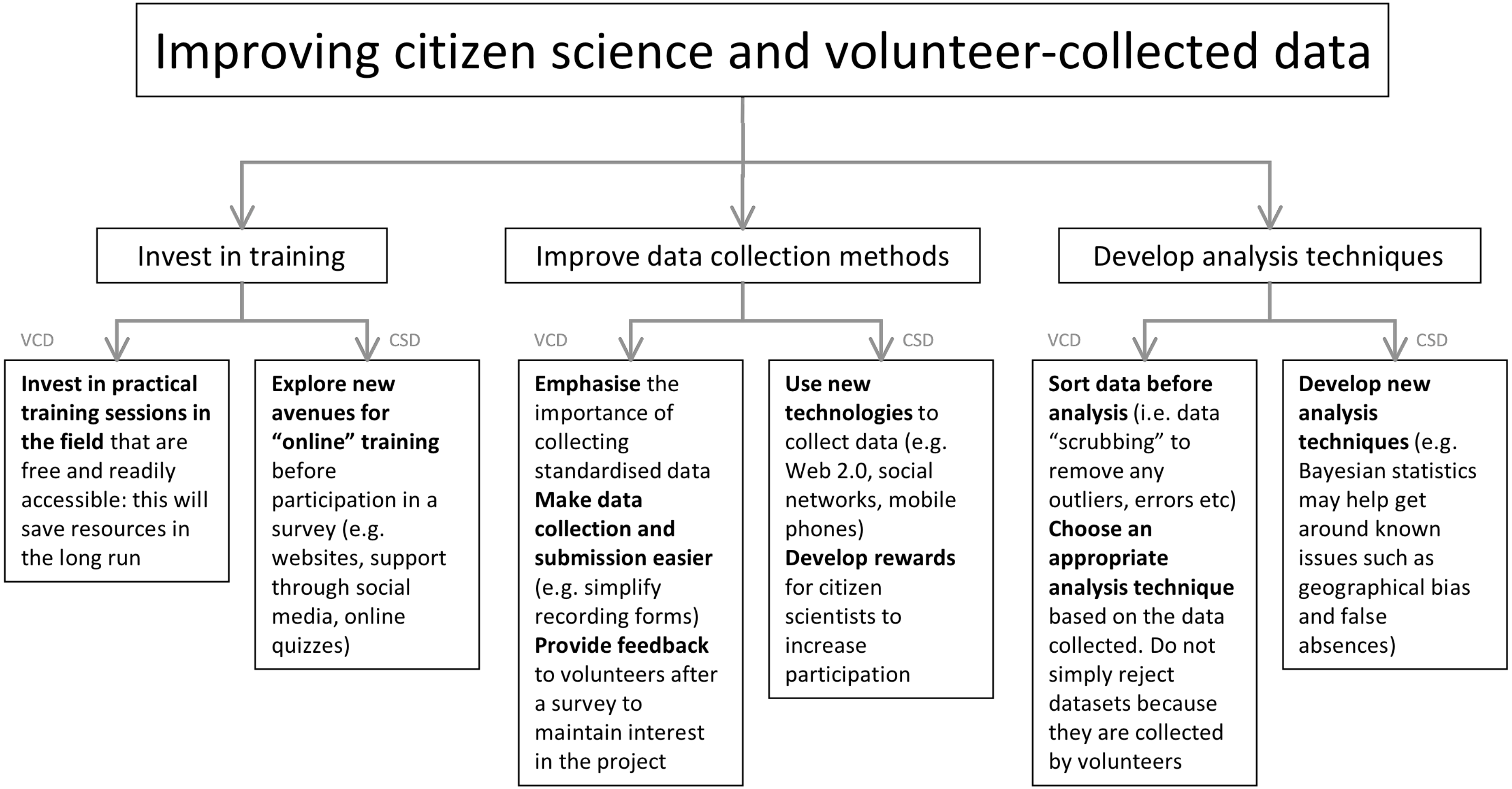

Figure 6.1) Recommendations to improve the quality of citizen science and volunteer-collected data
VCD = volunteer-collected data; CSD = citizen science data

Table 6.2) Examples of training materials provided by four large British wildlife conservation organisations

Organisation	Type of training material	Description	Cost
Bat Conservation Trust	Online tutorials	The "Bat Sound Library" provides learning material about bats to aid with identification for the volunteer surveys	Free, but exclusively available to members and volunteers (user name and password required)
British Trust for Ornithology	"In person" training courses Online material	Workshops designed for volunteers who wish to learn bird identification skills (through classroom and practical-based sessions) Online videos and fact files to learn bird identification skills	£45 for a day course, but highly subsidised for members and/or volunteers Online material is freely accessible to anyone
Mammal Society	"In person" training courses	Classroom based and practical, field-based sessions to develop relevant mammal survey skills	£95 for a day course, 10% discount for members
Royal Society for the Protection of Birds	Online material	Online "Bird Identifier" guide, instructions, frequently asked questions and a Community group forum for the "Big Garden Birdwatch" citizen science survey	All instructions are freely available to access or download but the community group forum requires an account (free to set up)

6.5.2) Increasing participation

Wildlife organisations rely heavily on volunteers and citizen scientists to collect data because of evermore restricted budgets, and are continually looking to increase voluntary participation. Another important benefit is that higher participation rates increase data accuracy because accuracy is a function of sample size (Catlin-Groves, 2012a). Citizen science is effective for detecting rare species (Losey *et al*., 2007; Dickinson *et al*., 2010), however, large sample sizes are needed to study the distribution of rare species (e.g. 500 records) compared to common species (30-50 records) (Stafford *et al.*, 2010 – see Appendix 7).

Participation rates may be increased in several ways. Drawing from experience gained during this thesis, one way of doing this is to make the whole process as simple and enjoyable as possible, from training through to data-collection and feedback. Indeed, providing engaging, fun training sessions might also make people more likely to collect data. For instance, the BeeID research project was publicised at a science festival by educating members of the public about bee biology and conservation, thus indirectly providing training and increasing participation in the survey (Stafford *et al*., 2010 – see Appendix 7). Additionally, asking for fewer data may indirectly increase participation: Sewell *et al.* (2010) found that volunteers were deterred when asked to record the temperature during surveys. However, in some cases, dedicated volunteers may wish to provide as much information as possible to a project. Hence, the framework of 'engagement' presented in chapter 1 is important to bear in mind when designing citizen science or volunteer surveys (see discussion below).

There is a trade-off between data quality and quantity: asking for very simple data may have adverse effects as the data may not provide enough detail. There is also a fine line between making data collection too painstakingly "scientific", for example, by asking volunteers to visit a site on five separate occasions using four different methods to accurately detect species absence (as in Sewell *et al.*, 2010), and letting volunteers decide when and where to record data. For example, untrained citizen scientists can participate in the Bat Conservation Trust's "sunset and sunrise bat counts", during which they record the flight direction of bats at the site of their choice (no identification skills are required). However, this survey produces data that are of no real value for research: the principal aim of the survey is to recruit people who may become interested in seeking further training to undertake more detailed surveys (Barlow, 2012).

Some individuals enjoy recording extra details, and should be given the option to do so. Occasionally, citizen scientists participating in the hedgehog garden questionnaire added extra details that they felt were important, but that were irrelevant to the questions, and this meant that it was time-consuming to extract the necessary data (Chapter 5). Similarly, volunteers sometimes recorded the temperature during dormouse surveys at Midger wood (Chapter 3), but these data have never been analysed are not a requirement of the NDMP (PTES, 2012). Keen birdwatchers also enjoyed recording the weather conditions during their surveys for their own personal records (Wernham *et al*., 2012). Questionnaires and recording forms clearly need to be standardised, but should contain an extra field for any additional information provided by volunteers so that this can easily be filtered and ignored if necessary.

Submission processes should also be improved so as not to deter participants from submitting their valuable data. An easy submission process was deemed important when citizen scientists were asked to submit photographs of bees to a social media website, and even though this was thought to be relatively straightforward, 41% of participants did not complete all required information when submitting photographs (Stafford *et al*., 2010 – see Appendix 7). This suggests that further research is required to design even more simple methods to submit data. There are debates over using paper or online submission forms, but many organisations still use both methods in order to appeal to a younger generation who are accustomed to using the internet, and to their older volunteers who prefer paper forms (Wernham *et al*., 2012).

Finally, another way to increase participation and enjoyment is to provide feedback to participants, regardless of the size of their contribution to a survey. This can be done by simply thanking participants for their records (e.g. Stafford *et al*., 2010 – see Appendix 7) or by keeping them up to date with results through a newsletter or annual report so that they can watch their contributions become part of a bigger picture, thus maintaining their interest (Crick *et al*., 2003; Catlin-Groves, 2012a). Both the BTO and PTES provide reports to volunteers involved in their monitoring programmes, sharing results and providing advice and encouragement (Crick *et al*., 2003; PTES, 2012).

6.6) Final conclusion

This thesis has investigated both a range of volunteers, classed by engagement type, and the types of data the volunteers can collect (i.e. habitat, species presence, behaviour). The conclusions are robust for a given classification of volunteer and data type, as presented in each chapter, however, this does not mean that all volunteers should be considered identical. For example, dedicated volunteers could collect accurate ethogram behaviour data, but doing so would require an understanding of random or regular sampling to collate activity budgets. Many casual volunteers embarking on citizen science projects, especially those with smart-phone applications, are unlikely to be interested in such details, and the level of detail and type of data they would be able to collect and needs careful consideration. The roles of training and education of volunteers need consideration in terms of data accuracy, but also of participation rates and motivation to partake in a study. Training may improve the accuracy and motivation of some volunteers, but may deter a large proportion of possible volunteers from taking part.

By necessity, volunteer data collected in this thesis are frequently compared to a single set of data collected by a professional. While it cannot be guaranteed that professional-collected data are perfectly correct, results can still show whether the use of volunteer data would result in different conclusions to a conventional scientific study (i.e. a study involving data collected by a single professional). Certainly scientists show inter-observer variation in measurement of biometric data such as wing length (Goodenough *et al.*, 2010; 2012), and whether or not there is similar inter-observer variability in terms of measurement of factors such as percentage cover (such as in Chapter 2) is an area for further investigation. Throughout this thesis, the results of the professional differ to those of volunteers, but there is some uncertainty as to whether the professional is representative of all professionals. As such, in order for the results to be truly transferable, there needs to be a measure of error around both the professional and volunteer estimates (equivalent to standard error around a sample mean estimate). This should be an important consideration in future studies.

This limitation needs to be clearly spelled out and the need for further research to explore the mechanisms underlying such differences needs to be discussed.

Overall, it is felt that volunteers and citizen scientists are an extremely valuable resource both in terms of collecting data, and for promoting conservation messages. In-depth inter-disciplinary studies on the motivations and aptitudes of volunteers and citizen scientists would provide a valuable contribution to knowledge, and may help to improve survey design. Furthermore, while this thesis has focussed primarily upon the study of British mammals, it is clear that many other taxa, and even other fields, also benefit from volunteer-collected data and citizen science. As such, it would be highly beneficial to promote collaboration between different researchers, not only within Britain but also across Europe, to ensure that volunteer-collected data and citizen science continue expanding our knowledge of ecology, and contribute to practical conservation measures.

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Photograph credits

All photographs are my own, except those listed below:

Box 2.1
Water vole: Terry Whittaker at www.flpa-images.co.uk
Distribution map: NBN database (NBN, 2012)

Box 3.1
Dormouse: I.R. Beames at www.ardea.com
Distribution map: NBN database (NBN, 2012)

Box 4.1
Distribution map: Wilson, D.E. and Ruff, S. (1999) The Smithsonian Book of North American Mammals, Smithsonian Institution Press

Chapter 5
Hedgehog photograph under Abstract: Damon Cannard at www.damoncannard.com

Box 5.1
Hedgehog: Damon Cannard at www.damoncannard.com
Distribution map: NBN database (NBN, 2012)

Box 6.1
European otter: Laurie Campbell at www.lauriecampbell.com
Distribution map: NBN database (NBN, 2012)

Appendix 1: Handout given to students to collect data on water vole habitat

Your name:
Your group's name:

Site number →	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Canopy overhang (0-5)										
Bank angle (0-4)										
Depth of water (0-3)										
Flow rate at edge of bank (0-3)										

Site number →	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Trees or saplings										
Shrubs (can't wade through: scratchy/woody, e.g. bramble)										
Field layer (could wade through: non-woody, e.g. ferns, long grass, nettles)										
Herb layer (could walk on: e.g. short grass and small plants)										
Submerged/floating plants (on or under water)										
Emergent plants (sticking out of water)										

Site number →	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Rushes (very straight, leafless, smooth, round spiky stems)										
Sedges (rough, triangular stem, "M" shaped leaf cross-section and have sharp edges)										
Grasses and reeds (soft, floppy round stems. Reeds look like grass sticking out of the water)										
Nettles										
Yellow flag iris										
Willowherb										
Meadowsweet										
Himalayan balsam										
Japanese knotweed										

Guide to different scales

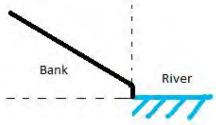
Canopy overhang (0-5 scale) – potential shade over the course of the day. Remember the sun moves throughout the day… so if it isn't in the shade now, it could be later.

0 = no shade at all
1 = few leaves or bare branches would create light shade (10% shade)
2 = noticeable amount of shade (25%)
3 = bank could be half shaded (50%)
4 = bank could be very shaded (50 to 75%)
5 = thick vegetation - bank is very heavily shaded for most/all of the day (100%)

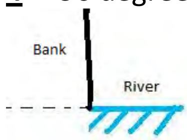
Bank angle (0-4 scale)

0 ~ flat

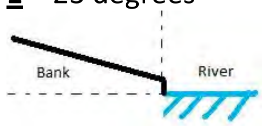
2 ~ 45 degrees



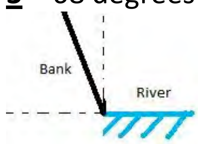
4 ~ 90 degrees (vertical)



1 ~ 23 degrees



3 ~ 68 degrees



Depth of water: 0-3 scale – Look at the bottom of the river and estimate the depth
0 = no water
1 = shallow (ankle deep)
2 = medium (between ankle and knee)
3 = deep (above knee deep)

Flow rate (0-3 scale) – estimate by looking at debris in the current and ripples
0 = stagnant
1 = very slow (no visible ripples, hard to tell if water is moving)
2 = medium (water moving quite noticeably)
3 = fast (ripples or white water visible)

DAFOR scale:
Dominant >75% ground cover
Abundant ~ 50% ground cover
Frequent ~ 25% ground cover
Occasional ~ 10% ground cover
Rare ~ 5% ground cover
Put an "X" if it is absent

Species identification

Willowherb – lance-shaped leaves (5-15cm long) pointing upwards with smooth margins, reddish stems, bright pink flowers from June-August  dsgardening.btinternet.co.uk	Meadowsweet – shiny dark green leaflets (4-8cm long) with serrated margins, tufts of creamy white flowers June-August  i54.photobucket.com
Yellowflag iris – very tall thick leaf "blades", grows out of or right beside water, large bright yellow flowers May-June  geograph.org.uk	Hopefully you know what a stinging nettle is! Don't get too close...  veggies-only.blogspot.com
Himalayan balsam – Elongated, oval, serrated leaves (5-23 cm long), green or red stems. Pink flowers July-August  dgsgardening.btinternet.co.uk	Japanese knotweed – broad heart-shaped leaves (7-14 cm long), sprigs of tiny white flowers in late summer  allisonenterprises.co.uk

Appendix 2: Publication arising from Chapter 3

Williams, R.L., Goodenough, A.E., Hart, A.G., and Stafford, R. (2013) Using long-term volunteer records to examine dormouse (*Muscardinus avellanarius*) nestbox selection, *PLoS One*, 8 (6), e67986

See following page

Using Long-Term Volunteer Records to Examine Dormouse (*Muscardinus avellanarius*) Nestbox Selection

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Abstract

Within ecology, there are unanswered questions about species-habitat interactions, which could potentially be resolved by a pragmatic analysis of a long-term volunteer-collected dataset. Here, we analysed 18 years of volunteer-collected data from a UK dormouse nestbox monitoring programme to determine the influence of habitat variables on nestbox choice by common dormice (*Muscardinus avellanarius*). We measured a range of habitat variables in a coppiced woodland in Gloucestershire, UK, and analysed these in relation to dormouse nestbox occupancy records (by dormice, other small mammals, and birds) collected by volunteers. While some characteristics of the woodland had changed over 18 years, simple transformation of the data and interpretation of the results indicated that the dataset was informative. Using stepwise regressions, multiple environmental and ecological factors were found to determine nestbox selection. Distance from the edge of the wood was the most influential (this did not change over 18 years), with boxes in the woodland interior being selected preferentially. There was a significant negative relationship with the presence of ferns (indicative of damp shady conditions). The presence of oak (a long-lived species), and the clumped structural complexity of the canopy were also important factors in the final model. There was no evidence of competition between dormice and birds or other mammals. The results provide greater understanding of artificial dormouse nest-site requirements and indicate that, in terms of habitat selection, long-term volunteer-collected datasets contribute usefully to understanding the requirements of species with an important conservation status.

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Introduction

Many animals, both invertebrate and vertebrate, build nests (e.g. stingless bees *Trigona spinipes* [1]; grass-cutting ants *Atta vollenweideri* [2]; chimpanzees *Pan troglodytes* [3]; great tits *Parus major* [4]). Selecting a suitable nest-site is important as it provides shelter from predators or adverse weather conditions, and increases fitness and survival of young [5–7]. Most nest-building birds, for example, invest considerable time and energy choosing their nest-site because certain sites greatly influence reproductive success [8] and the same is true for large mammals (e.g. badgers *Meles meles* [9]), and for many small mammal species (e.g. [5,10,11]). Knowledge of nest-site requirements is essential for the conservation of rare or specialist species [7,12], especially where nest-site availability limits population sizes, as has been observed in a variety of arboreal mammals (e.g. grey mouse lemurs *Microcebus murinus* [13]; northern flying squirrels *Glaucomys sabrinus* [14]; greater gliders *Petauroides volans* [15]; common dormice *Muscardinus avellanarius* [16]).

In the UK, a lack of appropriate woodland management and habitat fragmentation has resulted in the reduction of suitable habitat for dormice, at the edge of their range, leading to extirpations [17]. As a result, and despite legal protection, dormouse distribution has reduced by more than half since the 19th century, and the species is now of conservation concern in the UK [18]. Dormouse nesting ecology is difficult to study because dormice are cryptic, nocturnal and arboreal; their natural nests are difficult to locate as they are usually concealed in thick foliage or in tree cavities, and may be as high as 15 m in the canopy [17,19]. This makes studies relying on natural nest-sites logistically challenging, or even misleading, because of the high risk of not finding nests [20]. Nestbox occupation data provide an opportunity to estimate relative abundance and distribution of dormice with minimal labour [21]. Dormice are found in nestboxes from mid-May to October, and are known to use them across their range, thereby allowing the comparison of findings across similar studies [22]. Nestboxes also benefit dormouse conservation. Bright and Morris [20] conducted a radio-tracking survey and found that artificial nestboxes were by far the most frequently used nest-sites compared to natural nests. They argued that, where nestboxes are present, almost the whole population would use them, and providing nestboxes appeared to double the number of dormice present in an area [20]. Some cavity-nesting bird species such as blue and great tits are known to use artificial nestboxes almost exclusively when they are available, and numerous studies have benefited from the study of these species in nestboxes [23]. As dormice also readily breed in nestboxes [24], this also allows the study of their breeding ecology. Both male and female dormice use nestboxes, and they can be found either singly or in groups of two or more (e.g. male-female breeding pairs, groups of juveniles, mothers with litters) and this fluctuates depending on the time of year. Dormice can have several litters per year, although exact numbers of litters and young per litter differ across their range [22] (note that two litters per year were commonly found in some nestboxes at the present study site; one in early summer and one in the autumn). Any findings that relate habitat features to nestbox preference or breeding success in nestboxes could therefore easily be used in an applied sense (e.g. changing nestbox location) and may have more immediate conservation implications than findings relating to habitat features in natural nest-sites (because these cannot be moved), although factors influencing the selection of natural and artificial sites may not be identical.

There is a growing focus on long-term volunteer-collected datasets in ecology [25,26] because volunteer-run programmes provide large quantities of data at minimal cost [27,28]. Deploying a team of volunteers can also save substantial amounts of time compared to using professional ecologists [27]. In the UK, many conservation organisations rely heavily on volunteers to collect data (e.g. the British Trust for Ornithology BTO, the Royal Society for the Protection of Birds RSPB, the People's Trust for Endangered Species PTES, the Mammal Society, the Marine Conservation Society, the Wildlife Trusts and the Bat Conservation Trust), however, volunteer-collected data are often questioned because they lack the rigour and precision of scientific studies (e.g. [29]).

The dormouse is a popular and charismatic species in the UK. Currently, over 1,000 volunteers participate in the National Dormouse Monitoring Programme (NDMP) run jointly by the PTES and Natural England. These volunteers have been submitting records since 1988, and in 2011, there were 305 sites involved in the scheme (with some annual variation – S. Sharafi, PTES, pers. comm.). Volunteers are required to check nestboxes at a site at least twice a year (May/June and Sept/Oct) to monitor evidence of dormouse occupation. The records are analysed by the PTES to estimate national trends in dormouse numbers and distribution.

Understanding breeding dormouse population nestbox requirements is crucial if nestboxes are to be maximally effective for conservation. Using long-term (18-year) volunteer-collected data collected as part of the NDMP, this study: (1) tests whether dormice actively choose (rather than randomly occupy) nestboxes; (2) examines some of the biotic and abiotic factors responsible for this selection; and (3) provides recommendations on using large volunteer datasets, discussing the attributes and limitations such datasets present.

Methods

Site Description

This study was undertaken at Midger Wood Nature Reserve (51° 36' 15.8", 2° 17' 26.9"), a 9 ha site in Gloucestershire, UK, managed by the Gloucestershire Wildlife Trust. The site is an ancient semi-natural coppiced woodland, dominated by ash (*Fraxinus excelsior*) with some Pedunculate oak (*Quercus robur*) and beech (*Fagus sylvatica*), with an understory of hazel (*Corylus avellana*), hawthorn (*Crataegus monogyna*), and holly (*Illex aquifolium*) [30].

Data Collection

The presence of dormice, other small mammals (combining records for woodmice *Apodemus sylvaticus*, yellow-necked mice *Apodemus flavicollis*, and shrews *Sorex* spp.), and birds (mainly blue tits *Cyanistes caeruleus* and great tits *Parus major*) was recorded monthly from April to November in 97 wooden dormouse nestboxes between 1994 and 2011 inclusive (no other species were found, and there was no indication of grey squirrels *Sciurus carolinensis* entering the nestboxes to compete with, or depredate, dormice). Nestboxes were located at chest height, and were distributed along transects across the hazel coppice coupes of the wood, such that they were at least 20 m apart, in accordance with NDMP guidelines [31] (note that the number and location of the nestboxes remained the same over the 18 year period). Although the nestboxes were situated substantially lower than the potential height of natural nest-sites for logistical reasons (following NDMP guidelines), there is no evidence to suggest that this makes them less attractive to dormice than higher natural nest-sites (see 20). Additionally, Sara et al. [32] found no significant difference between nestboxes placed at 1.5 m, 3 m and 5 m above ground. Nestbox monitoring was undertaken by volunteers for Gloucestershire Wildlife Trust (GWT), who manage the site. New volunteers were trained by long-term volunteers who accompanied them until they had enough experience to qualify for a dormouse handling license (a legal requirement in the UK [33]). Nestboxes measured 140x140 mm at the base, had a slanted roof with a mid-point height of 160 mm and a rear entrance hole of 30 mm in diameter, and were fixed to trees at chest height. Volunteer-collected data included presence or absence of nests and the number of individuals found in the nestbox during the survey. Volunteers did not search for natural nest-sites, since 1) this is not a requirement of the National Dormouse Monitoring Programme; and 2) there would have been considerable difficulty locating natural nests [17,19]. Summary data can be requested from the Gloucestershire Centre for Environmental Records (GCER). Dormouse occupation of nestboxes was relatively low, with an average of 7.3% of boxes occupied in any given year (S.D. = 3.3, minimum 2%, maximum 13%).

Table 1. Variables measured at each nestbox.

Measurement	Units and Further Information
Small mammal and bird nests	Percentage of occasions when nests were found in each box over 18 years
Circumference of the nestbox tree	As above (cm, measured at the height of the nestbox)
Distance of the nestbox from ground*	(m)
Angle of the nestbox floor*	Degrees from horizontal
Accessibility	Number of branches directly touching the nestbox
Distance from the edge of the woods	(m)
Distance from the nearest footpath	(m)
Distance from the stream (Kilcott Brook)	(m)
Number of trees in a 10 m radius	Trees were defined as plants taller than chest-height
Number of shrubs in a 10 m radius	Shrubs were defined as plants below chest-height
Woodland management regime*	Age of the coppice coupe in which the nestbox was situated (Obtained from the Gloucestershire Wildlife Trust)
Canopy cover	(%)
Canopy clumpiness	Index of dispersion value indicating the aggregation of the canopy
Mean structural complexity	(%) mean taken from two photos (see Methods for details)
Structural complexity clumpiness	Index of dispersion value indicating the aggregation of the shrub layer
Moss (Bryophyta)	Presence or absence in 10 m radius (1 = present; 0 = absent)
Ash (*Fraxinus excelsior*)	As above
Bramble (*Rubus fruticosus* agg.)	As above
Pedunculate oak (*Quercus robur*)	As above
Honeysuckle (*Lonicera periclymenum*)	As above
Ferns (Pteridophyta)	As above
Dog's mercury (*Mercurialis perennis*)	As above
Holly (*Ilex aquifolium*)	As above
Hawthorn (*Crataegus monogyna*)	As above
Hart's-tongue ferns (*Asplenium scolopendrium*)	As above
Ivy (*Hedera helix*)	As above
Grasses (Poeace)	As above
Sycamore (*Acer pseudoplatanus*)	As above
Crab apple (*Malus sylvestris*)	As above
Other vegetation	As above

Hazel (a dominant species in the wood) was excluded as it was always found within 10 m of every nestbox. Other vegetation refers to plants growing from the ground. For details of canopy cover, clumpiness and structural complexity parameters, see Methods. * Angle of the nestbox floor and distance of the nestbox from the ground were not included in the analysis because these varied when nestboxes were handled during dormouse monitoring surveys and would not, therefore, be consistent over time. Woodland management regime was also disregarded because several coppicing dates could not be determined.

Volunteers removed nests and cleaned nestboxes at the end of winter each year unless the nestbox contained a dry, intact dormouse nest, as the volunteers hoped that this may encourage dormice to re-use the nestbox in the following year. Since dormouse nests were sometimes left over successive years, this variable could not be assured to be independent between years, and certainly not between monthly surveys. Furthermore, historic records showed that dormice were occasionally absent from nestboxes even when recently-made nests were found during a survey. As such, the presence of individuals in a nestbox at any point during the year was used as a dependent variable, since this removed the confounding results of nests being present between successive recordings, but also accounted for the lower likelihood of sightings of individuals compared to nests (this variable is termed dormouse occupancy).

The percentage of occupancy for each nestbox was calculated over the 18-year period (e.g. 9 years of occupancy = 50% occupancy). We hypothesised that leaving nests in nestboxes over successive years may have an influence on dormouse nestbox selection, alongside habitat variables surrounding the nestbox. To remove this effect, dormouse nestbox selection was also examined by treating dormouse nests as a binary variable (whereby nestboxes that had contained a nest at any time over the 18-year period were given a value of 1, and those which had never contained a nest were given a value of 0 – see below).

Local habitat variables were recorded in December 2009 when dormice were hibernating (note: these habitat variables were recorded by the lead author of this paper, RLW, not the volunteers, such that there was no scope for inter-observer variability). The number of trees and shrubs, and the plant species present, were recorded during a five-minute search within a 10 m radius of each nestbox to give an indication of the overall complexity and species diversity. Percentage ground cover was not calculated as cover varied greatly throughout the year. Data were collected during winter to better assess structural complexity related to tree branches. This provided a more meaningful value for this study than if foliage was dense, because dormice travel on branches, not leaves. Bird and small mammal nestbox data were obtained from the historic volunteer records (Table 1). Bird and small mammal nests were always removed from one year to another (bird nests were removed soon after young had fledged from the nest), and individuals were rarely found in a nest during the surveys. Consequently, nests were thought to be a more reliable indicator of bird or small mammal presence in a given year, so this variable was used in all analyses, instead of occupancy (as described for dormice in the previous section).

To record canopy complexity and structural complexity of the surrounding shrub layer, three photographs were taken at each nestbox, one vertically upward and two horizontally at nestbox height (these standard images were taken using a Canon IXUS 860 IS compact digital camera rather than hemispherical images taken with a fish-eye lens, so picture distortion did not need to be accounted for [34]). The shrub layer photographs, one behind and one in front of the nestbox, were taken against a white sheet for contrast. Vegetation density and complexity were calculated using CanopyDigi [34]. This digital image analysis provided an objective quantification of vegetation cover and an index of dispersion value to assess vegetation aggregation and identify significant gaps (high values = clumping with gaps; low values = more uniform vegetation – [35]. Shrub layer structural complexity was calculated using the mean of the two photographs, creating a mean percentage cover and mean index of dispersion.

Statistical methods

To test whether actual nestbox occupation data showed significant departures from a random distribution, as expected if nestboxes were actively chosen but not if they were randomly selected, the frequency of dormouse occupation in each nestbox over the 18 years was compared to a hypothetical Poisson distribution. This was done using a Kolmogorov-Smirnov test (as per [36]).

All percentage variables were converted to proportions and arcsine transformed. Given that the circumference of trees would have increased over the study period, values in this variable were ranked (1 = smallest circumference) rather than using absolute values. The age of coppice, angle of nestbox floor and height of nestbox were not included in the analysis because coppice dates were not known for all sections of the wood, and the height and angle of the nestbox would have changed during the monthly surveys as the volunteers monitored the contents of the nestboxes.

A stepwise regression was used to determine which independent variables were predictors of dormouse nestbox selection, using both forward and backward procedures (the default for the 'step' command in the R statistical software package) and Akaike's Information Criterion (AIC) as a method of model reduction. This allows the optimal (sub) set of predictors to be identified and maximum parsimony to be achieved. This analysis used the percentage of dormouse occupancy over the 18-year period as the dependent variable. Standardised residuals of the final regression were normally distributed, as verified by a Lilliefors test for normality ($D = 0.08$, $p = 0.12$) (as per [37]).

To remove any bias that could have arisen from dormice reselecting nestboxes in which nests remained from one year to another, a stepwise binary logistic regression was run (1 = nestbox containing a nest sometime during the 18-year period; 0 = never occupied by dormice). Note that the number of nestboxes each year remained the same (n = 97). The independent variables of small mammal nests and bird nests were still percentages (as above) because these nests were always cleared out from year to year, thus removing any confounding effects. The logistic regression was more robust to the assumptions of the data than the use of percentage occupancy over 18 years. This conversion to simple presence or absence of a nest in the entire 18 year period also lost valuable information on the preference of nestboxes, i.e. a box occupied once in 18 years was given the same value as a box occupied in most years. Given that our aim was to understand factors influencing nestbox selection, this detail of preference was useful. Similar results from both analyses would strengthen the evidence that significant factors were of biological importance.

To further investigate the relationship between bird nests and dormouse occupancy within years (this was found to be significant in the first stepwise model – see Results), a Spearman's Rank correlation was run comparing the percentage of dormouse occupancy and bird nests for all nestboxes together over each individual year. Finally, possible competitive effects between dormice and birds were examined between individual nestboxes, in each individual year. The percentage of cases where dormouse and bird nests were found (along with percentage of cases where only bird nests, only dormouse nests, or neither of these, were found) were compared against expected values calculated by the equation:

$p(D|B) = p(B|D) = B * D$,

where the probability of dormice being found when bird nests were present is equal to the probability of bird nests being found when dormice were present at any point during the year (i.e. when no facilitation or competition is occurring), and B is the average percentage of bird nests found in all nestboxes over all years, and D is the average percentage of dormice found in all nestboxes over all years. Differences between expected and observed values were tested with a chi-squared test.

Ethics statement

This study was conducted on publicly accessible land owned by Gloucestershire Wildlife Trust, who were aware that the study was being undertaken. No specific permissions were required to access the land or to undertake the study. Dormice are a protected species in the UK, requiring a handling license if they are being disturbed, however, no dormice were handled during the collection of habitat data for this study: these data were collected during winter when dormice were hibernating, thus ensuring that dormice were not disturbed. Occupancy data were collected before the study began, as part of a national monitoring programme, by trained volunteers with dormouse handling licenses. Dormice were put back inside their respective nestboxes promptly after the necessary data were recorded. No dormice were harmed during this procedure. licenses were granted only after volunteers had proven that they could handle dormice safely without harming them. For the purpose of this study, the lead author (RLW) also obtained a dormouse handling license issued by Natural England to undertake the work (license number 20121036); the conditions of this license were observed at all times. See [33] for further information.

Results

Occupation of nestboxes was relatively low, with an average of 7.3% of boxes occupied in any given year (S.D. = 3.3, minimum 2%, maximum 13%). Occupation of nestboxes was not random ($Z = 5.07$, $n = 97$, $p < 0.01$), indicating active nestbox selection. The final stepwise-reduced model was highly significant ($F_{8,88} = 5.68$, $p < 0.01$) and the suite of habitat variables entered explained 28% of variability in dormouse occupancy (adjusted $r^2 = 0.28$) (Table 2). It is important to note that the stepwise approach creates a best-fit model of numerous predictor variables in a multivariate framework,

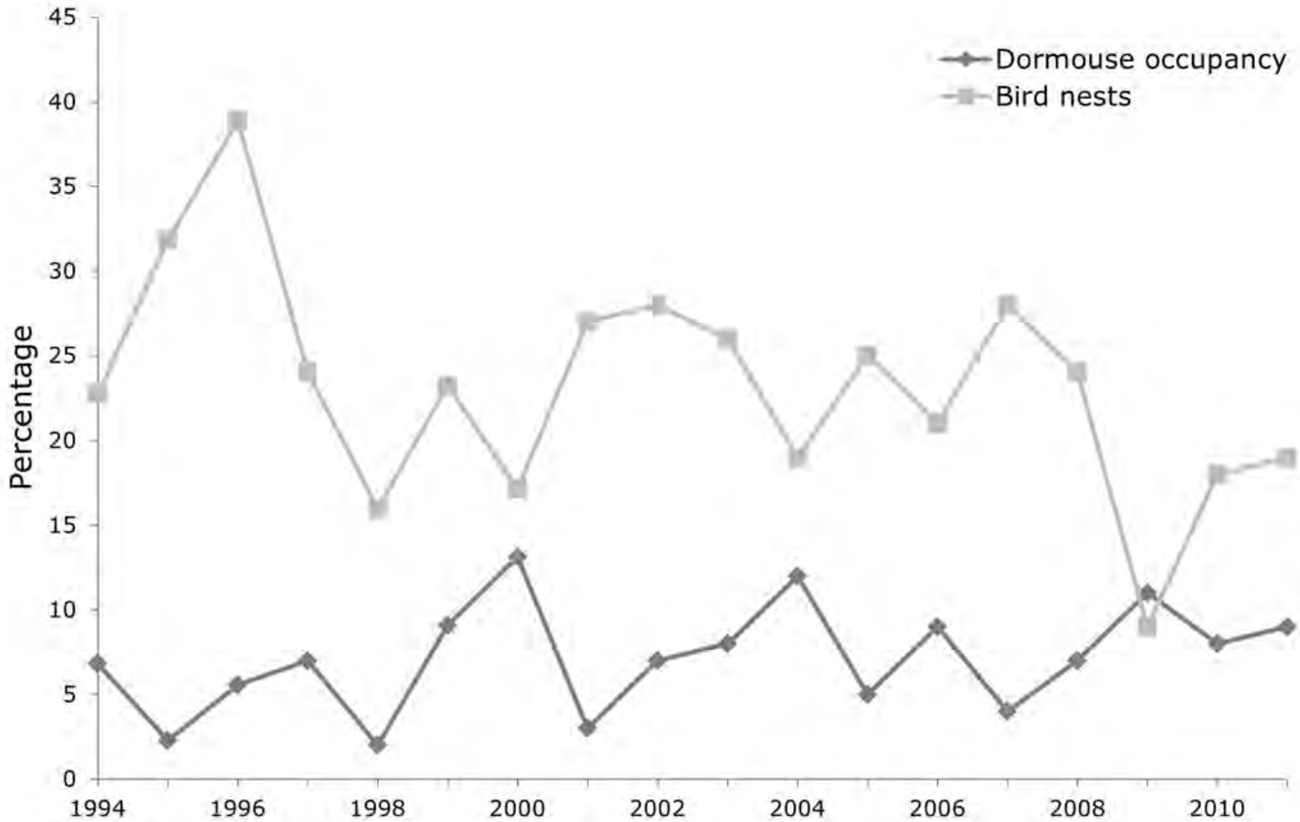

Figure 1. Percentage of nestboxes containing bird nests and dormice (individuals rather than nests) between 1994 and 2011.

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Table 2. Variables found to be important for dormouse nestbox selection, as determined by a stepwise regression.

	df	AIC	Delta AIC	Relationship	p-value
Hawthorn	1	-312.4	0	Negative	p = 0.14
Number of trees	1	-311.9	9.6	Positive	p = 0.11
Oak	1	-311.5	11.7	Positive	p = 0.08.
Canopy clumpiness	1	-311.1	13.2	Positive	p = 0.07.
Ferns	1	-310.4	13.9	Negative	p = 0.05*
Birds	1	-308.9	14.3	Positive	p = 0.02*
Circumference of the tree	1	-306.8	14.7	Negative	p < 0.01**
Distance from edge of wood	1	-297.2	15.2	Positive	p < 0.01***

Significance codes: '*** ' p < 0.001 '** ' p < 0.01 '* ' p < 0.05 '.' p < 0.1

balancing model explanatory power and parsimony. Overall, this model is highly significant, and all explanatory variables in the model are important in achieving the overall significance and R^2 value, and warrant further discussion. Not all explanatory variables are independently significant in this final model (Table 2) since many of these are important in association with other variables (i.e. there is no simple univariate relationship). The most important factor determining occupancy was the distance from the wood edge. This was a positive correlation, indicating that dormice preferred nestboxes towards the centre of the wood. There was a negative relationship between occupancy and the circumference of the nestbox tree; smaller trees were associated more strongly with nestbox use than larger trees. There was also a negative relationship with the presence of ferns. Presence of oak and canopy clumpiness, as well as the number of trees and the presence of hawthorn were also important factors in the final best-fit model.

The stepwise regression also showed that there was a positive relationship between dormouse occupancy and bird nests (Table 2), indicating: (1) no evidence of competition in the study population and (2) that nestboxes were selected on the basis of similar, or at least closely correlated, variables. When bird nests and dormouse occupancy were further examined for all nestboxes within years, a relatively strong significant negative correlation was found (r_s = -0.56; n = 18; p = 0.016), implying potential competition or mutual exclusion on a yearly basis (Figure 1). Comparison of the observed percentage of occupation of each nestbox in a given year by birds, dormice or both showed no significant difference to calculated expected values where dormouse and bird occupation were calculated independently of one another (χ^2 = 0.01; df = 3; p > 0.99), hence, there was no evidence of competition between birds and dormice at this site.

Table 3. Variables found to be important for dormouse nestbox selection, as determined by a binary stepwise logistic regression.

	df	AIC	Delta AIC	Gradient	p-value
Honeysuckle	1	122.9	0	Positive	p = 0.16
Ferns	1	124.4	1.5	Negative	p = 0.07.
Sycamore	1	125.8	2.9	Negative	p = 0.10
Canopy clumpiness	1	126.2	3.3	Positive	p = 0.03*
Distance from edge of wood	1	129.5	6.6	Positive	p < 0.01**

Significance codes: '** ' p < 0.01 '* ' p < 0.05 '.' p < 0.1

In the stepwise binary logistic regression, five factors were found to be significant and these explained 28% of dormouse nestbox selection in total (estimated $R^2 = 0.28$, Wald = 0.83, $p < 0.01$). Distance from the edge of the wood remained the most significant explanatory variable ($p < 0.01$), followed by canopy clumpiness ($p = 0.03$). Ferns, honeysuckle and sycamore were also important in the final best-fit model (Table 3).

Discussion

This study demonstrates three main points. Firstly, dormice actively select nestboxes, a point often overlooked or impossible to test in habitat selection studies (e.g. [36,38]). Secondly, a suite of habitat factors can explain a considerable degree of this nestbox selection, which could inform the placement of nestboxes for the purpose of dormouse research and conservation. Thirdly, volunteers can collect useful data on dormouse nestbox occupation.

Several of the factors included as candidate variables in the model influenced dormouse nestbox selection, together explaining 28% of variability in occupancy. The most influential factor was the distance from the edge of the wood, which may be due to edge effects (such as increased predation or competition [39]), although some nestboxes were occupied despite being close to the wood edge and the presence of potential dormouse predators was not recorded in this study (for example, corvid birds are potential predators of dormice in edge habitats – see 40. As Midger Wood is a small wood (9 ha), it is not possible to determine at what point distance to the edge of the wood would cease to be important, for example, in a much larger wood. Additionally, the shape of the woodland might affect the importance of the distance to edge variable on dormouse nestbox selection, since this affects the edge:interior ratio. The influence of edge effects on nest-site selection has been studied mainly in avian populations [41] and there are currently no studies on its effect on dormice, although edge effect influences in smaller woods have been proposed [42]. Contradictory results show that dormice readily occupied nest tubes on the fringe of dense scrub in Dorset (S. Eden, pers. comm.), possibly because these were less favoured by competing small mammals (note: nest tubes consist of a length of corrugated plastic tubing and square in section containing a sliding wooden tray [43]). There may be very different selection pressures influencing populations across different habitats.

Since dormice selected nestboxes on thinner trees in this study, it may be that larger trees supported more natural nest-sites such as cavities or dense foliage in the canopy. There is much contention as to whether dormice prefer to use nestboxes or natural nest-sites and factors vary greatly in different habitats. In young woodlands, hedgerows and scrub, dormice may favour unenclosed natural nest-sites (e.g. woven into bramble) over tree hollows or artificial nest-sites [16,44], although in diverse, low-growing woodlands, radio-tracked dormice preferred nestboxes over natural nest-sites [20]. In coppice-with-standards woodland, radio-tracked dormice spent the majority of time either in nestboxes (34% of dormouse tracking days) or in natural tree hollows (41%) and far less time in natural nests in bramble (8%) [19]. Juškaitis [22] found that dormouse nestbox occupation was negatively, but weakly, correlated with tree crown density; the positive relationship with canopy clumpiness found in this study might be due to similar reasons, as gaps in the canopy would mean fewer arboreal routes, which may cause dormice to descend to nestboxes. High canopy clumpiness meant that there were areas of dense cover but also large gaps that let through direct sunlight, which would benefit the plant species that dormice use for food and nest material. It is still unclear how selection for natural nest-sites interacts with nestbox selection mechanisms, and this would be an interesting area for further investigation. Note that studies into natural nest-sites in woodland are facilitated by radio-tracking, and this is unlikely to be feasible using NDMP volunteers due to the legislation surrounding fitting radio-tracking devices to dormice, and the prohibitive costs involved. Nestboxes therefore remain a more practical way of studying dormice with the help of volunteers.

The presence of certain plant species influenced dormouse nestbox selection: dormice were positively correlated with oak and honeysuckle, and negatively correlated with ferns, sycamore and hawthorn. Food sources influence nestbox selection, as dormice rarely travel further than 100 m from their nests but require a diversity of food sources to ensure that food is available continuously throughout the active season [12,20]. Honeysuckle and oak are important food sources [12,18,45,46], with honeysuckle also forming an important component of dormouse nests in Midger Wood [30]. It is therefore unsurprising that these plant species are important explanatory variables in the final models. The presence of ferns is characteristic of dark and damp areas [47], which may be avoided by dormice. The negative relationship with sycamore is unlikely to be biologically meaningful as this species was only present near three nestboxes (these never contained dormice, and this is the reason for its statistical inclusion in the stepwise regression).

The lack of competition between dormice and other nestbox inhabitants was of particular interest in this study because competition for nestboxes occurs in other studies (e.g. [22,48]). Although the lack of competition between birds and dormice agreed with the findings of Morris et al. [24]), years in which dormice occupied more nestboxes generally coincided with years in which birds occupied fewer nestboxes, implying that larger scale effects such as population fluctuations might influence nestbox occupancy. The amount of volunteer-collected data available on birds and dormice might provide an opportunity to investigate this relationship further.

The remaining variability in our study might be explained by chance, variables that were not measured as part of this study (e.g. climate, predators, parasites, pathogens etc), or by dormouse learning and previous experience. Indeed, Marsh and Morris [49] found that boxes favoured by dormice in one year tended to be reselected by them in the following year; however, since individuals were not individually marked for identification at the study site, it was not possible to investigate this. Furthermore, since our study only investigated one small woodland in the UK, it is possible that the results may be site and size specific, and further exploration would be needed to elucidate the generality of the results. The temporal span of the dataset was 18 years, and some of the explanatory factors may have changed over this time despite consistent management by GWT. The influence of parasites and predators on dormouse nestbox selection would be an interesting topic for future study, but as this would require annual records of the relevant variables, it was not possible to examine this here using a historical dataset.

Using volunteer-collected data has both advantages and disadvantages. Alongside the usual benefits of saving time and money compared to recruiting professionals [e.g. 27, 28], a key advantage of this volunteer-collected dataset was its longevity; this can also be an important attribute of useful volunteer-collected data [50]. Additionally, volunteers surveyed the nestboxes monthly from April to November, the highest recommended number of nestbox checks in a year [51]. As a result of this, the dataset was large (>30,000 data points: 97 boxes * 6 months * 18 years * 3 species – dormice, small mammals and birds), which reduced the chance of a type II error.

Volunteer-collected data also has indirect benefits. For example, volunteers also monitored any issues at the site (e.g. fallen trees across footpaths) and reported these back to GWT, thus facilitating the overall management of the site. Most of the regular volunteers at Midger Wood were members of GWT, providing financial support through their memberships and therefore contributing to the cost of managing the site as well as collecting data. Newman et al. [27] found that at least 30% of their volunteers joined conservation organisations after they had volunteered on their project. Meaningful interactions with the natural world also have the potential to enhance human wellbeing and quality of life [52,53] and volunteers who participated in mammal surveying projects gained fulfilment and knowledge [27]. When asked, volunteers at Midger Wood stated that they gained enjoyment from monitoring the nestboxes and some had been participating in dormouse surveys at the site for 18 years.

The volunteer dataset did, however, present some analytical challenges. Although nestbox occupancy data were collected regularly and followed the majority of NDMP guidelines, volunteers did not collect any habitat data, despite habitat data being requested at 5-year intervals for the NDMP. These habitat data would have proved extremely useful in the present study. Habitat characteristics were measured by the authors at the end of an 18-year period, and we were aware that some of these would have changed during this time. A careful analysis and a consideration of variables that may have changed resulted in useful trends being identified. Some nestbox records were difficult to interpret and, if they could not be confirmed, they had to be discarded from the dataset (<5% of the records). There was a certain degree of variability in the records that made computerising the dataset time-consuming (e.g. a record of "*DORMOUSE*" was described as an unoccupied dormouse nest at the bottom of the recording form, not the presence of a dormouse as suggested). Exact records (i.e. how nestbox contents were recorded on the form) were variable between different people despite using the same data recording forms, and this issue increased with the fluctuating number of volunteers.

Conclusions and Recommendations

This study has developed work by previous researchers and has furthered understanding of dormouse nestbox selection. It indicates that dormice select nestboxes based on a combination of factors. While views on the importance of nestboxes for dormouse conservation differ, many, but not all of the results of this study are likely to be relevant for natural nest selection too. Large scale features, such as distance to the edge of the wood, or combinations of plant species in the nearby vicinity are likely to apply equally to natural nests and nestboxes. Some localised factors may differ, as nestboxes provide shelter that may be absent on thin trees with low structural complexity, which would prevent dormice from building natural nests on these trees. Nevertheless, these results are important in informing conservation management decisions where nestboxes are used, and, in combination with other studies, in understanding the broad principles of dormouse habitat selection in any woodland.

Monitoring dormice using volunteers can provide an adequate quantity of analysable data, and useful information can be extracted from data that might usually be considered less reliable compared to rigourous scientific data, as shown in other studies (e.g. [50,54]). Volunteer schemes with large historical datasets are irreplaceable and invaluable as they can produce important ecological information and can help identify important sites and management strategies [28,54]. NDMP records vary greatly in quantity and quality between sites and years (S. Sharafi, PTES, pers. comm.), so it would be useful to determine the reasons behind this variation in order to uncover ways in which to reduce it, thus improving the national database. Volunteers should be informed of the importance of completing forms consistently and of collecting regular habitat data, and guidance on this matter should be given to the leaders of monitoring groups. Volunteer schemes would undoubtedly benefit from scientific input to improve data collection, thereby facilitating scientific study of those data and allowing the results to be of maximum usefulness for applied ecology and conservation.

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Author Contributions

Conceived and designed the experiments: RW AG AH RS. Performed the experiments: RW RS. Analyzed the data: RW AG AH RS. Contributed reagents/materials/analysis tools: RW AG RS. Wrote the manuscript: RW AG AH RS.

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Appendix 3: Publication arising from Chapter 4

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Research Article

The Accuracy of Behavioural Data Collected by Visitors in a Zoo Environment: Can Visitors Collect Meaningful Data?

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Volunteer data collection can be valuable for research. However, accuracy of such data is often a cause for concern. If clear, simple methods are used, volunteers can monitor species presence and abundance in a similar manner to professionals, but it is unknown whether volunteers could collect accurate data on animal behaviour. In this study, visitors at a Wetlands Centre were asked to record behavioural data for a group of captive otters by means of a short questionnaire. They were also asked to provide information about themselves to determine whether various factors would influence their ability to collect data. Using a novel analysis technique based on PCA, visitor data were compared to baseline activity budget data collected by a trained biologist to determine whether visitor data were accurate. Although the response rate was high, visitors were unable to collect accurate data. The principal reason was that visitors exceeded the observation time stated in the instructions, rather than being unable to record behaviours accurately. We propose that automated recording stations, such as touchscreen displays, might prevent this as well as other potential problems such as temporal autocorrelation of data and may result in accurate data collection by visiting members of the public.

1. Introduction

Animal behaviour data are important across the field of biological sciences, from evolution and population biology to ethology in captive or domesticated animals. However, collecting these data is time consuming. Given that the duration of data collection for behavioural studies can range from several weeks [1, 2] to several years [3], funding professional researchers can be prohibitively expensive for many studies, especially those conducted by zoological parks and wildlife organisations [4, 5]. However, animal behaviour is of considerable interest to the general public (or at least a subset of the public with environmental and zoological interests), and many people spend considerable time observing animals as a hobby (e.g., watching pets, wild birds, or animals in zoos). Professionals could use this interest to recruit volunteers to record animal behaviour.

There are many advantages of using volunteers to collect data. Volunteers can collect data at little or no financial cost to the organisation running the project [4–6]; indeed large numbers of untrained members of the public have been collecting biodiversity data for wildlife organisations for several decades. For example, in 2011, over 600,000 members of the public took part in the Royal Society for the Protection of Birds' "Big Garden Birdwatch" [7]. Several studies have shown that volunteer-collected data on, for example, species identification and quantifying abundance, can be as accurate as basic biodiversity data recorded by scientists [4, 6, 8, 9], especially when projects offer basic training and are closely supervised by scientists. Moreover, several methods have been developed to enhance the accuracy of volunteer-run surveys, either in terms of the methods used to collect the data or in subsequent analysis [4, 10–14]. Collection of behavioural data, however, is subject to a certain degree of interpretation and may be more complex to record than counting or identifying species. It is not known whether the quality of volunteer-collected behavioural data would be sufficient to calculate accurate activity budgets or to test behavioural ecology hypotheses.

Monitoring animal behaviour is particularly important in zoos because of the importance of animal welfare [15, 16]. Zoos may encourage their zookeepers to participate in research [17] but data collection often cannot be a priority amongst the zookeepers' daily husbandry activities [18]. Research activities can be supplemented with undergraduate and postgraduate students under the supervision of lecturers and scientists, with no financial cost for the zoos involved [19, 20], but while this provides useful and reliable data, it relies on the availability of students and on University course content.

An alternative approach could be to use zoo visitors to collect data on a voluntary basis. The benefits of asking zoo visitors to collect data while they visit could be numerous. Zoos are popular attractions worldwide, attracting more than 700 million people each year [21], so there is no shortage of potential volunteers. Many visitors have a keen interest in animals and wildlife conservation [22, 23], and this could be a strong incentive to participate in research that may benefit the animals they are observing. Furthermore, behavioural data could be collected almost continuously throughout the day as and when visitors pass the animal enclosures. This should create a database from which daily activity budgets can be calculated. Finally, interactive activities create more positive experiences for visitors when compared to passive exhibit viewing [24], so an activity such as this could make the zoo more attractive to its visitors.

While some research suggests that zookeepers' casual observations throughout the day provide a good indication of the overall activity budgets of the animals [18, 25, 26], and keepers are generally well acquainted with individual animals and their behaviours, they may not be acquainted with recording behaviour in a scientific and rigorous manner. It also seems reasonable to assume that the vast majority of visitor-based "volunteers" would have no prior experience of collecting behavioural data and it would be logistically difficult, or impossible, to train and/or supervise them while they collect data. However, if visitors are able to collect accurate data on captive animals, there is a potential for volunteer projects to collect behavioural data on wild animals, especially where there are large concentrations of people and animals, such as in nature reserves or game parks. The aim of this study is to determine whether visitors can collect accurate data on the behaviour of a small group of animals in a captive environment. Visitor data were compared to data collected by a trained biologist.

2. Methods

2.1. Study Site. The study was conducted at the Wildfowl and Wetlands Trust (WWT) centre at Slimbridge, Gloucestershire, UK (OS grid reference SO722047). A group of three female captive North American river otters (*Lontra canadensis*) were selected for the study because of their popularity with visitors and the fact that this species demonstrated a rich suite of behaviours during the daily opening hours of the centre (R. L. Williams pers. obs.). It was important that visitors could see the otters in order to record their behaviour, and the layout of the otter enclosure facilitated this. Large panels of clear glass around the enclosure allowed visitors to view the otters easily from the walkway that spanned the front of the enclosure (Figure 1). There was also a small indoor sleeping chamber in which visitors could see the otters through small glass windows in a walkthrough tunnel. Otters could access all parts of the enclosure at any time of the day, and no parts of the enclosure were closed during routine cleaning of the exhibit.

2.2. Ethogram Data

2.2.1. Ethogram Construction and Scientific Data Collection. To determine whether visitors could record data that would accurately represent the otters' behaviour, reliable baseline data were required for comparison. A biologist with experience in collecting behavioural data (RLW) created an ethogram as per Martin and Bateson [27] to record the otters' behaviour based on prior observations in a pilot study. Behaviour categories were adapted from a behavioural study done by Anderson et al. [24] on a similar species (Asian small-clawed otters—*Aonyx cinerea*). Behaviours were grouped into simple, easily definable, categories to ensure that members of the public should be able to recognise them in the latter part of the study (Table 1). The study took place over 7 days during the opening hours of the park (10 am until 5 pm). Each hour was divided into six 10 minute periods and the otters' behaviour was recorded during two randomly selected 10-minute periods each hour [28]. An instantaneous scan sampling method [27–29] was used to record the behaviour of each of the 3 otters systematically every 10 s during the recording periods. This was the shortest interval in which data could be recorded by watching each otter consecutively. By using this sampling technique for each of the otters, the problem of missing out individual behaviours was minimised and an overall activity budget for all three otters could also be calculated. Subtle differences in size and coat colouration were used to distinguish each otter to calculate individual activity budgets. If an individual otter was out of view at any time during the recording period, it was noted as such. In total, 16.5 h of data were collected for each otter, with a data point collected from each otter simultaneously, giving 1,980 ethogram observations per otter (6 recordings per minute, that is, one every 10 seconds, $\times 20$ minutes of observation per hour $\times 16.5$ hours in total $= 1,980$). This sample size is comparable to those used in studies of a similar nature [18, 30].

2.2.2. Interobserver Variability. To examine the potential for interobserver variability in the collection of behavioural data, a second biologist (herein referred to as CK; not an author of this study and independent from its planning and prior implementation but with the same level of experience as RLW) collected ethogram data over one day, during exactly the same recording periods (14×10 min). The paired data were then compared.

Figure 1: Otter enclosure at Slimbridge, a photograph taken from the front of the enclosure and showing the visitors' viewpoint.

2.3. Questionnaires

2.3.1. Otter Behaviour Questionnaire. The ethogram was simplified to a multiple-choice questionnaire to determine whether visitors could collect accurate data on otter behaviour. The instructions on the questionnaire were as clear, concise, and self-explanatory as possible, as recommended by previous studies [6, 8, 10, 12, 31]. Visitors had to fill in basic information (e.g., write the time down, answer "yes" or "no" if they could see otters inside and/or outside), and tick the behaviours they saw when the otters were outside (i.e., not in the sleeping chamber) during a 30 s period. This method was adapted from the one-zero sampling method in that all behaviours which were observed within the interval were ticked once (1) and those that were not observed were not ticked (0). It is recognised that the two datasets differed not only in who had collected the data (biologist or visitors) but how the data had been collected (ethogram instantaneous scan sampling or questionnaire extended one-zero sampling, resp.). The differences in data collection methods were undertaken for good reason-one-zero sampling was the easiest type of sampling for visitors (and thus the most likely to be reliable) whereas instantaneous scan sampling is a more robust method for generating data for activity budgets. Therefore, although it could be argued that different methods will give different results, the study aimed to determine whether visitor-collected data (at its simplest) could be compared to maximally robust and reliable data, validating the approach taken.

The layout of the questionnaire was an important consideration [32]. Colour photographs were used to illustrate each of the behaviours with the exception of "other", which was represented by a question mark with space underneath for visitors to write down what they had seen. Visitors were not asked to distinguish between individual otters, because identifying them reliably would have been very difficult given the short recording period and subtlety of the differences between otters. Consequently, they were requested to record all of the behaviours they observed, regardless of which individual was performing the behaviour. The "out of view" category from the ethogram was not included in the questionnaire because visitors did not know how many otters were in the enclosure. If they could not see any of the otters, they should have answered "no" to the questions asking whether they could see any otters inside or outside.

Visitors were asked how long they spent at the otter enclosure overall to determine whether this was related to the number of behaviours recorded, and because this could be a potential indication that visitors might be spending longer than the requested 30 s recording data. Visitors were asked some anonymous personal information questions (e.g., their age group, whether they had volunteered before, whether they were a member of a wildlife organisation) to determine whether any of these factors influenced their ability to record accurate data. Finally, visitors were required to indicate how many people had helped them fill in the questionnaire.

The study took place over 8 consecutive days, for 7 hours each day. Visitor data were collected for a day more than the ethogram data because of logistical issues when undertaking both activities was not possible. However, analysis of daily otter activity budgets after the data were collected showed that this did not affect the results. The study was advertised using A3-sized posters at the entrance of the centre and near the otter enclosure, and was promoted by the mammal keeper during the twice daily otter feeding demonstrations (11.30 am and 3.30 pm). Visitors approaching the otter enclosure were asked whether they would be willing to fill in a questionnaire as part of a research project on otter behaviour. No other details were given unless visitors asked questions, as the aim of the study was to determine whether visitors could collect data without supervision. In order to compare ethogram- and questionnaire-derived data, both were collected on the same days (in order to ensure consistent activity levels of the otters—Anderson et al. [24]). The study was carried out on four days before the school holidays and on four days during the school holidays. This allowed a comparison between uptake of the questionnaire during quiet and busy periods at the centre, as well as increasing the range of different visitors filling in the questionnaire (e.g., more families during school holidays).

2.3.2. Visitor Segmentation Questionnaire. The WWT developed a questionnaire as part of a survey to learn more about their visitors, and this was used as a complementary tool in this study [33]. This questionnaire (named the visitor segmentation questionnaire) was stapled behind the otter behaviour questionnaire, but was optional so that length of the two combined questionnaires did not deter visitors from participating. It consisted of a list of questions with the instruction "tick the statement that best describes you". The questions concerned topics such as motivations for visiting the centre, personal interests and affinity for nature, and preferences for various animals at the centre. Analysis of the results determined which "segment" a visitor belonged to (Table 2) and, subsequently, allowed examination to test whether different segments of visitors could record otter behaviour more effectively than others.

Table 1: Ethogram used by a trained biologist to record simple otter behaviours.

Behaviour	Comments and additional information
Inside	"Inside" is not a behaviour, but it was necessary to record this so that the period of time that the otters spent inside was included in the activity budget (it was speculated that visitors may underrecord otters when they were inside—Section 4).
Swimming	In water, not interacting with other otters and/or showing signs of play.*
Eating	This occurred mainly during twice-daily public demonstrations.
Playing	Any playful interaction with another otter (such as chasing, play fighting) or playing alone (diving/rolling in the water, playing with an object).*
Walking or running	As stated.
Grooming	Self-grooming or mutual grooming (if mutual grooming occurred, all otters involved were recorded as grooming).
Rolling	Rolling on land.
Sitting or lying down	Inactive animal (included pausing for a few seconds but also sleeping outside).
Fighting	This was never recorded with the ethogram, though the otters did display aggressive behaviour over food on one occasion (outside a recording period), so it is possible that visitors could have recorded this.
Other	Any behaviour not mentioned above, for example, sprainting, climbing a tree, and drinking.
Out of view	If an otter was not observable at any point during a sampling interval such that its behaviour could not be recorded (i.e., under the pedestrian walkway or hidden in vegetation).

* See Section 4 for comments about the differentiation of swimming and playing.

Table 2: Segmentation pen portraits—Modified and adapted from WWT visitor segmentation report [33].

Visitor segment	Description and comments
Learn together families	They believe in life-long learning for their family. Accessing the outside plays an important role in their leisure time, and they are generally open to all forms of nature, rather than visiting specifically to see birds.
Fun time families	Doing something that entertains and satisfies their children is the main priority in their day out. If their children learn something along the way, then this is an added bonus.
Social naturalists	Their interest in nature is broad; it is not about acquiring detailed knowledge on specific species but more about simply enjoying any kind of wildlife.
Interested naturalists	Interested naturalists are not active birdwatchers but visit to improve their knowledge and learn new things, driven by a broad interest in the natural world.
Interested birders	For interested birders, trips in the outside are a significant part of their life, and the majority are active birdwatchers. Whilst they are mainly looking to develop their interests, their interest in birds is often tied into other hobbies such as walking, photography, and painting.
Social birders	Social birders are seeking to spend quality time with other people in natural surroundings where they are guaranteed to see interesting birds.
Expert birders	Expert birders are applied birdwatchers who tend to take their hobby relatively seriously. This segment has the most knowledge about the WWT's wider conservation activities.
Sensualists	Experiencing the outside is essential to sensualists' lives; to them, it is food for the soul and is a space in which they can relax and experience nature's beauty.
Social day-outers	Wildlife and the outside are not of prime interest to them; their main focus is to spend quality time with others in a nice environment.

2.4. Data Processing and Analysis

2.4.1. Uncorrected and Corrected Data. When data were entered into a spreadsheet, two copies were made: an uncorrected version with data exactly as they were recorded by visitors and a corrected version, whereby any mistakes visitors had made that were noticed by RLW were rectified when possible or omitted from the dataset if the whole questionnaire was unusable (c. 10% of the questionnaires were affected). Mistakes that resulted in exclusion from the corrected dataset included writing the wrong time (pers. obs.), not answering all of the questions, and ticking all of the boxes haphazardly (such questionnaires were usually filled in by young children—pers. obs.). Questionnaires that could be rectified were those in which visitors had interpreted a behaviour as "other" when it could be reclassified as one of the categories listed, for example, "kissing" or "licking" = grooming; "going through tunnel" = playing, and so forth. These datasets are henceforth referred to as uncorrected visitor data and corrected visitor data.

2.4.2. Calculating Activity Budgets. Ethogram data and questionnaire data were converted into activity budgets to indicate the percentage occurrence of specific behaviours as per Stafford et al. [30]. An activity budget was calculated for each individual otter and for the whole group (using ethogram data), as well as for the group of otters using visitor data (using corrected and uncorrected data). In addition to the full questionnaire datasets, various subsets were extracted for separate analysis, for example, for each visitor segment and from adapted or standardised datasets (see below).

2.4.3. Adaptation of the Visitor Datasets and Extraction of Subsets . In addition to the full activity budgets mentioned above, activity budgets were also calculated with the behaviours playing and swimming combined into one category because these behaviours often overlapped. This was similar to the adaptations of Margulis and Westhus [18] where "swim" and "stereotypic swim" were combined to allow the comparison of keeper-collected data and scientist data on brown bear (*Ursus arctos*) behaviour.

There was a disparity in the number of visitors at different times of day, which could have led to an underrepresentation of inside in the mornings when there were fewer questionnaires completed (because there were fewer visitors in the centre) and an overrepresentation of eating when many questionnaires were filled in during the otter demonstrations. To reduce the effect of pseudoreplication and temporal autocorrelation (visitors recording the same behaviours at the same time) that may result from this, an average activity budget was calculated over each half hour period taking into account the number of questionnaires answered in each period. Given the varying length of time that visitors had the questionnaire (including filling in the segmentation questionnaires) it was not logistically possible to calculate an average from the questionnaires over a shorter time interval than 30 min, and in some cases, autocorrelation between questionnaires was likely. The effects of this possible autocorrelation are discussed below.

Separate activity budgets were also calculated from subsets of questionnaires extracted from the complete dataset. These were based on the personal information questions at the end of the behaviour questionnaire. Activity budgets were calculated based on the removal of all questionnaires that had been filled in by a child aged 10 or under from the initial dataset (because children may have difficulty giving accurate answers [34]), as well as separate subsets for the visitors who had prior experience volunteering and for those who had none, and for visitors who were members of a wildlife organisation and for those who were not.

2.4.4. PCA and Analytical Framework. To compare the ethogram activity budgets with the activity budgets calculated for the visitor datasets and subsets, bootstrapped principal components analysis (PCA) was conducted in the *R* statistical package [35], following methods in Stafford et al. [30]. Rather than plotting each activity budget on a two-dimensional scatterplot (as in conventional PCA), this approach involved plotting the mean value of calculated principal components in three dimensions with the radius of the resulting sphere, or "bubble", indicating the confidence radius. Plots were constructed using the RGL library and rgl.sphere function for *R* [36]. Each bubble represented the overall activity budget, with the centre representing the mean of the first three principal components and the radius representing the 95% confidence interval. Statistical inferences were made on the basis that overlapping bubbles signify no significant difference between the activity budgets represented by the bubbles while no overlap indicates significant differences in the activity budgets ($\alpha = 0.05$). In order for the plot to be reliable, the cumulative proportion of the variance explained by the first three principle components (i.e., those used to create the plots) needs to be greater than 0.95 [30]; in this study, all values exceeded 0.95.

A chi-square test for association was performed to test whether the number of behaviours recorded related to the length of time spent at the otter enclosure. The corrected visitor data were used to calculate the number of behaviours recorded, and any questionnaires where the question regarding time spent at the enclosure was left blank were excluded. Number of behaviours recorded were combined into 5 categories for the chi-square test (0, 1-2, 3-4, 5-6, and 7-8) and time periods were classed as less than 2 mins, 2–5 mins, 6–10 mins, and over 10 mins. It is worth noting that, although visitors could have recorded up to 10 behaviours, this did not occur (one visitor did record 9 behaviours, but this was excluded from the analysis because the visitor was a young child and data accuracy was questionable).

2.5. Simulations to Test Accuracy of Visitor-Collected Data. The selection of the time period in which the visitors were asked to collect data was based on the concept that a 30 s period would capture more data than a single instantaneous scan, yet would not be likely to result in all behaviours being observed; hence an estimate of frequency of behaviours could be obtained using this method. Given that preliminary observations indicated that visitors vastly exceeded this time period (see below), a computer simulation was developed to determine if the 30 s sampling period would produce comparable data to ethogram recordings given assumptions that incorrect identification of behaviour and temporal autocorrelation of the data did not exist (i.e., data were collected perfectly, except for the time of recording). The simulation was constructed using *R* [35]. The simulation was parameterised according to the relative probability of the behaviours, as collected from ethogram recordings, making the assumption that the ethogram data collected in this study were an accurate representation of the otters' activity budget (see results, Figure 2).

The simulation produced a random number (score) between 1 and 100, which corresponded to a particular behaviour based on the proportion of its occurrence (see results for details, but otters were seen swimming 11% of the time, so a score between 1 and 11 would correspond to the behaviour "swimming"). After this initial score had been set, the simulation ran with a timestep of the

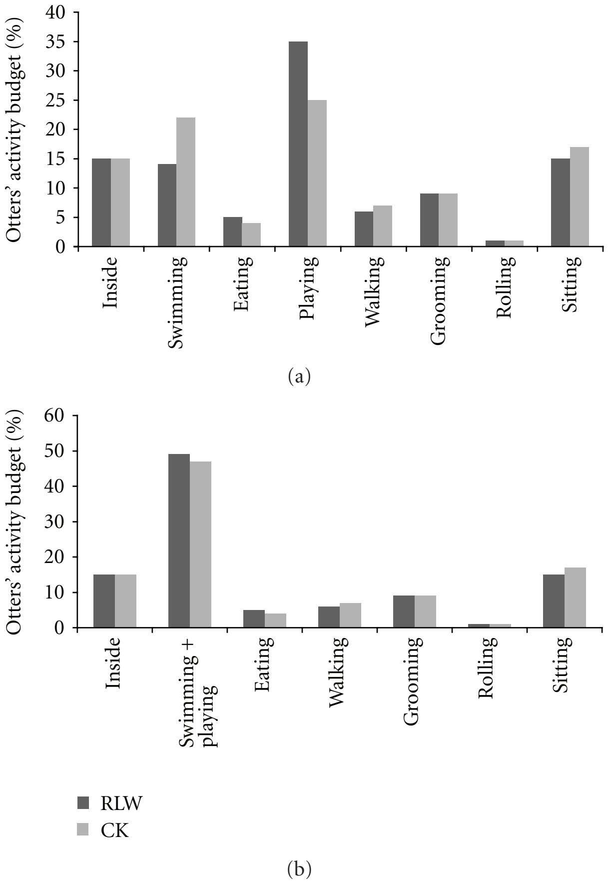

Figure 2: (a) Comparison of otters' activity budgets calculated from ethogram data collected by two biologists (RLW and CK) over one day. Note: categories "fighting" and "other" are not displayed on the graph because neither occurred on that day. (b) As above, swimming and are playing combined as one category.

simulation of 5 s. At each timestep, the score was modified by adding or subtracting a second, randomly generated number (between 3 and −3 from a uniform distribution), from the current score. This new score then indicated the behaviour of the otter at the next timestep. In practise, this meant that successive time steps normally resulted in the same behaviours being recorded, which corresponded to observations on behaviour (i.e., behavioural inertia is more likely than behavioural change).

To parameterise this alteration (named the "change by" variable), results from the ethogram recordings were used. Results indicated that the otters performed on average 3.6 behaviours in a 10 min period. Therefore, we systematically changed the "change by" variable, and for each value, we simulated 100,000 individuals 10 min periods (with sampling every two 5 s timesteps—equating to the 10 s recording periods that were used in this study) to produce a number of behaviours as close as possible to 3.6. The "change by" variable of 6 (i.e., between −3 and 3) produced the most accurate representation, producing an average of 3.5 behaviours over 10 min. (when the "change by" variable was 7 (±3.5), the model produced an average number of behaviours of 3.8, and when 5 (±2.5) produced an average of 3.2 behaviours).

We next simulated data that represented 30 s of sampling by visitors. Although these simulated data were free from confounds such as temporal autocorrelation and misidentification of behaviours, they would give an accurate indication of whether the 30 s recording period would have allowed visitors to collect accurate data on the otters' activity budget. As such, we simulated 574 visitor responses (the same number collected in the study). We compared simulated data and real visitor-collected data in terms of the number of behaviours recorded in a questionnaire to examine the average length of time that visitors may have recorded data for. We also compared the 30 s simulated visitor data to ethogram data and real visitor data using modified PCA or "bubble" analysis, to determine whether recording behaviour for 30 s would result in significant differences to either of these recording methods.

3. Results

3.1. Interobserver Variability. The activity budgets collected by the two biologists were very similar except for the categories of playing (35% for RLW and 25% for CK) and swimming (14% for RLW and 22% for CK). Because playing and swimming were sometimes difficult to differentiate (playing often occurred in water), the differences between the two activity budgets were less apparent when these categories were combined as a single category (Figures 2(a) and 2(b)). There was no significant difference between activity budgets collected by the two biologists. However, when playing and swimming were combined, the bubbles overlapped more, indicating greater similarity (Figures 3(a) and 3(b)).

3.2. Uptake of Questionnaires and Potential Errors. In total, 574 questionnaires were collected during the study. A very low number of visitors declined to fill in the questionnaire when they were asked (estimated at <5%), and the main reason given for this was that they did not have time. Of the questionnaires collected, 39.2% were collected outside of school holidays and 60.8% during the school holidays, reflecting the increase in visitor numbers in the centre. Some visitors left various questions unanswered in the otter behaviour questionnaire (Table 3). The segmentation questionnaire was completed by 62.4% of visitors who had filled in the otter behaviour questionnaire, but of these, 5.6% could not be used because visitors had not followed the instructions and had ticked more than one answer, meaning that they could not be classified into a visitor segment.

While the questionnaires were being filled in, personal observations indicated that visitors were watching the otters for longer than 30 s. This was reflected in the responses to the question concerning the length of time visitors had spent at the enclosure. A chi-square test showed that the length of time a visitor spent at the enclosure affected the number of behaviours recorded ($\chi^2 = 41.7$, $df = 12$, $P < 0.001$). This was because visitors who stayed at the otter enclosure for shorter lengths of time recorded significantly

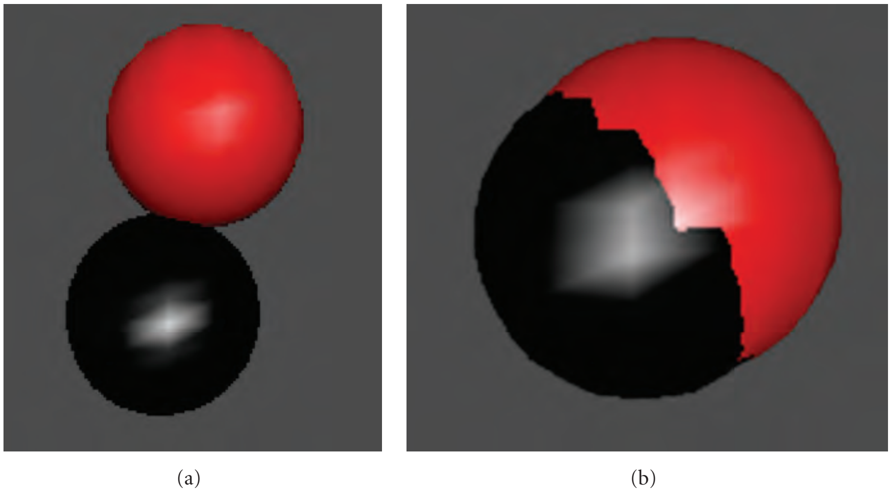

Figure 3: Results of bootstrapped PCA examining differences between ethogram data collectedby two biologists for the group of otters over one day. Black = RLW, red = CK. Cumulative proportionof variance explained by first 3 principal components > 0.999. (b) as above but with playing and swimming combined.

Table 3: Percentage of questions not answered in the otter behaviour questionnaire.

Question	Questionnaires where this was left unanswered
What time is it?	0.2%
Approximately how long have you spent at the otter enclosure in total today?	5.7%
Are you, or someone who helped fill in this questionnaire a member of any wildlife charities?	8.3%
Have you or anyone who helped fill in this questionnaire volunteered or done something to help any wildlife charities? (e.g., habitat improvement, wildlife surveys, helped at events, raised money, etc.)	11.6%
What age are you/the people who helped fill in this questionnaire? Write down the number of people in each age group.	9.9%

fewer behaviours than those who stayed at the enclosure for longer (mean number of behaviours recorded: <2 mins = 2.14; 2–5 mins = 2.34; 6–10 mins = 2.93, >10 mins = 3.33).

3.3. Comparing Ethogram Activity Budgets with Activity Budgets Calculated from Visitor Data. The otters' activity budget calculated using ethogram data consisted mainly of time spent inside (28%), followed by playing (21%) (Figure 4). "Other" behaviours (e.g., sprainting, drinking, climbing. . .), and rolling amounted to the smallest proportion of the activity budget (2%). Fighting is not represented in the ethogram activity budget, but visitors did record fighting (1%), and it was observed during the study (outside of the randomly allocated observation periods). Compared to the ethogram data, visitors underrecorded sitting, time spent inside and playing and overrecorded all of the other behaviours, with the exception of "other" in the corrected visitor data, which was identical to the ethogram data. The most noticeable differences between ethogram and visitor data lie between time spent inside (28% for ethogram data and 11% for visitor data) and swimming (10% for ethogram data and 25% for visitor data).

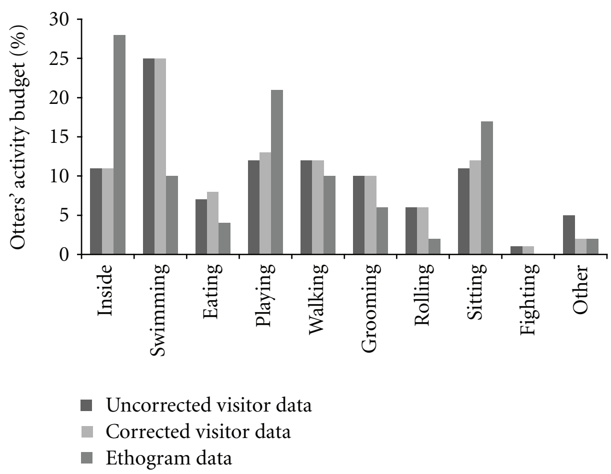

Figure 4: Differences in otters' activity budgets calculated using corrected and uncorrected visitor data and ethogram data.

There were significant differences between ethogram data and visitor data, but there were no significant differences between uncorrected visitor data and corrected visitor data (Figure 5). Additionally, there were no significant differences between each individual otter and the average taken for the group, so to simplify subsequent analyses, only corrected visitor data and ethogram data for the group of otters were used. Significant differences also occurred between ethogram data and data collected by different visitor segments, but there were no significant differences between the behavioural data recorded by different types of visitor (as quantified using the visitor segments used in the analysis: learn together families, fun time families, sensualists, social naturalists and expert birders, note: other segments could not be used because of small sample sizes) (Figure 6).

There was a significant difference between ethogram data and visitor data, but no significant difference between corrected visitor data before and after questionnaires filled in by children were excluded from the dataset. There was no significant difference between visitors who had prior experience volunteering, or were a member of a wildlife organisation and those who were not. All visitor datasets were still significantly different to the ethogram dataset (Figures 7(a) and 7(b)). There were still significant differences between ethogram and visitor data when playing and swimming were combined in the activity budgets and when visitor data was reclassified taking into account time periods in which the data had been collected (Figures 7(c) and 7(d)).

3.4. Simulation of Test Accuracy of Visitor Data Collection Methods. The average number of behaviours recorded by visitors in the study was 2.9, whereas the average number of behaviours recorded in the simulation running for 30 s was 1.4. Changing the length of time that visitors took to record behaviours in the simulation indicated that visitors may have watched the otters for up to 8 min, instead of following the instructions and recording behaviour for 30 s. Comparing the overall behaviour of all three otters combined using bootstrapped PCA demonstrated that there was no significant difference in overall behaviour when observations took place for 30 s (from simulated data) and the real ethogram data, but when compared with the longer 8 min observation period or the visitor collected data, significant differences to the ethogram data occurred (Figure 8).

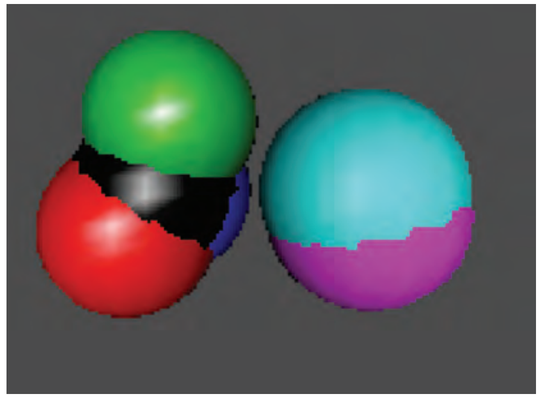

Figure 5: Results of bootstrapped PCA examining differences between ethogram and visitor data. Black = ethogram data for group of otters, red = ethogram data for otter 1, green = ethogram data for otter 2, dark blue = ethogram data for otter 3, light blue = corrected visitor data, and pink = uncorrected visitor data. Cumulative proportion of variance explained by first 3 principal components = 0.995.

4. Discussion

4.1. Visitors Cannot Accurately Collect Behavioural Data. The ethogram method used to determine otter activity budgets was repeatable between trained biologists, and this suggests that it is a reliable way of determining activity budgets. However, visitors were unable to collect accurate data on the otters' behaviour regardless of which visitor segment they were in, their age, prior experience volunteering or whether they were a member of a wildlife organisation. This did not differ when behaviours that overlapped (playing and swimming) were combined in the analysis, nor when much of the potential pseudoreplication caused by varying numbers of visitors throughout the day was removed. It may seem intuitive that an "expert birder" with experience of collecting scientific data on birds may be more likely to collect accurate data than a "fun time family" that is on a recreational trip, but this was not the case in this study.

4.2. Where Did They Go Wrong?

4.2.1. Ignoring the Instructions. One of the most important instructions on the questionnaire was the length of time required to observe the otters for. This length of time was chosen because it was thought to be short enough not to deter visitors from participating and would allow the recording data as and when visitors walked past the enclosure. Ease of data collection and reliability were both a key aspect of this study because visitors were assumed to be untrained. Therefore, 30 s was considered to be a reasonable length of time for visitors to scan the otter enclosure and be able to identify behaviours while imposing a time limit so that all visitors should spend approximately the same length of time recording data. Results of the simulation model of visitors undertaking 30 s sampling periods when filling in questionnaires showed that this length of time should have resulted in the accurate representation of the otters' activity budgets.

Despite the instruction to watch for 30 s being underlined and in bold font, most visitors did not follow this and recorded data for much longer than 30 s (pers. obs.). When visitors stayed longer at the otter enclosure, they ticked significantly more behaviours. This is probably one of the main reasons why their activity budgets were incorrect. In some cases, visitors admitted watching for longer. One visitor ticked rolling and wrote "when arrived," indicating that they felt this was an interesting behaviour and that they should record it, even though it was not in their 30 s recording period. Another visitor wrote "the otters came out at 10.36," which also indicates that they watched for longer than 30 s but may have thought that adding extra detail would benefit

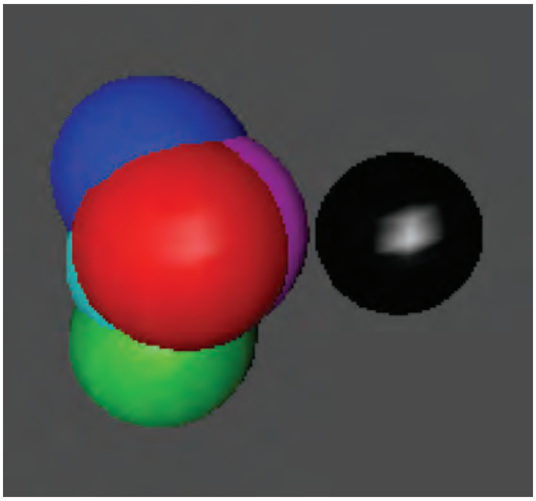

Figure 6: Results of bootstrapped PCA examining differences between ethogram data and different visitor segments. Black = ethogram data for group of otters, red = fun time families, green = sensualists, dark blue = social naturalists, light blue = expert birders, and pink = learn together families. No other visitor segments were included, since in total they contained <20 responses. Pairwise comparisons between social naturalists and sensualists also indicated no significant differences occurred between these categories. Cumulative proportion of variance explained by first 3 principal components = 0.997.

the study. At the end of one questionnaire that had been filled in by a parent and child (where all but one of the boxes had been ticked), the parent wrote, "hence saw all of the above because watched for a long time." Another visitor wrote that they "saw the otters outdoors earlier" so had filled their questionnaire in for a previous time (based on their memory of what they saw the otters do) as well as the present (when the otters were indoors), thus confounding their results. Some visitors demonstrated attention to detail by adding detailed notes on their questionnaires. However, these details are often impossible to analyse unless they can be reclassified, and this process can be time consuming (pers. obs). It seems that attention to detail and enthusiasm, while generally considered key attributes for volunteering, can hinder the quality of behavioural data collected.

4.2.2. Making Mistakes and Adding Extra Details. Occasionally, visitors admitted that they were wrong on their questionnaires, despite understanding the instructions. One visitor ticked rolling but wrote "in water" next to the box despite the fact that the behaviour was entitled "rolling—e.g. on soil or rocks", another ticked sitting but specified that the otters were indoors. However, only the obvious mistakes could be removed from the corrected dataset, and it is highly likely that some mistakes remained undetected (i.e., if visitors wrongly interpreted behaviours or deliberately ticked boxes even though they had not seen a particular behaviour). It was impossible to measure this. Furthermore, the question "What age are you/the people who helped fill in this questionnaire? Write down the number of people in each age group" could not be analysed because visitors misunderstood the question. Most visitors wrote down the number of people in their party, regardless of whether or not they had helped fill in the questionnaire.

The fact that visitors underrecorded sitting and time spent inside may be because these could be ignored if they appeared less interesting for visitors than more active behaviours. Sitting generally occurred for short periods of time (with otters pausing for a few seconds), in which case visitors could have missed this. The underrecording of time spent inside may have been caused by visitors missing otters inside if some of the otters were outside. If this was the case, visitors often observed the otters that were outside and did not check the sleeping chamber (pers. obs.). Another contributing factor could be that otters spent more time inside during quiet times when there were no visitors around to record this (early morning and late afternoon). The underrecording of playing is probably correlated with the overrecording of swimming; it is likely that some visitors confused the two behaviours and ticked swimming instead of playing when otters were playing in the water (Figures 2(a) and 2(b)). Playing may have been difficult for some visitors to interpret. Indeed, most "other" behaviours that were reclassified in the corrected dataset were reclassified as playing. However, removing mistakes and omissions and grouping behaviours did not change the overall results. This suggests that misidentification of behaviours by visitors was not the prime reason for the differences between ethogram and visitor activity budgets.

4.2.3. Item Nonresponse. Item nonresponse, in which a questionnaire is returned with one or more questions unanswered, can have an impact on results of a survey but these impacts are difficult to measure [37–39]. There could be various reasons why some visitors left questions blank (Table 3). For example, the visitor who missed out the question asking for the time may not have been able to find out what the time was as they did fill in all of the other questions. Boredom or rushing to finish the questionnaire may have been reasons why 1.6% of visitors filled in the time and ticked behaviours but did not answer any other questions that appeared later in the questionnaire [40]. It is also possible that some of the visitors who did not answer questions on the second page did not realise they were there, despite the staple and instruction "please turn over" in bold and underlined at the bottom of the first page: some visitors only realised this when another visitor pointed it out to them (pers. obs.). Another possibility is that visitors may not have wanted to fill in the questionnaire but felt obliged to do so out of politeness and as a result, may have rushed through the questions, missing some out.

This lack of attention to detail could be caused by the fact that the questionnaire was *impromptu*: visitors were on a day out not expecting to have to concentrate on a task. They may also have been distracted by the surrounding environment (e.g., by their children or by other visitors). Slightly more visitors avoided answering the question about volunteering than the question about being a member of a wildlife

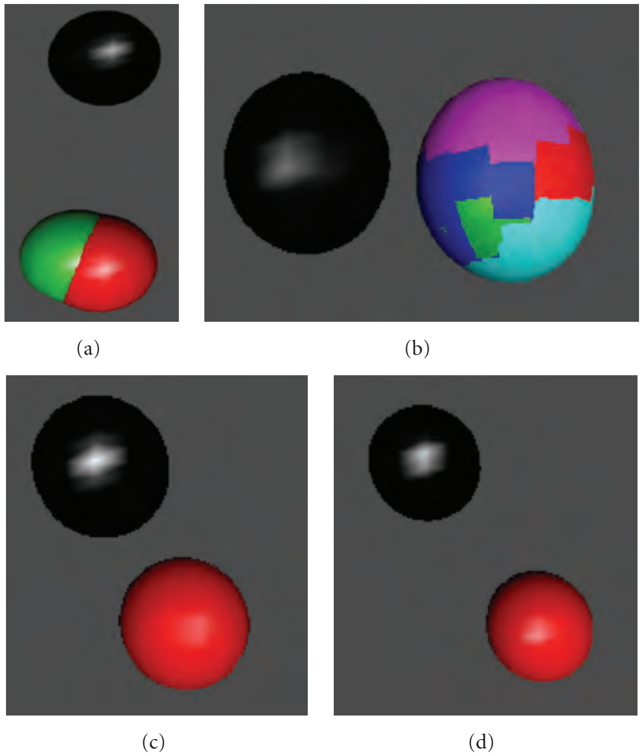

Figure 7: (a) Results of bootstrapped PCA examining differences between ethogram data, corrected visitor data, and uncorrected visitor data when all questionnaires filled in by children were removed from the dataset. Black = ethogram data for group of otters, red = children's questionnaires removed from corrected visitor data, and green = corrected visitor data. Cumulative proportion of variance explained by first 3 principal components >0.999. (b) As above but examining visitor segments. Black = ethogram data for group of otters, red = corrected visitor data, green = visitors who had previous experience volunteering, dark blue = visitors who did not have prior experience volunteering, light blue = visitors who were members of a wildlife organisation, and pink = visitors who were not members of a wildlife organisation. Cumulative proportion of variance explained by first 3 principal components = 0.995. (c) As above but examining ethogram data for group of otters and corrected visitor data when playing and swimming were combined. Black = ethogram data for group of otters and red = corrected visitor data. Cumulative proportion of variance explained by first 3 principal components >0.999. (d) As above but examining ethogram data and visitor data with standardised time periods. Black = ethogram data for group of otters and red = corrected visitor data. Cumulative proportion of variance explained by first 3 principal components = 0.987.

organisation or charity (Table 3). This may be because the membership question can be more easily interpreted, as membership to the WWT is well advertised throughout the centre and 57% of all visitors to the centre during the study were members of WWT. The volunteering question may confuse those who are unfamiliar with the idea of volunteering; one visitor said that she considered visiting the centre as volunteering (pers. comm.).

4.2.4. Temporal Autocorrelation of the Data. Questionnaires were handed to visitors as and when they arrived at the otter enclosure. As such, it is highly likely that some of the otters' behaviours were simultaneously recorded by many visitors, especially at busy times such as during the feeding demonstrations. While it would have been possible to hand out only one questionnaire at a time, such an approach would reduce the uptake of the questionnaire, and also would have a negative influence on visitor experience, with visitors either waiting a long time to participate or feeling left out if they could not participate. In a zoo environment, it would be very difficult to fully control the spread of questionnaires over time because of the irregular flow of visitors, not only at different times of day (e.g., when the centre first opens or when visitors are hurrying to leave before the closing time), but also in adverse weather conditions when visitors would be less likely to want to fill in a questionnaire. Additionally, there were often more visitors at the enclosure when the otters were active, with large crowds often attracting passers by because the formation of a crowd could indicate that the otters were doing something interesting or unusual (pers. obs.). In this study, the averaging of data over 30 min periods helped reduce autocorrelation effects due to the effects mentioned previously, but would not completely eliminate them if there was a difference in recorder effort within a 30 min period.

However, the effects of temporal autocorrelation on the results of this study appear minimal. Firstly, "standardised" data (where an average activity budget was calculated over each 30 min period taking into account the number of

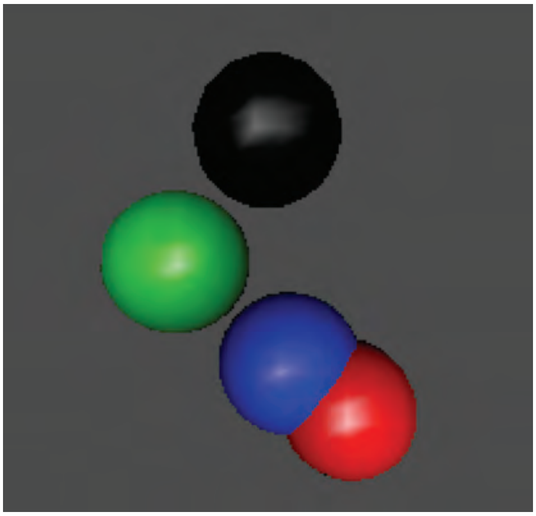

Figure 8: Results of bootstrapped PCA examining differences between real data and simulated data. Black = real visitor data, red = real ethogram data, green = simulated visitor data where data were collected for 8 min, and blue = simulated visitor data where data were collected for 30 s. Cumulative proportion of variance explained by first 3 principal components = 99.8.

questionnaires answered) and "unstandardised" data both differed significantly from ethogram data. Secondly, when data were simulated (and autocorrelation effects were eliminated) results corresponding to visitors collecting data for a long period of time (8 min) were highly significantly different from ethogram recordings. Hence, it appears that it was the length of time in which visitors recorded behaviour that was the largest source of error, rather than potential errors inherent to the sampling design used. Nevertheless, methods to eliminate temporal autocorrelation and enhance the visitor experience are given in the Recommendations Section.

4.3. A Success: The High Questionnaire Uptake Rate. The questionnaire uptake rate may not have been so high if the questionnaires had not been handed out in person [41]. Indeed, very few visitors were observed picking up a questionnaire themselves when the questionnaires were laid out on a wall next to the otter enclosure, despite posters advertising the study. In this situation, children were more curious than adults, often picking up questionnaires and filling them in of their own accord. Curiosity is a strong motivational force in children [42–44] and it is often believed that curiosity decreases with age [44], which may explain why fewer adults picked questionnaires up. Distributing questionnaires in the manner described in this study could cause logistical problems for zoos (for financial and temporal reasons discussed in Section 1). However, it may be possible that handing questionnaires upon entry to the park along with a quick explanation or instruction leaflet could be a suitable method to increase participation, similar to the method described in Dillman [41].

Uptake rate may be less high when animals are out of view or in an indoor area. As discussed previously, otters were less popular with visitors when they were inside, visitors walked past and/or did not see the point of filling in the questionnaire until it was explained that it was important to find out how much time the otters were spending inside. This has been discussed in previous studies. Indeed, Altman [45] and Anderson et al. [24] found that zoo visitors paid more attention to an animal's behaviour when the animals were most active compared to when they were less active or inactive. Jackson [46] and Johnston [47] found that visitors spent less time in front of enclosures where animals were inactive. Additionally, mammals are the most popular class in zoos [48], and larger animals may be preferred by visitors over smaller animals [49]. It is possible that a behavioural study would not prove as popular with visitors if it involved less appealing classes or species. Indeed, Hoff and Maple [50] found that some visitors deliberately avoided going to reptile exhibits.

4.4. Recommendations for Further Study. A visitor who had completed the questionnaire made the following comment: "you could tell us more about the otters than we could tell you". This statement underlies the concept of volunteer data collection: a scientist's work can be more reliable than that of a volunteer, as was the case in this study. However, it is the large number of volunteers that can make them a powerful tool for research. Although the method in this study did not allow visitors to collect accurate activity budgets, it did have some success. The high uptake rate suggests that getting visitors to collect data on active and entertaining animals can be successful. Public engagement and distributing the questionnaires by hand also undoubtedly had a major influence on the uptake rate.

Several improvements could be made in future research. When asking volunteers to collect behavioural data, it is important that behaviours are simple enough that volunteers can distinguish them without confusion. Clear instructions are needed when designing questionnaires, but in situations where a time limit is necessary, it is important to try to facilitate this to ensure that methods are followed as closely as possible, perhaps by providing a large clock in front of the enclosure. A time limit could also be imposed with the use of technology, for example, through multimedia or interactive video screens, which have previously been used in zoos and aquaria to convey information to visitors [51–53]. This type of technology has also been used by the National Marine Aquarium in Plymouth, UK to allow visitors to collect data on fish in an exhibit (pers. obs). Visitors could also collect data with the use of smart phone technology as this has already been used for other types of volunteer data collection [54]. Technology such as this may also reduce the number of questions that are unanswered by imposing a response, or could be used to eliminate any temporal autocorrelation of responses by either only having a single display, or by accurately recording the time of the response, so replication in time can be removed.

Overall, many of the aims of volunteering were completed in this study as visitors were keen to participate, enjoyed observing the otters, gave positive feedback, and asked questions about the study. Visitors were generally able to recognise different behaviours and recorded a rare behaviour that the scan sampling method did not detect [27]. They were also often eager to provide detailed notes on their observations. The "*ad libitum*" behaviour sampling method may be more suited to volunteers as it would remove the need for a restrictive time limit and would allow volunteers to record behaviours as they wished. This technique is commonly used in preliminary studies or to record rare but important events [27]. However, data collected in this manner would be difficult to analyse and could not be used to calculate activity budgets. New data collection techniques need to be tested if volunteers are to be used to collect behavioural data effectively.

Acknowledgments

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Appendix 4: Questionnaire given to visitors to record otter behaviour in Chapter 4

Thank you for helping me to find out what otters get up to during the day!

You can fill this form in on your own or as a group. ***<u>Please hand it back to me</u>*** *along with your pencil and clipboard* ***<u>or put everything in the box</u>*** *when you've finished. You can find more information about each behaviour on your clipboard underneath the questionnaire.*

1. What **time** is it?
2. Can you see otters **indoors** through the window in the tunnel?
   <u>Circle one answer</u>: Yes / No
3. Can you see otters **outdoors**?
   <u>Circle one answer</u>: Yes / No
4. If there ***are*** any otters **outdoors**, watch them for **<u>about 30 seconds</u>** and tick what the otters were doing **<u>during that time</u>**

Swimming ☐

Eating ☐

Playing ☐

Walking or running ☐

Grooming ☐
(themselves or another otter)

Rolling ☐
(e.g. on soil or rocks)

Sitting or lying down ☐

Fighting ☐

?

Other ☐
Tell us what: ________________

5. Approximately how long will you have spent at the otter enclosure in total today?

Less than 2 minutes ☐ 2 to 5 minutes ☐ 6 to 10 minutes ☐ Over 10 minutes ☐

PLEASE TURN OVER

Finally, please could you answer 3 quick questions about yourself? It will be very useful for me to know a little bit more about who is willing to complete this type of questionnaire!

1. Are you, or someone who helped fill in this questionnaire a **member** of any wildlife charities?
   Circle one answer: Yes / No

2. Have you or anyone who helped fill in this questionnaire **volunteered or done something to help** any wildlife charities? (e.g. habitat improvement, wildlife surveys, helped at events, raised money...)
   Circle one answer: Yes / No

3. What age are you / the people who helped fill in this questionnaire? Write down the number of people in each age group.

Age group	Number of people in this age group
Under 5	
5 – 10	
11 – 17	
18 – 29	
30 – 49	
50 +	

Thank you for completing my questionnaire!

If you have some spare time, the staff at Slimbridge would love you to answer a few questions ***on your experience at Slimbridge.*** *You can find this questionnaire on the next page.*

Appendix 5: Visitor segmentation questionnaire handed out in Chapter 4

WWT

Please help us find out about who's visiting the centre today by answering the following questions about yourself…

1. Are you visiting today with children under 16 years of age?

- ☐ YES (*please answer the question below)*
- ☐ NO (*please answer the questions overleaf*)

2. If you are here today with children, which of the following <u>best</u> describes you? (tick one)

1. I want to stimulate my **child's interest in the natural world**
2. We're just here to have **fun**
3. I want my **child to learn something** but we'll have **fun while we're here**
4. We're **mainly here for fun** and if my child learns something, **it's a bonus**

3. Thinking about the reasons that you visit WWT centres, several of the following are probably true for you. However, please consider carefully and choose the <u>one</u> MAIN reason. Tick one answer

☐ 1 To spend quality time with friends or family in a nice place *(go to Q4)*
☐ 2 General relaxation *(go to Q4)*
☐ 3 This is one of the major attractions in the area *(go to Q4)*
☐ 4 To enhance my physical health and well-being *(go to Q4)*
☐ 5 To enjoy the facilities (café, shop etc) *(go to Q4)*
☐ 6 To encourage an interest in birds, nature and wildlife in others *(go to Q5)*
☐ 7 To improve my own knowledge or learn new things *(go to Q5)*
☐ 8 To pursue a personal or hobby interest *(go to Q5)*
☐ 9 To enhance my emotional health or mental well-being *(go to end)*
☐ 10 To see awe-inspiring things, experience beauty of nature or get a sense of being at one with the world – *(go to end)*
☐ 11 To stimulate my creativity or feel inspired *(go to end)*
☐ 12 For peaceful, quiet contemplation or to escape and recharge my batteries *(go to end)*

4. When visiting outdoor places like WWT centres, which of the following best describes you? Please tick only one answer

☐ 1 Seeing birds is the most important part of the visit
☐ 2 Seeing birds enhances the experience, but is not the most important part of the visit

☐ 3 I'm just happy seeing any kind of wildlife
☐ 4 I'm just happy being outdoors
☐ 5 I'm just happy being on a day out

If you answered qu 4 – this is the END of questionnaire

5. How often do you birdwatch? Please tick only one answer

☐ 1 Often *(go to Q6)*
☐ 2 Sometimes *(go to Q6)*
☐ 3 Rarely *(go to end)*
☐ 4 Never *(go to end)*

6. When following your interest in bird-watching, which of the following do you regularly do? Please tick all that apply

☐ 1 Use my binoculars and/or telescope
☐ 2 Compile bird lists
☐ 3 Contribute to monitoring lists
☐ 4 Visit bird hides
☐ 5 Feed birds in my garden
☐ 6 Travel to try to see a rare bird where there's been a reported sighting
☐ 7 Take a bird identification book with me

End of questionnaire

Appendix 6: Handout given to volunteers for the hedgehog footprint tunnel survey (Chapter 5)

Here are a few instructions to make sure that the survey runs smoothly…

The survey should run over 5 nights from the day that you receive the tunnel.

1. ***Every evening (as close to dusk as possible)***

   - Place one hotdog sausage in the centre of the tunnel between the two ink strips.
   - Secure the two sheets of paper for the corresponding night, one at each end of the tunnel, with the paper clips. The paper I have given you has the days of the week printed on the back – so on Sunday night, use the paper with "Sunday" on it, and so on. This is to make sure I know which night corresponds to which footprints.

2. ***Every morning***

   - Remove the paper and keep it safe for me, even if it is blank.
   - Remove and discard any leftover bait (to discourage uninvited guests from visiting the tunnel during the day, e.g. cats!).

3. ***Check that the ink remains damp***

   - If the ink looks like it is drying out, use the sponge to dab a little bit more on from the pot I have given you. Be careful to use the gloves provided and take care not to stain your clothes when doing this.

4. ***On the last day of the survey…***

   - You should still have 10 sheets of paper, two for each day, with (or without) footprints on them. I will collect these, along with the tunnel and the rest of the equipment.
   - When I have identified the footprints, I will let you know what has been visiting your garden, and what else has been found in the gardens of Gloucestershire!

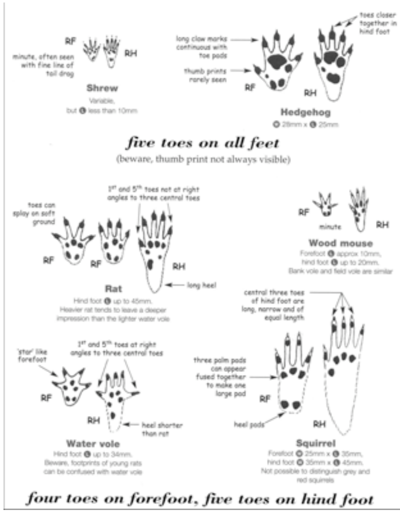
If you have any problems or questions, I will be on e-mail the whole week and will be happy to help! You can also reach me on 01242 714559 during the day.

Thank you very much for participating! ☺

How to ID a Hedgehog Footprint

Here is a diagram which shows the hedgehog footprint (right front (RF) and hind (RF) feet) in relative comparison to other small mammal prints you could encounter during the survey.

© Image from The Mammal Society/ FSC Guide to Mammal Tracks and Signs



Appendix 7: Publication from previous research on citizen science

Stafford, R., Hart, A.G., Collins, L., Kirkhope, C.K., **Williams, R.L.**, Rees, S.G., Lloyd, J.R. and Goodenough, A.E. (2010) Eu-social science: the role of internet social networks in the collection of bee biodiversity data, Plos One, 5 (2), e14381

See following page

PLoS one

Eu-Social Science: The Role of Internet Social Networks in the Collection of Bee Biodiversity Data

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Abstract

Background: Monitoring change in species diversity, community composition and phenology is vital to assess the impacts of anthropogenic activity and natural change. However, monitoring by trained scientists is time consuming and expensive.

Methodology/Principal Findings: Using social networks, we assess whether it is possible to obtain accurate data on bee distribution across the UK from photographic records submitted by untrained members of the public, and if these data are in sufficient quantity for ecological studies. We used Flickr and Facebook as social networks and Flickr for the storage of photographs and associated data on date, time and location linked to them. Within six weeks, the number of pictures uploaded to the Flickr BeeID group exceeded 200. Geographic coverage was excellent; the distribution of photographs covered most of the British Isles, from the south coast of England to the Highlands of Scotland. However, only 59% of photographs were properly uploaded according to instructions, with vital information such as 'tags' or location information missing from the remainder. Nevertheless, this incorporation of information on location of photographs was much higher than general usage on Flickr (~13%), indicating the need for dedicated projects to collect spatial ecological data. Furthermore, we found identification of bees is not possible from all photographs, especially those excluding lower abdomen detail. This suggests that giving details regarding specific anatomical features to include on photographs would be useful to maximise success.

Conclusions/Significance: The study demonstrates the power of social network sites to generate public interest in a project and details the advantages of using a group within an existing popular social network site over a traditional (specifically-designed) web-based or paper-based submission process. Some advantages include the ability to network with other individuals or groups with similar interests, and thus increasing the size of the dataset and participation in the project.

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Introduction

Citizen science involves volunteers collecting and reporting data for scientists to analyse in subsequent studies [1]. This has many potential benefits. For example, it allows citizens to be actively involved with the natural world and enhances their education [2], while data collection can occur potentially on a global scale, and provide more comprehensive and rapid coverage, than is possible with a team of scientific researchers [3]. Data can also be collected rapidly and cheaply, although there are also potential problems with these methods of data collection [4] (see below).

Many citizen science projects exist and thousands of people are participating in these projects globally. For example, in the UK the National Biodiversity Network now has over 31 million records of plant and animal species largely submitted by amateur naturalists [1]. While some projects have localised scope (for example, UK country-specific bird reports such as that produced in Gloucestershire [5]), others span a wide geographical range. For example, in Australia there are large-scale citizen science projects mapping distributions of species as diverse as possums, whale sharks and frogs [3]. International schemes are also in place; a good example is the EURING bird ringing and recovery scheme that operates across over 30 European countries.

In the past decade, the internet has provided a key advance for citizen science projects, allowing data to be directly entered by users and eliminating the costs and effort associated with paper-based data entry [1]. The development of Web 2.0– or websites that interact with the user – particularly the development of social networks where comments or photographs can be shared with an online community – has many benefits for citizen science data collection. Many citizen science projects therefore have incorporated a social network element or are based solely within social network sites (Table 1).

Distribution data for a particular taxonomic group (e.g. birds or butterflies) can normally be collected easily through volunteers, but identification problems can make collecting species level taxonomic data difficult for those projects which appeal to the general public (i.e. crowd sourcing projects, rather than data collected by participants with a specific interest in a particular group) [6]. Collecting accurate population size data can also be difficult

Table 1. Examples of both general, and bee related, web-based citizen science or biodiversity sites. A brief description of the projects is given, as are details regarding of the use of social networks data collection.

Name	Website	Type of Project	Main online presence	Links to social network sites[1]	Link (or twitter tags)
OPAL	http://www.opalexplorenature.org	Citizen science data collection	Interactive Web-based	None	
iSpot[2]	www.ispot.org	UK biodiversity identification	Self-contained Social network	None	
Encyclopaedia of Life	http://www.eol.org/	Web based, wiki style encyclopaedia for biology	Website	Flickr group use to collect images for main project	http://www.flickr.com/groups/encyclopedia_of_life
Great Blue Heron	http://www.flickr.com/groups/csgreatblueheron	Citizen science data and distribution	Flickr Based Group	Flickr based	http://www.flickr.com/groups/csgreatblueheron
BBC Springwatch/ Autumnwatch	http://www.bbc.co.uk/nature/uk/	Public entertainment and education	Cooperate website	Flickr Based Group[3] Twitter messaging	http://www.flickr.com/groups/bbcspringwatch @bbc_autumnwatch @bbc_springwatch
BBC Bee Part of It	http://www.bbc.co.uk/breathingplaces/beepartofit/	Education and conservation	Cooperate website	Flickr Based Group[3]	http://www.flickr.com/groups/bbc_beepartofit/
Great Sunflower Project	http://www.greatsunflower.org/	Citizen Science Bee identification	Group website	Photographs on Flickr link to traditional web-based data submission	http://www.flickr.com/groups/greatsunflower/
Bee Spotter	http://beespotter.mste.illinois.edu/	Citizen science bee identification through photographs	University website	None[4]	

[1]Links to key social network sites where information is collected or disseminated are given. Simple 'fan' pages on social networks such as Facebook, which just link to other sites are not included.
[2]iSpot is a social network component of OPAL.
[3]The Flickr site is a collection of photographs of bees, and is not related to the main project aims of setting up bee colonies.
[4]Links to many social networks for the purposes of disseminating the project, through individual participants status updates, are given.
doi:10.1371/journal.pone.0014381.t001

because of the aggregated nature of data collection and unequal effort between individuals [4]. For behavioural studies, collecting data using different observers has also indicated problems of bias; for example men and women can differ in objective decisions relating to animal behaviour [7,8].

With greater uptake in new methods of data analysis, such as Bayesian networks that can assign different priors as levels of confidence for the accuracy of the data [9], many of the problems of bias can be overcome, for example, incorrect identifications of species in spurious locations, outside of the normal range, can be detected and accounted for (R. Stafford and J. R. Lloyd, unpublished data; see also discussion below regarding quantification of effort). However, the issues of volunteer motivation (or crowd sourcing) and accuracy of results (in terms of location, species identification etc.) still need to be addressed.

In this study we examine the BeeID project, a citizen science project that maps the distribution of bees throughout the UK. This project attempts to eliminate many of the problems of 'citizen' collected data through the use of new technologies such as smartphones. It is based around the use of social network sites, potentially broadening interest and increasing the number of participants. This study compares the success of participation in the project, the scientific validity of the data collected, and the benefits of using social networks for this type of research, with other data collection techniques.

Methods

The BeeID project was run through the Flickr photosharing website (www.flickr.com). Flickr is a web 2.0 application that allows users to upload their photographs and videos to their server, as well as allowing discussion threads and comments on photographs posted. The BeeID project was set up as a special interest group at in order to keep the project focussed and discrete. The photographs and other discussion material are available to view at (www.flickr.com/groups/beeid).

To attract potential users to the Flickr group, a publicity-oriented Facebook group was set up (the number of users of Facebook vastly exceeds those of other social network sites [10]). Facebook was not used as the main photograph upload site since, although it allows photographs to be uploaded, it removes much of the useful information attached to digital photographs in the Exchangeable Image File format (EXIF) for privacy reasons.

The Flickr group contained instructions for participants. Photographs were requested to be uploaded, added to the BeeID group, and given the unique tag 'BEEID2010'. Participants were also asked to add their photographs to the Flickr map, either manually, or automatically using the GPS data incorporated in their photograph's EXIF information if GPS was present on the camera or smartphone with which the photograph had be captured.

Images were searched by a computer program written in Python 2.3, which searched for the BEEID2010 tag (see supplementary material Text S1 for the code, which is released under the GNU GPL). The program was capable of extracting the date and time information from the EXIF information (as recorded by the camera) directly, as well as GPS coordinates if present in the EXIF information or on 'geotagged' photographs (those with location information added as a machine tag or through the Flickr map). The program used the Python Flickr API software written by James Clark (http://stuvel.eu/projects/flickrapi) as a basis of the interface with the Flickr Application Programming Interface (API).

Images were identified by a team of faculty staff, research students and recent graduates from the Biosciences degree programmes at the University of Gloucestershire. Photographs not readily identifiable were marked as such, and then presented to a team of experts. Photographs were identified to species level where possible (see Table 2 for a list of species/genera identified by the project). A short comment, thanking the contributor for the contribution, and a further tag for the photograph, based on the identification, was given (see Table 2 for tag information).

A processed photograph was tagged with the initial part of the tag reading 'processbeeid2010' (see Table 2 for full tags) and such photographs were ignored in subsequent runs of the program to ensure that only newly-submitted photographs were highlighted for action.

Publicity for the project was initially only through social networking sites (Flickr and Facebook) and included posts on other similar discussion boards. During mid-June 2010, the project was disseminated at the Cheltenham Science Festival, through a free public display in the discovery zone.

Results

The BeeID project was officially launched on the 11th April 2010. Initially it was promoted solely through Facebook and Flickr groups and obtained 10 contributing members for the Flickr group, but 86 members for the Facebook group. With the promotion of the BBC's Springwatch and BeePartOfIt Flickr sites, and through messages agreed by the group moderators on these groups' Flickr sites, the number of members of the Flickr site increased from 10 to 23 members within 4 days of the posting (posted on the 16th May 2010). As of the end of 23rd June 2010, after promotion at the Cheltenham Science Festival (during the period of 9th –13th June) and promotional work at a "social network" night (Cheltenham Social Media Café), there are 36 members and 206 photographs of bees in the BeeID group pool (equivalent to 4.8 photographs added per day).

Of these photographs, 149 were placed on the Flickr map, and 156 photographs were correctly tagged and found by the Python API programme (some photographs were therefore correctly tagged but not on the map, and some on the map but not correctly tagged). Distributions ranged from the Isles of Scilly in the west, to Lowestoft in the east (the full longitude of the UK), and from Scilly to Glencoe in Scotland in terms of latitude. In total, 11 species were identified from the 156 photographs correctly tagged (numbers of each species are given in Table 2). Bees could not always be identified to species level from these submitted photographs (some species of solitary bee were recorded to genus level only for simplicity – see Table 2). However, there was a particular problem for full identification of photographs of bumblebees, with 35% of uploaded photographs of bumblebees only being identified to genus level. Example distribution patterns obtained for given species are displayed in Figure 1. In total, the number of photographs correctly processed by the public (i.e. both tagged and added to the map) was 121; 59% of the total photographs received. Only 12 photographs (7.7% of the 156 correctly tagged images) had GPS data in the EXIF information, and these were all taken on mobile smartphones.

Discussion

Comparison with other citizen science projects

Given that data collection only ran for a short time (10 weeks), there was no funding for this project, the project had no association with any established taxonomic data collection scheme, and that promotion was initially solely through social network sites, the amount of data generated was relatively large. While not a direct comparison for a national project, many regional databases have very few records. For example, calls for members of the public to report Amphibian and Reptile sightings across Gloucestershire in 2008 as part of an annual countywide recording scheme resulted in only 22 sightings of slow worms (*Anguis fragilis*) being submitted; with slow worms being the highest-reported species [11]. Even charismatic species such as basking sharks (*Cetorhinus maximus*), where sightings are both relatively common on the UK coast, but also perceived to be rare and exciting enough to

Table 2. The number of each species of bee uploaded, correctly tagged and located on the Flickr map (through geotagging or incorporated GPS data) until 30th June 2010.

Common name	Scientific name	Number correctly tagged	Number correctly 'geotagged'	Number with GPS data	Processed tag used to search Flickr map
Buff tailed bumblebee	*Bombus terrestris*	22	21	2	processbeeid2010_buff_tail
White Tailed bumblebee	*Bombus lucorum*	3	2	0	processbeeid2010_white_tail
Early Bumblebee	*Bombus pratorum*	20	13	1	processbeeid2010_early_bb
Common carder bee	*Bombus pascuorum*	18	13	0	processbeeid2010_common_carder
Red Tailed Bumblebee	*Bombus lapidarius*	7	7	2	processbeeid2010_red_tail
Bumblebee – not to species	*Bombus* spp.	38	32	4	processbeeid2010_bumblebee_no_id
Honeybee	*Apis mellifera*	14	12	2	processbeeid2010_apis
Mining bee	*Andrena* spp.	13	8	1	processbeeid2010_Andrena
Red mason bee	*Osmia rufa*	8	6	0	processbeeid2010_red_mason
Hairy footed flower bee	*Anthophora* spp.	3	1	0	processbeeid2010_hairy_footed_flower
Mining bee	*Lasioglossum* spp.	2	1	0	processbeeid2010_Lasioglossum
Nomad bee	*Nomada* spp.	4	3	0	processbeeid2010_nomad
Other (non bees)		4	2	0	

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Figure 1. Distribution patterns of species of bees generated from searching by tag (see Table 1 for tags) using the Flickr map. (a) Distribution of the buff tailed bumblebee (*Bombus terrestris*) – showing similar patterns to those previously reported (i.e. scarce is Scotland). (b) Distribution of the buff tailed bumblebee (*Bombus lapidarius*) indicating its coverage over a wide latitude, even though only 7 photographs were added to the Flickr map. In this case, both the southern and northern most pictures had GPS information attached to the photograph, indicating a high confidence of it being found throughout this range.
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be 'newsworthy' and reportable, have relatively low numbers of reported sightings. A national survey run by a well-established conservation group (the Marine Conservation Society) only received ~10,000 records over 20 years [12].

In comparison with other internet-based ecology or taxonomic projects, the amount of data collected by BeeID was significantly higher than iSpot (www.iSpot.org.uk) during its first year of operation (summer 2009), where only a few photographs were added each day for all taxa covered (mammals, birds, amphibians and reptiles, fish, fungi, lichens and plants). Given the low initial contribution (which, however, was significantly reversed in 2010 by significant funding, prominent links on the BBC's nature website and promotional leaflets available at many wildlife sites throughout the UK, with >50 photographs of insects currently being uploaded per day as of June 2010), this suggests that the use of existing and well established social networking sites have considerable power in increasing participation in citizen science projects. Indeed, large amounts of data generated by the social network approach, could mirror the success of other campaigns, such as political campaigns, conducted via social network sites [10].

The BeeID project received over 200 photographs in the period of operation between April and June 2010. Although this is significantly lower than other similar (but better publicised and longer running projects) such as the BBC's Bee Part of It campaign (with a little under 2,000 photographs as of November 2010), the percentage of photographic submissions to BeeID that contained spatial information (either from EXIF information or from location on the Flickr map) was far higher than for Be Part Of It. Only 25% of photographs from the Be Part of It campaign, as compared to 59% in the BeeID project, had geographical information – despite a request for this to be included in the guidelines. The 59% of BeeID photographs containing spatial data was much higher than general Flickr usage. A search for the tag 'bee' produced 393,913 photographs, with only 53,043 (or 13%) containing any sort of location information. This clearly indicates the use of a formal group with clear aims and instructions, but within the framework of an existing social network site, can enhance the collection of scientific data over less formal approaches within social network sites that use images submitted ad-hoc, rather than as part of a specific project.

The ability to use social networking techniques within Flickr – in terms of data collection by group administrators (i.e. posting requests for photographs on discussion forums of other groups) or in terms of the contributors being able to add multiple tags to photographs or submit the same photograph to multiple groups – is a clear method of increasing participation in a project and indicates a clear advantage over developing a specific (non-networking-enabled) data collection site for a new project. Essentially, ease of use for participants is key to success, and indicates why it can be advantageous to use a social network site to collect data directly, rather than a remote website that links to a social network site. In the current study, over 30% of photographs submitted to the BeeID pool were also part of the BBC's Be Part of It campaign, with contributors uploading photographs or adding appropriate tags to already uploaded photographs after a forum post on the Bee Part of It Flickr site. This clearly indicates the use of social networking to increase participation in the project. Other citizen science projects based solely on Flickr use similar techniques. The Great Blue Heron project (see Table 1 for details) asks its members to search for other photographs of the birds on Flickr in general and post a comment asking the contributor of the photograph to submit the photograph to the Great Blue Heron group and include additional information if required.

Accuracy and limitations of data

Within the BeeID project, slightly over 40% of photographs submitted were not correctly uploaded – not following the instructions precisely or not containing the required information (especially not including geographic information). However, it was easy to exclude these photographs from subsequent analysis using the 'search by tag' function of the Flickr API, and using the Flickr map to generate distribution patterns. These processes can be used to eliminate photographs with 'negligent' mis-reporting of data. Crucially, the fact that in this project, crowd sourced citizen scientists were only involved in taking the photographs, and not identification, also avoided mistaken identification [1,6], such that the resultant data were scientifically much more robust than other large scale participation or crowd sourcing projects. However, it must be noted, that this method of increasing accuracy may not be important in many citizen science projects, especially those in which data are generally provided by volunteers with many years of expertise in identification (i.e. experienced amateur naturalists). In fact, identification by such 'expert' volunteers may well be more accurate than by practising scientists – especially when dealing with a secondary source of identification – for example from a photograph.

It is also important to note that while 'negligent' mis-reporting of data was avoided, wilful mis-reporting was also reduced by the current study. By being able to obtain information on the date the photograph was taken from EXIF information, we could be sure that the majority of photographs were taken during 2010. It is possible to alter the EXIF information of a photograph, but this is a relatively complex and time-consuming task, which is likely to deter most potential data saboteurs. The most recommended program for this on internet forums is ExifTool (http://www.sno.phy.queensu.ca/̃phil/exiftool), which operates with a command line interface, and thus is not user friendly.

The requirement of participants to send in photographs of bees resulted in the collection of presence data for a particular species, but not of absence data (i.e. it is unknown if a species is absent from a location or if it is present, but no data has been submitted). Indeed, most photographs are likely to come from areas of, or areas close to, high human populations, where as many bees may be found away from such areas. Areas where bees are not reported could thus be because of a real absence or simply a lack of sampling in these areas [13].

A project such as this, that only requests presence data, can never fully eliminate these problems of sample bias relating to presence-only data. However, the potential ability of social networks to increase the number of participants can at least begin to reduce uncertainty. Where large numbers of volunteers in a given area have submitted presence data for some species, but no data on presence of other species, confidence can be increased that the lack of data on the absent species is due to the true absence of the species, rather than from a lack of sampling effort. While sampling by participants in such a project as this will never be randomised, balanced and fully independent, as required in a well designed scientific survey or experiment (e.g. [14,15]) the number of photographs submitted from a given location can easily act as a proxy measure for sampling effort, effectively allowing statistical corrections for estimates of diversity to be applied if required [16–18].

Given that a crowd sourcing project such as this could result in the collection of long-term data sets, that could be easily used to study changes in the distribution of species over time, common approaches to analysing presence-only data such as that of the 'climate envelope' – assuming that a species will exist in areas where climate, or habitat conditions are similar – would be wholly disadvantageous [16]. Even unmodified presence-only data would be able to indicate an extension or contraction of a species' range, as long as a sufficient number of photographs (or effort) had been submitted from a wide geographical area in all years during which the study was operational. However, for such a process to be able to occur, the number of submitted photographs for a study on range distribution would need to be much higher than in the present study. For example, to be sure that a relatively common species, such as the buff tailed bumblebee was changing range or density within an area, an absence in an area covering two or three standard counties of the UK ($\sim$10,000 km^2) should be determinable from around 30 to 50 submitted photographs of bees from such a region – where other common species were all recorded by photograph. However, for rarer species, a reduction in geographic range or density of a population would be very difficult to determine even if there were 500+ photographs submitted yearly over this area.

Clearly, required numbers of photographs such as those given above do not allow the full exploitation and examination of such data. Analysis techniques such as tracking submission year on year by the username of a contributor who frequently uploaded photographs of rare species would greatly increase the power of the analysis, essentially allowing a 'repeated measures' type of analysis to be performed. Indeed, the development of sophisticated analysis techniques that could be used to carefully examine data such as this could potentially be very large, and be very cross disciplinary in nature, clearly spanning the natural sciences (in terms of species distributions) and social sciences (in terms of participant motivation and input).

The current study provides a user-friendly, cheap and effective way to collect biodiversity data for any taxon that can be easily identified from photographs. Moreover, with the increases in demand for the latest smartphones (with higher resolution cameras and better GPS facilities), it is likely to be possible to collect higher numbers of better quality photographs containing GPS data in the EXIF information in the future [19,20] to further ensure the accuracy of the information obtained.

It is clear from the results of this study that full identification to species level can be difficult from some photographs, even with the well-characterised species studied here. This was especially true for the buff tailed bumblebee (*Bombus terrestris*) and the white-tailed bumblebee (*B. lucorum*) where the main distinguishing feature is in the end of the abdomen, which was not clearly visible in many photographs. While a better definition of photographic protocol (to include abdomen detail) would be useful, it can be difficult to capture this detail photographically, and such a protocol may reduce the number of images submitted. As such, there are potential limitations (as well as the benefits outlined above), in not getting participants to directly identify bees to species level, since this identification would be easier if the the actual insect was seen.

Recommendations and further work

There are currently a large number of social networks, which could be used for the collection of ecological data. These range from dedicated, specialist self-contained applications such as iSpot, through the development of specialist websites that can link to social network sites to obtain information and images, to the general collection of data from social networks based on what has been uploaded, rather than through specialist groups or using any form of instructions to participants. Advantages and disadvantages of these approaches are given in Table 3. However, we suggest the

Table 3. Advantages and disadvantages of different methods for the incorporation of social networks within citizen science projects.

Technique	Example(s)	Web address(es)	Advantages	Disadvantages	Ideal usage
Self-contained social network	iSpot	www.ispot.org	Total control of upload and information collection process	No immediate public presence. No methods to share data directly with similar groups. High cost of set up and publicity*	Long-term and well funded studies
Web portal with links to social networks to collect data*	Great Sunflower Project	http://www.greatsunflower.org/	High level of control of data collection. Use of alternative data-bases for storing of data such as photographs (reduced cost and enhanced backup)	More than one interface for users Still a reliance on standard web-based information upload (including possible mistakes).	Where photographs are supplementary to the main data collection process
Self-contained group within existing social network	BeeID Great Blue Heron	http://www.flickr.com/groups/beeid http://www.flickr.com/groups/csgreatblueheron	Negligible set up costs. Able to network with similar groups to share data and increase participation. Generally a high degree of conformation with instructions. Contributors can monitor results themselves in real time (i.e. generate distribution maps)	Extraction of data best achieved though interfacing with website's API Limitations of social networks rules and regulation No (or limited) ability for 'branding'	Short- to long-term focussed projects where immediate participation is important or where funding for set up and publicity is limited
Data mining of existing social networks	Unknown for biological research See [25] for examples	n/a	Instant access to large (if messy) datasets. Geographical spread of images could be very large (world-wide). This could also be a disadvantage if species of interest has limited range.	Diverse types of data, not standardised in terms of information present and of unknown quality/robustness. Most images do not contain information such as location, making mapping opportunities rare.	Speculative research on existing data.

*http://scratchpads.eu/is a resource for developing websites for biodiversity projects with integrated support for connecting to social network APIs and therefore reducing setup time and costs.

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best approach, especially if funds and time are limited, is the use of a specialist group within an existing social network. The potential of establishing a group within an existing social network for the collection of scientific data is large. Use of social networking sites both facilitates participation in projects, and reduces or eliminates the costs of storing the photographic records on specialised databases. Furthermore, social networks engage the participants in citizen science projects, allowing them to keep track of the project in real time, essential for continued success [1,21]. Currently, the use of photosharing social network sites (e.g. Flickr or Picasa) appears to be the most useful. Although number of users of sites such as Facebook are much larger, EXIF information is removed from the photograph by the website on upload. Sites such as Twitter could also be useful for citizen science projects, where photographs including key EXIF information such as time, date and location can be uploaded, and it may be possible for participants to 'follow' activity of a certain species, or contributor, to keep informed on the progress of the project.

Conclusions

Use of social networks can have many potential uses for collecting scientific data. Not only can these include interactive maps of species distributions, as shown here, be generated, but also, given time and date information in EXIF information, phenology of species could also be studied. Furthermore, given the development of individual recognition techniques for many species such as turtles, cetaceans or other large charismatic marine or terrestrial vertebrates [22–24](Arzoumanian et al., 2005; Kitchen-Wheeler, 2010; Lloyd et al., 2010); it may be possible to use similar techniques of social network photosharing to monitor population sizes and measure behaviour and movement of individual animals using citizen scientists' photographs.

In order to facilitate uptake of the technique, we supply the Python source code for searching the Flickr website and extracting data as supplementary material (Text S1). The corresponding author will be happy to advise or make minor changes to this code for other biodiversity or ecology based projects.

Supporting Information

Text S1 Python code used to interface with the Flickr API and search by tag for unprocessed photographs

Found at: doi:10.1371/journal.pone.0014381.s001 (0.02 MB TXT)

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Author Contributions

Conceived and designed the experiments: RS AH JL AG. Performed the experiments: LC CK RW SR. Analyzed the data: CK RW SR. Contributed reagents/materials/analysis tools: RS JL. Wrote the paper: RS AH LC AG.

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