

Defra Research Project WM0322

**Improving mitigation success where bats occupy houses and
historic buildings, particularly churches**

**Final Report
(January 2014)**

University of Bristol

**Dr. Matt Zeale, Dr. Emma Stone, Dr. Emily Bennitt,
Dr. Stuart Newson, Philip Parker, Dr. Karen Haysom,
Professor William J. Browne, Professor Stephen Harris,
Professor Gareth Jones**

Executive Summary

As European Protected Species, bats are strictly protected under European and United Kingdom legislation because of concerns about their conservation status. Current legislation (Conservation of Habitats and Species Regulations 2010) protects all bat roosts from destruction, damage or disturbance, whether occupied or not. This legislation also places a duty on all competent authorities, including Diocesan Advisory Committees and Consistory Courts, to take bats into account adequately when works such as building restoration have the potential to damage roosts or disturb bats. At times, conflict can arise between humans and bats, especially in houses and churches. In such situations, Defra authorises Statutory Nature Conservation Organisations (SNCOs) to grant licences for management and mitigation activities to help resolve the conflict. The aim of this research was to examine the impact of current licensable activities and investigate new mitigation activities that could be employed to reduce conflict between humans and bats while maintaining the Favourable Conservation Status of bats. The concept of 'Favourable Conservation Status' is central to the EC Habitats Directive. The conservation status of a species can be defined as the sum of the influences acting on the species that may affect the long-term distribution and abundance of its populations.

The research focused on two areas where conflict can be substantial: (i) when large maternity roosts occur in dwellings, and house owners or tenants are affected severely by their presence (e.g. by phobias) and (ii) in churches where, for example, droppings and urine might damage artefacts of historic and cultural significance and/or impact the use of a church for worship or other community functions.

Project 1: Exclusion of house-dwelling soprano pipistrelles (*Pipistrellus pygmaeus*)

The project had six objectives:

- 1:** Estimate the proportion of bats excluded from houses that are able to find alternative roosts.
- 2:** Establish whether the local population remains unaffected through emigration following exclusion by estimating the proportion of excluded bats that remain in the same locality.
- 3:** Model the likely population trends of the affected local population following exclusion.
- 4:** Confirm whether the breeding success of the local population is significantly adversely affected.
- 5:** Assess whether excluded bats are forced to use sub-optimal roosts.
- 6:** Compare spatial behaviour before and after exclusion to determine whether excluded bats change their foraging areas.

Roost exclusions were performed under licence at five sites throughout England during spring, when females were in the early stages of pregnancy. At each site, 20-25 bats were radio-tracked for up to seven days prior to (control) and immediately after exclusion, and

complete exclusions were achieved in a day. The roosting and foraging behaviours of soprano pipistrelles during control periods were similar to those described previously by other researchers. Bats shared core foraging areas close to roosts and showed a preference for feeding over riparian habitats, followed by woodland. Bats made use of a wide variety of alternative roosts i.e. any roost other than that at which we performed the exclusion, some of which were clustered closely around the original colony roost i.e. the roost from which bats were excluded, and switched between roosts frequently. Some of these roosts were considered to be suitable substitute colony roosts.

All radio-tagged bats that we excluded found alternative roosts. We found no difference in the use of alternative roosts before and after exclusion; both the frequency of roost switching and the perceived quality of roosts used by bats remained unchanged. We also found no change in foraging behaviour; bats foraged in the same areas, travelled similar distances to reach foraging areas and showed similar patterns of habitat selection after exclusion. At all sites, a new colony roost was established within three days following exclusion and in each case the new roost was located within 1.5 km of the original colony roost. At two sites, the new roost was located in a neighbouring property within 25 m of the original roost. In all cases, the new roost had been used already as an alternative roost by one or more tagged bats during control periods prior to exclusion. At three sites, emergence counts revealed large numbers of bats roosting in the new colony roost before we excluded bats from the original roost, and tagged bats moved between these two roosts frequently, suggesting that the colony was split between two significant roosts prior to exclusion. Although we detected no short-term change in the behaviour of bats following exclusion, the long-term implications of exclusions on survival and productivity, i.e. number of female young reared, requires further investigation. Evidence from population models suggests that any reduction in survival as a result of exclusion could impact negatively on population growth. Any reduction in productivity resulting from exclusion is predicted to have less impact on populations.

While we predict that the impact on local populations may be small from the limited number of exclusions that are licensed at present to cover situations where house dwellers experience problems caused by bats, extrapolated impacts from situations where roosts are destroyed frequently during development may be of concern and warrants investigation. In the future, measures of the effects of exclusion on productivity, and especially survival will be informative for better understanding long-term consequences of exclusions, though obtaining such measures is logistically difficult. The availability of suitable alternative roosts is an important factor in determining the impact of future exclusions on these bats and soprano pipistrelles are able to make use of a wide variety of both natural and man-made structures for roosting.

Project 2: Strategies to mitigate the impact of bats in churches

The project had eight objectives:

- 1:** Collate information from (i) a literature review, and (ii) stakeholder focus group discussions and Project Advisory Group meetings to inform experimental trials.
- 2:** Develop mitigation options that allow the retention of bats within churches but aim to reduce the deposition of bat droppings and urine inside buildings and/or the damage they cause.
- 3:** Determine the key environmental conditions of occupied roosts to inform the creation of effective alternative roost sites.
- 4:** Construct and mount alternative roosts in and around churches and determine occupancy rates by bats.
- 5:** Quantify, through physical measurements of individual bats, the impact of deterrents on the welfare of a representative sample of the local bat population.
- 6:** Determine the cost of management actions and assess their practicality. Seek to minimise the cost of the management actions, including techniques and equipment used.
- 7:** Describe and, where possible, quantify the impact of the management actions taken to deter bats or limit the damage they cause and model the likely impact on local bat populations.
- 8:** Determine the “bat-friendliness” of the landscape surrounding a local population in a church, particularly in relation to use of alternative roosts.

The response of bats to the provision of artificial roosts in the form of heated bat boxes, and to different forms of deterrence, was investigated using radio-tracking at churches in Norfolk, England. Artificial roosts were used in combination with deterrents to examine if bats could be encouraged to move away from sensitive areas of churches where conflict with people was considered greatest. The selection of deterrents and bat box types was informed by literature reviews of each. Following pilot studies of three forms of deterrence, acoustic (ultrasound) and lighting were tested empirically at churches that contained summer colonies of Natterer’s bats. Initially, short-term applications of deterrents were used to examine the merits of each deterrent type. Longer-term applications of deterrents were used subsequently to determine i) if bats habituate to deterrents, and ii) if the welfare or Favourable Conservation Status of bats is compromised during prolonged exposure to deterrents. Response data from bats were recorded during pre-deterrent (control), deterrent, and post-deterrent periods.

Radio-tracking data revealed that bats made use of multiple roosts inside churches and moved between these roosts frequently. Few alternative roosts were used outside churches and most alternative roosts we recorded were in trees, used by single bats, close to core foraging areas. Bats did not roost in neighbouring churches, even when neighbouring churches were within range of foraging bats i.e. bats were faithful to, and appeared to be dependent on, one church for roosting. Individual bats were faithful to exclusive foraging

patches that were up to 8 km from church roosts and exhibited a preference for foraging in woodland habitat, followed by pasture. Colonies may use foraging ranges that are colony-specific and not shared by bats from adjacent colonies in neighbouring churches.

Bats were not observed using the artificial roosts we provided for them during experimental periods; however, some limited use was observed subsequently. The adoption of bat boxes by bats is dependent on many factors and may take several months, or years.

Acoustic deterrence was effective at excluding Natterer's bats from roosts and keeping them away i.e. bats did not habituate to this form of deterrence. Bats will continue to roost elsewhere inside churches but in some cases the presence of a deterrent may exclude bats from the building. The presence of an acoustic deterrent inside the church did not affect the home ranges, habitat preferences or nocturnal behaviour of foraging bats. A prototype acoustic deterrent, developed during this project as a practical and affordable deterrent option that could be licensed for use by churches in the future, was effective at deterring many bats from roosts but will benefit from further development to improve long-term performance. We do not know how deterrents might impact on reproduction or survival rates; however, if bats are forced out of churches they may struggle to locate suitable alternative maternity roosts, and if this results in reduced productivity then our models suggest that population growth may be reduced subsequently. Our models predict that a small reduction in adult survival could impact negatively on population growth.

Directed use of artificial lighting to raise ambient light levels in churches is effective at excluding Natterer's bats from large areas of a church. Costs involved for lighting are lower than for acoustic deterrence; however, with directed lighting there is potential to cause a detrimental effect on the emergence and foraging time of bats. *Pipistrellus* spp. may be less deterred by lights and may habituate to this form of deterrence. Lights shone at roost entrances have the effect of entombing Natterer's bats in roosts. Evidence from other studies suggests that this phenomenon may be shared among *Myotis* spp. generally, and that sustained use of lights in this way can result in the death of large numbers of bats. Use of lighting to manage the impact of bats in churches, therefore, has the potential to cause serious harm to bats and should be strictly regulated to avoid inappropriate use.

British populations of Natterer's bats are important in an international context. Exclusion of these bats from churches may have serious consequences for local populations if they are not able to locate suitable alternative roosts quickly. Nevertheless, with judicious use of acoustic and lighting deterrents and dialogue between church bodies and SNCOs, our results suggest that Natterer's bats can be deterred from roosting and flying in areas of churches where they cause problems and that this can be achieved without detrimental effects on behaviour, at least in the short-term. By limiting the spread of droppings and urine, deterrents can reduce problems to congregations and to artefacts of historic and cultural significance and can reduce the time required to clean churches. In order to protect

Favourable Conservation Status, deterrents will need to be used under licence. Our results also emphasise the importance of obtaining prior knowledge on the behaviour of bats in species-specific and site-specific contexts prior to performing actions such as deterrence or exclusion.

A follow-on pilot study is planned that will enable selected churches that are severely affected by bats to implement measures to protect heritage of national and international significance. These measures will benefit congregations, as well as members of the public who have an interest in the historic value of churches, by helping to ensure the upkeep and continued use of churches.

1 Introduction

1.1 Scope of report

We outline findings from the project: “Improving mitigation success where bats occupy houses and historic buildings, particularly churches”, under contract from Defra (WM0322). The contract comprises two work packages:

1. Exclusion of house-dwelling soprano pipistrelles (*Pipistrellus pygmaeus*).
2. Strategies to mitigate the impact of bats in churches.

1.2 Research Team

Project lead/Principal Investigator: Professor Gareth Jones – University of Bristol (UoB)

Co-Investigator: Professor Stephen Harris – UoB

Researchers/Co-investigators: Dr. Matt Zeale, Dr. Emma Stone, Dr. Emily Bennitt – UoB

Expert Statistician: Professor William J. Browne – UoB

Expert Population modelling: Dr. Stuart Newson – British Trust for Ornithology (BTO)

1.3 Subcontractors

Conservation Advisor: Dr. Karen Haysom – Bat Conservation Trust (BCT)

Technical Advisor: Philip Parker – Philip Parker Associates (PPA)

1.4 Project Advisory Group (PAG)

Richard Brand-Hardy – Defra

Alison Elliott – Defra

Stephen Rudd – NE

Katherine Walsh – NE

Dr. David Bullock – The National Trust (NT)

Canon Nigel Cooper – Church Buildings Council (CBC)

Dr. Karen Haysom – BCT

Julia Hanmer – BCT

Jen Heathcote – English Heritage (EH) (previously Linda Monkton)

Philip Parker – PPA

Simon Marks – Coordinator with Ecclesiastical Architects and Surveyors Association

2 Exclusion of house-dwelling soprano pipistrelles (*Pipistrellus pygmaeus*) (Project 1)

2.1 Introduction

Throughout Europe many bat species roost in buildings or other man-made structures (Stebbing 1988; Thompson 1992; Entwistle, Racey & Speakman 1997; Briggs 2004; Lourenco & Palmeirim 2004). Soprano pipistrelles (*Pipistrellus pygmaeus*) and common pipistrelles (*P. pipistrellus*), for instance, are so well adapted to man-made sites that they are rarely found in natural roosts (Thompson 1992; Altringham 1996; Bartonička, Bielik & Řehák 2008). Some species have probably benefitted from the increased roosting opportunities provided by human development (Whitaker & Gummer 1992; Whitaker & Gummer 2000); however, bats that occupy buildings are at increased risk of disturbance. As European Protected Species, bats are strictly protected under European and United Kingdom legislation due to concerns over their conservation status. Current legislation (Conservation of Habitats and Species Regulations 2010) protects all bat roosts from destruction, damage or disturbance, whether occupied or not. In situations where bat colonies form in human dwellings, and house owners or tenants are affected severely by their presence, Defra authorises Statutory Nature Conservation Organisations (SNCOs) to grant licences for management and mitigation activities to help resolve the conflict.

One assumption of current legislation is that licensed activities will not be detrimental to the Favourable Conservation Status of species. In exceptional circumstances the exclusion of bats from roosts can be licensed but the fate of excluded bats and the impact on survival and reproduction is not well understood. Evidence from North American studies on big brown bats *Eptesicus fuscus* (Brigham & Fenton 1986) and little brown bats *Myotis lucifugus* (Neilson & Fenton 1994) suggests bats of some species may struggle to find alternative roosts and reproductive success may be affected negatively following exclusion.

We investigated the impact of exclusion on colonies of soprano pipistrelles, a species that forms large and stable maternity colonies in buildings (Barlow & Jones 1999) and is encountered frequently during colony exclusion applications in the United Kingdom (Bat Helpline Database, BCT). Of 139 exclusion licenses administered by BCT during 2011-13, 87/139 cases (63%) involved roosts where soprano pipistrelles were present. The common pipistrelle was the next most frequently encountered species (44%), followed by the brown long-eared bat *Plecotus auritus* (6%). *Myotis* spp. and serotines *Eptesicus serotinus* combined were encountered in 4% of cases.

We used radio-tracking to determine if bats are able to find suitable alternative roosts following exclusion and to test if the roosting behaviour, home range areas and habitat preferences of bats change significantly. Using models that consider local population density and a range of negative impacts on reproductive success that might arise from exclusions, we also make predictions about the impact that exclusion has on local populations. Specific project objectives are listed in Table 2.1.1.

Table 2.1.1 – Description of project objectives (Project 1).

Objective	Description
1	Estimate the proportion of bats excluded from houses that are able to find alternative roosts.
2	Establish whether the local population remains unaffected through emigration following exclusion by estimating the proportion of excluded bats that remain in the same locality.
3	Model the likely population trends of the affected local population following exclusion.
4	Confirm whether the breeding success of the local population is significantly adversely affected.
5	Assess whether excluded bats are forced to use sub-optimal roosts.
6	Compare spatial behaviour before and after exclusion to determine whether excluded bats change their foraging areas.

2.2 Methods

2.2.1 Study sites and experimental procedure

Suitable roost sites were identified initially from exclusion applications received by the Bat Conservation Trust's Bat Helpline, which administers exclusion requests on behalf of Natural England. Sites that had already been granted an exclusion licence were preferred over other known roost sites, where no exclusion was due, to avoid excluding bats unnecessarily. Suitable sites were those with large numbers of bats (>100) and where a complete exclusion could be achieved successfully in a day, to fit with time-frames for experiments. Exclusion experiments were undertaken at Willaston (Cheshire), Bentham (Yorkshire), Crakemarsch (Staffordshire), Shackleford (Surrey), and Studland (Dorset) between 1st May and 7th June 2012-13. With the exception of Studland, all study sites were known maternity roosts, occupied by colonies of adult female bats each year for the purpose of rearing offspring. The roost at Studland was known to contain bats throughout the year, occasionally in high numbers, but the use of the roost specifically as a maternity site had not been confirmed.

Roost exclusions were performed following method statements issued by Natural England (Appendix 1). To avoid causing disturbance to heavily pregnant bats, dependant young or hibernating bats, licences normally require exclusions to be completed during October or April. In this study, numbers of bats at roosts remained low until 1st May, and so exclusions were permitted during May and early June to ensure that a suitable number of replicate sites could be achieved in the short time-frame available for experiments. Indeed, conducting experiments within the normal time-frames for licensed exclusions would not have been feasible for this study because bats would not have been active for periods long enough for us to document their movements. The condition of bats was determined at the start of each experiment to ensure that neither heavily pregnant females nor dependant young were present. At Willaston, Bentham, Crakemarsch and Shackleford, bats were excluded permanently from roosts in line with licence acquisitions for these sites. At Studland, because no prior licence request had been made to exclude bats, a temporary exclusion was performed, whereby bats were allowed to return to the roost as normal after

an exclusion period of four days. The temporary exclusion at Studland was necessary because bats did not return at three sites that we had identified and earmarked for the study from exclusion applications.

We used radio-tracking to determine the roosting behaviour, home range areas and habitat preferences of bats during 4-7 day pre-exclusion (control) and post-exclusion (exclusion) periods. To meet recommendations that n fixes ≥ 30 for each bat-period i.e. pooled control data and pooled exclusion data for each bat (Aebischer *et al.* 1993; Amelon *et al.* 2009), only data from Bentham ($n = 4$ bats), Crakemarsh ($n = 14$ bats), Shackleford ($n = 7$ bats) and Studland ($n = 15$ bats) were included in analyses of home ranges. Procedures for trapping bats and acquiring and analysing radio-tracking data are provided in Appendix 2. All experiments were performed under license from Natural England and were conducted after approval by the University of Bristol Home Office Liaison Team (HOLT) and the University Ethical Review Group (ERG), and after consultation with the PAG.

2.2.2 Data analysis

We use the terminology 'original colony roost' to define roosts at which we performed exclusions, 'alternative roost' to define all roosts other than those at which we performed exclusions and 'new colony roost' to define the alternative roost that bats moved to following exclusion. To determine if the roosting behaviour of bats was affected significantly by exclusion we employed an event history-type modelling process whereby the probability of an event occurring (i.e. the movement of a bat) at each of a series of time-points (i.e. days throughout the experiment) was investigated. Logistic regression models were fitted to the data to examine i) whether bats switched roost more frequently following exclusion, and ii) if bats used poorer quality roosts more frequently following exclusion. For the first model, the movement of bats over each consecutive day of the experiment was identified by linking the roost location of a bat on one day to its location on the previous day and the response of bats became either to 'move' from or to 'stay' at a roost. For the second model, alternative roosts were compared to the original colony roost at each site and scored subjectively according to roost type, roost structure, cavity type, location of cavity, and an estimate of available cavity space, to identify roosts that had high potential to serve as a substitute colony roost i.e. capable of supporting a colony of bats equivalent to that excluded. The scoring of roosts was informed also by a review of literature for soprano pipistrelle roost preferences (Jenkins *et al.* 1998; Davidson-Watts 2007). Soprano pipistrelles have a propensity to roost close to preferred riparian and woodland foraging habitat (Davidson-Watts 2007) and so the proximity of roosts to these habitat types was also considered when scoring alternative roosts. Each roost was categorised as either a 'suitable' alternative colony roost or an 'unsuitable' colony roost, and the response of bats became either to 'move' from or to 'stay' at a roost type. The aim of these models was to test whether the response of bats to 'move' or to 'stay' differed significantly according to period

(i.e. control or exclusion; both models) and roost type (i.e. the category of roost location in which a bat roosted; model 2). All statistical modelling was performed in MLwiN v2.1 (Rasbash *et al.* 2009).

To examine if i) bats were forced to travel further to foraging areas, and ii) the size of foraging areas changed following exclusion, we calculated mean range spans (distance from day roost to centroid of cluster core foraging area) and size of foraging areas (90% cluster core polygons) for each bat-period (pooled control data and pooled exclusion data for each bat). Data were non-normally distributed and control and exclusion datasets for each response were compared using a Wilcoxon Signed Rank Test, with significance set at $p < 0.05$. To examine if the location of foraging areas changed following exclusion, we calculated the mean percent overlap of control-exclusion pairs of foraging areas for each bat. $(O/C)+(O/E)/2$ was used as a measure of overlap, where a control foraging area C and an exclusion foraging area E overlap each other by area O . Variability is described throughout as standard deviations (SD) of the mean.

Habitat preferences were examined for both control and deterrent periods by comparing the habitat compositions of areas in which each bat foraged (90% cluster cores) to that available (colony home range; 100% minimum convex polygon (MCP)) (Davidson-Watts & Jones 2006; Davidson-Watts, Walls & Jones 2006; Zeale, Davidson-Watts & Jones 2012). The used and available habitat compositions were compared using compositional analysis (Compositional Analysis Plus Microsoft Excel tool 6.2, Smith Ecology Ltd, UK) to determine whether habitats were used in line with availability or if selection was occurring, and to determine the ranking of habitat types. To meet the requirement that n bats $>$ n habitat categories ($n = 5$), only data from Crakemarsh, Shackleford and Studland were used in compositional analyses to determine habitat selection. Habitat data were extracted from digital maps developed in-house using ArcGIS 10 (Esri Inc., Redland, CA, USA) using the five broad habitat categories described in Appendix 2 (Table A2.1).

2.2.3 Population modelling

Currently there is little basis on which to monitor how exclusions might affect the Favourable Conservation Status of the soprano pipistrelle because we do not know which critical life-cycle parameters should be monitored. To examine this, we developed a stochastic matrix population model that describes soprano pipistrelle demography, and provides a method whereby productivity (number of female young reared) and age-specific survival can be simulated and the effects on population growth rate examined. For details of model formulation and assumptions of the model refer to Appendix 3.

2.3 Results

2.3.1 Roosting behaviour

In total, across the five study sites, we recorded over 700 day roost fixes from 114 bats and found 89 alternative roosts (Table 2.3.1). Biometric data for tagged bats is provided in Appendix 4 (Table A4.1). Bats used a wide variety of alternative roosts, including domestic dwellings (ranging from small bungalows to large manor houses) ($n = 45$), small uninhabited buildings (garages, sheds, etc.) ($n = 11$), industrial warehouses ($n = 3$) and trees ($n = 30$) (Table 2.3.2). These roosts were typically within a few hundred metres of foraging areas but up to 5 km from the original colony roost (Fig. 2.1). Nearly half (46%) of the 89 alternative roosts that we identified were perceived to be ‘suitable’ alternative colony roosts (Table

Table 2.3.1 – Radio-tracking data obtained from adult female soprano pipistrelles before (control) and after (exclusion) being excluded from roosts.

Site	estimated colony size**	Date	n bats tagged	n alternative roosts ^{†*}		n foraging fixes*	
				Control	Exclusion [‡]	Control	Exclusion
Willaston	150	May 2012	25	17	12 (9)	27	72
Bentham	300	May 2012	23	9	6 (4)	305	143
Crakemarsh	150	May 2013	25	15	19 (10)	507	665
Shackleford	200	May 2013	20	20	11 (6)	340	333
Studland	150	May-June 2013	25	9	3 (3)	709	634
Total			118	70	51 (32)	1888	1847

** estimated maximum number of bats using the original colony roost prior to exclusion.

[†] n roosts used by tagged bats; excludes roost data where bats were not located or where tags had failed.

[‡] Parentheses = number of roosts that were used during both control and exclusion periods.

* Data accumulated over 4-7 day control and exclusion periods.

Table 2.3.2 – Roost use by adult female soprano pipistrelle bats at Willaston ($n = 25$), Bentham ($n = 23$), Crakemarsh ($n = 25$), Shackleford ($n = 20$) and Studland ($n = 25$). Shows the total number of day roost locations (n roost fixes) recorded for bats at each site during exclusion experiments as well as the number of different roosts (n) identified for each roost type, the number of roosts (parentheses) perceived to be ‘suitable’ alternative colony roosts i.e. capable of supporting the colony of bats excluded at each site, and the proportional use (‘use’) of each roost type (calculated as the number of incidences that a bat was found roosting in a roost type divided by the total number of day roosting locations recorded for the site).

Site	n roost fixes	Building (inhabited)		Building (uninhabited)		Industrial warehouse		Tree	
		n	use	n	use	n	use	n	use
Willaston	110	16 (15)	0.77	2 (0)	0.13	0 (0)	0.00	2 (0)	0.1
Bentham	147	8 (7)	0.60	1 (0)	0.01	1 (1)	0.39	1 (0)	0.01
Crakemarsh	176	10 (10)	0.76	2 (0)	0.05	2 (0)	0.01	10 (0)	0.19
Shackleford	174	9 (8)	0.59	5 (0)	0.23	0 (0)	0.00	11 (0)	0.18
Studland	188	3 (3)	0.94	0 (0)	0.00	0 (0)	0.00	6 (0)	0.06

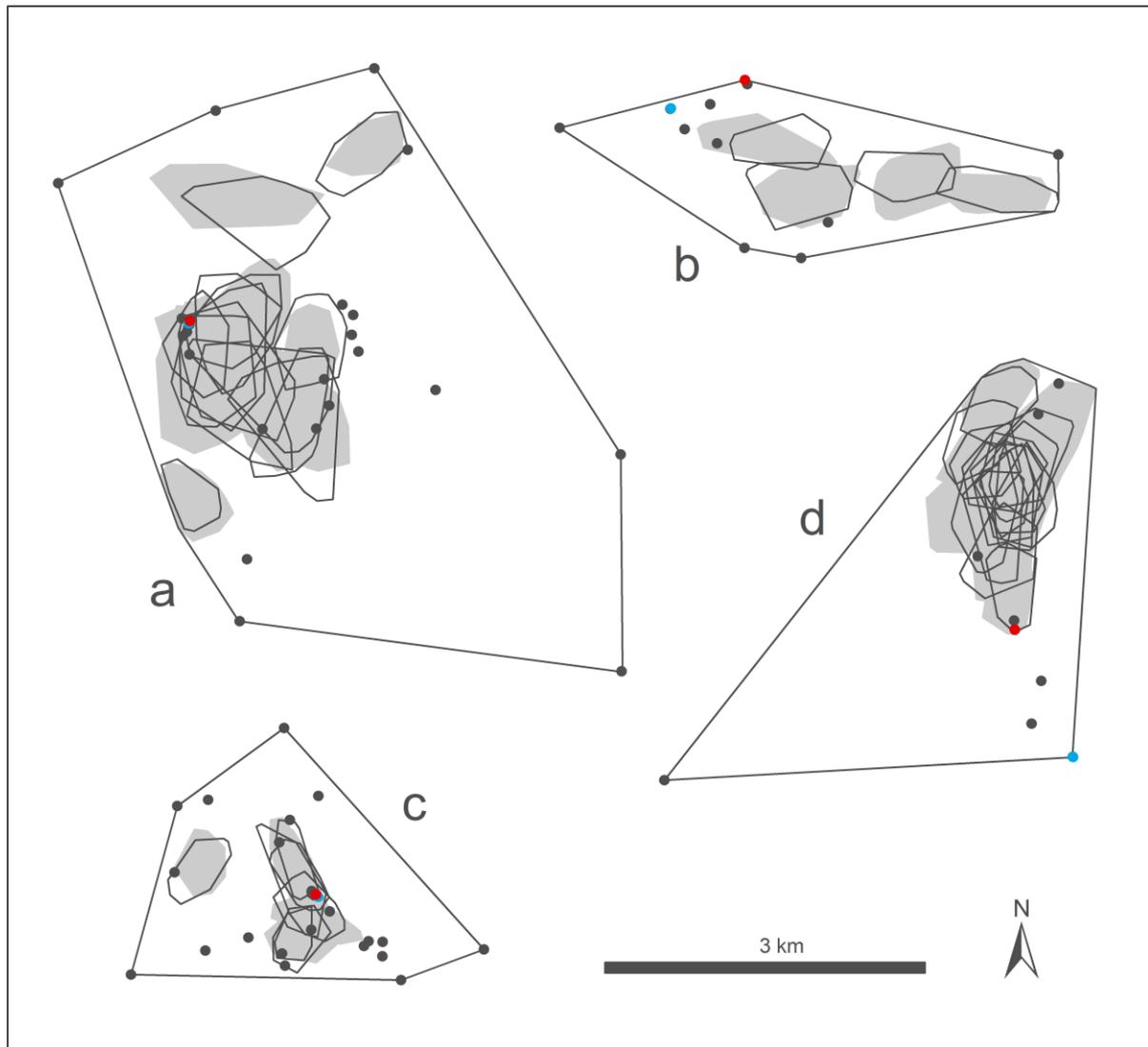


Figure 2.1 – Spatial data collected from bats at (a) Crakemarsh ($n = 25$ bats), (b) Bentham ($n = 23$ bats), (c) Shackleford ($n = 20$ bats) and (d) Studland ($n = 25$ bats). Locations of the original colony roost before exclusion (red point), the new colony roost after exclusion (blue point), and alternative roosts (black points) are shown, together with the encompassing colony home range areas (100% minimum convex polygon (MCP)). 90% cluster core foraging areas are shown for bats with ≥ 30 radio-tracking fixes for both control (solid grey polygons) and exclusion (hollow black polygons) periods ($n = 14$ bats at Crakemarsh, four bats at Bentham, seven bats at Shackleford and 15 bats at Studland).

2.3.2). Of 114 radio-tagged bats, 110 made use of one or more alternative roosts during the short 4-6 day control period. Forty-one bats were not recorded in the original colony roost after being caught there i.e. they roosted exclusively in alternative roosts. We performed emergence counts at 24 alternative roosts during control periods and found that most ($n = 21$) contained relatively few bats (mean 7.6 ± 8.6 , range 1-33 bats) compared to the original colony roost from which bats were excluded (190.0 ± 65.2 , range 150-300 bats). At Bentham, Shackleford and Studland we identified one alternative roost during the control period that contained a large number (>100) of bats, and tagged bats moved between these roosts and the original colony roosts frequently, indicating that at each of these sites the colony was split between two significant roosts prior to exclusion.

We successfully excluded all tagged bats from the original colony roost at each site i.e. none returned after the exclusion measures were put in place. Within three days the bulk of the colony settled on one of the alternative roosts already identified during the control period and we otherwise observed no obvious difference in use of alternative roosts during control and exclusion periods. Following exclusions at Bentham, Shackleford and Studland, the significant alternative roost that we identified during the control period became the 'new' colony roost. At every site, the new colony roost was located within 1.5 km of the original colony roost. At Crakemarsh and Shackleford, the colony moved to a neighbouring property <25 m away. On average, across all sites, bats used a single roost for 2.1 ± 1.3 days and 2.0 ± 1.2 days during control and exclusion periods respectively. However, the frequency of roost switching varied considerably between bats, with some individuals switching roost every day and others using a single alternative roost for the duration of the experiment. At Studland, bats were recorded using the original colony roost on the day after the temporary exclusion measures were removed.

When we fitted logistic regression models to transition data we found no effect of exclusion on frequency of roost movements i.e. bats changed roost equally often during control and exclusion periods. When we considered roost type, we found that bats were significantly less likely to move from a 'suitable' colony roost than they were from an 'unsuitable' colony roost i.e. bats stay for longer periods in colony-type roosts before moving compared to other roost types. The model also indicated that following exclusion there was a small but significant increase in the likelihood that bats would roost in a 'suitable' colony roost, from 79% probability in control to 87% probability after exclusion.

2.3.2 Foraging behaviour

Across the five study sites we recorded over 3700 foraging fixes from 103 bats (Table 2.3.1). Range data for control and exclusion periods (Table 2.3.3) show that, on average, bats foraged close to day roosts and used only a small fraction (4.2 ± 1.8 %, $n = 40$ bats) of the colony home range area for foraging. At Crakemarsh, Shackleford and Studland, the foraging areas of bats were highly clustered and overlapping, suggesting a sharing of resources by bats at these sites (Fig. 2.1). At Bentham, foraging areas were clustered but non-overlapping. The small sample size ($n = 4$ bats) likely accounts for the limited overlap of foraging areas observed at Bentham. We found no evidence that foraging behaviour was affected by exclusion. Bats foraged in similar sized core areas (control mean = 43.6 ± 20.5 ha; exclusion mean = 46.5 ± 21.8 ha; $Z = -1.358$, $p = 0.175$) that were located in more or less the same place (mean overlap of control and exclusion core foraging areas = 76.4 ± 9.7 % (minimum 51.2, maximum 88.4)), and bats travelled similar distances to reach foraging areas (control mean = 1.5 ± 0.9 km; exclusion mean = 1.48 ± 1.0 km; $Z = -0.704$, $p = 0.482$), after they had been excluded from roosts.

Table 2.3.3 – Colony home range areas (100% MCPs), foraging areas (90% clusters cores) and range spans (mean maximum nightly distance from roost to centroid of cluster core foraging area) for 40 adult female soprano pipistrelles radio-tracked before (control) and after (exclusion) being excluded from roosts.

Site	Date	<i>n</i> bats	Period	Colony home range (ha)*	Foraging area (ha)*	Range span (km)*
Bentham	May 2012	4	Control	482.0	40.3 ± 5.4	1.72 ± 0.98
			Exclusion	491.2	38.7 ± 5.8	1.75 ± 1.37
Crakemarsh	May 2013	14	Control	1856.8	61.6 ± 22.2	0.74 ± 0.25
			Exclusion	2071.1	66.4 ± 22.6	0.81 ± 0.33
Shackleford	May 2013	7	Control	493.3	23.2 ± 4.6	0.70 ± 0.51
			Exclusion	493.3	23.0 ± 6.2	0.46 ± 0.05
Studland	May-June 2013	15	Control	935.5	37.2 ± 11.1	2.45 ± 0.49
			Exclusion	643.9	40.9 ± 10.0	2.53 ± 0.41

* Mean ± SD. Calculated as mean (*n* bats) of means (*n* bat-days).

Table 2.3.4 – Habitat preferences exhibited by soprano pipistrelles (Crakemarsh *n* = 14 bats; Shackleford *n* = 7 bats; Studland *n* = 15 bats) during control and exclusion periods. Habitat categories to the left of > are selected over those to the right with >>> showing a significant difference between adjacent habitat types.

Site	Period	Ranked habitat types								<i>p</i> *	
Crakemarsh	Control	Riparian	>	Woodland	>	Grassland	>	Built-up	>	Arable	<0.001
	Exclusion	Riparian	>	Woodland	>	Grassland	>	Built-up	>	Arable	<0.01
Shackleford	Control	Riparian	>	Woodland	>>>	Grassland	>	Arable	>	Built-up	<0.05
	Exclusion	Riparian	>	Woodland	>>>	Grassland	>	Built-up	>	Arable	<0.01
Studland	Control	Riparian	>>>	Woodland	>>>	Grassland	>	Built-up	>	Arable	<0.001
	Exclusion	Riparian	>>>	Woodland	>>>	Grassland	>	Built-up	>	Arable	<0.001

* *P*-values <0.05 show selection of habitat types is non-random.

Compositional analyses to determine habitat preferences of bats at each site revealed that bats consistently preferred to forage in riparian habitat, followed by woodland, over other habitat types (Table 2.3.4). Arable habitat and built-up areas (consisting mainly of medium density residential areas (>40 % cover)) were preferred least. Habitat preferences of bats were the same during control and exclusion periods (Table 2.3.4).

2.3.3 Population model

With a starting population of 100 females, in order to bring about population extinction (extinction probability = 1) over an arbitrary 500 year period (all other parameters being equal), annual survival would need to decline by 16% for individuals less than a year old (S_1), 13% for individuals in their second year (S_2), or by 4% for individuals in their third year or older (S_3). In terms of the constituents of productivity, mean litter size of individuals breeding in their first breeding season (L_1) and in their second breeding season or later (L_2) would need to decline by 81% and 18%, respectively. The proportion of individuals breeding in their first season ($Alpha_1$) and in their second season or later ($Alpha_2$) would need to decline by 81% and 17%, respectively, for a population decline to occur. While the number

of years of simulation here is arbitrary, this highlights that demographic monitoring should focus on obtaining robust estimates for adult survival, with a lower priority to obtain robust estimates of first and second year survival, mean litter size of bats in their second breeding season or later, and the proportion of individuals breeding in their second season or later. Additional detail for model results is provided in Appendix 5.

2.4 Discussion

Our data show that in spring and early summer soprano pipistrelles form fission-fusion societies, with bats moving between one or two main roosts, which sustain relatively high numbers of bats, and a large number of alternative roosts with varying frequency. Soprano pipistrelles, along with probably all temperate-zone bat species, enter regulated torpor to maximise energy conservation when confronted with periodic food shortages and/or adverse environmental conditions (Stone & Weibers 1967; Speakman & Thomas 2003; Stawski, Willis & Geiser 2013), and so the use of a wide variety of alternative roosts during the spring, from single bats roosting behind ivy on trees to substantial colony roosts in inhabited i.e. heated dwellings, may reflect, in part, efforts by bats to seek out a variety of roost microclimates to facilitate this behaviour. Factors such as predation risk, parasite load within roosts, social behaviour and anthropogenic disturbance may also influence roost switching (Lewis 1995; Vonhof & Barclay 1996; Entwistle *et al.* 1997; Willis & Brigham 2004; Reckardt & Kerth 2007).

At all sites, alternative roosts encompassed communal foraging areas that were close to the main roost, and so colony home ranges were determined largely by the locations of alternative roosts. The selection of roosts close to preferred foraging habitat appears to be consistent among soprano pipistrelle colonies (Davidson-Watts 2007). Other features thought to be important in the selection of maternity roosts include the close proximity of tree cover and mean daily roost temperatures of around 23 °C (daily temperature range: 16-33°C) (Davidson-Watts 2007). In this study, tree cover was absent at the original colony roost at three of our five study sites, and so the preference for this feature may be site-specific. We were not able to record temperatures in roosts because roost cavities were located in inaccessible crevices in roofs or in cavity walls.

Nearly half (46%) of the alternative roosts used by bats were considered to be suitable for supporting colonies equivalent in size to those excluded. At all sites there was a cluster of 'suitable' alternative colony roosts around the original main roost, often in neighbouring buildings of similar construction. Some of these roosts may serve as the main colony roost at different times of the year, or in different years. At Bentham and Shackleford, during the respective control periods, colonies were split between the original colony roost and a significant alternative roost which, following exclusion, became the 'new' colony roost. At Shackleford the original and new colony roosts were in neighbouring buildings less than ten metres apart. Similarly, at Crakemarsh, an alternative roost in a neighbouring building less

than 25 metres from the original colony roosts was used regularly by small numbers of bats during the control period and, following exclusion, this roost became the new colony roost. At the three sites that we had earmarked for experiments but where bats did not return i.e. sites where we were unable to perform experiments, it is probable that the colonies at those sites formed in an alternative roost nearby.

At Studland, all tagged bats moved to an alternative roost before we attempted to exclude them. Emergence counts indicated that the majority of bats in the colony made this move. The experiment at Studland was the latest, seasonally, that we performed. At the original colony roost (Appendix 1, Fig. A1.3), which was located on the edge of a large area of preferred riparian foraging habitat, bats roosted under timber cladding. Conversely, the alternative roost that bats moved to was a thick stone-walled cottage located 1.5 km from the foraging area. Emergence counts at both roosts revealed twice as many bats (<300 bats) roosting in the cottage compared to the original roost (approximately 150 bats), and so we probably witnessed a natural movement of bats from a temporary transition roost, positioned advantageously close to foraging grounds, to a significant maternity roost. The structure of the cottage was such that it probably provided more stable roost temperatures than the original roost, which may provide advantages for breeding females and the development of young.

We were successful at excluding bats from roosts. The method statements currently issued with licences provide advice that is appropriate for performing exclusions safely and effectively. We detected no change in the use of alternative roosts by bats following exclusion and all tagged bats that we excluded found alternative roosts nearby (objectives 1, Table 2.1.1). Crucially, at all sites, the colonies congregated on an alternative roost within three days and these roosts were within 1.5 km of the original roost i.e. bats did not emigrate following exclusion (objective 2, Table 2.1.1). We observed no change in the frequency of roost movements and bats were not forced to use roosts that we perceived to be sub-optimal (objective 5, Table 2.1.1). Bats also continued to forage in the same areas (objectives 6, Tables 2.1.1). Our data on roosting and foraging mirrors that described previously for soprano pipistrelles (Davidson-Watts & Jones 2006; Davidson-Watts, Walls & Jones 2006; Nicholls & Racey 2006a; Nicholls & Racey 2006b; Davidson-Watts 2007).

Our 'shotgun' approach to collecting foraging data (Appendix 2), while unorthodox, was considered appropriate given the low ratio of trackers ($n = 4$) to tagged bats ($n = 20-25$) at each site. The decision was taken, in agreement with the PAG, not to follow individual bats intensively using a traditional 'focal bat' approach because this would have resulted in obtaining foraging data for only 20 (17%) of the total 118 bats that we radio-tagged. Moreover, bats foraged typically for just one or two hours after sunset, and so a 'focal bat' approach would have yielded far fewer foraging fixes than the number we obtained using the 'shotgun' approach (1888 control fixes, 1847 exclusion fixes). Bias in foraging data, incurred as a result of unbalanced sampling (n fixes) from bats during control and exclusion

periods, was controlled by removing bats with fewer than 30 control or exclusion fixes from analyses of home ranges and habitat preferences. Using our 'shotgun' approach, we were able to obtain an informative dataset on ranging and foraging behaviour, comprising data from 103/118 (87%) of radio-tagged bats, and perform robust analyses of home range areas and habitat preferences for 40 (34%) bats i.e. double that which would have been possible if each tracker ($n = 4$) followed a single bat at each site ($n = 5$) using a traditional 'focal bat' approach.

The timing of exclusions is critical to avoid causing disturbance to heavily pregnant bats, dependant young and hibernating bats. Our experiments were conducted closer to the summer breeding period than would normally be permitted and we observed no significant detrimental impact on bats. Even if bats breed earlier in the year than would normally be expected, the current recommendation that exclusions are performed during October or April should provide ample protection against disturbing bats at sensitive times of the year. Extending licensing windows to permit exclusions after April may be desirable, providing allowances are made for annual variations in weather that affect the timing of pregnancy and adequate support is available to ensure pregnancy is not too far advanced. At this time of year, as we observed, bats are moving between a range of roosts, interacting frequently, and potentially exchanging information about suitable alternative roost sites. Although we studied bats over relatively short time periods, soprano pipistrelles radio-tracked in Hampshire and Wiltshire (Davidson-Watts 2007) and in East Anglia (Madeleine Ryan, unpublished data) also used several different roosts during the spring and early summer, and continued to move between roosts over extended tracking periods, so we infer that the response of bats to exclusion will be similar throughout this period. It is likely that roost-switching will become less frequent during lactation given the difficulties and costs incurred by mothers transporting pups to new sites.

Although we observed no significant change in the behaviour of bats during our short-term experiments, currently there is almost no information regarding the longer-term impacts of exclusion on productivity and survival rates for soprano pipistrelles, or indeed any bat species. Due to commitments on Project 2, and in agreement with the PAG, it was decided that sites in this study would not be visited later in the year to obtain data on the breeding success of bats that were excluded (objective 4, Table 2.1.1). Most roosts are inaccessible in any case, as bats roost away from view in recesses such as cavity walls. To our knowledge, the only study to date to examine the demographic consequence of roost exclusion for a bat species is that by Brigham & Fenton (1986) for the big brown bat, *Eptesicus fuscus*, which found that despite individuals relocating to roosts nearby, mean litter size was significantly lower (56% reduction) following exclusion (0.86 ± 0.30 at control sites; 0.38 ± 0.30 following exclusion). A change of similar magnitude in L_2 could have profound consequences for soprano pipistrelle populations.

If the roosting behaviour that we observed during our experiments is shared among soprano pipistrelles generally, and colonies have a large number of alternative roosts that they could move to quickly if they are excluded from a single roost, this may be adequate to buffer populations against the limited number of exclusions that are licensed at present to cover situations where house dwellers experience problems caused by roosts. However, it is important to note that we do not know what the impact on local populations would be from multiple exclusion events. Each year, exclusions are conducted at a large number of bat roosts during development work but only limited information is provided on the consequences of mitigation (Stone *et al.* 2013). On a larger scale, the impacts of exclusions are likely to be more substantial. While we believe that exclusion is perhaps most likely to impact on demographic rates through a reduction in productivity, we have no information to be able to speculate on the impact of exclusion on survival. However, the modelling here demonstrates that fairly small reductions in annual survival, particularly of adult survival, would result in a declining population growth rate, at least for the year following exclusion (objective 3, Table 2.1.1).

These results should be treated as species-specific and should not be extrapolated to other species. This includes the common pipistrelle which, despite being a cryptic species of the soprano pipistrelle, shows distinct behavioural differences (Barlow & Jones 1997; Davidson-Watts & Jones 2006; Davidson-Watts, Walls & Jones 2006). The colonies that we studied are typical in size (150-300 bats) for soprano pipistrelles (Barlow & Jones 1999; Davidson-Watts 2007) and while colonies of more than 1500 bats are known, we predict that bats will respond similarly to exclusions irrespective of colony size. Further research is, however, encouraged to examine the impact of exclusion on larger colonies of soprano pipistrelles. While we acknowledge that our conclusions are derived only from short-term responses of bats, arguably these are useful proxies for detriment. However, long-term measures of productivity and survival are required to make definitive statements regarding impacts on Favourable Conservation Status, and so investigations comparing productivity and survival in excluded versus control (non-excluded) populations will be informative for determining long-term consequences of exclusion, although obtaining these measures from inaccessible roosts will be difficult logistically. Further research is encouraged also to determine the impact of exclusions on other species that are encountered most frequently during exclusion requests, namely the common pipistrelle and the brown long-eared bat *Plecotus auritus*.

2.5 Conclusion

We have shown that, following exclusion, a soprano pipistrelle colony is able to relocate to a new colony roost quickly and without an obvious short-term impact on behaviour or welfare. The availability of suitable alternative roosts is a critical factor in determining the impact of future exclusions on these bats but soprano pipistrelles are able to make use of a wide variety of both natural and man-made structures for roosting. We cannot be certain what affect exclusion has on the Favourable Conservation Status of soprano pipistrelles

because we have no measure of the long-term impact on survival and productivity. While we predict that the impact may be small from the limited number of exclusions that are licensed at present to cover situations where house dwellers experience problems caused by bats, extrapolated impacts from situations where roosts are destroyed frequently during development may be of concern.

3 Strategies to mitigate the impact of bats in churches (Project 2)

3.1 Introduction

Parish churches are treasured and enduring features of the English landscape. Approximately 60% of pre-16th century churches are estimated to contain bat roosts and some have provided valuable roosting sites for many generations of bats. In Norfolk, the level of occupancy is particularly high. Recent surveys of 141 medieval churches revealed low levels of bat activity at 81 churches (occupied by 1-10 bats), moderate levels of activity at 46 churches (11-100 bats comprising small to moderate maternity colonies), and high levels of activity at 13 churches (>100 bats comprising large maternity colonies) (Philip Parker Associates, unpublished data) i.e. almost all churches contained bat roosts.

At least eight species are known to use churches for roosting, including Natterer's bat (*Myotis nattereri*). In some cases, the presence of bats goes unnoticed by people and does not result in conflict, particularly if bats roost in wall cavities or roof voids. However, where bats roost and fly internally within churches, the deposition of droppings and urine can result in damage to furnishings and fittings. This is of concern especially if such items are irreplaceable artefacts of historic or cultural significance. In some cases, large quantities of droppings can restrict the use of a church for worship or other community functions.

The population of Natterer's bats in Britain is regarded as internationally important (Stebbing 1993). Churches can be home to colonies comprising more than 100 bats but as yet the importance of churches as roost sites is not clear. Current legislation (Conservation of Habitats and Species Regulations 2010) protects all bat roosts from destruction, damage or disturbance, whether occupied or not. This legislation also places a duty on all competent authorities, including Diocesan Advisory Committees and Consistory Courts, to take bats into account adequately when works such as building restoration have the potential to damage roosts or disturb bats. Church communities require support to reduce the impact of bats such that the needs of people can be addressed without compromising the welfare or Favourable Conservation Status of bats.

We investigated methods of artificial roost provision and deterrence that could potentially be used to encourage bats to move from sensitive areas of churches without adversely affecting their welfare. Our approach involved the provision of alternative roosting areas both within and outside churches. Due to the high level of occupancy of churches by bats in Norfolk, incidences of conflict between people and bats are especially high, and so for this reason, and for logistical considerations, all churches used in experiments were located in Norfolk. Using radio-tracking we examined how Natterer's bats use churches and the surrounding landscape for roosting and for foraging and determined the relative importance of churches as roost sites for local bat populations. We piloted three deterrent types and tested empirically two forms of deterrence (ultrasound and lighting). Initially, short-term applications of deterrents were used to determine the merits of each form of deterrence.

Table 3.1.1 – Description of project objectives (Project 2).

Objective	Description
1	Collate information from (i) a literature review and (ii) stakeholder focus group discussions and Project Advisory Group meetings to inform experimental trials.
2	Develop mitigation options that allow retention of bats within churches but aim to reduce the deposition of bat droppings and urine inside buildings and/or the damage they cause.
3	Determine the key environmental conditions of occupied roosts to inform the creation of affective alternative roost sites.
4	Construct and mount alternative roosts in and around churches and determine occupancy rates by bats.
5	Quantify, through physical measurements of individual bats, the impact of deterrents on the welfare of a representative sample of the local bat population.
6	Seek to minimise the cost of management actions (including any techniques and equipment used), and determine the full cost of management actions and assess their practicality.
7	Describe and, where possible, quantify the impact of the management actions taken to deter bats or limit the damage they cause, and model the likely impact on local bat populations.
8	Determine the “bat-friendliness” of the landscape surrounding a local population in a church, particularly in relation to use of alternative roosts.

Longer-term applications of deterrents were used subsequently to examine if i) bats habituate to deterrents, and ii) if bat welfare is compromised during prolonged use of deterrents. Using models that consider local population density and a range of negative impacts on reproductive success that might arise from exclusions we also make predictions about the impact that deterrence has on local populations. Specific project objectives are listed in Table 3.1.1.

3.2 Methods

3.2.1 Study sites

Suitable church sites were identified initially using past survey records of bat occupancy (Philip Parker Associates, unpublished data). Roost and emergence surveys were conducted at more than 25 churches to confirm the presence of colonies of Natterer’s bats. Ten churches were found to contain colonies of 30 bats or more and were selected for experiments following consultation with church wardens (Table 3.2.1). All experiments were undertaken during July and September 2011-13 and the condition of bats in each church was identified prior to each respective experiment to avoid causing disturbance to heavily pregnant bats or dependant young. All of the churches used have medieval origins, but the size, shape and design of buildings varies considerably. Examples of the range of church buildings included in this study are provided in Appendix 6.

We used radio-tracking to determine the roosting behaviour, home range areas, habitat preferences, and nocturnal activity of bats and to examine the response of bats to deterrents. Procedures for trapping bats and acquiring and analysing radio-tracking data are

Table 3.2.1 – Church sites used in deterrence experiments. Shows the total number of Natterer’s bats radio-tagged during the period 2011-13 and the estimated colony size at each site.

Site	Church	<i>n</i> radio-tagged bats	Estimated colony size (<i>n</i> bats)
Cley	St. Margaret	27	70-90
Deopham	St. Andrew	10	60-80
Great Hockham	Holy Trinity	10	60-80
Guestwick	St. Peter	24	60-80
Holme Hale	St. Andrew	25	>100
Ingham	Holy Trinity	6	>100
Salle	St. Peter & St. Paul	21	30-40
Swanton Morley	All Saints	25	80-100
Toftrees	All Saints	26	>100
Wood Dalling	St. Andrew	6	30-40

† Bats tagged with radio telemetry tags

provided in Appendix 2. A literature review of Natterer’s bat ecology and deterrent types (Appendix 7) was produced to inform experimental procedures. Focus Group Meetings with stakeholder groups (Appendix 8) were held to establish communication with local churches and to provide a platform on which to voice ideas and concerns about problems caused by bats and what might be done to alleviate them. All experiments were conducted after approval by the University of Bristol Home Office Liaison Team (HOLT) and the University Ethical Review Group (ERG), and after consultation with the PAG. All experiments were conducted under licence from Natural England and permitted by the Diocese of Norwich.

3.2.2 Pilot studies of deterrents

Pilot studies were completed between 20th and 26th July 2012. Three deterrent types were piloted, including lights (2x 400 Watt Halogen lamps), acoustic (four speaker units each containing 16 transducers emitting continuous broadband (20-100 kHz) ultrasound), hereafter referred to as the ‘Deaton’ deterrent (Arnett *et al.* 2013), and radar (marine radar unit emitting a 60 kW 9.4 GHz (X-band) radio signal). Details of each deterrent type are provided in Appendix 9. Pilot studies were designed to examine the effect of deterrents on bat flight activity within churches. Deterrents were positioned in the church nave approximately 1-2 metres above ground level but were not located directly below known roost entrances. Each deterrent type was tested twice using a repeated measures experimental design (5 minutes control (deterrent off), 5 minutes deterrent (deterrent on), 5 minutes post deterrent (deterrent off), repeated up to 12 times and beginning soon after emergence). Bat activity (number of bat passes) was recorded using Anabat bat detectors (Titley Scientific, Columbia, MO, USA), or an infrared digital camera (Y-cam Cube HD 720; Y-cam Solutions Ltd, Surrey, UK) when testing acoustic deterrence.

3.2.3 Short-term acoustic deterrence of roosting bats

Experiments designed to examine the response of bats to short four-day applications of acoustic deterrence, using the Deaton deterrent, were undertaken at six churches (Cley, Guestwick, Holme Hale, Salle, Swanton Morley and Toftrees) between 4th August and 9th September 2012. The experimental procedure used at each site is described in Table 3.2.2 and specifications for the Deaton deterrent are provided in Appendix 9. Four speaker blocks were positioned inside churches directly below 1-2 roost(s) (occupied by most, if not all tagged bats at the start of the deterrent period) that had been identified during the control period of the experiment. The vertical distance from speaker to roost was standardised across sites (mean 9.5 ± 0.7 metres). The deterrent emitted a loud continuous signal that included some frequencies within the audible spectrum for humans and therefore it was switched off during the day to avoid disturbing visitors to churches. At each church one heated bat box (Appendix 10) was installed at ceiling height to provide an alternative roost for bats. It was agreed with the PAG that it was not necessary to fulfil project objective 3 (Table 3.1.1) i.e. to determine the key environmental conditions of occupied roosts to inform the creation of affective alternative roost sites, because Smith & Racey (2005) provide these data already. The choice of box type was informed by a literature review Natterer's bat roosting preferences (Appendix 7), and a heat mat (Habistat vivarium heat mat; Euro Rep, Middlesex, UK) and thermostat (Habistat dimming thermostat; Euro Rep, Middlesex, UK) were built in to each box to prevent temperatures inside boxes falling below that preferred by Natterer's bats (*circa.* 22°C; Appendix 7). The specific location of boxes varied between churches depending on accessibility and negotiations with church wardens. Radio-tagged bats were located during the day to identify day roosts and six bats were radio-tracked continuously from dusk to dawn to determine foraging behaviour (Appendix 2). Droppings that accumulated below the roost(s) where deterrents were installed were collected each day and the dry mass of daily sample collections was recorded.

Table 3.2.2 – Experimental procedure to examine the response of Natterer's bats to short-term applications of acoustic (ultrasound) and lighting deterrents.

Day	Period	Activity
1	Trapping	Up to 17 adult female bats caught and radio-tagged (Appendix 2).
2-5	Control	Deterrent installed on day 2 to control for effect of physical presence of deterrent on bat behaviour (deterrent remains switched off until midnight of day 6). Data from first night of control period removed from analysis due to effect of disturbance caused by trapping and tagging on the previous evening.
6-9	Deterrent	Deterrent switched on at midnight after bats emerged from church. On days 7-9 deterrent switched on before emergence and switched off at dawn after bats had returned to day roosts.
10-13	Post-deterrent	Deterrent switched off at dawn on day 10 and removed from church.

A second acoustic deterrent, developed in collaboration with Concept Research Ltd (Stevenage, UK) and hereafter referred to as the 'CR' deterrent, was tested at two churches (Salle and Toftrees) between 7th August and 13th September 2013 following the same experimental procedure used for the Deaton deterrent (Table 3.2.2). This prototype deterrent was designed to deliver substantial size, weight and cost savings over the Deaton deterrent (objective 6, Table 3.1.1) but at a cost of reduced performance. Specifications for the CR deterrent are provided in Appendix 9. Three deterrent devices were installed inside each church approximately one metre from roost entrances to maximise the chance of deterrence. All units pointed directly at roost entrances, and where possible up into roost cavities. The roost locations of radio-tagged bats were recorded each day and the number of bats emerging from the roosts each evening was recorded by an observer on the ground using a Batbox III D heterodyne bat detector (Batbox Ltd., Steyning, England) and a night vision monocular (Yukon Advanced Optics Worldwide, Vilnius, Lithuania).

3.2.4 Long-term acoustic deterrence of roosting bats

Experiments designed to examine the response of bats to long-term applications of acoustic deterrence were completed at three churches (Deopham, Guestwick, and Swanton Morley) between 26th July and 12th September 2013. The Deaton deterrent was applied in the same way as that described for short-term experiments but for an extended period of 15 days. The experimental procedure used at each site is provided in Table 3.2.3. A bat box (Appendix 10) was installed on the outside of each church (either under the church eaves or in a tree in the surrounding churchyard) at the start of each experiment, in addition to those already installed inside the church during short-term acoustic deterrence experiments, to provide additional roosting opportunities for bats.

3.2.5 Deterrence of roosting bats using artificial lighting

The use of artificial lighting to deter bats from roosts inside churches was tested empirically at one site (Salle) between 26th July and 2nd August 2012 using the experimental procedure described in Table 3.2.2. The deterrent in this case consisted of two 400 W halogen lamps mounted on a tripod (Appendix 9). The lamps were positioned one metre above ground level below the roost occupied by the majority of tagged bats at the start of the deterrent period, and lamps were directed upwards to illuminate roost exits. The response of bats to lights was recorded in the same way as for short-term acoustic deterrence experiments (3.2.3). Concerns over bat welfare prompted this experiment to be terminated early and it was agreed with the PAG that this experiment should not be repeated. Given that lighting had a strong impact on bats, we tested an alternative application of artificial lighting that avoided illuminating roosts directly during the following year (3.2.6).

3.2.6 Creation of bat 'no-fly zones' using artificial lighting

The use of artificial lighting to exclude bats from large areas within churches was tested empirically at four sites (Cley, Great Hockham, Holme Hale, and Salle) between 25th July and

Table 3.2.3 – Experimental procedure to examine the response of Natterer’s bats to long-term applications of acoustic (ultrasound) deterrents.

Day	Period	Activity
1	Trapping	Up to 10 adult female bats caught and radio-tagged (Appendix 2).
2-5	Control	Deterrent installed on day 2 to control for effect of physical presence of deterrent on bat behaviour (deterrent remains switched off until midnight of day 5). Two emergence surveys conducted (days 3 & 5). Surveys begin at sunset and last for 2 hours. Number of bats emerging from ‘original’ roost inside the church (roost affected by deterrent during deterrent period) and from the church building are recorded by observation from the ground using Batbox III D heterodyne bat detectors (Batbox Ltd., Steyning, England) and night vision monoculars (Yukon Advanced Optics Worldwide, Vilnius, Lithuania). Droppings that accumulated below the ‘original’ roost are collected immediately prior to each emergence survey. Tagged bats located to day roosts on every day of the experiment.
6-21	Deterrent	Deterrent positioned directly below the roost used most heavily by bats during the control period. Deterrent switched on at midnight of day 5 after bats emerge from roosts. On all subsequent deterrent days deterrent switched on at sunset before bat emergence. Seven emergence surveys conducted (days 7, 9, 11, 13, 15, 17 & 19), tagged bats located during the day and dropping collections made following the same protocol as for the control period.
22-25	Post-deterrent	Deterrent is switched off on the morning of day 21 after bats have returned to day roosts. Deterrent stays <i>in situ</i> until day 25. Two emergence surveys conducted (days 23 & 25), tagged bats located during the day and dropping collections made following the same protocol as for the control period.

12th September 2013 following the experimental procedure described in Table 3.2.2. Two or four 400 W halogen lamps were used in a directed way to raise ambient light levels in one area of the church (chancel) while keeping other areas of the church in relative darkness. Care was taken to keep light levels at roosts and at exits from the church to a minimum. Bat activity (number of bat passes) was monitored in the chancel ‘lit zone’ and at the opposite (west) end of the church ‘dark zone’ in a standardised way using Anabat automated frequency division bat detectors (Titley Scientific, Columbia, MO, USA), which recorded bat activity throughout the night, and infrared digital cameras (Y-cam Cube HD 720; Y-cam Solutions Ltd, Surrey, UK), which recorded bat activity for two hours after sunset. The emergence time of radio-tagged bats from churches was recorded each night and the locations of bats were recorded each day to identify day roosts. Light levels (illuminance in lux) were measured at the centre of lit and dark zones using a Konica Minolta T-10 illuminance meter (Konica Minolta Inc., Tokyo, Japan) held vertically, and oriented towards the lamps, at a height of 1.7 m above ground level. Standardised collections of droppings were made each day from 2 m x 3 m plastic sheets that covered the ground in both lit and dark zones, i.e. one sheet in each zone, and the dry mass of daily sample collections was recorded.

3.2.7 Data analysis

To determine if the roosting behaviour of bats was affected significantly by short-term applications of acoustic deterrence we employed an event history-type modelling process whereby the probability of an event occurring (i.e. the movement of a bat) at each of a series of time-points (i.e. days throughout the experiment) was investigated. We identified three categories for roost location data, including 'original roost' (the roost affected by the deterrent during the deterrent period), 'alternative roost' (a roost inside the church but away from the deterrent), and 'outside' (any roost not inside the church) and categorised the responses of each bat on each day of the experiment at each church accordingly. The movement of bats over each consecutive day of the experiment was then identified by linking the roost location of a bat on one day to its location on the previous day, resulting in nine possible movement 'states'.

To model the transition data we fitted two multistate models. All statistical modelling was performed in MLwiN v2.1 (Rasbash *et al.* 2009). For the first model, the roost categories 'alternative' and 'outside' were merged and transition states were reduced to two such that the roost categories became 'original' and 'other' and the response of bats became either to 'move' from or to 'stay' at a roost. For the second model, transition states were reduced as in the first model but 'original' and 'alternative' roost categories were merged to give the categories 'inside' and 'outside' the church. The aim of these models was to test whether the response of bats to 'move' or to 'stay' differed significantly according to two explanatory fixed effect variables: roost type (i.e. the category of roost location that the bat was in) and period (i.e. control, deterrent or post-deterrent).

To determine if individual home ranges (100% MCPs), core foraging areas (80% clusters), maximum range spans, time of emergence, time of return, and time spent foraging were affected significantly by short-term applications of acoustic deterrence, we fitted a series of general linear mixed models (GLMMs) to each of these response variables. Data for individual home ranges, core foraging areas and time of emergence were log-transformed prior to fitting models. The explanatory variables tested in each model included two categorical fixed effects (site ($n = 6$) and period (control versus deterrent)) along with the interactions between site and period (to investigate site-dependent effect of the deterrent). The data were nested, with nightly measurements nested within bats, and so to control for dependence within bat we fitted bat identity as a random effect.

To determine if short-term acoustic deterrence affected where, specifically, individual bats foraged i.e. whether bats foraged in different locations during control versus deterrent periods, we calculated core foraging areas for each bat-night in the dataset and recorded the percentage overlap of pairs of foraging areas for each possible pairing of nights within bats. This amounted to 356 overlap observations (76 control-control pairs, 69 deterrent-deterrent pairs, 211 control-deterrent pairs) taken from 34 bats across six sites. To determine whether foraging site overlap (response variable) was affected significantly by

the presence of the deterrent we fitted a multiple membership multiple classification (MMMC) model with MCMC estimation (Browne 2009) to the data to account for the structure of each overlap measurement being nested within a pair of nights within a bat. Explanatory fixed effect variables included site, comparison type (control-control, deterrent-deterrent, control-deterrent) and time interval (time (n days) between nights within each night-pair). No effect of site was found and so site was removed from the model.

Habitat preferences were examined by comparing the habitat composition of areas in which each bat foraged (80% cluster cores) to that available (individual MCP home ranges). The used and available habitat compositions were compared using compositional analysis (Compositional Analysis Plus Microsoft Excel tool 6.2, Smith Ecology Ltd, UK) to determine whether habitats were used in line with availability or if selection was occurring, and to determine the ranking of habitat types. Habitat data were extracted from digital maps developed in-house using ArcGIS 10 (Esri Inc., Redland, CA, USA) using the five broad habitat categories described in Appendix 2 (Table A2.1). Variability is described throughout as standard deviations (SD) of the mean.

3.2.8 Population models

There is little basis on which to monitor how the use of deterrents in churches might impact on the Favourable Conservation Status of Natterer's bat because we do not know which critical life-cycle parameters should be monitored. To examine this, we developed a stochastic matrix population model that was very similar in structure to that described in section 2.2.3 for the soprano pipistrelle. This model describes Natterer's bat demography and provides a method where productivity, in terms of number of female young reared, and age-specific survival can be simulated and the effects on population growth rate examined. For details of model formulation and model assumptions refer to Appendix 3.

3.3 Results

3.3.1 Ecology of Natterer's bats that occupy churches

Radio-tracking data were obtained from 99 adult female bats across eight churches (Table 3.3.1) between July and September 2011-12. Biometric data for tagged bats are provided in Appendix 4 (Table A4.2). Bats roosted almost exclusively within the church buildings they inhabited and rarely used alternative roosts outside of the church. Out of 304 day roost records ($n = 87$ bats) only 31 (10.2%) represent bats roosting outside. When bats did roost outside they typically roosted alone in trees close to foraging grounds. This may be a consequence of foraging during short summer nights when bats may be forced to forage until dawn when the risk of predation during commuting back to the church is high. Inside churches, bats made use of numerous roosts and switched between roosts frequently. At most churches, the colony as a whole typically moved roost once every week (observational data). When data from experimental trials in 2013 are included, the total dataset on

Table 3.3.1 – Radio-tracking dataset used to examine the ecology of Natterer’s bats that roost in churches.

Site	Date	<i>n</i> tagged bats	Data from foraging bats		
			<i>n</i> bats	<i>n</i> nights/bat*	<i>n</i> fixes/bat*
Wood Dalling	Aug 2011	6	6	3.0	110
Ingham	July 2012	6	6	2.8	114
Guestwick	Aug 2012	14	6	3.0	152
Holme Hale	Aug 2012	16	6	3.0	164
Swanton Morley	Aug 2012	14	6	2.3	121
Toftrees	Aug 2012	15	6	2.2	116
Cley	Aug 2012	17	6	1.8	93
Salle	Sept 2012	11	6	3.0	112

* Shows mean (*n* bats)

roosting for the project includes data obtained from 180 bats at 10 churches (Table 3.2.1). During tracking of these bats, only one significant alternative roost, which may serve as a maternity roost, was discovered (at Wiveton Hall, Cley).

Data on foraging from six bats that were followed as focal individuals at each site show that home ranges of different bats vary considerably (Table 3.3.2). On average bats travelled 4.0 ± 1.4 km (range 1.4–7.7 km) from roosts to foraging areas. Only a small percentage (9.6 ± 4.1 %) of home range areas was used specifically for foraging. These ‘core foraging areas’

Table 3.3.2 – Home range areas (100% minimum convex polygons), core foraging areas (80% clusters cores) and range spans (mean maximum nightly distance from roost to centroid of cluster core foraging area) for 48 adult female Natterer’s bats (*n* = 6 bats per site).

Site	Home range area (ha)*	Core foraging area (ha)*	Max. range span (km)*
Wood Dalling	880.0 ± 810.5 (345.6 – 2345.5)	63.0 ± 41.5 (29.2 – 119.8)	4.0 ± 1.7 (2.7 – 6.4)
Ingham	1186.6 ± 703.9 (557.5 – 2468.7)	107.4 ± 50.8 (56.1 – 193.4)	4.7 ± 1.9 (2.5 – 7.7)
Guestwick	757.6 ± 280.4 (419.7 – 1138.1)	74.4 ± 33.0 (45.9 – 134.1)	5.0 ± 0.9 (3.9 – 5.9)
Holme Hale	483.3 ± 286.1 (194.5 – 878.6)	33.7 ± 23.0 (12.3 – 54.0)	3.2 ± 0.8 (2.4 – 4.2)
Swanton Morley	702.0 ± 318.3 (357.6 – 1228.9)	64.9 ± 35.3 (24.5 – 106.9)	3.8 ± 0.8 (3.1 – 5.0)
Toftrees	869.7 ± 651.7 (324.1 – 1968.9)	74.8 ± 60.3 (32.3 – 194.0)	4.6 ± 1.4 (2.9 – 6.6)
Cley	369.2 ± 63.3 (279.5 – 456.7)	44.9 ± 10.4 (34.0 – 62.4)	2.7 ± 0.7 (1.6 – 3.3)
Salle	484.59 ± 18.51 (130.9 – 754.5)	36.1 ± 18.5 (13.6 – 65.3)	3.5 ± 1.2 (1.4 – 4.7)

* Mean \pm SD (range)

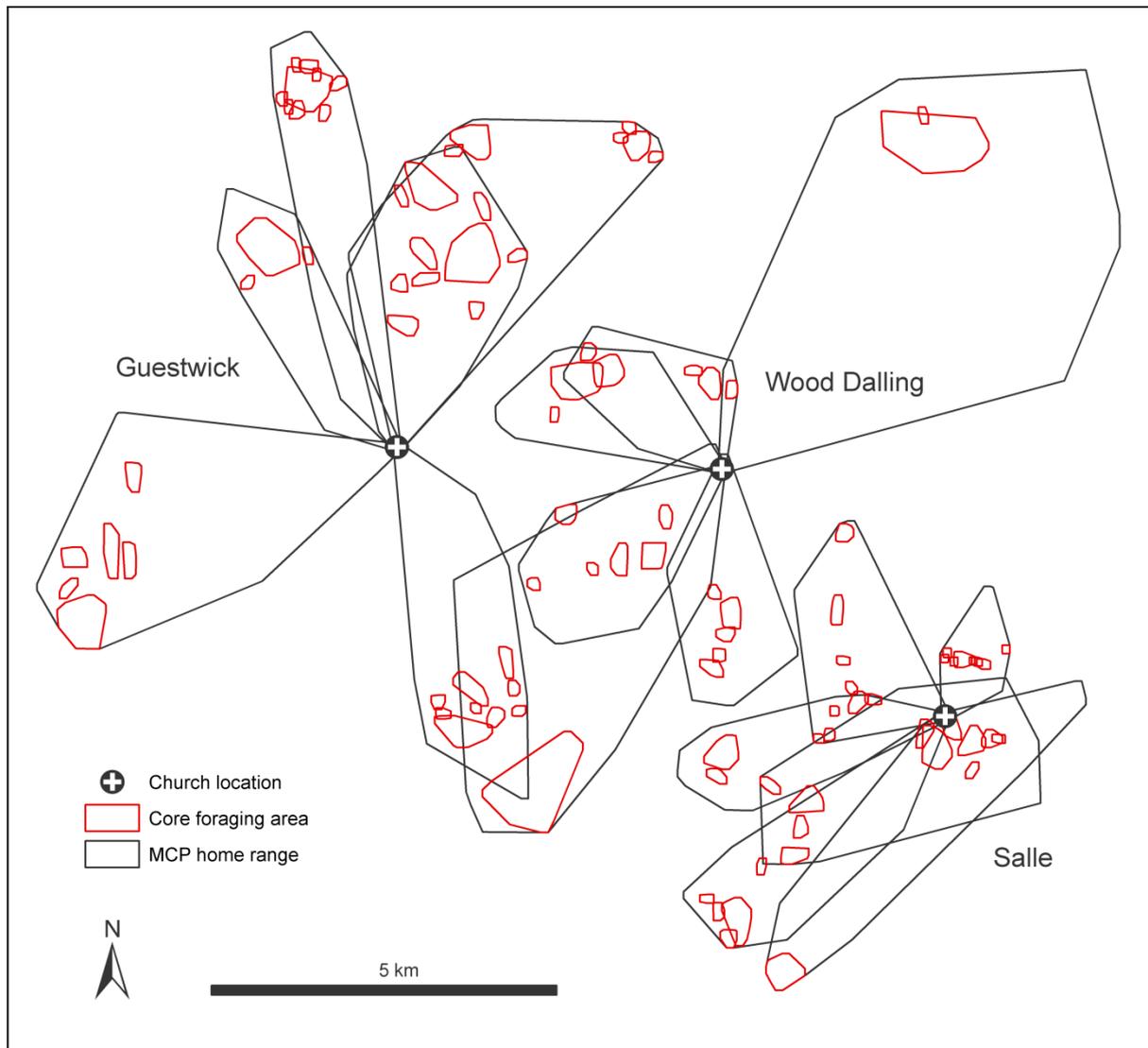


Figure 3.1 – Examples of individual bat home range areas (100% MCP; black polygons) and core foraging areas (80% cluster cores; red polygons) from 18 adult female Natterer's bats. Data are from six bats radio-tracked at Guestwick, Wood Dalling and Salle, respectively.

were similar in size among bats (mean 63.6 ± 41.8 ha) and individual bats were faithful to private foraging patches i.e. there was little or no overlap of core foraging areas among bats during the time that we followed them. Interestingly, adjacent colonies seemed to occupy exclusive and non-overlapping ranges (e.g. Fig. 3.1). Compositional analyses for each site revealed bats consistently preferred to forage in woodland, which on average comprised only 11% of available land cover, followed by grassland, over other habitat types (Table 3.3.3). A description of habitat types is provided in Appendix 2 (Table A2.1).

Arable and riparian (including fresh water, marsh, wet woodland and grassland) habitats were not preferred. Overall, built-up habitat, used here to define areas of low to medium density (<40% cover) rural residential land cover i.e. absent of urbanised areas such as cities or industrial sites, was preferred least. Cases where built-up habitat was not ranked last (Guestwick and Salle) can be explained as a random association of bats with a rare habitat

Table 3.3.3 – Habitat preferences exhibited by Natterer’s bats at eight different maternity colony sites ($n = 6$ bats per site). Habitat categories to the left of > are selected over those to the right with >>> showing a significant difference between adjacent habitat types.

Site	Ranked habitat types								p^*	
Wood Dalling	Woodland	>	Pasture	>	Arable	>	Riparian	>	Built-up	<0.01
Ingham	Woodland	>	Pasture	>	Arable	>	Riparian	>	Built-up	<0.01
Guestwick	Woodland	>	Pasture	>	Arable	>	Built-up	>	Riparian	<0.05
Holme Hale	Woodland	>	Pasture	>	Riparian	>	Arable	>	Built-up	<0.01
Swanton Morley	Woodland	>	Pasture	>	Riparian	>	Arable	>	Built-up	<0.001
Toftrees	Woodland	>	Pasture	>	Riparian	>	Arable	>	Built-up	<0.05
Cley	Woodland	>>>	Pasture	>	Arable	>	Riparian	>	Built-up	<0.05
Salle	Woodland	>	Pasture	>	Built-up	>	Riparian	>	Arable	<0.001

* P -values <0.05 show selection of habitat types is non-random.

type at these sites, rather than as a specific preference *per se* of one habitat type over another. Built-up habitat was not selected significantly over either riparian or arable in any case. On average bats emerged 85 ± 38 minutes after sunset, foraged for a total of 373 ± 57 minutes, and returned well before sunrise (mean 114 ± 37 minutes) ($n = 48$ bats). Bats rarely night roosted, either inside or outside churches (only recorded in 12 of 121 bat-nights), and so foraging is normally condensed into a single foraging bout. Night roosting events lasted on average for 27 ± 13 minutes ($n = 48$ bats).

3.3.2 Pilot studies of deterrents

Results from pilot studies of deterrents are shown in Table 3.3.4. Among the deterrent types tested, lights had the greatest effect on bat activity (combined activity of all bats present in the church, irrespective of species). On each occasion that lights were switched on bats typically ceased flying immediately and roosted until lights were switched off. Bats re-emerged soon after lights were switched off. The behavioural response to the acoustic deterrent was less pronounced but a significant reduction in activity was observed at one site (Catfield). We did not observe an effect of radar on bat activity in our tests; a small but non-significant increase in activity was observed at both sites. Following the pilot studies, it

Table 3.3.4 – Results from six pilot studies showing the effect of three deterrent types on bat flight activity in churches. Flight activity recorded as n bat passes using automated bat detectors and infrared video.

Deterrent	Site	Church	Percent change in activity*
Acoustic	Catfield	All Saints	-83.5
Acoustic	Swanton Morley	All Saints	-12.1
Lights	Necton	All Saints	-96.9
Lights	Swanton Morley	All Saints	-99.2
Radar	Wood Dalling	St Andrew	13.6
Radar	Catfield	All Saints	22.1

* Mean ($n = 10-12$ repeats) percent change in activity when deterrent applied (compared to control period).

was agreed with the PAG that experiments should be undertaken to test thoroughly the response of bats to acoustic and lighting deterrence. It was agreed also that radar would not be used subsequently in deterrence experiments, having performed least well in pilot studies and because it was prohibitively expensive for widespread use in churches.

3.3.3 Short-term acoustic deterrence of roosting bats (*Deaton deterrent*)

Across all sites the observed response of bats to the presence of an acoustic deterrent was strong. On average, almost all bats were deterred from the original roost within two days of deterrent use (Fig. 3.2). Broadly speaking we observed three ‘types’ of responses to the deterrent among sites. Response graphs for each church are provided in Appendix 11. First, all bats moved away from the original roost on the first day after the deterrent is switched on and roosted elsewhere in the church ($n = 3$ sites). Second, bats continued to use the original roost for up to two days, albeit in decreasing numbers, but eventually most roosted elsewhere in the church ($n = 1$ site). Third, the majority of tagged bats eventually roosted outside the church after 1-2 days of deterrent use ($n = 2$ sites). Table 3.3.5 summarises the types of roosts used by bats when they roosted outside of churches.

Examination of the movement states of bats during control, deterrent, and post-deterrent periods (Table 3.3.6) shows that during the control period bats in the original roost tend to stay there (94% chance of returning to this roost each day) and there is a roughly fifty-fifty chance that bats roosting in an alternative roost or outside of the church will either stay in those locations or move back to the original roost. During the deterrent period, initially some bats continue to use the original roost (37% chance of returning) but once bats leave

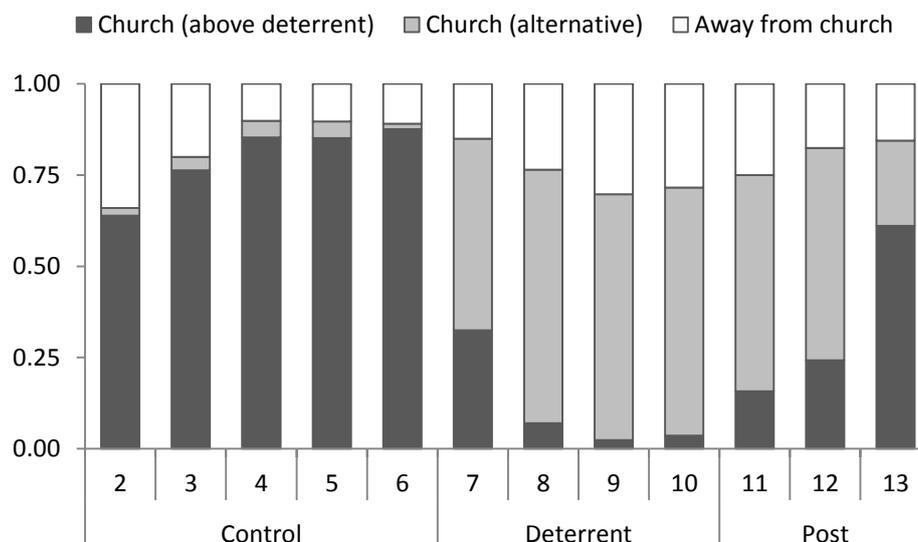


Figure 3.2 – Mean response of Natterer’s bats ($n = 87$ bats) to short-term (four day) applications of the Deaton acoustic (ultrasound) deterrent at six churches. Shows proportion of radio-tagged bats roosting in each roost location on each day. Bats tagged on day 1. Post refers to post-deterrent period.

Table 3.3.5 – Incidences of radio-tagged Natterer’s bats roosting outside churches during 13-day experiments, including control, deterrent (Deaton ultrasound deterrent) and post-deterrent periods. Shows the number of occasions (bat-days) a bat was found in a particular roost type. The total number of bats radio-tagged at each site is provided in Table 3.3.1.

Site	<i>n</i>	Tree	Building (uninhabited)	Building (inhabited)	Unknown	Alternative Colony roosts
Guestwick	12	11	0	0	1	0
Holme Hale	38	6	0	0	32	0
Swanton Morley	0	0	0	0	0	0
Toftrees	79	29	0	* 12	38	0
Cley	37	3	* 26	2	6	1
Salle	4	0	1	0	3	0
Total	170	49	27	14	80	1

* Single building shared simultaneously by at least two tagged bats on at least one occasion

this roost it is extremely unlikely that they will return either from an alternative roost (1% chance) or from outside (3% chance), and so generally it takes 1-2 days for all bats to be deterred from using the original roost. After bats move away from the original roost it is most likely that they stay either in alternative roost locations within the church (91%) or in locations outside the church (84%). After the deterrent is removed the probability that bats return to the original roost increases and bats that make this move typically stay in this location (87%). It is more likely, however, that bats do not return to the original roost but continue to use alternative roosts (77%) or roosts outside of the church (71%). When we

Table 3.3.6 – Probability matrices showing the mean (*n* = 6 sites) probability of bats moving between different roost ‘states’ during control (deterrent off), deterrent (deterrent on) and post (deterrent off) periods; ‘original’ = roost affected by deterrent during the deterrent period, ‘alternative’ = a roost inside the church not affected by the deterrent, ‘outside’ = any roost not inside the church. ‘Post’ refers to post-deterrent period.

Period	Move from	Move to			<i>n</i> records
		original	alternative	outside	
Control	original	0.94	0.01	0.05	196
	alternative	0.45	0.45	0.10	9
	outside	0.50	0.00	0.50	34
Deterrent	original	0.37	0.49	0.14	99
	alternative	0.01	0.91	0.08	115
	outside	0.03	0.13	0.84	63
Post	original	0.87	0.13	0.00	30
	alternative	0.21	0.77	0.02	85
	outside	0.11	0.18	0.71	45

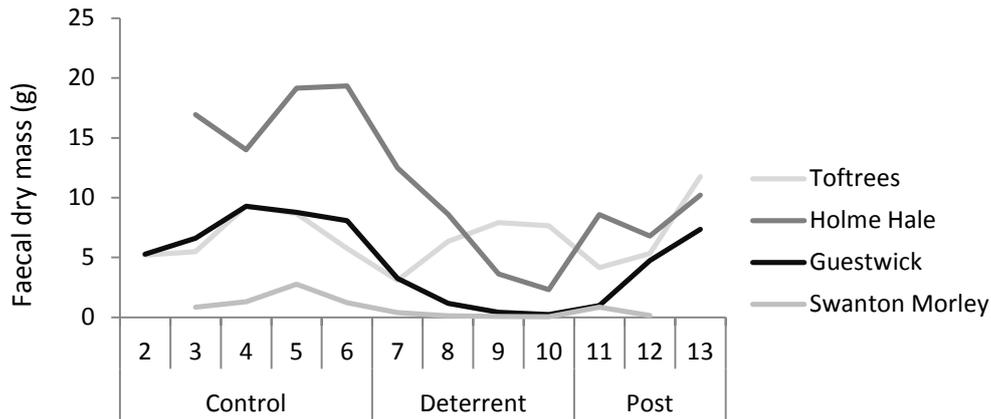


Figure 3.3 – Bat faecal material collected daily below roosts affected by the Deaton ultrasound deterrent during control, deterrent and post-deterrent periods at four churches.

fitted multistate models to transition data, in both models we found that both roost type and period contributed significantly to explaining variation in the probability of roost transition, indicating that the presence or absence of a deterrent affected significantly the movements that bats made to and from specific roost locations.

At three sites (Guestwick, Holme Hale and Swanton Morley), the volume of droppings collected below the respective original roosts reduced to zero, or near to zero, by the final day of the deterrent period (Fig. 3.3). At Toftrees, the number of droppings did not differ substantially between control and deterrent periods, probably because Toftrees is a small church with a large bat population (>100 bats) and many of the droppings that we collected will have originated from bats passing frequently over the sampling area during flight rather than from bats roosting above deterrents *per se*. Data for two sites (Cley and Salle) are not displayed because the volume of droppings that reached ground level was negligible due to bats using roosts located above ledges or in ceiling voids.

Over the 13-day experiment at each church, bats were not recorded using the bat boxes that we provided. Generally, boxes were located farther from deterrents than the distance

Table 3.3.7 – Mean (SD) distance (metres) of church-roosting bats from original main roost (roost where the Deaton acoustic (ultrasound) deterrent was applied). Calculated as mean (*n* bats) of means (*n* days) for each period (control, deterrent, post-experiment). Also shows the horizontal distance of bat boxes from deterrents.

Site	Control	Deterrent	Post	Bat box
Guestwick	0.0 (0.0)	8.0 (2.6)	0.8 (2.4)	18.9
Holme Hale	0.5 (1.9)	5.3 (4.3)	3.7 (4.5)	9.6
Swanton Morley	0.6 (1.4)	15.0 (0.0)	15.0 (0.0)	9.3
Toftrees	1.2 (1.6)	1.9 (1.8)	3.1 (1.4)	13.3
Cley	0.0 (0.0)	8.8 (6.7)	12.5 (2.0)	6.4
Salle	6.4 (13.2)	22.3 (5.1)	22.9 (4.6)	30.4

Table 3.3.8 – Foraging data obtained from Natterer’s bats during experiments to examine the response of bats to short-term applications of the Deaton acoustic (ultrasound) deterrent.

Site	Date	n bats	Mean nights/bat		Mean fixes/bat	
			Control	Deterrent	Control	Deterrent
Guestwick	Aug 2012	6	3.0	2.8	152	147
Holme Hale	Aug 2012	4	3.0	2.0	164	109
Swanton Morley	Aug 2012	6	2.3	2.3	121	130
Toftrees	Aug 2012	6	2.2	2.2	116	118
Cley	Aug 2012	6	1.8	2.3	93	118
Salle	Sept 2012	6	3.0	3.0	112	147

[†] Number of bats for which data were obtained from both control and deterrent periods

moved by bats to alternative roosts inside churches (Table 3.3.7), and so it is unlikely that the distance of boxes from deterrents was a determining factor in their lack of use.

Radio-tracking data obtained from foraging bats are recorded in Table 3.3.8. The combined ranging and nocturnal activity data for all bats across all sites (Table 3.3.9) showed that on

Table 3.3.9 – Foraging data obtained from Natterer’s before and during application of the Deaton deterrent.

	Control (n = 86 bat-nights)	Deterrent (n = 84 bat-nights)
<i>Dataset</i>		
n bats	34	34
n nights (per bat)*	2.5 ± 0.8 (1-3)	2.5 ± 0.7 (1-3)
n fixes (per bat)*	124 ± 43 (37-190)	129 ± 39 (36-190)
<i>Home ranges</i> [†]		
100% MCP area (ha)	618.5 ± 374.8 (130.9-1968.9)	610.3 ± 294.6 (138.4-1290.7)
80% Cluster area (ha)	56.0 ± 36.3 (12.3-194.0)	50.9 ± 30.8 (11.9-135.7)
Prop. of MCP as Cluster	0.10 ± 0.04 (0.03-0.23)	0.09 ± 0.05 (0.03-0.26)
Maximum Range Span (km)	3.8 ± 1.2 (1.4-6.6)	3.9 ± 1.1 (1.7-6.4)
<i>Nocturnal activity</i> [‡]		
Emergence (min after sunset)	83 ± 35 (48-183)	92 ± 47 (49-253)
Final return (min before sunrise)	115 ± 38 (73-273)	127 ± 56 (21-249)
Total foraging time (min)	367 ± 54 (199-447)	371 ± 58 (261-471)
Foraging as prop. of total activity	98.7 ± 3.2 (86.1-100.0)	99.4 ± 1.5 (93.8-100.0)
<i>Night roosting</i>		
n bats that night roosted (≥15 min)	8 (23.5%)	8 (23.5%)
n bat-nights where roosting recorded	11 (12.8%)	9 (10.7%)
Mean length of roosting bout (min)	29 ± 13 (15-50)	23 ± 16 (15-63)

* Mean ± SD (range); [†] Mean (bats) using MCP and cluster polygons calculated for each control and deterrent period for each bat; [‡] Mean (bats) of means (bat-nights).

average the foraging behaviour of bats appeared to be unaffected by the presence of an acoustic deterrent. When we fitted models to home ranges (100% MCPs), core foraging areas (80% clusters), maximum range spans, time of emergence, time of return, and time spent foraging, in all cases we found a significant effect of site i.e. bat foraging behaviour was site-dependent; however, no effect of deterrent was found for any of the response variables tested. When interactions between site and period were modelled we found a significant effect for time of emergence only, suggesting that the deterrent may influence emergence time at specific sites. More specifically the model indicated that at Salle the presence of the deterrent caused bats to emerge earlier than during control periods. A closer inspection of the data revealed that mean emergence time for bats at Salle during the deterrent period (72 ± 30 minutes, $n = 18$) was similar to the mean across all sites (92 ± 47 minutes, $n = 84$) but emergence time during the control period (141 ± 44 minutes, $n = 18$) was considerably later than the mean (83 ± 35 minutes, $n = 86$).

Examination of foraging area overlap among bat-nights revealed that the mean percent overlap among control-control, deterrent-deterrent and control-deterrent pairs was 32.9 ± 17.0 %, 33.5 ± 17.4 % and 28.9 ± 16.4 % respectively, indicating a smaller (approximately 4%) overlap for pairs of different night types compared to overlap for same night types. There was a negative correlation between the time period between pairs of nights and overlap i.e. nights that are close together have greater overlap, which might also explain the smaller overlap for pairs of different night types, given that control nights and deterrent nights were grouped together temporally. When we fitted an MMMC model with MCMC estimation to these data, initially comparison type, i.e. control-control, deterrent-deterrent or control-deterrent pairs of foraging areas, described some of the variation in the data i.e. there was a significant effect of comparison type; however, this effect disappeared when time interval was also included in the model. Indeed, removing comparison type from the

Table 3.3.10 – Habitat preferences of Natterer’s bats ($n = 6$ bats per site) radio-tracked at five churches during control and deterrent periods, using the Deaton ultrasound deterrent. Habitat categories to the left of > are selected over those to the right with >>> showing a significant difference between adjacent habitat types.

Site	Period	Ranked habitat types							P^*		
Guestwick	Control	Woodland	>	Pasture	>	Arable	>	Built-up	>	Riparian	<0.05
	Deterrent	Woodland	>>>	Pasture	>	Arable	>	Built-up	>	Riparian	<0.001
Swanton	Control	Woodland	>	Pasture	>	Riparian	>	Arable	>	Built-up	<0.001
	Deterrent	Woodland	>>>	Pasture	>	Riparian	>	Arable	>	Built-up	<0.001
Toftrees	Control	Woodland	>	Pasture	>	Riparian	>	Arable	>	Built-up	<0.05
	Deterrent	Woodland	>	Pasture	>	Riparian	>	Arable	>	Built-up	<0.01
Cley	Control	Woodland	>>>	Pasture	>	Arable	>	Riparian	>	Built-up	<0.05
	Deterrent	Woodland	>	Pasture	>	Riparian	>	Built-up	>	Arable	<0.01
Salle	Control	Woodland	>	Pasture	>	Built-up	>	Riparian	>	Arable	<0.001
	Deterrent	Woodland	>	Pasture	>	Arable	>	Built-up	>	Riparian	<0.001

* P -values <0.05 show selection of habitat types is non-random.

analysis resulted in a more parsimonious model. The sets of random effects for the bats and the pairs of nights within each bat both contributed significantly to explaining the overlap data we recorded. It appears that individual bats may shift the focus of their foraging effort to different areas within patches on a nightly basis, perhaps to maintain encounter rates with prey by avoiding foraging in areas that were exploited during the previous night(s), but importantly this effect is not influenced by the presence of a deterrent at roosts.

Habitat preferences of bats were also unaffected by deterrent use. Woodland, followed by pasture, were the most preferred habitat types during both control and deterrent periods across all sites (Table 3.3.10). The preference for lower-ranking habitat types varies between sites but rarely between control and deterrent periods (Table 3.3.10).

3.3.4 Short-term acoustic deterrence of roosting bats (CR deterrent)

We observed a mixed response by bats to the CR deterrent (Fig. 3.4). At Salle, the response mirrored that recorded for the Deaton deterrent, with numbers of bats using the roost falling dramatically from around 90 to three after one day of deterrent use. No radio-tagged bats were recorded in the original roost during the deterrent period and most bats (78.1 ± 9.4 bats) moved to one alternative roost inside the church approximately 20 metres away. At Toftrees the CR deterrent did not deter bats effectively from the roost. Approximately one quarter of the colony (28-37 bats) continued to use the roost for the first three deterrent days and on the fourth deterrent day this number increased to 84 bats i.e. more than half of bats returned to roost above the deterrent. Between one and three tagged bats were recorded in the original roost on each deterrent day. Those bats not in the original roost moved to alternative roosts nearby (2-4 metres away). When the deterrent units were taken down at Toftrees we found that droppings and urine had accumulated in the conical speaker wells and this may have reduced the intensity of ultrasound reaching the roost, allowing bats to return. Alternatively, the bats may have habituated to the ultrasound.

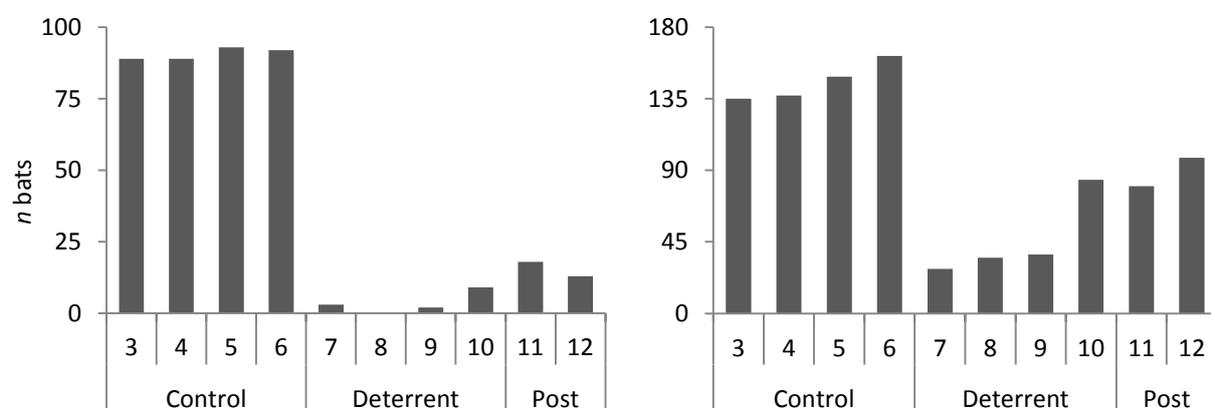


Figure 3.4 – Response of bats to short-term applications of the CR acoustic (ultrasound) deterrent at two churches, Salle (left) and Toftrees (right). Shows emergence count data for control (deterrent on), deterrent (deterrent on) and post-deterrent (deterrent off) periods.

3.3.5 Long-term acoustic deterrence of roosting bats

We found no evidence of habituation to the Deaton deterrent and similar numbers of bats continued to roost in churches throughout the experimental period i.e. long-term exposure to the deterrent did not appear to result in bats being excluded from churches (Fig. 3.5).

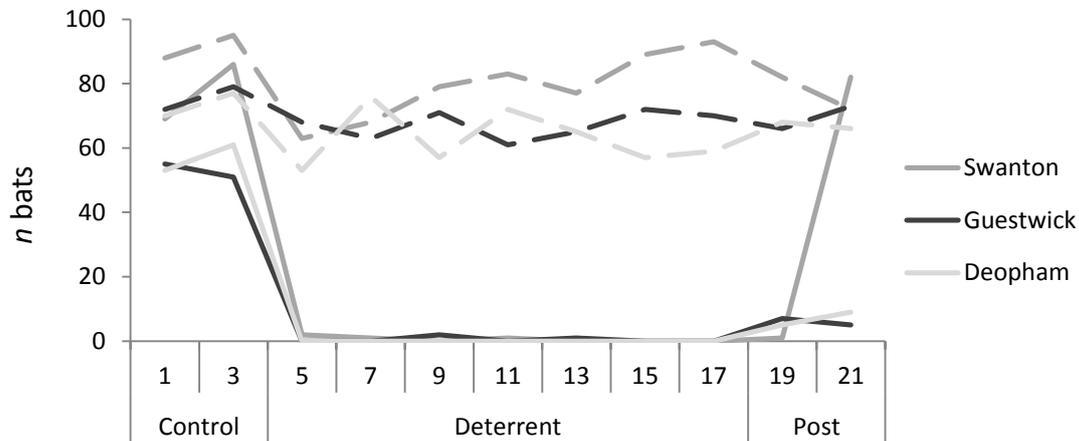


Figure 3.5 – Response of Natterer’s bats to long-term applications of the Deaton acoustic (ultrasound) deterrent. Shows the number of bats roosting inside the church (dashed lines) and in the roost above the deterrent (solid lines) at three churches during control (deterrent off), deterrent (deterrent on), and post-deterrent (deterrent off) periods. Data were recorded every other day i.e. on days 1, 3, 5 etc. during each experiment.

3.3.6 Deterrence of roosting bats using artificial lighting

After an initial control period of five days, lights were switched on at midnight. Almost all Natterer’s bats flying in the church at that time headed for the original roost immediately and stopped flying. By the following morning all tagged bats were in the original roost. On the following evening (lights on all night) no bats emerged from the roost. On the next deterrent night (again lights on all night) only two bats emerged and both bats returned to the roost after foraging. At this point concerns over bat welfare prompted the experiment to be terminated early and the lights were switched off. The following night (without lights) all bats with functioning tags ($n = 8$) emerged from the roost but substantially earlier than during the control period, suggesting that they were energetically stressed. On the next night (again without lights) 7 of 8 bats emerged at the normal time. It was agreed with the PAG that this experiment should not be repeated due to concerns over bat welfare when using lights as a deterrent in this way.

3.3.7 Creation of bat ‘no-fly zones’ using artificial lighting

The response of bats to lights was marked. The number of bat passes recorded in lit-zones reduced dramatically when lights were switched on compared to control periods (lights off). This was evident from both bat detector (Fig. 3.6) and video (Fig. 3.7) data. The few passes that we recorded during lit periods tended to be pipistrelles, with the number of Natterer’s

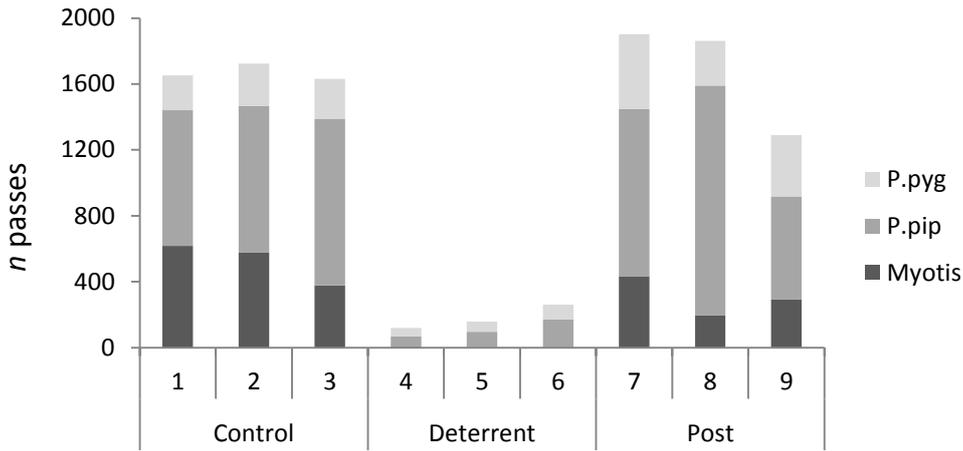


Figure 3.6 – Response of bats to artificial lighting in churches. Shows cumulative bat passes ($n = 4$ church sites) recorded by automated bat detectors in lit zones (chancel) of churches where ambient light levels were raised during deterrent periods. Shows data for control (lights off), deterrent (lights on) and post-deterrent (lights off) periods. *Myotis* spp. are not readily distinguishable from Anabat bat detector recordings and so are lumped together as ‘Myotis’. *P.pyg* = soprano pipistrelle *Pipistrellus pygmaeus* and *P.pip* = common pipistrelle *P. pipistrellus*.

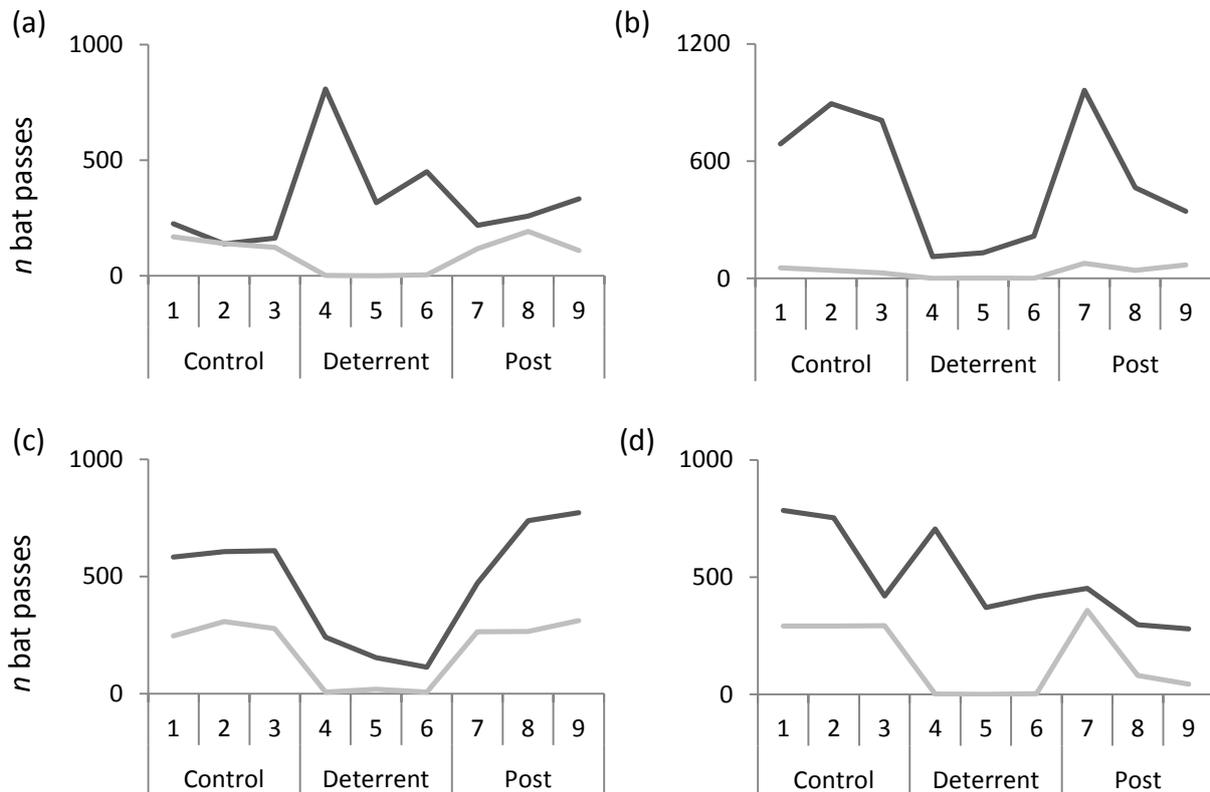


Figure 3.7 – Number of bat passes recorded each night, for two hours after sunset, by infrared video cameras in lit (light) and unlit (dark) zones during lighting deterrence experiments. (a) Cley, (b) Great Hockham, (c) Holme Hale and (d) Salle for control (lights present but switched off), deterrent (lights switched on) and post-deterrent (lights not present) periods.

Table 3.3.11 – Lux levels in lit and dark zones during control and deterrent periods of four lighting deterrence experiments. Also shows distance of dark zones to lights.

Site	Lit zone		Dark zone		
	Lux Control	Lux Deterrent	Lux Control	Lux Deterrent	Distance to lights (m)
Cley	<0.1	98.9	<0.1	0.4	31.7
Great Hockham	<0.1	72.3	<0.1	1.0	15.9
Holme Hale	<0.1	223.9	<0.1	1.4	15.5
Salle	<0.1	273.0	<0.1	0.3	31.3

bat passes reducing to zero, or near to zero, at all sites. The effect on bats in dark-zones was variable. During lit periods, activity reduced at two churches (Great Hockham and Holme Hale), increased at one church (Cley), and changed little at another (Salle) (Fig. 3.7). This variability is likely due to the relative success experienced with controlling light spill into dark zones at each church, which was influenced by the size of churches i.e. the distance of dark zones from lit zones. At Holme Hale and Great Hockham, two churches with relatively small spatial foot prints, the distance of dark zones from lit zones was half that for Cley and Salle, two churches with relatively large spatial foot prints, and as a result, light levels in dark zones were noticeably higher (Table 3.3.11). Thus, light spill at Great Hockham and Holme Hale may have been sufficient to deter some bats from dark zones.

At all churches, we observed an effect of lighting on the emergence and nocturnal activity of Natterer’s bats. Emergence times of radio-tagged bats were later and more variable (mean 162 ± 203 minutes after sunset; range 49-304 minutes) than during the control period (86 ± 46 minutes after sunset; range 46-117 minutes). We also recorded 23 incidences (bat-nights) where bats did not leave the church during a deterrent night. This accounted for nearly one fifth of all ‘emergence’ records ($n = 120$) during deterrent periods i.e. 20 % of the time bats remained in the church all night. This represents a substantial decrease in the amount of time spent outside churches i.e. time spent foraging, and as a result, bats may have been energetically stressed.

3.3.8 Population models

With a starting population of 100 females, in order to bring about population extinction (extinction probability = 1) over an arbitrary 500 year period (all other parameters being equal), annual survival would need to decline by 10% for individuals less than a year old (S_1), 11% for individuals in their second year (S_2), or just 2% for individuals in their third year or older (S_3). In terms of the constituents of productivity, changes in mean litter size of individuals in their first breeding season (L_1) or the proportion individuals breeding in their first season ($Alpha_1$) are likely to have little effect on the population growth rate. The mean litter size of individuals in their second breeding season or later (L_2) and the proportion of individuals breeding in their second season or later ($Alpha_2$) would both need to decline by

about 8%. As was the case for soprano pipistrelles, these analyses highlight that demographic monitoring should focus on obtaining robust estimates for adult survival, with a lower priority to obtain robust estimates of first and second year survival, mean litter size of bats in their second breeding season or later, and the proportion of individuals breeding in their second season or later.

Our radio-tracking data suggest that if Natterer's bats are forced outside of a church they may struggle to locate suitable alternative maternity roosts. It is possible then that the productivity of Natterer's bats could be reduced in a similar way to that described for big brown bats following an exclusion event (Brigham & Fenton 1986). If we were to assume a similar proportional reduction in litter size in Natterer's bats to big brown bats, resulting in a decline in litter size from 1.00 to 0.44 across all age-classes, this would result in a population growth rate of 0.93, i.e. a 7% annual decline, which would reduce the local population size to below the current level in the following year. If we assume, as a best case scenario, that this species is able to find a suitable roost by the following breeding season (which is highly questionable given that church colonies seem to occupy non-overlapping territories and finding suitable roosting sites within established foraging areas may be problematic) and that litter size would return to normal values at that point, the local Natterer's bat population should almost recover to the pre-exclusion level following a subsequent breeding season. In reality, we do not know how Natterer's bats would respond following exclusion but this illustrates that the Favourable Conservation Status of the species is likely to be adversely affected under certain conditions. Whilst we hypothesise that exclusion is perhaps most likely to impact on demographic rates through a reduction in productivity, we have no information to be able to speculate on the impacts of exclusion on survival. However, the modelling here demonstrates that small reductions in annual survival, particularly of adult survival, would result in a declining growth rate. Additional detail for model results is provided in Appendix 5.

3.4 Discussion

We have shown conclusively that the behaviour of bats inside churches can be manipulated using deterrents. If used judiciously, lighting and high intensity ultrasound can deter bats from sensitive areas within churches and limit the spread of droppings and urine without obvious detrimental impacts on behaviour or welfare (objective 2, Table 3.1.1). However, there is potential to cause serious harm to bats, and so the use of deterrents needs to be strictly regulated.

Our data show that in Norfolk, Natterer's bats appear to be dependent on churches as roosts. This dependence may vary geographically but we found little evidence that bats use significant alternative roosts away from churches, including other churches (objective 8, Table 3.1.1). Out of more than 1000 day roost records ($n = 180$ bats), we never recorded an individual bat roosting in more than one church, even when we radio-tracked bats from

neighbouring churches four kilometres apart. Our data on foraging suggest that individual bats and colonies occupy exclusive and non-overlapping ranges, indicating territoriality. Bats were also highly faithful to their core foraging areas. This type of spatial organisation, similarly described by Smith & Racey (2008), and fidelity to foraging sites and to churches means that Natterer's bats may struggle to relocate quickly to new roosts if excluded from churches and that relocation may have a detrimental effect on foraging behaviour if bats are required to established new foraging areas.

Due to commitments fulfilling other project objectives, and in agreement with the PAG, physical measurements to examine the impact of deterrents on the welfare of a representative sample of the local population were not recorded from bats (objective 5, Table 3.1.1). Our models suggest that if forcing bats out of churches resulted in reduced productivity, as observed by Brigham and Fenton (1986) for big brown bats, *Eptesicus fuscus*, then population growth may be reduced subsequently. Moreover, exclusion may result in bats becoming energetically stressed, which could affect survival, and our models suggest that a small reduction in adult survival could impact negatively on population growth (objective 7, Table 3.1.1). We conclude that excluding Natterer's bats from churches is likely to be detrimental to their welfare and Favourable Conservation Status.

Inside churches, Natterer's bats make use of multiple roosts and may move between roosts frequently. The specific roosting behaviour at each church depends on the availability of suitable roost features and probably also the size of the colony present. At Toftrees and Holme Hale, two churches with relatively small spatial footprints and large numbers of bats (>100), bats expressed high fidelity to one or two specific roosts. At larger churches bats were typically more transient. This has important implications for deterrent use. When the Deaton deterrent was applied at Toftrees and Holme Hale, large numbers of bats were excluded from the church, probably because they were unable to find suitable alternative roost space away from the deterrent. At all other churches bats were not forced outside. Careful consideration is needed, therefore, when applying deterrents in churches; prior knowledge of the roosting behaviour of bats is essential to gauge the most appropriate level of deterrent use on a case-by-case basis.

The types of deterrents employed in this study were selected based on a review of literature (objective 1, Table 3.1.1). While we have provided proof of principle that these deterrents can be effective, none were designed specifically for use in churches, and so further development of these tools will be necessary to make them more practical and to ensure that they are as safe as possible for bats. Due to it emitting loud audible noise, the Deaton deterrent was switched off during the day. Given that bats roost mainly during the day, the effect of this deterrent may be significantly stronger if frequencies audible to humans were removed by filtering so that the devices could be switched on permanently. Our experiments with the CR deterrent show that it should be feasible to create an effective acoustic deterrent in a form that is practical and affordable for churches (objective 6, Table 3.1.1).

Further investment in and development of low cost ultrasonic deterrents with higher duty cycles and higher intensity will be valuable.

The overall costs associated with applying deterrents in churches will vary on a case-by-case basis depending on what application of deterrence is considered most appropriate. The correct level of deterrence will depend on, *inter alia*, numbers and species of bats present, the size and structure of churches, and the manner in which bats make use of the church e.g. the number and location of roosts and the location of exits from the building. Lighting is potentially a much more cost-effective method of deterrence than acoustic techniques. The lighting units we used cost £24 per unit. Sometimes two of these were used in large churches. In contrast the Deaton acoustic deterrents cost £1110 per church. This estimate includes two speakers and one power supply but does not include shipping costs of these bulky items. The CR deterrents cost £600 for the three units we deployed. Concept Research Ltd estimated development costs of a further £20K to refine their speakers to make them more effective in terms of optimising frequency output and increasing intensity (objective 6, Table 3.1.1). Development costs are needed because there is no commercial market for bat deterrents; funding will enable Concept Research Ltd to produce the relatively small number of units required for use under licence. Apart from deterrent costs, churches will also be faced with costs of employing ecological consultants to survey for bat presence as well as the time constraints of obtaining necessary Faculty permissions if deemed necessary. An explanation of Faculty Jurisdiction (the Church of England's regulation of works to church buildings, their contents and churchyards) can be found at <http://www.churchcare.co.uk/churches/guidance-advice/making-changes-to-your-building/permissions/faculty-jurisdiction>.

While lights may represent the most affordable deterrent option, further research is required to determine the safest application of this deterrent type. When left on at night, lights can entomb Natterer's bats in their roosts and this may result in death. Evidence from Germany (Karl Kugelschafter, unpublished data), where thousands of Greater mouse-eared bats (*Myotis myotis*) were entombed in roosts and died after lights were left on inside a church, suggests that this is a behavioural response that is shared among *Myotis* spp. Indeed, Bechstein's bats (*Myotis bechsteinii*) roosting in mines also show reluctance to exit roosting sites that are illuminated (Karl Kugelschafter, unpublished data). Illuminating roosts and roost entrances, therefore, either at churches or at other roost sites, poses a serious threat to bats. Although we did not pursue this approach to deterrence in this project, investigations of different light intensities or light types may reveal a lighting strategy that could be employed at roost entrances to deter bats from roosts with no risk of entombment.

We have shown that directed use of lighting to raise ambient light levels is an effective technique for creating bat 'no-fly zones' in large areas of churches. However, light-spill into dark areas can have an effect on emergence which, if sustained, could impact adversely on bat welfare by restricting foraging time. During our directed lighting experiments, all radio-tagged bats left the church to forage at least once during deterrent periods i.e. bats were

not entombed in roosts, and bats continued to fly through dark zones during deterrent periods. The lights were probably disrupting the ability of bats to determine accurately the time of day via light-sampling, and so when lights were left on in churches, emergence time may have become dictated predominantly by hunger rather than by perceived ambient light levels outside churches. With further research into different light-types, appropriate light intensities, and effective baffles to control light spill, it should be possible to reduce the adverse impacts of directed lighting on bat emergence and foraging.

It is important to note that while Natterer's bats are deterred effectively by lights, *Pipistrellus* spp. may be less deterred. In our experiments, numbers of common and soprano pipistrelle passes dropped dramatically in lit zones when lights were switched on; however, neither species was deterred completely from lit zones. We also have observed hundreds of soprano pipistrelles flying inside St Peter and St Paul church at Heydon when internal security lights were left on at dusk (Zeale *et al.*, unpublished data), which suggests that this species can habituate to lights. No *Myotis* spp. were recorded at Heydon. Future research should examine the tolerance of *Pipistrellus* spp. to light to determine whether this form of deterrence can be effective over the long-term.

Compared to lights, the potential risk to bats from acoustic deterrence is comparatively low. If gauged correctly, acoustic deterrence will allow bats to continue to roost in churches while preventing them from roosting in sensitive locations and above furnishings, fittings and artefacts of historic and cultural significance. Our data also show that the foraging behaviour of bats is not affected and, crucially, bats do not habituate to this form of deterrence.

Due to difficulties accessing roosts inside churches, we were not able to determine the key environmental conditions of occupied roosts prior to the design and installation of bat boxes (objective 3, Table 3.1.1). In agreement with the PAG, this objective was not pursued because temperature profiles of Natterer's bat maternity colonies have been recorded previously by Smith & Racey (2005), and so their data were used to inform the temperatures used in our bat boxes. A literature review of box types was produced to identify the most appropriate box (objective 1, Table 3.1.1). Despite this, we recorded only limited evidence of occupancy by bats (objective 4, Table 3.1.1). The rate of occupancy of bat boxes can be affected by a number of variables, such as microclimate within the box, including the amplitude of fluctuations in temperature over a 24 hour period, and external factors such as light levels and proximity to sources of disturbance. Additionally, as we observed, bats may already use a number of alternative roosts inside churches and these roosts may have been used historically over long periods of time. Existing alternative roosts will probably be selected preferentially over new box installations and, consequently, it may take years, rather than days, for colonies of bats to adopt bat boxes, as has been shown for soprano pipistrelles in Norway (Michaelson 2011). Despite this, it may be possible to improve the rate of uptake of boxes by improving their design. Further research should be carried out to inform the design of boxes that simulate closely the preferred roosting conditions of bats.

Further research should also focus on examining the responses of different species to deterrent use, as responses are likely to be species-specific given inter-specific differences in audition and light tolerance. Investigating the impact of introducing deterrents early in the season to deter bats returning to maternity roosts will also be valuable for highlighting whether there are times of year when it is more appropriate to deter bats than when we conducted experiments. Some of these research avenues will be followed up in a pilot study funded by English Heritage due to begin in the spring of 2014.

3.5 Conclusion

We have shown that in Norfolk, Natterer's bats appear to be dependent on churches for roosting. We predict that excluding Natterer's bats from churches is likely to impact negatively on their welfare and Favourable Conservation Status. Even so, with judicious use of deterrents, problems caused by bats in churches can be mitigated. Deterrents can be used to move roosting sites within churches and limit the spread of droppings and urine so that problems to congregations and to artefacts of historic and cultural significance can be much reduced. In order to protect Favourable Conservation Status, these deterrents will need to be used under licence.

A follow-on pilot study is planned that will enable selected churches that are severely affected by bats to implement measures to protect heritage of national and international significance. Outcomes could also include reducing the time required to clean churches, as bats and their waste would be concentrated into smaller areas. These improvements would benefit congregations, as well as members of the public who have an interest in the historic value of churches, by helping to ensure the upkeep and continued use of these buildings.

4 References

- Aebischer, N.J., Robertson, P.A. & Kenward, R.E. (1993) Compositional analysis of habitat use from animal radiotracking data. *Ecology*, **74**, 1313-1325.
- Altringham, J.D. (1996) *Bats Biology and Behaviour*. Oxford University Press, Oxford.
- Arnett, E.B., Hein, C.D., Schirmacher, M.R., Huso, M.M.P. & Szewczak, J.M. (2013) Evaluating the effectiveness of an ultrasonic acoustic deterrent for reducing bat fatalities at wind turbines. *PLoS ONE*, doi:10.1371/journal.pone.0065794.
- Amelon, S.K., Dalton, D.C., Millspaugh, J.J. & Wolf, S.A. (2009) Radiotelemetry: Techniques and Analysis In: *Ecological and Behavioural methods for the Study of Bats* (2nd ed.) (eds Kunz, T.H. & Parsons, S.). John Hopkins University Press.
- Barlow, K.E. & Jones, G. (1997) Function of pipistrelle social calls: field data and a playback experiment. *Animal Behaviour*, **53**, 991-999.
- Barlow, K.E. & Jones, G. (1999) Roosts, echolocation calls and wing morphology of two cryptic species of *Pipistrellus pipistrellus*. *Zeitschrift für Säugetierkunde*, **64**, 257-268.
- Bartonička, T., Bielik, A. & Řehák, Z. (2008) Roost switching and activity patterns of the soprano pipistrelle *Pipistrellus pygmaeus* during lactation. *Annales Zoologici Fennici*, **45**, 503-512.
- Briggs, P. (2004) Effect of barn conversion on bat roost sites in Hertfordshire, England. *Mammalia*, **64**, 353-364.
- Brigham, R.M. & Fenton, M.B. (1986) The influence of roost closure on the roosting and foraging behaviour of *Eptesicus fuscus* (Chiroptera: Vespertilionidae). *Canadian Journal of Zoology*, **64**, 1128-1133.
- Browne, W.J. (2009) MCMC Estimation in MLwiN v2.1. Centre for Multilevel Modelling, University of Bristol.
- Davidson-Watts, I. (2007) Roost selection, foraging behaviour and habitat use by two cryptic species of pipistrelle bat. PhD thesis, University of Bristol.
- Davidson-Watts, I. & Jones, G. (2006) Differences in foraging behaviour between *Pipistrellus pipistrellus* (Schreber 1774) and *Pipistrellus pygmaeus* (Leach 1825). *Journal of Zoology*, **268**, 55-62.
- Davidson-Watts, I., Walls, S. & Jones, G. (2006) Differential habitat selection by *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus* identifies distinct conservation needs for cryptic species of echolocating bats. *Biological Conservation*, **133**, 118-127.
- Entwistle, A.C., Racey, P.A. & Speakman, J.R. (1997) Roost selection by the brown long-eared bat *Plecotus auritus*. *Journal of Applied Ecology*, **34**, 399-408.
- Lewis, S.E. (1995) Roost fidelity in bats: a review. *Journal of Mammalogy*, **76**, 481-496.
- Lourenco, S.I. & Palmeirim, J.M. (2004) Influence of temperature in roost selection by *Pipistrellus pygmaeus* (Chiroptera): relevance for the design of bat boxes. *Biological Conservation*, **119**, 237-243.
- Michaelson, T. C. (2011) BCI bat houses pay off in Norway. In: *Bats: Bat Conservation International*, **29**, 9-11.

- Neilson, A.L. & Fenton, M.B. (1994) Responses of little brown myotis to exclusion and to bat houses. *Wildlife Society Bulletin*, **22**, 8-14.
- Nicholls, B. & Racey, P.A. (2006) Contrasting home-range size and spatial partitioning in cryptic and sympatric pipistrelle bats. *Behavioural Ecology and Sociobiology*, **61**, 131-142.
- Nicholls, B. & Racey, P.A. (2006) Habitat selection as a mechanism of resource partitioning in two cryptic bat species *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*. *Ecography*, **29**, 697-708.
- Rasbash, J., Charlton, C., Browne, W.J., Healy, M. and Cameron, B. (2005) *MLwiN Version 2.02*. Centre for Multilevel Modelling, University of Bristol.
- Reckardt, K. & Kerth, G. (2007) Roost selection and roost switching of female Bechstein's bats (*Myotis Bechsteinii*) as a strategy of parasite avoidance. *Oecologia*, **154**, 581-588.
- Smith, P.G. & Racey, P.A. (2005) The itinerant Natterer: physical and thermal characteristics of summer roosts of *Myotis nattereri* (Mammalia : Chiroptera). *Journal of Zoology (London)*, **266**, 171-180.
- Speakman, J.R. & Thomas, D.W. (2003) Physiological Ecology and Energetics of Bats In: *Bat Ecology* (eds Kunz, T.H. & Fenton, M.B.). The University of Chicago Press.
- Smith, P.G. & Racey, P.A. (2008) Natterer's bats prefer foraging in broad-leaved woodlands and river corridors. *Journal of Zoology*, **275**, 314-322.
- Stawski, C., Willis, C.K.R. & Geiser, F. (2013). The importance of heterothermy in bats. *Journal of Zoology (Lond.)*, doi:10.1111/jzo.12105.
- Stebbing, R.E. (1988) *Conservation of European bats*. Christopher Helm, London.
- Stebbing, R.E. (1993) *The Greywell Tunnel: An internationally important haven for bats*. English Nature. British Wildlife Publishing, Hampshire, UK.
- Stone, R.C. & Wiebers, J.E. (1967) Temperature regulation in the little brown bat, *Myotis lucifugus*. In: *Mammalian Hibernation* (eds Fisher, K.C., Dawe, A.R., Lyman, C.P., Schonbaum, E. & South, F.E., JR.), Vol. III, pp. 97-109. Oliver & Boyd and American Elsevier, New York.
- Stone, E.L., Jones, G. & Harris, S. (2013) Mitigating the effect of development on bats in England with derogation licensing. *Conservation Biology*, **27**, 1324-1234.
- Thompson, M.J.A. (1992) Roost site philopatry in female pipistrelle bats *Pipistrellus pipistrellus*. *Journal of Zoology*, **228**, 673-679.
- Vonhof, M.J. & Barclay, R.M.R. (1996) Roost-site selection and roosting ecology of forest-dwelling bats in southern British Columbia. *Canadian Journal of Zoology*, **74**, 1797-1805.
- Whitaker, J.O., Jr. & Gummer, S.L. (1992) Hibernation of the big brown bat, *Eptesicus fuscus*, in buildings. *Journal of Mammalogy*, **73**, 312-316.
- Whitaker, J.O., Jr. & Gummer, S.L. (2000) Population structure and dynamics of big brown bats (*Eptesicus fuscus*) hibernating in buildings in Indiana. *American Midland Naturalist*, **143**, 389-396.
- Willis, C.K.R. & Brigham, R.M. (2004) Roost switching, roost sharing and social cohesion: forest-dwelling big brown bats, *Eptesicus fuscus*, conform to the fission-fusion model. *Animal Behaviour*, **68**, 495-505.

Zeale, M.R.K., Davidson-Watts, I. & Jones, G. (2012) Home range use and habitat selection by barbastelle bats (*Barbastella barbastellus*): implications for conservation. *Journal of Mammalogy*, **93**, 1110-1118.

APPENDIX 1 – Project 1: study sites and exclusion procedures

Below are three examples of different techniques used during exclusion experiments to exclude soprano pipistrelle bats from roosts. In all three cases, all bats were excluded successfully from the roost in a single day. Successful exclusions rely on one-way measures at roost access points to allow bats to leave but not return. These temporary installations are eventually removed and roost exits are sealed permanently.



Figure A1.1 – One-way exclusion measure installed at Crakemarsh. In this example, gaps in brickwork are filled in and one hole is left open to create a single exit point for bats. Plastic guttering and a plastic bag ‘shoot’ create an effective one-way exclusion measure for bats. Images: Matt Zeale



Figure A1.2 – One-way exclusion measure installed at Shackleford. Plastic ‘flashing’ can be used to great effect to exclude bats from roosts where multiple roost exits exist along the length of a building under eaves. Images: Matt Zeale



Figure A1.3 – One-way exclusion measure installed at Studland. On buildings that have a large number of potential roost access points, plastic sheeting is a cheap material that can be used to seal off large parts of the building while leaving simple one-way measures at key exit points (identified during emergence surveys). Images: Matt Zeale

APPENDIX 2 – Bat trapping, radio-tracking and analysis of spatial data

Project 1 – Exclusion of house-dwelling soprano pipistrelles

Bats were caught using hand nets as they emerged from roost exits at dusk. Lightweight radio-telemetry tags (PicoPip Ag337, 0.31g, Biotrack Ltd, Wareham, UK) weighing <7% of the body mass of bats were fitted to up to 25 adult female bats using an ostomy adhesive solution (Salts Healthcare, Birmingham, UK). All tagged bats were fitted with aluminium bands (3.5 mm, Porzana Ltd, Icklesham, UK) to allow identification of recaptured individuals. Roosting bats were located each day using a R1000 receiver (Communications Specialists Inc., USA) and a 3-element Yagi antenna to identify alternative roosts. Emergence counts were performed at some alternative roosts using Batbox III D heterodyne bat detectors (Batbox Ltd., Steyning, England) and night vision monoculars (Yukon Advanced Optics Worldwide, Vilnius, Lithuania) to confirm the location of roost cavities and roost exits on buildings, and to estimate the number of bats occupying the roost. Radio-tracking fixes of foraging bats were recorded for up to four hours after sunset when bats were most active (typically bats returned to day roosts within four hours after emerging at dusk). A standardised ‘shotgun’ approach to collecting fix data from foraging bats was used at each site, whereby four trackers recorded bat fixes continuously and sequentially from all bats that were within detection range. Trackers were located strategically in the landscape, such that foraging fixes were obtained from all or most bats at each site during control and exclusion periods.

Home range areas were calculated after plotting tracking fixes in ArcGIS 10 (Esri Inc., Redland, CA, USA). Fix data were imported into Ranges 7 (Anatrack Ltd, Wareham, UK) and used to calculate colony home ranges (100% minimum convex polygons (MCP)) and core foraging areas (cluster cores). Analysis of utilisation distribution discontinuities showed that up to 10% of fix locations increased the size of foraging areas disproportionately and an examination of these fixes revealed that they were primarily recorded as bats commuted from roosts to foraging areas and *vice versa*. Thus, 90% cluster cores were used to define core foraging areas.

Habitat data were extracted from digital maps developed in-house in ArcGIS 10 using the five broad habitat categories described in Table A2.1 (below). To meet recommendations that n fixes ≥ 30 per bat-period i.e. pooled control data and pooled exclusion data for each bat (Aebischer *et al.* 1993; Kunz & Parsons 2009), only data from Bentham ($n = 4$ bats), Crakemarsh ($n = 14$ bats), Shackleford ($n = 7$ bats) and Studland ($n = 15$ bats) were included in analyses of home ranges. To meet the requirement that n bats $> n$ habitat categories ($n = 5$), only data from Crakemarsh, Shackleford and Studland were used in compositional analyses (Compositional Analysis Plus Microsoft Excel tool 6.2, Smith Ecology Ltd, UK) to determine habitat selection.

Project 2 – Deterrence of Natterer’s bats in churches

Bats were caught inside churches soon after emergence using harp traps and as they emerged from church buildings using harp traps and hand nets. Bats were fitted with lightweight radio-transmitter tags (PIP Ag317, 0.47g, Biotrack Ltd, Wareham, UK) weighing <7% of the weight of the bat using an ostomy adhesive solution (Salts Healthcare, Birmingham, UK). All tagged bats were fitted with aluminium bands (3.5 mm, Porzana Ltd, Icklesham, UK) to allow identification of recaptured individuals. Tagged bats were located in roosts during the day using a R1000 receiver and a 3-element Yagi antenna. At night, bat locations (fixes) were recorded continuously (every 5-10 minutes) from dusk to dawn using the ‘homing-in’ method. Any night of data resulting from less than 90% contact time with a bat was excluded from final analyses as the complete pattern of movements throughout the night could not be identified.

Home range areas were calculated after plotting tracking fixes in ArcGIS 10. Fix data were imported into Ranges 7 and used to calculate individual bat home ranges (100% minimum convex polygons (MCP)) and core foraging areas (cluster cores). Analysis of utilisation distribution discontinuities showed that up to 20% of fix locations increased the size of home ranges disproportionately and an examination of these fixes revealed that they were primarily recorded as bats commuted from roosts to foraging areas and *vice versa*. Thus, 80% cluster cores were used to define core foraging areas. Habitat data were extracted from digital maps developed in-house using the five broad habitat categories described in Table A2.1 (below).

Table A2.1 – Description of broad habitat types identified used in analysis of bat habitat preferences.

Habitat	Description
Arable	Ploughed land, cropland and recently reseeded grassland. Includes arable land and grassland in rotation, horticultural land and nurseries, and recently planted and established orchards.
Grassland	Any grassland not included under riparian. Includes improved, semi-improved and unimproved types, enclosed meadows and pastures, and amenity grasslands.
Riparian	Open water and marginal vegetation around any water body, including rivers, streams, brooks, lakes, ponds (including operational ponds), reservoirs, aquaculture, estuary and coastal waters, riparian woodland, wet heathland, tall vegetation along water courses, swamp vegetation around pools and all types of fen and mire.
Built-up	Roads, houses and residential land, built-up areas, including areas of commercial retail, industry, high density residential (>40% cover), agricultural buildings, transport areas, restored or active landfill sites, and active or inactive quarries.
Woodland	Any woodland not included under riparian. Includes broadleaved, conifer and mixed types, ancient and young stands, forestry scrub, and encompassing all management types including plantation, restoration, coppice, minimum intervention, etc.

APPENDIX 3 – Population models: formulation

Formulation of the model:

We used stochastic population models that describe soprano pipistrelle (*Pipistrellus pygmaeus*) and Natterer's bat (*Myotis nattereri*) demography. These models provide a method where productivity, in terms of number of female reared young and age-specific survival rates can be manipulated and their effects on population growth rate examined. A thorough review of these techniques is presented in Tuljapurkar & Caswell (1997); therefore the following is only a summary of the principles involved in formulating the model.

Population size n is defined as the number of female individuals in a population and can be defined as the sum of the numbers in each age class

$$n = n_1 + n_2 + n_3 \dots n_i \quad (1)$$

where n_i is the number of female individuals in age class i . A population with three age classes can be described by a set of difference equations, where P_i are age-specific productivities, i.e. the number of female young produced at each age class i and S_i are age-specific survival probabilities of age class i , such that

$$\begin{aligned} n_1(t+1) &= P_2 n_2(t) + P_3 n_3(t) \\ n_2(t+1) &= S_1 n_1(t), \\ n_3(t+1) &= S_2 n_2(t) + S_3 n_3(t) \end{aligned} \quad (2)$$

To illustrate, a generic age structured bat population can be represented as a life-cycle graph (Fig. A3.1).

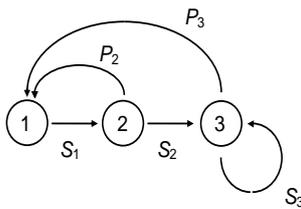


Figure A3.1 – Life cycle graph for soprano pipistrelle.

The difference equations describing the bat population can be written more simply in matrix form:

$$\mathbf{n}(t+1) = \mathbf{A}\mathbf{n}(t), \quad (3)$$

where \mathbf{n} is an age distribution vector

$$\mathbf{n}(t) = \begin{bmatrix} n_1(t) \\ n_2(t) \\ n_3(t) \end{bmatrix}, \quad (4)$$

and \mathbf{A} is a population projection matrix as described by Leslie (1945, 1948). The elements of the matrix can be obtained from the difference equations or from the life-cycle graph, so that

$$= \begin{bmatrix} P_1 & P_2 & P_3 \\ S_1 & 0 & 0 \\ 0 & S_2 & S_3 \end{bmatrix} \quad (5)$$

This is known as an extended Leslie matrix; it assumes the vital rates in the matrix are equal after age class two.

By repeatedly multiplying the matrix \mathbf{A} by the vector \mathbf{n} a series of vectors are obtained that stabilise out after a few generations, so they differ from each other by a scalar factor. This factor λ , is the dominant eigenvector of the population projection matrix \mathbf{A} , and is equal to the population growth rate, so that

$$\mathbf{n}(t+1) = \lambda \mathbf{n}(t), \quad (6)$$

where

$$\lambda = e^r, \quad (7)$$

r being the per capita rate or intrinsic rate of population growth. Successively multiplying \mathbf{n} by \mathbf{A} also results in the vector \mathbf{w} that is proportional to the stable age structure of the population.

$$\mathbf{w} = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix}, \quad (8)$$

The stable age structure \mathbf{w} and λ can be used to determine the population size \mathbf{n} at any time t , thus

$$\mathbf{n}(t) = \lambda^t \mathbf{w}. \quad (9)$$

Substituting this into (3) gives

$$\lambda^{t+1} \mathbf{w} = \lambda^t \mathbf{A} \mathbf{w}. \quad (10)$$

A scalar λ and vector \mathbf{w} that satisfy this equation are the dominant eigenvalue and right eigenvector of the matrix \mathbf{A} , respectively. These must satisfy

$$(\mathbf{A} - \lambda \mathbf{I}) \mathbf{w} = 0, \quad (11)$$

where \mathbf{I} is the identity matrix. \mathbf{w} has a nonzero solution only if the determinant of the matrix.

$\mathbf{A} - \lambda\mathbf{I}$ equals zero, hence the value of λ and \mathbf{w} can be solved using the characteristic equation

$$\det(\mathbf{A} - \lambda\mathbf{I}) = 0, \quad (12)$$

The characteristic equation can be solved using polynomial expansion, which for bats here with a matrix of three by three, produces seven eigenvalues and their associated eigenvectors, where λ is the dominant eigenvalue. This also produces a solution for the left eigenvector \mathbf{v} of the matrix \mathbf{A} which is known as the reproductive stage vector and represents the contribution of each age class to the population, so that

$$\mathbf{v}^* \mathbf{A} = \lambda \mathbf{v}^*, \quad (13)$$

where \mathbf{v}^* is the transpose of \mathbf{v} . The left and right eigenvectors can be scaled so that their scalar product equals one, so for the eigenvalue λ

$$\langle \mathbf{w}, \mathbf{v} \rangle = \mathbf{v}^* \mathbf{w} = 1, \quad (14)$$

where $\langle \mathbf{w}, \mathbf{v} \rangle$ is the scalar product of \mathbf{w} and \mathbf{v} . This allows calculation of the effect that a small additive change in any of the vital rates of the population projection matrix \mathbf{A} would have on λ , so that

$$s_{ij} = \frac{\partial \lambda}{\partial a_{ij}} = v_i w_j, \quad (15)$$

where s_{ij} is the sensitivity of λ to changes in the matrix element a_{ij} . The sensitivity of λ to changes in other parameters can then be calculated for any other vital rate (x).

$$\frac{\partial \lambda}{\partial x} = \sum_{i,j} \frac{\partial \lambda}{\partial a_{ij}} \frac{\partial a_{ij}}{\partial x}. \quad (16)$$

Often more important in conservation and management is to determine the proportional effect that a small change in each vital rate would have on λ . This can be examined using elasticity analysis, where

$$e_{ij} = \frac{a_{ij}}{\lambda} \frac{\partial \lambda}{\partial a_{ij}}. \quad (17)$$

where the elasticity to other parameters can be calculated by

$$e(x) = \frac{x}{\lambda} \frac{\partial \lambda}{\partial x} \quad (18)$$

$$= \frac{x}{\lambda} \sum_{i,j} \frac{\partial \lambda}{\partial a_{ij}} \frac{\partial a_{ij}}{\partial x}.$$

Assumptions of the model:

The above method has been used to construct stochastic matrix population models for *P. pygmaeus* and *M. nattereri* at the end of the breeding season (post-breeding census). For these analyses we assume that the sex ratios are equal and model the female part of the populations.

In order to assess the effects of random year-to-year variation in life-cycle parameters, we introduced stochastic variation in age-specific survival, but due to the lack of information on annual variation in litter size and proportion of individuals breeding each year, these are assumed to be constant rather than stochastic. We expect that density dependence is likely to be operating on these two species, although this is not considered here because the influence of this on the population growth rate is unknown. In the absence of information on movement from outside the local population, the models assume that the populations are closed i.e. there is no immigration or emigration.

Age structure:

In each model there are two immature age classes after which vital rates are assumed to be constant. The first age class corresponds to infants produced by the end of a breeding season, the second age class to individuals in their first year of life (second calendar year), and third age class to bats in their third calendar year or older.

Productivity:

Productivity, in terms of the number of independent young reared, is assumed to be 1 for Natterer's bat. Twins have been recorded but the level of twinning in Natterer's bat in the UK is believed to be negligible (Smith & Rivers 2008). Twins are also rarely recorded for the soprano pipistrelle in the UK, although several studies provide some information on litter size for this species (Hughes *et al.* 1989, Bishop *et al.* 1992, De Fanis 1994, De Fanis & Jones 1996). In combination these studies recorded three twins from 78 females (a 3.8% rate of twinning), an estimate which we use here. We assume an equal sex ratio of females at birth, and that female bats can start breeding at one year of age, such that

$$P_i = L_i * \alpha_i$$

where P_i is the productivity of age class i (where $i = \{1, 2\}$), L_i is the mean litter size and α_i is the proportion breeding of age class i . The productivity of age-class 0 (i.e. infants) will be 0.

In relation to the proportion of individuals breeding in any given year, Racey (1974) found that 110 of 118 (93%) of soprano pipistrelles examined at several points over a winter had been inseminated. While we do not know the proportion of first year versus older individuals breeding in a given year, we assume that this is 93% for both age-classes here. For Natterer's bat, data from maternity roosts during this project found that 170 of 233

adult females (73%) and 5 of 18 first year females (28%) showed signs of pregnancy, lactation or post-lactation. We used these as an estimate of the likely number of individuals of each age-class breeding, with the caveat that these figures may underestimate the true proportion of each age-class breeding, because it is difficult on occasions to confirm in the hand whether a bat has bred.

To summarise, bat productivity can be expressed as

$$P_1 = 0$$

$$P_2 = L_1 * \alpha_1$$

$$P_3 = L_2 * \alpha_2$$

Survival:

At the time of writing, there are currently no robust survival estimates for soprano pipistrelles. Where estimates are available (e.g. Gerell & Lundberg 1990) these are now believed to be underestimates of true survival, resulting from methodological drawbacks of the approaches used at the time, in particular unreliable assumptions for example about age-distribution and population stability, and a failure to account for variable recapture probabilities (Sendor & Simon 2003). Here we use survival estimates for the closely related common pipistrelle (*Pipistrellus pipistrellus*) (Sendor & Simon 2003).

Robust estimates of age-specific survival are available for Natterer's bat (Mortimer 2005, Rivers *et al.* 2006). Here we use estimates of first year, second year and adult survival calculated by Mortimer (2005). An estimate of female adult survival for Natterer's bat produced by Rivers *et al.* (2006) is comparable with the Mortimer estimate.

The Sendor & Simon (2003) survival estimates for common pipistrelle are presented with standard errors, which suggest that annual survival in that study varied by about 5-10%. Looking at the wider bat literature for Leisler's bat *Nyctalus leisleri* in Switzerland, Schorcht *et al.* (2009) found that first year survival varied by about 5% between years, and adult survival by 12%. For the long-fingered bat *Myotis capaccinii* in Greece (Papadatou *et al.* 2009) adult survival varied by about 10% between years, whilst for the Isabelline serotine *Eptesicus isabellinus* in Spain (Papadatou *et al.* 2011), adult survival varied by about 16%. With the level of annual variation in survival being broadly similar across studies, we assume a mean from these studies here of 11% for the soprano pipistrelle and for Natterer's bat.

Vital rates:

A summary of the vital rates used in the models for soprano pipistrelles and Natterer's bats are provided in Table A3.1 and Table A3.2, respectively. The starting population (colony size) was 100 females, chosen to represent a typical colony size, and distributed according to the stable age distribution of the equivalent deterministic model. 1000 realisations were run for

an arbitrary time-frame of 500 years. We recorded the mean stochastic growth rate for both species and the proportion of extinct trajectories at the end of the simulation, with an extinction threshold of 1. Matrix calculations were conducted using the program ULM (Legendre & Clobert 1995).

Table A3.1 – Vital rates used in population matrix models for soprano pipistrelle.

	Vital rate	Estimate (SE)	Source if available
Mean litter size of first years	L_1	1.038	Hughes <i>et al.</i> 1989, Bishop <i>et al.</i> 1992, De Fanis 1994, De Fanis & Jones 1996
Mean litter size of second years plus	L_2	1.038	“ “
Survival in first year	S_1	0.527 (0.095)	Sendor & Simon (2003)*
Survival in second year	S_2	0.799 (0.051)	“ “ “
Survival in third year plus	S_3	0.799 (0.051)	“ “ “
Proportion breeding at 1 year of age	$Alpha_1$	0.930	Racey (1974)
Proportion breeding at 2 years plus	$Alpha_2$	0.930	“ “

* Source data for the common pipistrelle, *Pipistrellus pipistrellus*, a closely related cryptic species of the soprano pipistrelle, *P. pygmaeus*.

Table A3.2 – Vital rates used in population matrix models for Natterer's bat

	Vital rate	Estimate (SE)	Source if available
Mean litter size of first years	L_1	1.000	
Mean litter size of second years plus	L_2	1.000	
Survival in first year	S_1	0.491 (0.088)	Mortimer (2005)
Survival in second year	S_2	0.684 (0.151)	“ “ “
Survival in third year plus	S_3	0.875 (0.118)	“ “ “
Proportion breeding at 1 year of age	$Alpha_1$	0.280	Zeale (unpublished data)
Proportion breeding at 2 years plus	$Alpha_2$	0.730	Zeale (unpublished data)

References

- Bishop, C.M., Jones, G., Lazarus, C.M. & Racey, P.A. (1992) Discriminant suckling in pipistrelle bats is supported by DNA fingerprinting. *Molecular Ecology*, **1**, 255-258.
- De Fanis, E. & Jones, G. (1996) Allomaternal care and recognition between mothers and young in pipistrelle bats (*Pipistrellus pipistrellus*). *Journal of Zoology, London*, **240**, 781-787.
- De Fanis, E. (1994) *Cues used in communication by Microchiropteran bats*. PhD thesis, University of Bristol.
- Gerell, R. & Lundberg, K. (1990) Sexual differences in survival rates of adult pipistrelle bats (*Pipistrellus pipistrellus*) in South Sweden. *Oecologia*, **83**, 401-404.

- Hughes, P.M., Speakman, J.R., Jones, G., & Racey, P.A. (1989) Suckling behaviour in the Pipistrelle bat (*Pipistrellus pipistrellus*). *Journal of Zoology, London*, **219**, 665-670.
- Legendre, S. & Clobert, J. (1995) ULM, a software for conservation and evolutionary biologists. *Journal of Applied Statistics*, **22**, 817-834.
- Mortimer, G. (2006) *Foraging, roosting and survival of Natterer's bats Myotis nattereri, in a commercial coniferous plantation*. PhD Thesis, University of St. Andrews.
- Papadatou, E., Butlin, R.K., Pradel, R. & Altringham, J.D. (2009) Sex-specific roost movements and population dynamics of the vulnerable long-fingered bat, *Myotis capaccinii*. *Biological Conservation*, **142**, 280-289.
- Papadatou, E., Ibáñez, C., Pradel, R., Juste, J. & Gimenez, O. (2011) Assessing survival in a multi-population system: a case study on bat populations. *Oecologia*, **165**, 925-933.
- Racey, P.A. (1974) Ageing and assessment of reproductive status of pipistrelle bats, *Pipistrellus pipistrellus*. *Journal of Zoology, London*, **173**, 264-271.
- Rivers, N.M., Butlin, R.K. & Altringham, J.D. (2006) Autumn swarming behaviour of Natterer's bats in the UK: population size, catchment area and dispersal. *Biological Conservation*, **127**, 215-226.
- Schorcht, W., Bontadina, F. & Schaub, M. (2009) Variation in survival drives population dynamics in a migrating forest bat. *Journal of Animal Ecology*, **78**, 1182-1190.
- Sendor, T. & Simon, M. (2003) Population dynamics of the pipistrelle bat: effects of sex, age and winter weather on seasonal survival. *Journal of Animal Ecology*, **72**, 308-320.
- Smith, P.G. & Rivers, N. M. (2008) Natterer's bat *Myotis nattereri* In: *Mammals of the British Isles: Handbook* (4th ed.) (Harris, S. & Yalden, D.W.). *Mammal Society*, pp. 323-328.
- Tuljapurkar, S. & Caswell, H. (1997) *Structured population models in marine, terrestrial and freshwater systems*. Chapman & Hall.

APPENDIX 4 – Bat biometric data

Table A4.1 – Biometric data for soprano pipistrelles radio-tagged during exclusion experiments at five sites. All bats were adult females tagged in spring and early summer i.e. prior to the summer breeding period.

Site	County	Date	<i>n</i> tagged bats	Weight†	Forearm length†
Willaston	Cheshire	May 2012	25	4.7 ± 0.2 (4.5 – 5.6)	31.7 ± 0.7 (30.4 – 33.4)
Bentham	Yorkshire	May 2012	23	4.9 ± 0.3 (4.5 – 5.4)	31.9 ± 0.6 (30.7 – 33.1)
Crakemarsh	Staffordshire	May 2013	25	4.7 ± 0.2 (4.5 – 5.3)	32.0 ± 0.6 (31.0 – 33.4)
Shackleford	Surrey	May 2013	20	4.2 ± 0.2 (4.0 – 4.5)	31.6 ± 0.8 (30.2 – 33.6)
Studland	Dorset	June 2013	25	4.8 ± 0.2 (4.5 – 5.3)	31.6 ± 0.6 (30.4 – 32.8)

† Mean ± standard deviation (range)

Table A4.2 – Biometric data for Natterer’s bats radio-tagged during deterrent experiments at churches in Norfolk. All bats were adult females tagged soon after the breeding, and so bats were either non-parous (i.e. no evidence to suggest that the bat had reared young that year) or post-lactating. No pregnant or lactating bats were tagged.

Site	Church	Date	<i>n</i> tagged bats	Weight†	Forearm length†
Cley	St. Margaret	Aug 2012/ Aug 2013	27	8.4 ± 0.4 (7.6 – 9.3)	39.7 ± 1.0 (38.8 – 41.6)
Deopham	St. Andrew	Aug 2013	10	7.7 ± 0.5 (7.1 – 8.9)	39.9 ± 0.7 (38.9 – 40.9)
Great Hockham	Holy Trinity	Sept 2013	10	8.4 ± 0.3 (8.1 – 9.2)	40.4 ± 0.8 (39.0 – 42.1)
Guestwick	St. Peter	Aug 2012/ Aug 2013	24	7.9 ± 0.3 (7.3 – 8.5)	40.4 ± 0.8 (38.8 – 42.1)
Holme Hale	St. Andrew	Aug 2012/ July 2013	25	8.2 ± 0.4 (7.8 – 9.1)	40.5 ± 0.7 (38.7 – 41.6)
Ingham	Holy Trinity	July 2012	6	8.2 ± 0.5 (7.6 – 9.4)	40.1 ± 1.0 (38.7 – 42.0)
Salle	St. Peter & St. Paul	Sept 2012/ Aug 2013	21	8.1 ± 0.5 (7.4 – 9.6)	40.4 ± 1.1 (38.1 – 43.3)
Swanton Morley	All Saints	Aug 2012/ July 2013	25	8.1 ± 0.4 (7.5 – 9.1)	40.5 ± 0.8 (38.8 – 41.6)
Toftrees	All Saints	Aug 2012/ Aug 2013	26	8.1 ± 0.4 (7.5 – 8.9)	40.1 ± 0.8 (38.4 – 41.6)
Wood Dalling	St. Andrew	Aug 2011/ Sept 2012	6	7.8 ± 0.4 (7.4 – 9.0)	40.2 ± 0.9 (38.5 – 41.9)

† Mean ± standard deviation (range)

APPENDIX 5 – Population models: results

A5.1 Soprano pipistrelles

Projected population growth rates:

The projection matrix model derived from the vital rates in Table A3.1 results in a mean stochastic population growth rate λ_s of 0.997 i.e. essentially stable, where none of the 1000 trajectories was extinct after 100 years.

Relative importance of vital rates:

First and second year survival S_1 and S_2 are the most important parameters contributing to population growth excluding the combined survival from three years onwards (Table A5.1). The elasticity of S_1 and S_2 are approximately equal to the sum of the combined elasticities of productivity for all age groups.

Individual components of productivity – mean litter size of bats breeding in their first season (L_1), and second season or later (L_2), and the proportion of individuals breeding in their first season (Alpha_1) and second season or later (Alpha_2) – have comparatively small elasticities. Therefore changes in these parameters are likely to have a comparatively small effect on the population growth rate (Table A5.2).

Table A5.1 – Elasticities and sensitivities of matrix cells derived from the population projection matrices for soprano pipistrelle

	Elasticity	Sensitivity
Survival		
S_1	0.17	0.32
S_2	0.17	0.21
S_3	0.66	0.83
Productivity		
P_2	0.04	0.08
P_3	0.14	0.28

Table A5.2 – Sensitivities and elasticities for the constituents of productivity derived from the population projection matrices for soprano pipistrelle.

	Vital rate	Elasticity	Sensitivity
Mean litter size of first years	L_1	0.04	0.04
Mean litter size of second years plus	L_2	0.13	0.13
Proportion breeding at 1 year of age	Alpha_1	0.04	0.04
Proportion breeding at 2 years of age plus	Alpha_2	0.14	0.14

Critical threshold of vital rates:

To investigate the influence of large perturbations in parameters, we altered the annual survival rates (S_1 , S_2 and S_3), annual productivity (P_2 and P_3) and the constituents of productivity (L_1 , L_2 , $Alpha_1$ and $Alpha_2$), keeping other rates constant to examine how change in each of these rates would influence the population growth rate λ_s (Figure A5.1) and to calculate the threshold at which a population of 100 females is likely to become extinct (extinction probability of 1) within 500 years.

Table A5.3 – Critical threshold of population parameters for the soprano pipistrelle, below which a population of 100 females is likely to become extinct within an arbitrary 500 years (vital rates used in the population matrix models).

	Critical values (vital rates)
Annual survival	
S_1	0.46 (0.527)
S_2	0.70 (0.799)
S_3	0.77 (0.799)
Productivity	
L_1	0.20 (1.038)
L_2	0.85 (1.038)
$Alpha_1$	0.18 (0.930)
$Alpha_2$	0.77 (0.930)

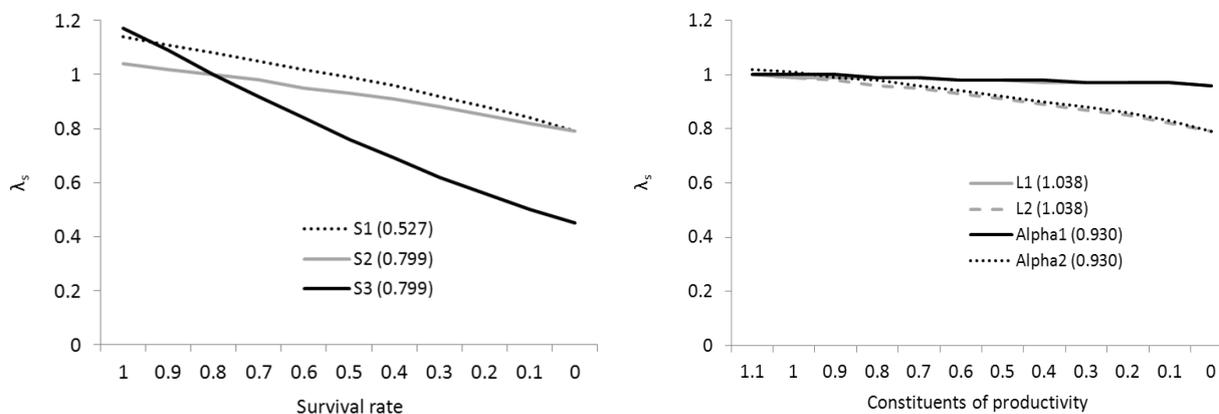


Figure A5.1 - The effects of changes in individual age-specific annual survival rates (left) and the constituents of productivity (right) on the population growth rate of soprano pipistrelles (rates used shown in brackets).

Population model interpretation:

As parameters with high sensitivity and elasticity values have a relatively greater effect on population growth, it is more important that those parameters with the highest values should be reliable (Tuljapurkar & Caswell 1997). As population growth shows high sensitivity and elasticity to changes in annual survival for both species, effort should be taken to

ensure reliable estimates are used. At the time of writing, robust age-specific survival estimates were not available for the soprano pipistrelle, requiring us to use estimates for the closely related common pipistrelle, which given the generally similar ecology and life-history of these species seems reasonable.

As sensitivity and elasticity analysis showed that mean litter size of bats in their first breeding season and the proportion of individuals breeding in their first season had very little influence on projected growth rates for soprano pipistrelle, the assumption that a similar proportion of first years to other age-classes breed, and have similar productivity to those in their second year or older, is unlikely to significantly influence projected growth rates. As would be expected, a change in mean litter size or in the proportion of soprano pipistrelle breeding in their second season or later would have a bigger influence on the project growth rates than those of bats in their first season.

A5.2 Natterer's bats

Projected population growth rates:

The projection matrix model derived from the vital rates in Table A3.2 results in a mean stochastic population growth rate λ_s of 0.986 i.e. a slow decline but close to stable.

Relative importance of vital rates:

Survival from three years S_3 onwards is by far the most important parameter contributing to population growth (Table A5.4).

Individual components of first and second year survival (S_1 and S_2) and productivity - mean litter size of bats in their first breeding season (L_1), and second season or later (L_2), and the proportion of individuals breeding in their first season ($Alpha_1$) and second season or later ($Alpha_2$) have comparatively small elasticities. Therefore compared with changes in survival from three years onwards, these parameters are likely to have a comparatively small effect on the population growth rate (Table A5.5).

Table A5.4 – Elasticities and sensitivities of matrix cells derived from the population projection matrices for Natterer's bat

	Elasticity	Sensitivity
Survival		
S_1	0.10	0.20
S_2	0.10	0.14
S_3	0.81	0.91
Productivity		
P_2	0.00	0.03
P_3	0.09	0.25

Table A5.5 – Sensitivities and elasticities for the constituents of productivity derived from the population projection matrices for Natterer's bat

	Vital rate	Elasticity	Sensitivity
Mean litter size of first years	L_1	0.00	0.00
Mean litter size of second years plus	L_2	0.09	0.09
Proportion breeding at 1 year of age	$Alpha_1$	0.00	0.02
Proportion breeding at 2 years of age plus	$Alpha_2$	0.09	0.13

Critical threshold of vital rates:

To investigate the influence of large perturbations in parameters, we altered the annual survival rates (S_1 , S_2 and S_3), annual productivity (P_2 and P_3) and the constituents of productivity (L_1 , L_2 , $Alpha_1$ and $Alpha_2$), keeping other rates constant to examine how change in each of these rates would influence the population growth rate λ_s (Figure A5.2) and to calculate the threshold at which a population of 100 females is likely to become extinct (extinction probability of 1) within 500 years.

Table A5.6 – Critical threshold of population parameters for Natterer's bat, below which a population of 100 females is likely to become extinct within an arbitrary 500 years (vital rates used in population matrix models).

	Critical values
Annual survival	
S_1	0.44 (0.491)
S_2	0.61 (0.684)
S_3	0.86 (0.875)
Productivity	
L_1	negligible effect (1.00)
L_2	0.92 (1.00)
$Alpha_1$	negligible effect (0.28)
$Alpha_2$	0.67 (0.73)

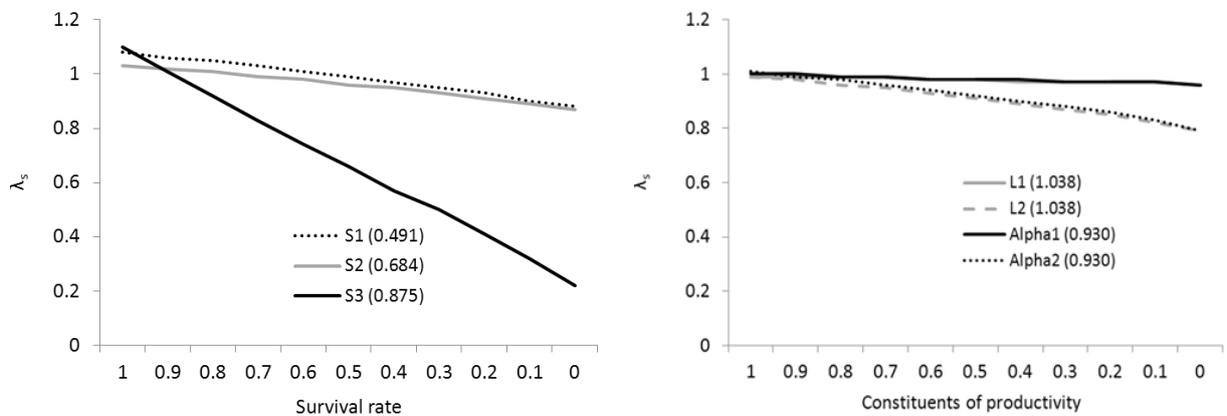


Figure A5.2 - The effects of changes in individual age-specific annual survival rates (left) and the constituents of productivity (right) on the population growth rate of Natterer's bat (rates used shown in brackets).

Population model interpretation:

As population growth shows high sensitivity and elasticity to changes in annual survival for individuals three years plus, it is good that robust estimates of age-specific survival are available for Natterer's bat.

As sensitivity and elasticity analysis showed that mean litter size of bats in their first breeding season and the proportion of individuals breeding in their first season had very little influence on projected growth rates for Natterer's bat, the limited quantitative data here, is unlikely to significantly influence projected growth rates. As would be expected, a change in mean litter size or in the proportion of Natterer's bat breeding in their second season or later would have a bigger influence on the project growth rates than those of bats in their first breeding season.

References

Tuljapurkar, S. & Caswell, H. (1997) *Structured population models in marine, terrestrial and freshwater systems*. Chapman & Hall.

APPENDIX 6 – Project 2: Church study sites and deterrents *in situ*

Below are examples of the range of different churches used during deterrence experiments of Natterer's bats in Norfolk. For each church we also provide an image of a deterrent *in situ* to show visually how different deterrents were installed in churches and below bat roosts.



Figure A6.1 – St Andrew's Church at Holme Hale. Shows (bottom right) speakers for the Deaton deterrent raised by four metres above ground level on A-frame ladders to standardise the distance from speakers to roosts between churches. The estimated size of the Natterer's bat colony at Holme Hale is >100. Images: Matt Zeale



Figure A6.2 – All Saints church at Toftrees. Shows (bottom right) three CR deterrent units mounted on a rig designed to broaden the directionality of the combined units. A colony of >100 Natterer's bats roost in among the mortise joints of the roof timbers. Note the staining on the wall from droppings and urine. Images: Matt Zeale



Figure A6.3 – St Margaret's church at Cley. Shows (bottom right) artificial lighting during a directed lighting experiment designed to create a bat 'no-fly zone' in the chancel. Note the light-spill into the nave, caused predominantly by reflection of light off white walls in the chancel (lit zone). The estimated size of the Natterer's bat colony at Cley is 70-90 bats. Images: Matt Zeale

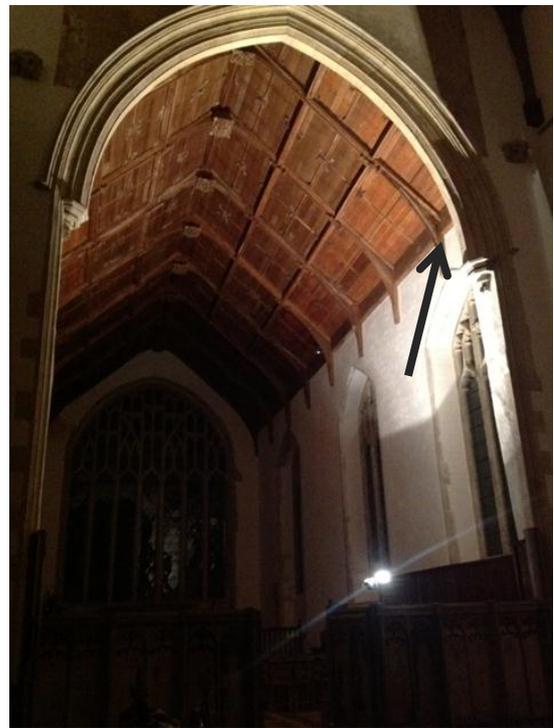


Figure A6.4 – St Peter & St Paul's church at Salle. Shows (bottom right) the use of artificial lighting to illuminate a roost in the chancel. Illuminating the roost in this way resulted in bats becoming entombed and so experiments using this form of deterrent were halted. Black arrow shows roost location. The estimated size of the Natterer's bat colony at Salle is 30-40 bats. Images: Matt Zeale

Roosting ecology of *Myotis nattereri*; the impacts of exclusion on bats; and potential strategies for mitigating the impacts of bats in churches

Emma Stone, December 2011

University of Bristol

Introduction

This review focuses on methods for mitigating human-bat conflict with an emphasis on methods for provision of alternative roosts and techniques to deter bats from using sensitive areas within churches. The review focuses on Natterer's bat *Myotis nattereri* and includes a summary of the current knowledge of the roosting ecology of this species. The information taken from this review has been taken from published literature but also 'grey' literature sources and the rigour of the sources has been evaluated accordingly.

Roosting ecology of *Myotis nattereri*

Maternity colonies of *M. nattereri* in Europe comprise up to 200 adult females (Stebbing 1991; Dietz, von Helversen & Nill 2009) including some males. Colony size ranged from 25-80 bats in Scotland and a quarter of individual bats in each roost were adult males (Swift 1997). *M. nattereri* typically roosts in crevices in trees, tunnels, caves and in old buildings including castles, churches, barns and large houses (Stebbing 1991; Swift 1997; Dietz, von Helversen & Nill 2009). Maternity colonies of *M. nattereri* also use bat boxes (Park, Masters & Altringham 1998; Siemers & Kaipf 1999; Hatton & Cohen 2000; Siemers & Swift 2006; Dietz, von Helversen & Nill 2009) and two of the largest known *M. nattereri* maternity colonies in Scotland use wooden bat boxes located in Scots/Corsican pine forest (Anon. 2007).

M. nattereri can show low within-year roost fidelity, switching between roost sites every two to five days, but exhibits high inter-annual roost fidelity often returning to the same roost year after year (Smith & Racey 2005). Day roosts are typically concentrated within core foraging areas that extend up to 2km² and roost sites (structures which can contain more than one roost location e.g. a building/ tree) in England and Wales were found to occur at a density of seven to 15 sites/km² (Smith & Racey 2005). In Scotland the majority of roosts (86%, $n = 7$) had access holes which opened into dark areas such as courtyards, barns or bridges and all roosts were connected to flight paths and foraging areas (Swift 1997).

Physical characteristics of roosts

Roosts in buildings:

Smith and Racey (2005) conducted a detailed study of the physical and thermal characteristics of 15 summer roosts of *M. nattereri* using radio tracking. One third (33%) of all day roosts located ($n = 45$) were in buildings. Details of roost characteristics are provided in Table A7.1. Bats preferred unobstructed open access points to a building containing a roost compared with smaller access points located closer to the actual roost location (Smith & Racey 2005).

Table A7.1 – Features of buildings ($n = 15$) containing day roosts of *M. nattereri* (Smith & Racey 2005)

Feature of buildings containing roost	Description	% of roosts
Type of building ($n = 15$)	Church	7%
	House	60%
	Barn/outbuilding	33%
Age of building ($n = 15$)	Median 150 years (range 40-850)	
Inhabited by people ($n = 15$)	Inhabited	60%
	Not inhabited	40%
Wall material ($n = 15$)	Stone	80%
	Wood	13%
	Brick outer wall breezeblock inner wall	7%
Cavity /solid walls ($n = 13$)	Solid walls	92%
	Cavity walls	8%
Roofing material ($n = 15$)	Slate	67%
	Stone	13%
	Iron	13%
	Tile	7%
Insulated ($n = 14$)	Insulated	21%
	Not insulated	79%
Lining material ($n = 13$)	Rough wooden planks	38%
	Under-felt	8%
	Not lined	54%
Features of roost site in relation to wider environment		
Distance to water ($n = 15$)	Median 100 m (range 10-270 m)	
Distance to woodland > 0.5 ha ($n = 15$)	Median 290 m (range 50-720 m)	
Distance to woodland > 2.5 ha ($n = 15$)	Median 600 m (range 50-880 m)	
Distance to woodland > 5.0 ha ($n = 15$)	Median 600 m (range 50-880 m)	

Tree roosts:

Trees comprised 67% of day roost sites ($n = 45$) in a study in England and Wales (Smith & Racey 2005). Characteristics of 19 day roosts in trees are provided in Table A7.2.

Thermal characteristics of roosts

Mean daily temperatures of three different types of roost recorded between August and September in England were: $22.5 \pm 1.2^{\circ}\text{C}$ (range 10.8-46.0, $n = 3$) in attic roosts adjacent to roofs; $20.0 \pm 0.0^{\circ}\text{C}$ (range 15.2-27.0, $n = 3$) in roosts located in mortise joints in attics, and $17.3 \pm 0.2^{\circ}\text{C}$ (range 10.3-25.6, $n = 3$) in roosts located in tree cavities (Smith & Racey 2005). Roosts located in attics adjacent to roofs and roosts in attic mortise joints were significantly warmer than those located in tree cavities (Smith & Racey 2005). Roosts located in attics adjacent to roofs showed greater diurnal temperature fluctuations and responded more closely to outside diurnal temperatures compared to roosts in attic mortise joints and tree cavities (Smith & Racey 2005). The warmest temperature recorded in an occupied roost was 32°C (Smith & Racey 2005) slightly below the upper tolerable limit (36°C) for bats as reported by Speakman & Thomas (2003). Roosts located in attics adjacent to roofs had the

Table A7.2 – Features of tree roosts ($n = 19$) used by *M. nattereri* (Smith & Racey 2005)

Feature of roost space	Description	% of roosts
Roost position ($n = 19$)	Cavity in trunk	42%
	Cavity in branch	58%
Type of cavity ($n = 19$)	Hollow in unbroken trunk or limb	53%
	Cavity formed by split in trunk or limb	32%
	Cavity formed in stump left by broken limb	10%
	Surface between two branches with no cavity	5%
Roost access height ($n = 19$)	Median 5.1 m (range 1.8-10.5 m)	
Width of access to cavity ($n = 19$)	Median 28 mm (range 13-50 mm)	
Length of access to cavity ($n = 1$)	Median 80 mm (range 37-500 mm)	
Features of trees containing roosts	Description	% of roosts
Live or dead ($n = 30$)	Live	100%
Species of tree ($n = 28$)	Oak <i>Quercus petraea</i> / <i>Q. robour</i>	50%
	Ash <i>Fraxinus excelsior</i>	21%
	Birch <i>Betula pendula</i> / <i>B. Pubescens</i>	7%
	Goat willow/grey willow <i>Salix caprea</i> / <i>S. cinerea</i>	7%
	<i>Cinerea</i>	4%
	Beech <i>Fagus sylvatica</i>	4%
	Field maple <i>Acer campestre</i>	4%
	Sweet chestnut <i>Castanea sativa</i>	4%
Walnut <i>Juglans regia</i>		
Tree diameter at breast height ($n = 28$)	Median 0.70 m (range 0.20-1.60 m)	
Features of roost site in relation to wider environment		
Distance to water ($n = 30$)	Median 260 m (range 0-510 m)	
Distance to woodland > 0.5 ha ($n = 30$)	Median 50 m (range 0-660 m)	
Distance to woodland > 2.5 ha ($n = 30$)	Median 65 m (range 0-720 m)	
Distance to woodland > 5.0 ha ($n = 30$)	Median 200 m (range 0-1400 m)	

warmest temperatures and provided conditions approaching the thermo-neutral zone for bats, whereby body temperatures can be maintained with minimum energetic expense (Speakman & Thomas 2003).

Impacts of development on bats

Disturbance and roost loss

Throughout Europe many bat species roost in buildings or other man-made structures (Stebbins 1988; Thompson 1992; Entwistle, Racey & Speakman 1997; Briggs 2004; Lourenco & Palmeirim 2004). *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*, for instance, are so well adapted to man-made sites that they are rarely found in natural roosts (Thompson 1992; Altringham 1996; Bartonicka, Bielik & Rehak 2008). Some species are believed to have benefitted from the increased roosting opportunities provided by human development (Whitaker & Gummer 1992; Whitaker & Gummer 2000). In America *Eptesicus fuscus* has adapted so well to anthropogenic roosts that records of natural roosts are rare (Barbour & Davis 1969). However, bats that roost in buildings are at increased risk of

disturbance especially during development projects that require modification and demolition of buildings, or alteration to habitats surrounding bat roosts. Renovation of buildings has been highlighted as a cause of the decline of some European bats (Blant, Blant & Moeschler 1991). Arthur & Lemaire (1999) recorded losses of bat roosts in France due to increasing popularity of second homes, resulting in renovation and conversion of buildings such as barns, mills and stables. In such situations, bats are at risk from disturbance at roost sites both during and after development, as well as loss of foraging areas and safe routes to these sites (Walsh & Harris 1996).

Many bats roosting in buildings in North America are subject to exclusion and eradication attempts (Brigham & Fenton 1986; Neilson & Fenton 1994; Williams & Brittingham 1997; Brittingham & Williams 2000). In Indiana USA, a 3.3% annual rate of roost loss was recorded over a 30 year period as a result of exclusions and demolitions (Cope, Whitaker & Gummer 1991). A study of *Pipistrellus pipistrellus* roosts in Germany recorded a 25% roost loss over eight years due to renovation and modification of buildings (Simon, Huttenbugel & Smit-Viergutz 2004). Stone (2011) assessed the impact of development on bat roosts using information contained in 37% of all derogation licences issued between 2003 and 2005. The majority of roosts affected by development were destroyed (67%, $n = 1182$ roosts), with an increasing probability of roost destruction each year. Currently there is a paucity of information regarding the impact of exclusions on bat reproduction and survival rates. Brigham and Fenton (1986) showed that despite relocating to roosts nearby, *Eptesicus fuscus* excluded from roosts had reductions in reproductive success. Only five of 547 bats excluded from roosts in an American study relocated to new roosts nearby, suggesting a local population decline may result after exclusion (Neilson & Fenton 1994).

Approaches to mitigation

Mitigation is defined in the EU Environmental Impact Assessment Directive 85/337/EEC (as amended by Directive 97/11/EC) as “measures envisaged in order to avoid, reduce and if possible remedy significant adverse effects”. Compensation and mitigation are employed globally as fundamental components of the Environmental Impact Assessment (EIA) process designed to counteract the adverse environmental impacts of development (Rundcrantz & Skärbäck 2003; Tischew *et al.* 2010).

Mitigation measures are of little value unless they are evaluated, and so effective mitigation relies on empirical evaluation of mitigation success. In North America and Canada the effectiveness of wildlife mitigation techniques such as installation of underpasses (Clevenger & Waltho 2000), and highway fencing (Clevenger, Chruszcz & Gunson 2001), construction of artificial wetlands (Balcombe *et al.* 2005) and use of modified wind turbines (Baerwald *et al.* 2009; Arnett *et al.*, 2011) have been investigated. In England, Edgar, Griffiths & Foster (2005) assessed the effectiveness of translocations as a tool for mitigating the effects of development on great crested newts (*Triturus cristatus*).

A review of Environmental Statements (ES) issued in Britain between 1988 and 1993 found that only 23% specified the ecological mitigation techniques and methods in detail, and only 4% outlined the likely success of strategies based on literature or evidence (Thompson, Treweek & Thurling 1997). In contrast, very few empirical studies have been conducted on the effectiveness of bat mitigation techniques in Britain (see Briggs 2004), and current knowledge and advice is based on anecdotal evidence from case studies (Mitchell-Jones 2004; Schofield 2008; Howard & Richardson 2009). Mitigating the impacts of bats in churches can involve encouraging bats to move to alternative sites. This can include the use of 'carrot and stick' methods, such as provision of alternative roosts (carrot) and deterrents (stick) to encourage bats to move.

Provision of alternative roosts (Carrots)

Bats have species-specific roosting requirements (Kunz 1982; Kunz & Lumsden 2003) which, therefore, must be considered when designing alternative roost sites. Although there are many case studies of bats using artificial roosts post-development/disturbance (Mitchell-Jones 2004; Kelleher & Marnell 2006; Reiter & Zahn 2006; Schofield 2008) there is a lack of empirical evidence quantifying the efficacy of bat boxes, lofts and barns as mitigation tools.

Temperature is the most important factor influencing the use of bat boxes by *P. pygmaeus* (Lourenco & Palmeirim 2004), *E. fuscus*, *M. lucifugus* (Brittingham & Williams 2000) and *M. bechsteinii* (Kerth, Weissmann & König 2001). A diversity of thermal conditions are important to enable behavioural thermoregulation, whereby bats move within the roost to maintain optimal roosting temperature and avoid heat stress during hot days (Licht & Leitner 1967). Reproductive females prefer warmer roosts to minimize energy expenditure, shorten gestation length and promote juvenile growth rates during the breeding period (Kunz 1974; Kunz 1982; Racey 1982; Hamilton & Barclay 1994, Kerth, Weissmann & König 2001).

Kerth, Weissmann & König (2001) assessed roosting preferences of female *M. bechsteinii* occupying 75 bat boxes in a deciduous forest in Bavaria. 52 boxes were hung on trees in pairs with half of the pairs located on shaded trees and half on trees exposed to the sun. One box of each pair was painted white and the other was black. Bat occupancy (measured as the number of individuals present x the number of days occupied) was recorded daily within the three phases of breeding (prelactation, lactation and postlactation). The minimum nightly temperature of boxes throughout the season was positively correlated with the number of females found in boxes. Bats significantly preferred cold roosts before parturition and preferred warm roosts post-partum. Throughout the season black boxes at sunny locations had significantly more bat days than white boxes at sunny locations, but there was no significant difference in occupancy between black and white boxes located in shaded sites.

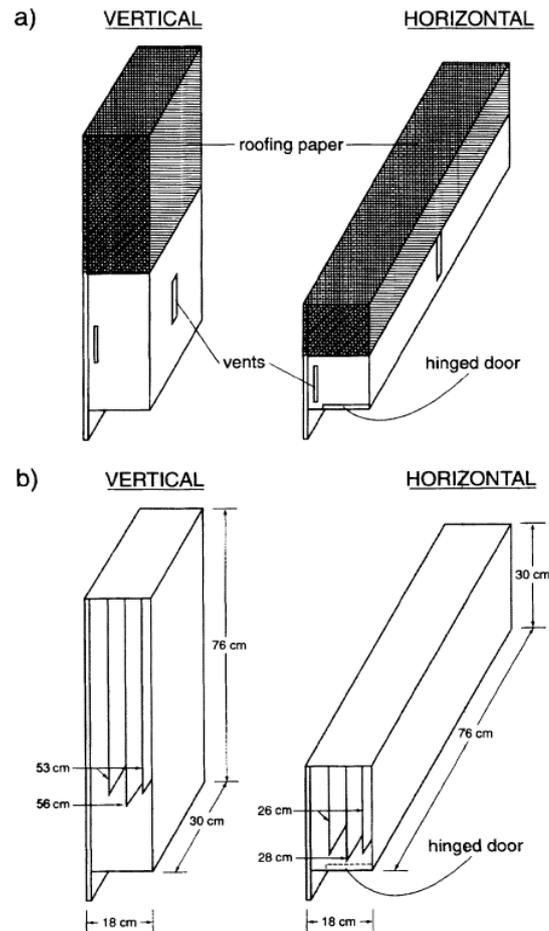


Figure A7.1 – Design of bat boxes used to house displaced colonies of *Eptesicus fuscus* in Pennsylvania summer 1991-1992 (Brittingham & Williams 2000). a) external features, b) cut-away view showing internal baffles. Internal crevices measured 2.5 cm, 2.0 cm, 2.5 cm, and 5 cm from front to back. Baffle lengths in the vertical box measured 53 cm, 56 cm, and 53 cm from top to bottom, and in the horizontal box measured 26 cm, 28 cm, and 26 cm.

Bat boxes were successful in attracting displaced colonies of *M. lucifugus* and *Eptesicus fuscus* in Pennsylvania (Brittingham & Williams 2000). Bats preferred boxes with high temperatures (8-10 °C), an internal temperature gradient and boxes in which numerous bats could roost side by side (76 cm wide). Boxes preferred by bats received ≥ 7 hours of sunlight and were located on the building in which the colony roosted prior to displacement, and located on the same side as the previous exit point. Boxes contained internal baffles to provide internal temperature gradients enabling bats to avoid heat stress and relocate to areas of optimum temperature (Fig. A7.1).

White (2004) investigated the factors influencing occupancy rates of 95 bat boxes in Colorado. Boxes were located on trees and buildings or farm houses in rural areas. The overall occupancy rate (presence of bats) for bat boxes was 11.6 % ($n = 11$ houses occupied). Occupancy rate was higher (63.6 %) for bat boxes located in areas where bats were recorded as roosting prior to installation of the box. The probability of occupancy was high

for bat boxes with larger landing areas and boxes located on buildings occupied by bats, particularly in areas with low canopy cover and low levels of human disturbance. Variables affecting roost temperature (box colour, aspect, exposure to sunlight) did not have a statistically significant effect on occupancy rates. This may be because most bat boxes were occupied by solitary males rather than breeding females and therefore temperature was less important. Length of time the bat box had been installed was not a significant predictor of bat occupancy, this was explained by the fact that most occupied boxes were located near to existing roosts, thereby making the time required to find alternative roosts very short.

A study of eight bat boxes provided as alternative roosts for *Pipistrellus pygmaeus* and *Plecotus auritus* in Scotland yielded mixed results (Table A7.3, Anon. 2006). Boxes were placed inside the attics of buildings containing roosts. One of the boxes failed to attract any bats at all. Reasons for failure included: the type and location of the box entrance (five boxes), box temperature (two boxes), inappropriate box size (two boxes), unsuccessful exclusions from other sites in the property (seven boxes), location of the box in the roof (three boxes), timing of box construction (one box) and wasps entering the boxes (two boxes).

Smith and Agnew (2002) assessed the use of 96 bat boxes in farm forestry plantations in Australia. Boxes were made from wood (Fig. A7.2) and attached to tree trunks either 3.2 m or 6.2 m above the ground. Boxes were occupied by a single bat species (*Nyctophilus gouldi*) and four species of marsupial. Although bats tended to prefer boxes with an easterly aspect and reject boxes with a northerly aspect, statistically bats did not select boxes according to aspect. Occupancy rates and number of bats per box were low compared to other studies in Australia (Bender & Irvine 2000).

Long, Kiser & Kiser (2006) conducted a seven year study to determine the importance of bat box design and location on the use of boxes by bats in California. Boxes were constructed of plywood with $\frac{3}{4}$ - 1 inch internal baffles and contained no artificial heat source (Fig. A7.3). Bat boxes were placed on barns at farms in California ($n = 186$ boxes). Boxes were mounted in different locations to test the effect of sun exposure and painted in a light, medium or dark colour to test the effect of temperature on occupancy. Bat box occupancy was 78 % (48 % for maternity roosts and 28 % for boxes used by individual bats). *Myotis* bats occupied 26 % of boxes. Initial occupancy rates of boxes by maternity roosts were 60 % within the first two years after installation and dropped to 27 % after four years. This suggests that boxes are most likely to be occupied within the first two years after installation and if boxes are not occupied after four years they were unlikely to be used and should be moved to a new location. Maternity colonies preferred boxes located on buildings where as individual bats preferred boxes located on poles. Maternity roosts preferred bat boxes with shade or morning sun compared with boxes with full or afternoon sun, and favoured boxes located

Table A7.3 – Success of bat boxes installed in eight bat roosts in Scotland (Anon. 2006)

Species	Roost location	Bat box size	Bat box location	Access	Heated	No. bats before	No. bats after	Reason for failure
<i>Pipistrellus</i> spp.	In the roof of a coach house (circa 1801)	120 cm high x 90 cm deep	Southern gable end in the roof	Slots 10 cm wide x 2 cm high	No	44	0	Wasps entered the box
<i>Pipistrellus pygmaeus</i>	Single storey cottage roof	60 cm wide x 30 cm high x 30 cm deep. Included baffles, plastic mesh and egg boxes inside.	Above the hot water tank in the roof	Hole in top corner	Yes (heaters below box)	546	455	
<i>Pipistrellus pygmaeus</i>	SE facing side of cottage roof – roosting in apex	200 cm long x 80 cm wide x 80cm high Included baffles	SE facing corner inside attic	Horizontal entrance tube which lead to outside (60cm long x 40 mm diameter)	No	950	0	Wasps Entrance pipe may be too smooth
<i>Pipistrellus pygmaeus</i>	SE side of roof of a converted stable	200 cm x 90cm x 90 cm	Inside roof space SE end	Gap 20 cm x 40 cm in gable end	No	769	277	Bats used the area around the box
<i>Pipistrellus pygmaeus</i>	Southern end of roof in lodge house at gateway of country estate	Not provided	Inside the roof by the chimney at the north end	Under the eaves	No	1,963	1,174	Perhaps increase numbers with box at South end
<i>Pipistrellus</i> spp.	Roof of converted 19 th Century coach house of SNH office	600 cm long with baffles 15-20 cm apart.	Along the wall-head inside the roof of the south side of the building	Routes created in stonework	Yes (heaters below box)	280	682	Crevices in box are too large, box allows access into roof, temperatures not high enough in box
<i>Plectous auritus</i>	Inside roof of a mansion house	Ridge Bat Box, 100 cm x 150 cm wide x 150 cm long	Inside the east wing of the loft in the ridge	Ridge ventilator tile and a short pipe 30 mm in diameter	No	20	0	Box too small for long eared bats, entrance pipe may prevent bats entering
<i>Pipistrellus pygmaeus</i>	North and south gable end in the loft of traditional stone house	Not given	Inside north end of west facing roof slope	Gap in gable wall end	Yes	950	1,331	

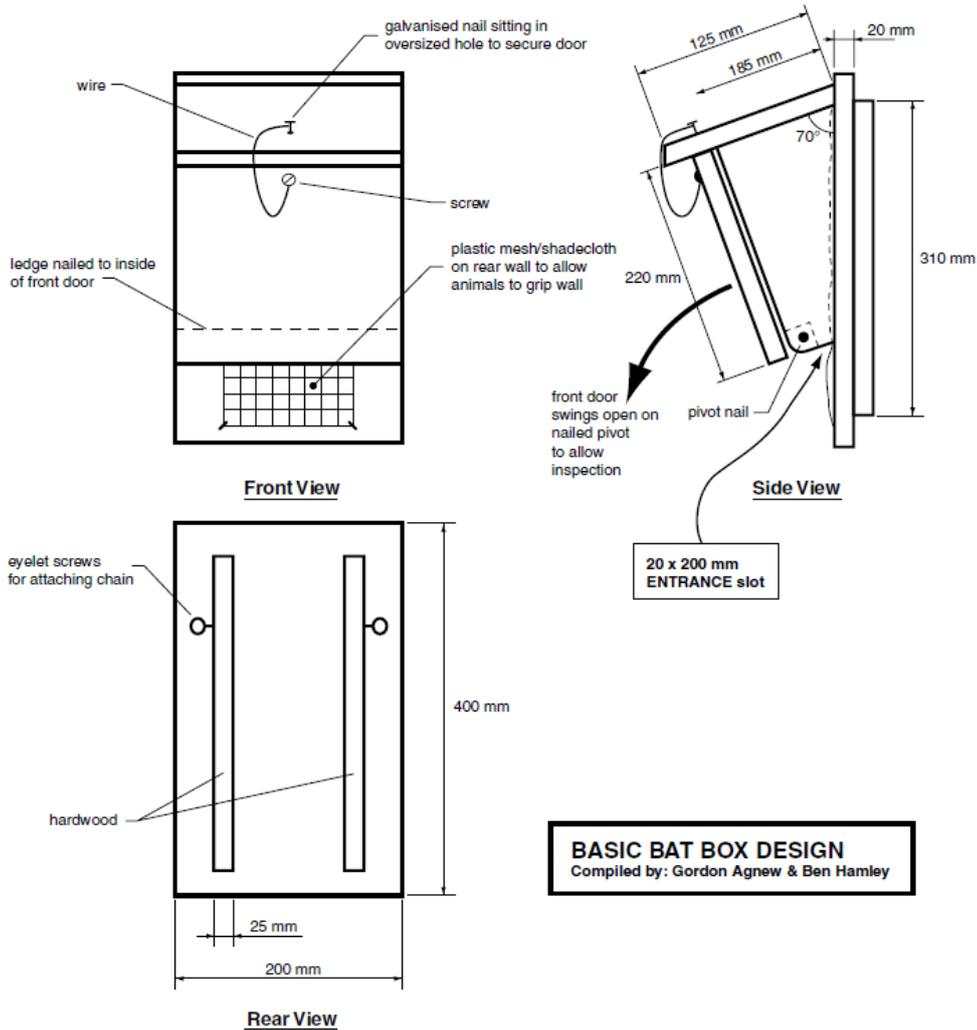


Figure A7.2 – Design of bat box used by Smith and Agnew (2002), is based on the Welsh bat box known as the Tanglewood Wedge, boxes were not painted.

within ¼ mile of a permanent water source. Height, size and colour of the bat box had little influence on occupancy rates by maternity roosts. Long Kiser & Kiser (2000) suggest mounting boxes at least ten feet above the ground (to avoid predation of bats by cats which can catch bats flying close to the ground), and at least 20 feet from obstacles (such as branches and wires) to prevent predators perching near the entrance.

Four different types of bat boxes were assessed for their suitability as alternative roosts of excluded colonies of *Myotis lucifugus* in New York State, USA (Fig. A7.4; Neilson & Fenton 1994). Bat boxes ($n = 43$) were installed on trees with different aspects, on the walls of buildings near the eaves and in the roofs of buildings. During the study 900 individual bats were captured and confined in the newly installed bat boxes to increase the chances of bats finding the boxes. None of the bat boxes were occupied by bats during the study. Average maximum temperatures appeared higher in naturally occurring bat roosts compared with bat box designs A and C, though this was not significant and was based on a comparison with a single occupied bat roost.



Figure A7.3 – Bat boxes placed on buildings or poles at farms in the central valley, California (Long, Kiser & Kiser 2006).

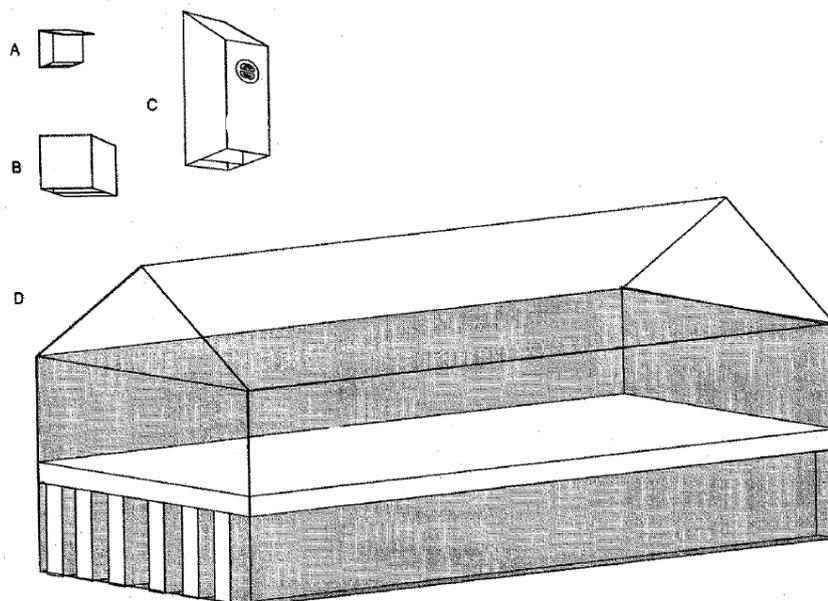


Figure A7.4 – Bat box/house designs tested by Neilson & Fenton (1994). Design A is a single opening with the longest dimension measuring <0.4 m; design B measures $0.2 \times 0.15 \times 0.15$ m with partitioned internal space; design C measures $0.5 \times 0.2 \times 0.15$ m with a partitioned internal space; and design D measures $2.3 \times 1.0 \times 1.0$ m with portioned internal space and an attic like space above.

Between 1992 and 1996 artificial roost structures ($n = 3204$ structures) were installed in wood-plots around Indianapolis International Airport USA to provide alternative roosts for the *Myotis sodalis* (Ritzi, Everson & Whitaker 2005; Whitaker, Sparks & Brack 2006). Nine different types of artificial structure were erected including: 715 single boxes, 259 triple boxes, 697 single shakes, 842 shake garlands, 56 Missouri-style boxes, 30 tar-paper boxes, 176 plastic/tarpaper skirts, 338 exfoliations, and 91 moved trees. Roosts were monitored over eight years to determine use and roost preference. One single box design was used by a small maternity colony of *Myotis sodalis* throughout the study. This box was located 10.5 m off the ground on a tree.

Aspect and location are key to the success of bat houses in managed forests (Dillingham, Cross & Dillingham 2003). Temperatures inside attics/lofts used by bats during the maternity period often exceed outside ambient temperatures (Schowalter & Gunson 1979; Williams & Brittingham 1997), minimizing energy expenditure and promoting growth of young (Lourenco & Palmeirim 2004).

Recommendations for provision of alternative roosts

The success of bat boxes as alternative roosts is likely to be a function of a number of factors including roost temperature, temperature range, location, aspect, size and access (Brigham & Fenton 1986; Anon. 2006; Schofield 2008). However, the absence of bats in boxes post-mitigation/disturbance does not necessarily indicate failure, as many bats frequently switch roosts (Whitaker & Gummer 1992; Lewis 1995), e.g. *M. nattereri* (Swift 1997) and *P. pygmaeus* (Bartonicka, Bielik & Rehak 2008), and may take time to find alternative roosts and reach pre-development numbers. In Northamptonshire, *M. nattereri* took three years to return to a roost subject to development and mitigation (Mitchell-Jones 2004). However, bat boxes in America were most likely to be occupied within two years of development (Long, Kiser & Kiser 2006).

The following recommendations are suggested to increase the success of bat boxes as alternative roosts for maternity colonies of *M. nattereri*:

- Boxes should be situated on the building in which bats have previously roosted ideally to ensure a minimum of 5 hours sunlight per day
- Boxes should be large enough to enable bats to roost side by side (minimum 76cm wide)
- Boxes should be located in areas which receive shade or morning sun rather than full or afternoon sun
- A range of thermal gradients should be provided in the box by providing internal baffles/chambers
- Boxes provided for *M. nattereri* should contain artificial heat sources to obtain temperatures between 21.3 and 23.7⁰C (no hotter than 32⁰C)
- Boxes should be located high enough and away from windows and obstacles (wires/branches) so as to prevent access from cats and other predators

Deterrents (Sticks)

Acoustic (ultrasound):

The use of ultrasonic deterrents has value given that the high frequencies used can be heard by bats and not by humans: they have considerable potential for use in this study. The use of ultrasonic deterrents has developed from our understanding of moths which emit high-frequency clicks to deter bats (Hristov & Conner 2005). The premise of acoustic deterrents is to produce broadband signals that effectively jam the echolocation systems used by bats, using a technique called broadband masking. Using this technique a continuous broadband waveform is generated that is built out of a series of randomly fluctuating frequencies which are misinterpreted, generating false detections which obscure any detection of the surrounding environment (Horn *et al.* 2008). In theory broadband masking will interfere with the bat's ability to orientate or reduce the acoustic 'visibility' of the surrounding environment thereby deterring bats from the area.

Early studies of effectiveness of acoustic deterrents for bats tested the effect of commercially available ultrasonic rodent-repellers on *Myotis lucifugus* (Hurley & Fenton 1980). Twenty bats were exposed to two rodent-repellers within their roost for a period of 24 hours and compared to a group of control bats with no ultrasonic repellers. Repellers emitted ultrasound at 120 dB at 10 cm at 19 kHz, 23.5 kHz, and 30.7 kHz. Bats showed no response to the ultrasound emitted by both repellers at any of the frequencies tested. Some bats remained hanging from the repeller even when it was switched on.

More recent studies using acoustic deterrents have been initiated by the Bats and Wind Energy Cooperative (BWEC) which was formed in 2004 with the mission to develop solutions to minimise or prevent bat fatalities at wind farms (www.batsandwind.org). Spanjer (2006) tested the effect of an acoustic deterrent on *Eptesicus fuscus* in a laboratory. A deterrent with eight speakers emitted white noise at frequencies from 12.5 to 112.5 kHz at approximately 100 dB SPL per speaker, located 1 m from the bat. Bats were subjected to ultrasound treatments and controls (with no ultrasound) in feeding and non-feeding trials in a flight room. In non-feeding trials bats landed significantly less often in the flight room during ultrasound treatments compared to controls. During feeding trials bats failed to successfully capture insects (tethered mealworms) when ultrasound was broadcast but captured insects near the ultrasound deterrent when it was silent in approximately 1/3 of trials. In both feeding and non-feeding trials bats flew through the flight room significantly less often during ultrasound treatments.

Horn *et al.* (2008) tested the first ultrasonic bat deterrent designed to deter bats from commercial-scale wind farms in America. Bat activity was measured using thermal imaging cameras at two experimental wind turbines (with deterrents installed) which were paired with two control turbines (with no deterrents). Deterrents (Binary Acoustic Technology, <http://binaryacoustictech.com>) emitted randomised (between 20 and 80kHz) and constant

ultrasound at 119 dB SPL at 1 m over ten consecutive nights. Two devices were placed on each tower located 36.5 m and 48.7 m above the ground. Each device contained three emitters which were placed equidistant from each other around the tower creating two horizontal omnidirectional doughnut-shaped 'keep out zones', extending to approximately 20 m. Experiment one showed a significant difference between bat activity around the treatment and control turbines but experiment two did not observe reduced bat activity. Horn *et al.* (2008) suggest that the mixed results may be due to differences in habitat or environmental parameters between paired experimental and control sites. As with Spanjer (2006), the acoustic envelope of the deterrents tested may not be large enough to produce a significant and consistent effect.

Szewczak & Arnett (2008) tested the impact of an acoustic deterrent on bat activity over six ponds at four sites in North America. A wideband ultrasound signal was broadcast using an AT800 portable ultrasonic amplifier (Binary Acoustic Technologies, Tuscon, Arizona) and transducer programmed to produce a continuous signal between 20 and 80 kHz. Bat activity was measured at each site using a Sony Nightshot TR818 camcorder supplemented with two infrared lights located either side of the camcorder (IRLamp6, Wildlife Engineering). Experiments lasted for five to seven nights per site and consisted of two control nights with no ultrasound to establish baseline bat activity, followed by three, four or five nights of ultrasound treatment. Experiments were only conducted on nights with particular weather conditions (no rain, wind below 5 mph and temperature more than 10 °C) to control for the effect of weather on bat activity. Bat activity was reduced significantly during ultrasound treatments, and was estimated to be between 2.5 % and 10.4 % of the activity levels recorded during controls. Bats did not habituate to the ultrasound deterrent as activity continued to decline over time when the ultrasound was being broadcast. Szewczak & Arnett (2008) suggest that bats may learn to avoid the treated airspace. The acoustic range of the particular deterrents used in this study was limited to 12-15 meters, and the authors suggest that large scale application of such deterrents may be limited due to rapid attenuation of ultrasound in air.

BWEC conducted a two year study of the effectiveness of acoustic deterrents for reducing bat fatalities at wind turbines in Pennsylvania (Arnett *et al.* 2011). Three ultrasonic acoustic deterrents were installed on ten turbines, each with 16 speakers emitting a resonance frequency of 50 kHz. Daily searches for dead bats were conducted beneath the ten treatment and 15 control turbines (with no acoustic deterrents). The average bat fatality rate per turbine was significantly lower at treatment turbines compared to control turbines, with an average of 20-53 % fewer bats killed at treatment turbines.

Radar:

Radar has also been identified as a potential deterrent to reduce mortality at wind turbines (Nicholls & Racey 2007; 2009). Long term observations of reduced bat activity around an Air Traffic Control (ATC) station near the University of Aberdeen led Nicholls & Racey (2007) to

believe that the Radio Frequency (RF) radiation associated with radar stations may act as a deterrent to bats. Radio Frequencies occur between 3 kHz and 300 GHz, and absorption of energy in the range 1 MHz to 300GHz results in tissue heating due to transfer of energy from the RF field to the biological medium (D'Andrea, Adair & de Lorge 2003). Therefore the thermal impact of electromagnetic radiation on animals may affect their biology and behaviour.

Nicholls & Racey (2007) tested the impact of electromagnetic radiation on bats at four civil ATC radar stations, three military ATC radars and three weather radars. At each radar station three static monitoring sites were located at increasing distances from the radar and matched for habitat and environmental characteristics (land class and altitude). At each site radar strength was measured using a portable electromagnetic field (EMF) monitor, resulting in a high EMF strength (< 200m from the radar, >2 volts/m,) site, intermediate EMF strength (200-400 m from the radar, <2 v/m) site and a control site (> 400 m from the radar, zero v/m). Bat activity was measured using remote static acoustic detectors (Batbox 3 station, Stag Electronics, Sussex, UK) connected to a count data logger (Gemini Data Loggers, Chichester, UK) via an analogue to digital converter (Skye Instruments, Ltd).

In addition to the static recorders bat activity was recorded along a 50 m transect at each site using a frequency division detector (S-25 Ultrasound Advice, London). Bat activity and the number of bat passes were significantly lower in high radar sites (within 200 m of the radar) compared to control sites for both static and transect surveys. There was no difference in bat activity at intermediate radar sites (200-400 m from the radar) compared to control sites. Radar type had a significant effect on bat activity as the difference in bat activity between treatment sites and control was greater at Civil ATC sites than at Military ATC sites.

Nicholls & Racey (2009) tested the impact of radar on foraging bats and their insect prey in field experiments using portable radar units. A portable radar (Furuno FR – 7062 X – band marine radar, peak power 6 kW, beam width: horizontal -1.9° , vertical -22° , rotation 24 rpm or 48 rpm) was placed on platform 2 m high at 20 sites located in foraging areas used by bats in Scotland. At each site experiments consisted of two 45 minute controls (radar switched off), one 45 minute experimental trial with the radar switched on at short pulse rate ($0.08 \mu\text{s}/2100 \text{ Hz}$), and one 45 minute experimental trial with the radar switched on at medium pulse rate ($0.3 \mu\text{s}/2100 \text{ Hz}$). The radar was tested in both fixed in position with the signal directed at the area of highest bat activity and using a rotating antenna (with the signal rotating through 120°). Bat activity was measured at each site at three distances from the radar (10, 20, 30 m) using static acoustic surveys according to (Nicholls & Racey 2007). Insects were trapped and counted at each site using two Pirbright-Miniature light suction traps with 8 watt UV light bulbs. There was no significant difference in bat activity between controls and trials with short pulse length radar signal ($0.08 \mu\text{s}/2100 \text{ Hz}$) from a rotating antenna. Bat activity and foraging rate was significantly lower at sites with both a short

pulse length (0.08 μs /2100 Hz) and medium pulse length (0.3 μs /2100 Hz) radar signals from a fixed antenna compared to controls. There was no significant difference in insect abundance between controls and experimental trials at either short or medium pulse length radar signals. Nicholls & Racey (2009) suggest that bats are unlikely to be affected by increased thermal burden from foraging within a radar beam. This is explained by the short pulse length of radar signals relative to the pulse repetition rate, resulting in a power density hundreds of times lower than the peak value of the radiation. Instead bats may be affected by a mechanism known as the auditory microwave hypothesis, which proposes that animals are affected by auditory perception of pulsed microwaves, caused by a thermoelastic expansion of brain tissue which generates a sound wave inside the head. The frequency of induced sound has been shown to be a function of animal head size and the acoustic properties of the brain tissue in animals. It is possible that the RF frequency produced in the brain would lie within the range of ultrasound frequencies used by bats for orientation, prey detection and capture, thereby interfering with their echolocation. Further research is required to understand the relationship between bat behaviour and radar, including experiments to investigate the long term impact of radar on foraging and roosting bats and to determine the mechanism of the deterrent.

Lighting:

Light pollution affects ecological interactions across a range of taxa and negatively affects critical animal behaviours including foraging, reproduction and communication (Longcore & Rich 2004; Rich & Longcore 2006). Lighting can have negative impacts bat roosting and foraging behaviour as summarised below.

Lighting inside roosts can disturb bats, causing increased activity and induced flight (Mann, Steidl & Dalton 2002) or in some cases roost abandonment (Laidlaw & Fenton 1971; Boldogh, Dobrosi & Samu 2007). A maternity roost of 1,000-1,200 female *Myotis emarginatus* was abandoned after lighting was installed which spilled directly onto the entrance (Boldogh, Dobrosi & Samu 2007). External lighting of roost exits is also disruptive, often delaying mean nightly emergence times, and thereby reducing nightly foraging time (Verkem & Moermans 2002; Boldogh, Dobrosi & Samu 2007). Duvergé *et al.* (2000) found that *Rhinolophus hipposideros* emerged later at exposed roost exits than in more protected situations, suggesting that emergence time and feeding performance were constrained in bright light conditions. This can have significant conservation consequences, causing bats to miss the peak in insect abundance that occurs at dusk (Jones & Rydell 1994) and hence a significant loss of foraging opportunities.

Downs *et al.* (2003) found that external lighting reduced the numbers of *Pipistrellus pygmaeus* emerging, and that light intensity affected bats more than light colour. There was no difference in the number of bats emerging when the roost exit was illuminated with a red filtered light compared with no light. In Hungary juveniles of *M. emarginatus* and *M.*

oxygnathus were smaller in illuminated compared with non-illuminated roosts, suggesting delayed parturition or slower growth rates. This can have serious conservation implications for such colonies (Boldogh, Dobrosi & Samu 2007).

Some bat species actively forage in lit areas, taking advantage of the high densities of insects attracted to lights (Eisenbeis 2006). Bats recorded feeding at lights include species of the genera *Pipistrellus*, *Eptesicus*, *Lasiurus*, *Nyctalus*, *Myotis*, *Vespertilio*, *Tadarida*, *Nyctinomops*, *Chalinolobus*, *Mormopterus* and *Eptesicus* (Fenton & Morris 1976; Shields & Bildstein 1979; Bell 1980; Bellwood & Fullard 1984; Geggie & Fenton 1985; Haffner & Stutz 1985/86; Furlonger, Dewar & Fenton 1987; Schnitzler *et al.* 1987; Kronwitter 1988; Barak & Yom-Tov 1989; Hickey & Fenton 1990; DeJong & Ahlén 1991; Rydell 1991, 1992; Catto 1993; Blake *et al.* 1994; Rydell & Racey 1995; Hickey, Acharya & Shannon 1996; Fullard 2001; Avila-Flores & Fenton 2005; Bartonicka, Bielik & Rehak 2008; Scanlon & Petit 2008).

In such cases bat densities can be much higher at street lights than in the surrounding dark landscape, e.g. densities of *Eptesicus nilssoni* in Sweden were 5-20 times higher in lit compared with dark areas (Rydell 1991), and activity of *Pipistrellus pipistrellus* was at least ten times higher in lit compared with dark areas in England (Rydell & Racey 1995). Bats may benefit from higher feeding rates under lights (Geggie & Fenton 1985; Rydell 1992, 1996), e.g. levels of energy intake for *Eptesicus nilssoni* under lights were more than twice those recorded in woodlands (Rydell 1992). Bats feeding on tympanate moths may have a competitive advantage under lit conditions as the moths' evasive behaviours are reduced under mercury vapour lights, increasing their vulnerability to predation (Svensson & Rydell 1998). However, Rydell (1992) found that feeding rates were higher over nearby pastures, suggesting that relationships between landscape features and foraging behaviour can be complex and deserve further research.

Sleep & Brigham (2003) found that UV lights set up in forests were most attractive to small rather than large insects and may therefore be most beneficial to bat species feeding predominantly on smaller insects (Barclay & Brigham 1991). In contrast observations of bats feeding at street lights suggest they were eating larger insects, particularly moths (Bellwood & Fullard 1984; Hickey & Fenton 1990; Acharya & Fenton 1999; Fullard 2001).

The effect of street lights on bats varies according to light type. To date the three main light types investigated are mercury vapour white, high pressure sodium (HPS, orange) and low pressure sodium (LPS, deep orange) lights. The highest levels of bat activity are recorded at white lights (Griffin 1958; Haffner & Stutz 1985/86; Rydell 1991, 1992; Blake *et al.* 1994; Rydell & Racey 1995; Avila-Flores & Fenton 2005). This is reflected in the high numbers of insects attracted to white lights (Blake *et al.* 1994), with five times more insects recorded at white versus sodium lights (Rydell 1992). In contrast LPS lights do not appear to attract insects, with insect numbers as low as those recorded on unlit streets (Rydell 1992). HPS lights attract insects but significantly fewer than white lights (Rydell 1992), e.g. in Germany HPS lights attracted 57% fewer insects than white mercury lamps (Eisenbeis 2009). Despite

the benefits for foraging at street lights, species attracted to lights along highways may suffer from increased mortality risk due to collision with vehicles: juveniles may be at higher risk due to their slower and less agile flight (Racey & Swift 1985).

There are also species-specific responses to light, with some species appearing to be light averse. In Canada and Sweden, *Myotis* spp. and *Plecotus auritus* were only recorded away from street lights (Furlonger, Dewar & Fenton 1987; Rydell 1992), and in Australia *Chalinolobus morio* avoided parks when lights were switched on (Scanlon & Petit 2008). Despite the presence of street-lit areas within their home range, lit areas were never utilised by *Rhinolophus ferrumequinum* (Jones & Morton 1992; Jones, Duverge & Ransome 1995). Acoustic tracking experiments demonstrated that *Eptesicus bottae* failed to forage in areas under lit conditions (Polak *et al.* 2011). HPS and LED street lights reduced commuting activity and caused spatial avoidance of commuting routes of *Rhinolophus hipposideros* and *Myotis* spp. even at low light levels (mean 3.7lux) (Stone, Jones & Harris 2009; Stone, Jones & Harris 2012). Artificial light reduced the foraging activity of *M. dasycneme* over rivers in the Netherlands (Kuijper *et al.* 2008), and torchlight significantly reduced *M. daubentonii* activity along two rivers in England, with no reduction when a red filter was used (Monhemius 2001). However, the results from these last two studies must be viewed with caution: sample sizes were limited and the analyses failed to account for repeated measurements within sites.

Species-specific responses are believed to be a function of flight morphology and echolocation, with fast-flying bats which typically forage in the open using long-range echolocation pulses (including *Pipistrellus*, *Nyctalus*, and *Eptesicus* species) more common around street lights, particularly white lights which attract insects (Rydell 1992; Blake *et al.* 1994). In contrast, slow-flying bats with echolocation and wing morphology adapted for cluttered environments (such as *Rhinolophus*, *Myotis* and *Plecotus* species) (Norberg & Rayner 1987), may be less likely to exploit insects attracted to street lights due to light-dependent predation risk. Fast-flying species are better able to avoid predation by diurnal birds of prey, and emerge earlier from their roosts when light levels are relatively high (Jones & Rydell 1994). Conversely, slow-flying species emerge later, and appear to have an innate intolerance of lit conditions, even when light levels are relatively low (Jones & Rydell 1994). Indeed in Switzerland it has been suggested that the competitive advantage afforded to the relatively light-tolerant species *Pipistrellus pipistrellus* has caused the competitive exclusion of the more light-averse *Rhinolophus hipposideros* (Arlettaz, Godat & Meyer 2000). The theory of light-dependent predation risk is supported by the emergence behaviour of *Rhinolophus hipposideros*, which delays emergence at exposed roost exits compared with protected exits (Duvergé *et al.* 2000).

Light also negatively affects the ability of bats' to orientate (McGuire & Fenton 2010), causing them to collide with large objects under lit conditions. The number of echolocation calls emitted by *M. lucifugus* was reduced under lit conditions (McGuire & Fenton 2010),

suggesting that the light may have confused bats, causing them to switch from acoustic to visual orientation (Orbach & Fenton 2010). The retinas of some bats have cone photoreceptors (Kim *et al.* 2008; Müller *et al.* 2009) which mediate colour vision in bright light (Jacobs 1981). This may explain the collisions as visual sensitivity in some bat species declines with increasing light levels (for a review see Eklof 2003; Orbach & Fenton 2010).

The spectral sensitivity of bats may also contribute to light avoidance behaviour. The retinas of some bat species (e.g. *Rhinolophus ferrumequinum*, Kim *et al.* 2008) contain cones which are prerequisites for daylight vision, colour and Ultraviolet (UV) perception. Cones may be advantageous for visual orientation at twilight, predator avoidance and detection of UV-reflecting flowers for nectar-feeding bats (Müller *et al.* 2009). Molecular studies of the eyes of *M. velifer* found S opsin genes which indicate this species is sensitive to UV light (Wang *et al.* 2004). If the eyes of such bats do not possess a UV absorptive lens, exposure to high levels of UV could result in damage. At present the role of bat spectral sensitivity in relation to behavioural responses to artificial light is unclear.

Summary of deterrents

Acoustic (ultrasound):

There is evidence that ultrasound acoustic deterrents cause spatial avoidance by bats, but they are limited by the detection range and subject to atmospheric attenuation. In addition bats may become habituated. However, they are cheap to run, and are not visible or audible to humans.

Radar:

Radar has considerable potential as a deterrent and has been shown to cause spatial avoidance. Radar is not visible or audible to humans; however, the cost of individual units is relatively high.

Lighting:

Light (white light in particular) has been shown to cause avoidance behaviour in bats. However, the effects are species specific and vary with light intensity and spectral content. Lighting may be a cheap approach to mitigation as units are very inexpensive and running costs low, however several units may have to be installed to light the entire target area and lighting can be considered obtrusive to humans which has legal implications under the Clean Neighbourhoods and Environment Act (2005) Clause 102.

The long term impacts of radar, acoustic deterrents and lighting on bat biology and behaviour need further investigation before they can be used as mitigation tools.

References

Acharya, L. & Fenton, M.B. (1999) Bat attacks and moth defensive behaviour around street lights. *Canadian Journal of Zoology*, **77**, 27-33.

- Altringham, J.D. (1996) *Bats Biology and Behaviour*. Oxford University Press, Oxford.
- Anon. (2006) *A review of the success of bat boxes in houses*. Bat Conservation Trust, Scottish National Heritage Commissioned Report No. 160 (ROAME No. F01AC310). London, UK.
- Anon. (2007) *BCT Mitigation Conference Proceedings, 25-26th April, 2007*. Bat Conservation Trust, University of Leicester.
- Arlettaz, R., Godat, S., and Meyer, H (2000) Competition for food by expanding pipistrelle bat populations (*Pipistrellus pipistrellus*) might contribute to the decline of lesser horseshoe bats (*Rhinolophus hipposideros*). *Biological Conservation*, **93**, 55-60.
- Arnett, E.B., Baker, M., Schirmacher, M., Hein, C.D., Huso, M.M.P. & Szewczak, J.M. (2011) *Evaluating the effectiveness of an ultrasonic acoustic deterrent for reducing bat fatalities at wind facilities: A final report submitted to the Bats and Wind Energy Cooperative*. . Bat Conservation International, Austin, Texas, USA.
- Arnett, E.B., Huso, M.M., Schirmacher, M.R. & Hayes, J.P. (2011) Altering turbine speed reduces bat mortality at wind-energy facilities. *Frontiers in Ecology and the Environment*, **9**, 209-214.
- Arthur, L. & Lemaire, M. (1999) *Les Chauves-souris maîtresses de la nuit*. Delachaux et Niestlé, Bibliothèque du Naturaliste, Lausanne, Switzerland.
- Avila-Flores, R. & Fenton, M.B. (2005) Use of spatial features by foraging insectivorous bats in a large urban landscape. *Journal of Mammalogy*, **86**, 1193-1204.
- Baerwald, E.F., Edworthy, J., Holder, M. & Barclay, R.M.R. (2009) A large-scale mitigation experiment to reduce bat fatalities at wind energy facilities. *Journal of Wildlife Management*, **73**, 1077-1081.
- Balcombe, C.K., Anderson, J.T., Fortney, R.H. & Kordek, W.S. (2005) Wildlife use of mitigation and reference wetlands in West Virginia. *Ecological Engineering*, **25**, 85-99.
- Barak, Y. & Yom-Tov, Y. (1989) The advantage of group hunting in Kuhl's bat *Pipistrellus kuhli* (Chiroptera). *Journal of Zoology*, **219**, 670-675.
- Barbour, R.W. & Davis, W.H. (1969) *Bats of America*. University Press of Kentucky, Lexington, USA.
- Barclay, R.M.R. & Brigham, M. (1991) Prey detection, dietary niche breadth, and body size in bats: why are aerial insectivorous bats so small? *American Naturalist*, **137**, 696-703.
- Bartonicka, T., Bielik, A. & Rehak, Z. (2008) Roost switching and activity patterns of the soprano pipistrelle *Pipistrellus pygmaeus* during lactation. *Annales Zoologici Fennici*, **45**, 503-512.
- Bell, G.P. (1980) Habitat use and response to patches of prey by desert insectivorous bats. *Canadian Journal of Zoology*, **58**, 1876-1883.
- Belwood, J.J. & Fullard, J.H. (1984) Echolocation and foraging behaviour in the Hawaiian hoary bat, *Lasiurus cinereus semotus*. *Canadian Journal of Zoology*, **62**, 2113-2120.
- Bender, R. & Irvine, R. (2000) Bat roosting boxes and factors affecting their success in Organ Pipes National Park 1992-1999. *Bat Research News*, **41**.
- Blake, D., Hutson, A.M., Racey, P.A., Rydell, J. & Speakman, J.R. (1994) Use of lamplit roads by foraging bats in southern England. *Journal of Zoology*, **234**, 453-462.

- Blant, M., Blant, J.D. & Moeschler, P. (1991) Research applied to bat conservation; impact assessments and protection of bats in buildings: the example of Perreux (The Neuchatel Jura, Switzerland). *Myotis*, **29**, 137-140.
- Boldogh, S., Dobrosi, D. & Samu, P. (2007) The effects of illumination of buildings on house-dwelling bats and its conservation consequences. *Acta Chiropterologica*, **9**, 527-534.
- Briggs, P. (2004) Effect of barn conversion on bat roost sites in Hertfordshire, England. *Mammalia*, **64**, 353-364.
- Brigham, R.M. & Fenton, M.B. (1986) The influence of roost closure on the roosting and foraging behaviour of *Eptesicus fuscus* (Chiroptera: Vespertilionidae). *Canadian Journal of Zoology*, **64**, 1128-1133.
- Brittingham, M.C. & Williams, L.M. (2000) Bat boxes as alternative roosts for displaced bat maternity colonies. *Wildlife Society Bulletin*, **28**, 197-207.
- Catto, C.M.C. (1993) *Aspects of the ecology and behaviour of the serotine bat (Eptesicus serotinus)*. PhD, University of Aberdeen, Scotland.
- Clevenger, A.P. & Waltho, N. (2000) Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology*, **14**, 47-56.
- Clevenger, A.P., Chruszcz, B. & Gunson, K.E. (2001) Highway mitigation fencing reduces wildlife-vehicle collisions. *Wildlife Society Bulletin*, **29**, 646-653.
- Cope, J.B., Whitaker, J.O. & Gummer, S.L. (1991) Duration of bat colonies in Indiana. *Proceedings of the Indiana Academy of Sciences*, **99**, 199-201.
- D'Andrea, J.A., Adair, E.R. & de Lorge, J.O. (2003) Behavioral and cognitive effects of microwave exposure. *Bioelectromagnetics*, **24**, S39-S62.
- DeJong, J. & Ahlén, I. (1991) Factors affecting the distribution pattern of bats in Uppland, central Sweden. *Holarctic Ecology*, **14**, 92-96.
- Dietz, C., von Helversen, O. & Nill, D. (2009) *Bats of Britain, Europe and Northwest Africa*. A&C Black Ltd., London.
- Dillingham, C.P., Cross, S.P. & Dillingham, P.W. (2003) Two environmental factors that influence usage of bat houses in managed forests of southwest Oregon. *Northwestern Naturalist*, **84**, 20-23.
- Downs, N.C., Beaton, V., Guest, J., Polanski, J., Robinson, S.L. & Racey, P.A. (2003) The effects of illuminating the roost entrance on the emergence behaviour of *Pipistrellus pygmaeus*. *Biological Conservation*, **111**, 247-252.
- Duverge, P.L., Jones, G., Rydell, J. & Ransome, R.D. (2000) Functional significance of emergence timing in bats. *Ecography*, **23**, 32-40.
- Edgar, P.W., Griffiths, R.A. & Foster, J.P. (2005) Evaluation of translocation as a tool for mitigating development threats to great crested newts (*Triturus cristatus*) in England, 1990-2001. *Biological Conservation*, **122**, 45-52.
- Eisenbeis, G. (2006) Artificial night lighting and insects: attraction of insects to streetlamps in a rural setting in Germany. In *Ecological consequences of artificial night lighting* (eds Rich, C. & Longcore, T.), pp. 281-304. Island Press, Washington.

- Eisenbeis, G. (2009) Insekten und kunstliches licht. In *Das ende der nacht, die globale lichtverschmutzung und ihre folgen* (eds Posch, T., Freyhoff, A. & Uhlmann, T.). Wiley VCH, Berlin, Germany.
- Eklöf, J. (2003) *Vision in echolocating bats*. PhD thesis, University of Goteborg, Sweden.
- Entwistle, A.C., Racey, P.A. & Speakman, J.R. (1997) Roost selection by the brown long-eared bat *Plecotus auritus*. *Journal of Applied Ecology*, **34**, 399-408.
- Fenton, B. & Morris, G.K. (1976) Opportunistic feeding by desert bats (*Myotis* spp.). *Canadian Journal of Zoology*, **54**, 526-530.
- Fullard, J.H. (2001) Auditory sensitivity of Hawaiian moths (Lepidoptera: Noctuidae) and selective predation by the Hawaiian hoary bat (Chiroptera: *Lasiurus cinereus semotus*). *Proceedings of the Royal Society B: Biological Sciences*, **268**, 1375-1380.
- Furlonger, C.L., Dewar, H.J. & Fenton, M.B. (1987) Habitat use by foraging insectivorous bats. *Canadian Journal of Zoology*, **65**, 284-288.
- Geggie, J.F. & Fenton, B. (1985) A comparison of foraging by *Eptesicus fiscus* (Chiroptera: Vespertilionidae) in urban and rural environments. *Canadian Journal of Zoology*, **63**, 263-266.
- Griffin, D.R. (1958) *Listening in the dark: the acoustic orientation of bats and men*. Yale University, New Haven.
- Haffner, M. & Stutz, H.P. (1985/86) Abundance of *Pipistrellus pipistrellus* and *Pipistrellus kuhlii* foraging at street-lamps. *Myotis*, **23/24**, 167-172.
- Hamilton, I.M. & Barclay, R.M.R. (1994) Patterns of daily torpor and day-roost selection by male and female big brown bats (*Eptesicus fuscus*). *Canadian Journal of Zoology*, **72**, 744-749.
- Hatton, L. & Cohen, K. (2000) Report on ringing of Natterer's bats in Tentsmuir Forest 1998-1999. *Scottish Bats*, **5**, 29-31.
- Hickey, M.B.C. & Fenton, M.B. (1990) Foraging by red bats (*Lasiurus borealis*): do intraspecific chases mean territoriality? *Canadian Journal of Zoology*, **68**, 2477-2482.
- Hickey, M.B.C., Acharya, L. & Shannon, P. (1996) Resource partitioning by two species of Vespertilionid bats (*Lasiurus cinereus* and *Lasiurus borealis*) feeding around street-lights. *Journal of Mammalogy*, **77**, 325-334.
- Horn, J.W., Arnett, E.B., Jensen, M. & Kunz, T.H. (2008) *Testing the effectiveness of an experimental acoustic deterrent at the Maple Ridge wind farm*. Bats and Wind Energy Cooperative, Available at <http://www.batsandwind.org>
- Howard, J. & Richardson, P. (2009) *Bats in traditional buildings*. English Heritage, National Trust, Natural England.
- Hristov, N. & Conner, W. (2005) Sound strategy: acoustic aposematism in the bat-tiger moth arms race. *Naturwissenschaften*, **92**, 164-169.
- Hurley, S. & Fenton, B. (1980) Ineffectiveness of fenthion, zinc phosphide, DDT and two ultrasonic rodent repellents for control of populations of little brown bats (*Myotis lucifugus*) *Bulletin of Environmental Contamination and Toxicology*, **25**, 503-507.
- Jacobs, G.H. (1981) *Comparative color vision*. Academic Press, New York, USA.

- Jones, G. & Morton, M. (1992) Radio-tracking studies and habitat use by greater horseshoe bats *Rhinolophus ferrumequinum*. In *Wildlife Telemetry, Remote Monitoring and Tracking of Animals* (eds Priede, I.G. & Swift, S.M.), pp. 521–537. Ellis Horwood, Chichester, England.
- Jones, G. & Rydell, J. (1994) Foraging strategy and predation risk as factors influencing emergence time in echolocating bats. *Philosophical Transactions: Biological Sciences*, **346**, 445-455.
- Jones, G., Duverge, P.L. & Ransome, R.D. (1995) Conservation biology of an endangered species: field studies of greater horseshoe bats. *Symposia of the Zoological Society of London*, **67**, 309-324.
- Kelleher, C. & Marnell, F. (2006) *Bat mitigation guidelines for Ireland*. Irish Wildlife Manuals, No.25. National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, Dublin, Ireland.
- Kerth, G., Weissmann, K. & König, B. (2001) Day roost selection in female Bechstein's bats (*Myotis bechsteinii*): a field experiment to determine the influence of roost temperature. *Oecologia*, **126**, 1-9.
- Kim, T.J., Jeon, Y.K., Lee, J.Y., Lee, E.S. & Jeon, C.J. (2008) The photoreceptor populations in the retina of the greater horseshoe bat *Rhinolophus ferrumequinum*. *Molecules and Cells*, **26**, 373-379.
- Kronwitter, F. (1988) Population structure, habitat use and activity patterns of the noctule bat *Nyctalus noctula* Scrb., 1774 (Chiroptera: Vespertilionidae) revealed by radio-tracking. *Myotis*, **26**, 23-85.
- Kunz, T.H. & Lumsden, L.F. (2003) Ecology of cavity and foliage roosting bats. In *Bat Ecology* (eds Kunz, T.H. & Fenton, M.B.), pp. 3-89. University of Chicago Press, Chicago, USA.
- Kunz, T.H. (1974) Reproduction, growth, and mortality of the vespertilionid bat, *Eptesicus fuscus*, in Kansas. *Journal of Mammalogy*, **55**, 1-13.
- Kunz, T.H. (1982) Roosting ecology of bats. In *Ecology of bats* (ed Kunz, T.H.), pp. 1-55. Plenum Press, New York.
- Laidlaw, G.W.J. & Fenton, M.B. (1971) Control of nursery colony populations of bats by artificial light. *The Journal of Wildlife Management*, **35**, 843-846.
- Lewis, S.E. (1995) Roost fidelity of bats: a review. *Journal of Mammalogy*, **76**, 481-496.
- Licht, P. & Leitner, P. (1967) Behavioral responses to high temperatures in three species of California bats. *Journal of Mammalogy*, **48**, 52-61.
- Long, R.F., Kiser, W.M. & Kiser, S.B. (2006) Well-placed bat houses can attract bats to Central Valley farms. *California Agriculture*, **60**, 91-94.
- Longcore, T. & Rich, C. (2004) Ecological light pollution. *Frontiers in Ecology and the Environment*, **2**, 191-198.
- Lourenco, S.I. & Palmeirim, J.M. (2004) Influence of temperature in roost selection by *Pipistrellus pygmaeus* (Chiroptera): relevance for the design of bat boxes. *Biological Conservation*, **119**, 237-243.

- Mann, S.L., Steidl, R.J. & Dalton, V.M. (2002) Effects of cave tours on breeding *Myotis velifer*. *Wildlife Management*, **6**, 618-624.
- McGuire, L.P. & Fenton, M.B. (2010) Hitting the wall: light affects the obstacle avoidance ability of free-flying little brown bats (*Myotis lucifugus*). *Acta Chiropterologica*, **12**, 247-250.
- Mitchell-Jones, A.J. (2004) *Bat mitigation guidelines*. English Nature, Peterborough, England.
- Monhemius, L.J. (2001) *The sensitivity of foraging Daubenton's bats (Myotis daubentonii) to light during torch surveys*. MSc Conservation University College London.
- Müller, B., Glösmann, M., Peichl, L., Knop, G.C., Hagemann, C. & Ammermüller, J. (2009) Bat eyes have ultraviolet-sensitive cone photoreceptors. *PLoS ONE*, **4**, e6390.
- Neilson, A.L. & Fenton, M.B. (1994) Responses of little brown myotis to exclusion and to bat houses. *Wildlife Society Bulletin*, **22**, 8-14.
- Nicholls, B. & Racey, P.A. (2007) Bats avoid radar installations: could electromagnetic fields deter bats from colliding with wind turbines? *PLoS ONE*, **2**, e297.
- Nicholls, B. & Racey, P.A. (2009) The aversive effect of electromagnetic radiation on foraging bats—a possible means of discouraging bats from approaching wind turbines. *PLoS ONE*, **4**, e6246.
- Norberg, U.M. & Rayner, J.M.V. (1987) Ecological morphology and flight in bats (Mammalia; Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. *Philosophical Transactions of the Royal Society of London B Biological Sciences*, **316**, 335-427.
- Orbach, D.N. & Fenton, B. (2010) Vision impairs the abilities of bats to avoid colliding with stationary obstacles. *PLoS ONE*, **5**, e13912.
- Park, K.J., Masters, E. & Altringham, J.D. (1998) Social structure of three sympatric bat species (Vespertilionidae). *Journal of Zoology*, **244**, 379-389.
- Polak, T., Korine, C., Yair, S. & Holderied, M.W. (2011) Differential effects of artificial lighting on flight and foraging behaviour of two sympatric bat species in a desert. *Journal of Zoology (London)*, **285**, 21-27.
- Racey, P.A. & Swift, S.M. (1985) Feeding ecology of *Pipistrellus pipistrellus* (Chiroptera: Vespertilionidae) during pregnancy and lactation. I. Foraging Behaviour. *Journal of Animal Ecology*, **54**, 205-215.
- Racey, P.A. (1982) Ecology of bat reproduction. In *Ecology of bats* (eds Kunz, T.H.), pp. 57-104. Plenum New York, New York.
- Reiter, G. & Zahn, A. (2006) *Bat roosts in the Alpine area: guidelines for the renovation of buildings*. INTERREG IIIB Living space network.
- Rich, C. & Longcore, T. (2006) *Ecological consequences of artificial night lighting*. Island Press, Washington, London.
- Ritzi, C.M., Everson, B.L. & Whitaker, J.O., Jr. (2005) Use of bat boxes by a maternity colony of Indiana myotis (*Myotis sodalis*). *Northeastern Naturalist*, **12**, 217-220.

- Rundcrantz, K. & Skärbäck, E. (2003) Environmental compensation in planning: a review of five different countries with major emphasis on the German system. *European Environment*, **13**, 204-226.
- Rydell, J. & Racey, P.A. (1995) Street lamps and the feeding ecology of insectivorous bats. *Symposium of the Zoological Society London*, **67**, 291-307.
- Rydell, J. (1991) Seasonal use of illuminated areas by foraging northern bats *Eptesicus nilssoni*. *Holarctic Ecology*, **14**, 203-207.
- Rydell, J. (1992) Exploitation of insects around streetlamps by bats in Sweden. *Functional Ecology*, **6**, 744-750.
- Rydell, J. (1996) Street-lamps increase bat predation on moths. *Entomologisk Tidskrift*, **117**, 129-135.
- Scanlon, A.T. & Petit, S. (2008) Effects of site, time, weather and light on urban bat activity and richness: considerations for survey effort. *Wildlife Research*, **35**, 821-834.
- Schnitzler, H.U., Kalko, E., Miller, L. & Surlykke, A. (1987) The echolocation and hunting behavior of the bat, *Pipistrellus kuhli*. *Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology*, **161**, 267-274.
- Schofield, H.W. (2008) *The lesser horseshoe bat conservation handbook*. The Vincent Wildlife Trust, Ledbury, UK.
- Schowalter, D.B. & Gunson, J.R. (1979) Reproductive biology of the big brown bat (*Eptesicus fuscus*) in Alberta. *Canadian Field Naturalist*, **93**, 48-54.
- Shields, W.M. & Bildstein, K.L. (1979) Bird versus bats: behavioral interactions at a localized food source. *Ecology*, **60**, 468-474.
- Siemers, B. & Swift, S. (2006) Differences in sensory ecology contribute to resource partitioning in the bats *Myotis bechsteinii* and *Myotis nattereri* (Chiroptera: Vespertilionidae). *Behavioral Ecology and Sociobiology*, **59**, 373-380.
- Siemers, B.M. & Kaipf, H.U.S. (1999) The use of day roosts and foraging grounds by Natterer's bats (*Myotis nattereri* Kuhl, 1818) from a colony in southern Germany. *Zeitschrift für Säugetierkunde*, **64**, 241-245.
- Simon, M., Huttenbugel, S. & Smit-Viergutz, J. (2004) *Ecology and conservation of bats in villages and towns*. Bundesamt für Naturschutz, Bonn, Germany.
- Sleep, D.J.H. & Brigham, R.M. (2003) An experimental test of clutter tolerance in bats. *Journal of Mammalogy*, **84**, 216-224.
- Smith, G.C. & Agnew, G. (2002) The value of 'bat boxes' for attracting hollow-dependent fauna to farm forestry plantations in southeast Queensland, doi:10.1046/j.1442-8903.2002.00088.x. *Ecological Management and Restoration*, **3**, 37-46.
- Smith, P.G. & Racey, P.A. (2005) The itinerant Natterer: physical and thermal characteristics of summer roosts of *Myotis nattereri* (Mammalia : Chiroptera). *Journal of Zoology (London)*, **266**, 171-180.
- Spanjer, G.R. (2006) *Responses of the big brown bat, Eptesicus fuscus, to an acoustic deterrent device in a lab setting*. Bats and Wind Energy Cooperative, Available at <http://www.batsandwind.org/pdf/detlab2006.pdf>.

- Speakman, J.R. & Thomas, D.W. (2003) Physiological ecology and energetics of bats. In *Bat Ecology* (eds Kunz, T.H. & Fenton, M.B.). The University of Chicago Press, Chicago.
- Stebbing, R.E. (1988) *Conservation of European bats*. Christopher Helm, London.
- Stebbing, R.E. (1991) Natterer's bat *Myotis nattereri*. In *The handbook of British mammals* (eds Corbet, G.B. & Harris, S.), pp. 102-105. Blackwell Scientific, Oxford.
- Stone, E.L. (2011) *Bats and development: with a particular focus on the impacts of artificial lighting*. PhD thesis, University of Bristol.
- Stone, E.L., Jones, G. & Harris, S. (2009) Street lighting disturbs commuting bats. *Current Biology*, **19**, 1123-1127.
- Stone, E.L., Jones, G., & Harris, S. (2012) Conserving energy at a cost to biodiversity? Impacts of LED lighting on bats. *Global Change Biology, In Press*.
- Svensson, A.M. & Rydell, J. (1998) Mercury vapor lamps interfere with the bat defence of tympanate moths (*Operophtera* spp.; Geometridae). *Animal Behaviour*, **55**, 223-226.
- Swift, S.M. (1997) Roosting and foraging behaviour of Natterer's bats (*Myotis nattereri*) close to the northern border of their distribution. *Journal of Zoology*, **242**, 375-384.
- Szewczak, J.M. & Arnett, E. (2008) *Field test results of a potential acoustic deterrent to reduce bat mortality from wind turbines* Bats and Wind Energy Cooperative, Available at <http://www.batsandwind.org/pdf/2007DeterrentPondStudyFinal.pdf>.
- Thompson, M.J.A. (1992) Roost site philopatry in female pipistrelle bats *Pipistrellus pipistrellus*. *Journal of Zoology*, **228**, 673-679.
- Thompson, S., Treweek, J.R. & Thurling, D.J. (1997) The ecological component of environmental impact assessment: a critical review of British environmental statements. *Journal of Environmental Planning and Management*, **40**, 157 - 172.
- Tischew, S., Baasch, A., Conrad, M.K. & Kirmer, A. (2010) Evaluating restoration success of frequently implemented compensation measures: results and demands for control procedures. *Restoration Ecology*, **18**, 467-480.
- Verkem, S. & Moermans, T. (2002) *The influence of artificial light on the emerging time of Geoffroy's bat Myotis emarginatus*. IXth European Bat Research Symposium (ed. Aulagnier, S. & Le Boulenger, F.), Le Havre.
- Walsh, A.L. & Harris, S. (1996) Factors determining the abundance of vespertilionid bats in Britain: geographical, land class and local habitat relationships. *Journal of Applied Ecology*, **33**, 519-529.
- Wang, D., Oakley, T., Mower, J., Shimmin, L.C., Yim, S., Honeycutt, R.L., Tsao, H. & Li, W.-H. (2004) Molecular evolution of bat color vision genes. *Molecular Biology and Evolution*, **21**, 295-302.
- Whitaker, J.O., Jr. & Gummer, S.L. (1992) Hibernation of the big brown bat, *Eptesicus fuscus*, in buildings. *Journal of Mammalogy*, **73**, 312-316.
- Whitaker, J.O., Sparks, D.W. & Brack, V. (2006) Use of artificial roost structures by bats at the Indianapolis International Airport. *Environmental Management*, **38**, 28-36.

- Whitaker, J.O.J. & Gummer, S.L. (2000) Population structure and dynamics of big brown bats (*Eptesicus fuscus*) hibernating in buildings in Indiana. *American Midland Naturalist*, **143**, 389-396.
- White, E.P. (2004) Factors affecting bat house occupancy in Colorado. *The Southwestern Naturalist*, **49**, 344-349.
- Williams, L.M. & Brittingham, M.C. (1997) Selection of maternity roosts by big brown bats. *Journal of Wildlife Management*, **61**, 359-368.

Bats in
Churches
Research Study
Discussion
Groups

**Report of meetings held
on 18th June 2012 at
Wendling Village Hall,
Wendling, Norfolk.**

Mike King & Associates

Bats in Churches Research Study: Discussion Groups

Report of meetings held on 18th June 2012 at Wendling Village Hall, Wendling, Norfolk, 1.00pm-3.15pm and 7.00pm-9.15pm

1. Introduction

Natterer's bats sometimes form large maternity colonies in churches, especially in East Anglia where they can cause severe problems for church users. Defra has commissioned research to develop strategies to reduce the impact of bats on church users while at the same time providing for the needs of the bats. The project is led by the University of Bristol, with Bat Conservation Trust and Philip Parker Associates as sub-contractors. The research began in May 2011 and is funded for three years.

The research will be focused on 6 church study sites, where the impact of bats is severe. The researchers will investigate the properties of churches and their immediate surrounding landscapes that attract bats, drawing on GIS, radio-tracking and data on surrounding habitat quality and microclimate characteristics of roosts. A key aspect of the project will involve manipulation of local environmental conditions to encourage bats to relocate to alternative, less sensitive areas of churches and will involve the provision of alternative roosting areas both inside and outside churches.

The project will draw on advice from a broad range of wildlife, ecclesiastical and heritage authorities including Natural England, Defra, the Church of England Church Buildings Council, English Heritage and the National Trust, to ensure the work is in the interests of both nature and heritage, addresses the concerns of all stakeholders, and is undertaken with the highest regard for the needs of church users, heritage, bat welfare and ecological requirements.

A key component of the research is to engage with church users who are affected directly by bats in their churches. Two workshops were held at All Saints Church, Necton, Norfolk in November 2012. Due to changes in the research project it was decided that two further consultation workshops should take place in June 2012 to ensure that a wide range of stakeholders had the opportunity to hear about and input into the project. This report relates to the June 2012 workshops.

The aims of these workshops were to bring together church users from churches in the study area with the research team to:

- provide information about the study (including feedback from the first 2 workshops), what it is researching, when it will be completed and how the findings will be used;
- provide information on contacts in the study team;

- help the study team understand church users' attitudes to bats and how bats affect them, including what issues give them most concern and might prevent their using church buildings;
- get feedback from church users on the proposed options for testing mitigation.

2. Who attended

The meetings were well attended by users of churches in the study area and surrounding areas including:

- St Andrew, Deopham
- St Peter and St Paul, Salle
- St Mary's, South Creake
- St Andrews, Framingham Pigot
- St Peter's, Guestwick
- All Saints, Toftrees
- All Saints, Necton
- St Andrews, Holme Hale
- St Mary's, Great Bircham
- St Andrew, Wood Dalling
- St Mary, West Tofts
- St Peter and St Paul, Shropham
- All Saints, Swanton Morley
- Holy Trinity, Great Hockham
- St Batholomews, Brisley

Organisations and individuals with an interest in the issue were also represented including:

- Church architects
- Organ builder
- Diocesan Advisory Committee
- English Heritage

Eleven people (in addition to the facilitators and the research team) came to the afternoon meeting and 15 to the evening meeting. One person who was a representative of another church could not attend but was keen to make an input. Comments this person sent by email have been included in Annex 1.

3. Format and recording of the meetings

Mike King (MK) an independent facilitator, facilitated the meetings, supported by Lisa Worledge (LW) and Julia Hanmer (JH) from the Bat Conservation Trust. Dr Karen Haysom (KH) Director of Conservation at the Bat Conservation Trust and conservation advisor to the

project, represented the research team, presenting information about the study and answering church users' questions.

The meetings were designed to encourage the start of a constructive dialogue about the study between church users and the research team through a combination of presentations and group discussions. The agenda for each workshop was as follows:

- Welcome & Introductions
- Presentation: What's the project?
- Discussion
- Feedback
- Presentation: Mitigation methods
- Discussion
- Summary
- Evaluation forms and close

Church users had the opportunity to ask questions about the study, identify and discuss how they are affected by bats in churches, and put forward their views on bats in the churches they use and the proposed mitigation measures. At the end of each meeting Karen, on behalf of the research team, summarised what the research team had learned and how that would be taken forward in the project. Feedback from church users was recorded in notes taken by the facilitators. These notes are not a verbatim record but attempt to broadly capture the questions and issues raised by the participants and the responses provided by the research team. A collation of the notes of the meetings is included in Annex 1 below.

4. Analysis of feedback

This section sets out the key issues from the feedback from participants.

How church users are affected by bats in churches

The feedback from participants was that they were severely, negatively affected by the presence of bats in churches. There was considerable common ground regarding the nature of the negative impacts and these can be grouped into the following headline issues:

a) Health concerns

Worries and uncertainty about the health risks from bats including bat droppings and urine and handling dead or live bats that have fallen from the roosts. This was particularly of concern to churches that regularly serve food and/or provide activities for children.

b) Cleaning

The presence of bats made cleaning, a job usually undertaken by volunteers, so much more difficult and unpleasant. Where the situation was particularly bad additional cost

had to be incurred to employ professional cleaners. There is concern that the churches' ability to attract volunteer cleaners is compromised because of this issue.

c) Maintenance

The presence of bats makes maintenance of the church more time consuming, costly and complicated and often restricts how churches can be used. There is considerable concern about the long term and irreparable damage to the historic fabric of the church buildings and artefacts they contain.

d) Restricting use

Bats, especially the droppings and urine, make coming to church unpleasant and put people off attending services and events. This diminishes the ability of the church to minister to the community.

e) Cost

There is a considerable cost implication of managing the regulatory requirements and the opportunity costs of using money on these activities instead of building conservation or other church activities. The amount of money that has to be spent to deal with bat problems is very demotivating for fundraisers.

Church users views on the presence of bats in churches

The majority of participants expressed views that, from their experience, people and bats in churches were not compatible. Most said that they appreciated the value of wildlife but felt that in the context of churches the balance was weighted too much in the bats favour, and that churches seemed to be providing a conservation service on behalf of everyone else – which was a very unfair situation. The point was made that if bats were present in other public places such as schools, restaurants, hotels, etc. action would be taken to prevent harm to humans – why are churches different?

Views on proposed mitigation measures

Participants gave some feedback on the proposed measures. Most were of the view that they were willing to put up with any inconvenience or nuisance from the mitigation measures if they felt there was a chance of success. There were a number of practical concerns which can be summarised as follows:

- effect of acoustic deterrents on hearing aids or hearing aid induction loops
- who would be responsible for paying for installation and running costs e.g. electricity for heated boxes
- concern as to how any structure such as a bat box might be anchored to the building surface (e.g. when drilling to fix boxes on a wall there is a need to stop if coloured dust appears as there could be a hidden wall painting)
- concern about lights – some churches have evening events so before lights go on or off there is a need to think about timing. Likewise there was concern that lighting might attract unwanted visitors and lead to an increase in vandalism and crime.

On a positive note it was felt that there would be a lot of local interest and that the local primary school might be interested in getting involved to study bats.

Risks, questions and issues

A number of additional issues emerged from the meeting that need to be addressed by the Research team:

Timescale: There was concern that a two- year research period would not be long enough to generate meaningful data about a natural population. Likewise, the limited period [referring to 9-day trials in each church in 2012] in which the mitigation measures were to be tested was also questioned. Both issues had implications for the communities and decision makers' confidence in the quality of any results generated.

The role of decision making bodies such as the church Faculty and Parochial Church Council as well as bodies such as English Heritage: Although the research project had got the green light from these bodies there was concern that future mitigation measures that could potentially come out from the research might fall foul of the bureaucracy.

Health risks: What are the health risks to church users of contact with bat urine and faeces or handling bats? This was a recurring theme in the workshops and one where there is perhaps a need for better information and maybe more research.

The bat problem is not really solved but just moved on, perhaps to another part of the church or another church entirely. This might be seen as a positive result but is not really a long-term sustainable solution.

Views on how stakeholders should be kept informed about the project

Email and direct contact through further meetings were the most popular channels of communication identified by participants. The project website was also seen as an important channel for communication but it must be updated regularly and provide the ability for people to subscribe to notifications. Consideration should also be given to linking the project website to the diocesan site and maybe to others such as community sites.

Participants expressed considerable interest in the science and would like to know more than just the conclusions. They would be interested in hearing more about what happened, lessons learnt and the mistakes. They would also be interested in hearing about any practical help and advice on dealing with the effect of bats such as the best way to clean droppings and urine. Sharing information between churches could be very useful in this respect.

Writing for church newsletters and providing literature about bats to go in churches were also seen as being effective ways to keep people informed.

5. Summing up

Karen Haysom thanked everyone for coming. She felt that by bringing a wider number of churches together at this event the research team had accessed wider perspectives and ideas. She thought the event had been very valuable and inspiring and was an incentive to keep trying to find the money for more work e.g. for volunteer training.

6. Evaluation of the Workshops

24 participants filled in evaluation forms to provide their feedback on whether the objectives of the meetings were achieved, what they felt was most useful about them and what could be improved. The results and comments are set out in detail in Annex 2 below.

Overall, most participants thought the meeting was successful and achieved its objectives. Participants were pleased to have the opportunity to find out about the research project and to voice and discuss their views on bats and felt that they had been heard by the research team.

In terms of how the meeting could be improved, some participants would have liked more of the research team to be present, some material to take away to help them inform others and more emphasis given to the financial implications of bats in churches, especially in respect to building work and maintenance.

ANNEX 1: Facilitators' workshop notes

These notes are not a verbatim record but attempt broadly to capture the questions and issues raised by the participants and responses provided by the research team.

Bats in Churches Research Study Discussion Meetings

Date: 18th June 2012

Venue: Wendling Village Hall, Wendling, Norfolk

Afternoon workshop – 1.00pm – 3.15pm

Presentation 1: Introduction to the Project – Karen Haysom, Director of Conservation, Bat Conservation Trust

Q: Why is the project taking place in this area?

A : The number of calls the BCT's national Bat Helpline gets is skewed in Norfolk & Suffolk where 26-29% of calls received are in relation to churches. We receive the greatest number of enquiries from churches in the east of England; the second biggest source of enquiries is south of England. These two regions make up approximately 60% of church-related enquiries to the Bat Helpline.

Q: Is the timetable for 2014 sustainable – can you pack in everything you need for a natural population study?

A: It is an ambitious project and not able to track [the effect on bat populations] in that time. Researchers record parameters relevant to population [collected from their studies at the churches and literature searches] and put these into computer population models to infer longer term population effects.

Q: I asked the question above about the timetable because of concern that the data produced will be deemed inadequate to support a change in legislation and will therefore need to be repeated in a few years? Is this the case?

A: This project is unlikely to result in a change in legislation, more likely a change in guidance.

Q: You referred to licensing decisions. Licensing by whom to do what?

A: Any work that impacts on bats or bat roosts needs a licence from Natural England.

Q: You are saying that at the moment we don't know what happens to bats and the project is designed so we can know more and then proceed accordingly. The question then is how do we get the legislation and guidance without a complete data set compiled over a realistic period of time?

A: We do have an evidence base but it is very broad and tends to be based on work done on bats in houses; we know populations have declined, we know there has been habitat loss. Now we want to understand why bats use churches and we also know very little about bats in East Anglia.

Discussion 1

Participants were asked to work in two groups, each with a facilitator, to answer the following questions:

- *How are you affected by bats in the churches you use?*
- *From your personal experience, what do you think about bats in churches?*

A record of the discussion was kept by the facilitators:

Group A

How are you affected by bats in the churches you use?

- Cleaning – all surfaces, sweeping up, polishing, contamination, droppings/ urine, floors and vertical surfaces
- Issues of access to some areas to clean properly e.g. organ wind pipes and high apron walls
- Effect on the structure and the damage from contact e.g. where it cannot be covered or cleaned

- Aesthetics – Conspicuous droppings or plastic sheeting or both
- Destroys sense of quiet and calm
- Historical visits are perhaps becoming less spiritual
- People are not stopping – the church as a place of worship is compromised
- Loss of cultural heritage – physical damage of irreplaceable items
- Physical effect on people
 - Fumes from ammonia in urine
 - Droppings
 - Until proven there is a belief that there is a deleterious effect on people's ability to use the church

From your personal experience, what do you think about bats in churches?

- Frustration – getting nowhere
- Happy to see the bats but not in the body of church e.g. in tower
- Bat boxes in church
- How can we get them out (legally)
- OK in small numbers but not in large
- Churches carry the can for the rest of the community – 'Bat Support Mechanism'
- Loss of trees, given as a reason why bats are in the church.

Group B

How are you affected by bats in the churches you use?

- By the filth they leave behind: urine and droppings everywhere – chancel, nave, aisle, tower
- Church cleaning – if we clean the day before a service we need to clean again just before the service
- We have to put white plastic sheeting down
- Distress to people cleaning the church – cleaners (all volunteers) dread June/July when bat populations are active. Our chief cleaner is 86 and she gets very upset
- Damage – Urine stains wood. Don't think it does the organ any good, stains pipes and may damage
- Dealing with fallen bats is distressing – sometimes dead, sometimes alive. Know that we are meant to take them somewhere miles away but not practical
- Bats fly up and down during service/concerts. At evening events at this time of year you feel the gentle spray of urine on your face or ingest faeces
- Degree of acceptance – can't kill – know the law but demoralising in sense of helplessness
- English Heritage restoration grant – amount of money having to spend to deal with bat problem distressing to fundraisers.

- 15 people in village, 2 churches, have to pay for ecological survey to find out if we have bats. This holds up the work. Holds up repairs to leaks in roof
- Bats within and without so timing constraints – builders can only work in the winter
- All adds to the stress of looking after 2 churches
- Do sympathise with Conservation – bee keeper
- Habitat and legal requirements conflict with building work – timing. Traditional materials e.g. lime mortar should not be applied after danger of frost
- Demoralising when trying to raise funds
- Cleaning costs
- Underlying hygiene worries
 - Churches are now used to serve food more
 - Communion bread and wine
 - More fundraising events with refreshments
- Impacts mission of the church – e.g. recently a couple came to see the church as they hoped to get married there – saw sheets all over the floor – explained bat problem – bat fell out of roof in front of couple!
- Have to be stoical to use church – come to services and performances. But concern puts off people with children
- Large military graveyard with constant flow of visitors who are quite emotional – not right to see plastic covered altar.

From your personal experience, what do you think about bats in churches?

- Accept bats have to go somewhere but we would rather somewhere else
- Delighted this project is happening – seems a sensible way forward
- I got involved some years ago – could not find a way through – tried petitions & MPs – seemed like a dead end. Nothing happened. Only when noticed the Church Building Council – Anne Sloman – she understood politicians/ EU – felt something was being done
- No illusions that there is a magic solution
- There is a conflict – science approach is a good idea
- Some building options are quite radical where bats inhabit body of the church
- English Heritage keen to see parish churches open their doors
- We would like to see the bats rehoused somewhere, not in my church
- If could be in tower would be better or village or trees
- Feeding habitat is important too – but as long as away from our church. Need habitat considerations too. New insecticides used by farms reduces forage for bats
- Always seems that bats are more important than congregation

Presentation 2 : Proposed mitigation methods to be used in the research - Karen Haysom

Q: How big is a bat roost?

A: It varies but in Norfolk a large Natterer's roost could be 100 or more. Different in different churches.

Q: Are there any studies into the health implications of bat droppings and urine?

A: An undergraduate project to screen bat droppings and urine for disease agents is scheduled at Anglia Ruskin University. Some samples of droppings have already been collected from churches for examination by this project. [The project is likely to go ahead as a scoping study in the next academic year, subject to the methods being agreed].

Q: Do bats carry diseases?

A: Explanation given about the European Bat Lyssavirus (EBLV), a rabies like virus. Since 1986, the Animal Health & Veterinary Laboratories Agency has tested over 10,000 bats. Only 10 individuals have been found in the UK with the live virus (EBLV2 strain) and all were Daubenton's bats. There hasn't been a positive case for three years. If you are bitten by a bat you should wash the wound immediately with soap and water, then seek immediate medical advice from your GP. There is advice on the BCT website (www.bats.org.uk) and you can call the Bat Helpline on 0845 1300 228.

Q: Do you have plans for press coverage?

A: Yes. We have agreed a communications plan for the project. We have not yet promoted the project in the media, and plan not to do much media work until the end of the project when we have results. During the project we are focusing our efforts on direct communication with key groups (local church user communities and bat-workers). We also have a project website www.batsandchurches.org.uk. This approach is due to the limited resources available for media work, and a wish to avoid inconvenience for the churches involved in the project while work is ongoing. However I agree that it would be nice to say that the project is underway and when research results will be available.

Discussion 2

Participants were asked to work in 2 groups, each with a facilitator, to answer the following questions:

- *How might the proposed mitigation affect you and how you use the church?*
- *How would you like to be kept informed of the project?*

A record of the discussion was kept by the facilitators:

Group A

How might the proposed mitigation affect you and how you use the church?

- Role of the Parochial Church Council & Diocesan Advisory Committee
 - will we get Faculty to do it if required?
 - lots of church involvement so should get agreement

- temporary project
- box on inside versus on outside – would this weaken scientific value of the project?
- roost location may change but they still fly around in the body of the church
- Who will pay for installation and running costs e.g. electricity for heated boxes?
- Consideration of timing and other events, e.g. evening services
- Lighting may attract unwanted people into the church. If neighbours not informed they may call the police
- Is 9 days long enough to be realistic?

How would you like to be kept informed of the project?

By email and direct contact.

Group B

How might the proposed mitigation affect you and how you use the church?

Q: Has Emma applied for Faculty?

A: Yes – a Group Faculty [Note: after the meeting it has been confirmed that a faculty is not needed for the installation of temporary bat boxes as part of the study].

We do not have and can't afford electricity

Cost of running electrical equipment for any length of time

Q: How will we know from a 9 day trial how long we need to operate these boxes for?

A: This year the trials will run for 9 days only and will provide preliminary information on whether the combination of heated bat boxes and deterrents used appears to result in bats using the boxes and relocating from the existing roost. If the management options trialled are effective in prompting the bats to use the boxes, without signs of harm or distress to the bats, then more extended trials lasting several weeks or more may run at the same churches next year. [More extended trials would be needed to inform on the strategy for using such management options (e.g. whether they would need to be applied for an extended period, whether the bats habituate to the deterrents, whether extended use of the deterrents causes harm that is not detectable in the very short trials)].

- No concerns – will make it work
- Willing to put up with issues/ changes that are appropriate to move bats from A to B
- To reach the long-term aim of addressing the bat problems it may be necessary to move bats from A to B to C to D to encourage them gradually away from sensitive areas in the church
- But not where there are children or holy communion – safety and hygiene issue
- Would be of interest to children, local primary school might be interested in getting involved to study bats

- Have other methods been considered – pheromones?
- Boxes – no problem if out of sight, out of mind
- Concern as to how they might be anchored to the surface
- Initial design may not look nice but they have been approved by the Diocesan Advisory Committee [Context of this is a discussion that the trials would be simple and issues such as appearance could be considered at a later date if the methods appear to work].
- Good if people can see things being done

Q. What do we do if we find a dead bat in the church?

A. If you find dead bats at your church they can be sent off for testing by the Animal Health and Veterinary Laboratories agency as part of their passive monitoring programme for rabies. Packs are available from the Bat Helpline, call 0845 1300 228 to request one.

How would you like to be kept informed of the project?

- Website – updated regularly, with last update on listed on page
- Would also like the ability to subscribe to notifications
- We are interested in the science, so would like to know more than just the conclusions – please show your workings!
- Interested in hearing about what is happening – lessons learned and mistakes. This is more reassuring than just good news.
- Concern over length of study – is it long enough for useful results?
- Also interested in any practical help you can share with us, e.g. best way to clear droppings & urine. Have other churches developed different approaches?

Evening workshop – 7.00pm – 9.15pm

Presentation 1 – Introduction to the Project – Karen Haysom

Q: Can financial implications of bats and churches be discussed or included in the research?

A: In terms of the research you should ask Karen and the research team but you can certainly raise it tonight, it came up this afternoon. [Clarification note: quantifying the financial implications of bats in churches is outside the remit of this research study. This study is focusing on options for practical management solutions].

Q: Requires Faculty approval – is there a chance that if a solution is to be found that there can be a blanket approach to implementing it in all churches?

A: It is likely that each situation will be different and therefore different solutions will apply. However a group Faculty has been arranged for this project.

[Stephen Thorpe comment – project inspired by Lambeth 2010 conference – therefore has high church backing. Also our own Bishop Graham is keen it should be pursued. For the purposes of this project there will be much support from church/ dioceses/ faculty.]

Q: Some years ago we were offered a quantity of bat boxes but Faculty said we couldn't do it. If we did do it do you think the bats would move to it?

A: Probably not as most often bat boxes are in outdoor locations. Bats use these differently compared with a maternity roost where they want somewhere warm. Heated bat boxes can be used in respect to maternity roosts and will be looked at during this research.

Discussion 1

Participants were asked to work in 2 groups, each with a facilitator, to answer the following questions:

- *How are you affected by bats in the churches you use?*
- *From your personal experience, what do you think about bats in churches?*

A record of the discussion was kept by the facilitators:

Group A

How are you affected by bats in churches you use?

- "If they like it warm why do they come to our churches!"
- Spoiling material/stone/ artefacts through their urine and droppings
- Like them being there
- Have to cover food and put books away
- When cleaning we then need to do certain places more thoroughly
- Do not like damage but price we have to pay. Cycle of nature
- People frightened
- Not seen flying in church but seen elsewhere at dusk
- £6K extra on recent building works for mitigation measures for bats
- Organs – droppings in pipes affects tuning and urine down façade creates staining

From your personal experience, what do you think about bats in churches?

- Darn nuisance
- Annoyed with Local Authority – allowing lots of barn conversions, bats have to go somewhere else. Need a stronger control of planning
- Why not have more bat boxes?
- Had to put boxes up as part of mitigation inside church. This has caused more problems as the droppings used to be all in one area but since disturbed the roost they are now all over the church.
- Limited flexibility as need to clean church before weddings and funerals etc
- Droppings are easily dealt with, main issue is with urine and smells
- Woodwork – use beeswax to protect pews

- Makes doing repairs and maintenance more difficult. Timing and scheduling challenges – can only do certain work at certain times. This does not always fit with Faculty procedures for grants which must be spent in a particular timeframe.
- Also cost implications for parishes of mitigation work.
- It's not just bats – other wildlife is a problem too!
- When the problem first occurred we did not know where to go
- Issue of disparity between churches with a small bat problem and those with a huge problem
- Helpful if we knew what species we had
- Improve planning system.

Group B

How are you affected by bats in the churches you use?

- Permanently cleaning
- Smell
- Damaging the pews (urine)
- Food – off-putting – assured no hygiene problems?
- Have to cover everything with plastic sheets: pews, altar, aisle and carpets
- Before service on Sunday we have to take sheets out – all sticky with bat urine
- Disincentive for purchasing new hymn books, order of service, leaflets – because they will get damaged.
- Small children – put things in their mouths – might put in droppings
- 4 fatalities from rabies in the UK? [BCT Note: there has only been one fatality as the result of European Bat Lyssavirus in the UK. This was a bat worker in Scotland in 2002. He was not vaccinated and was handling bats without wearing gloves when he was bitten. He did not seek immediate medical attention and sadly, by the time he became ill, it was too late for post exposure treatment. All other deaths resulting from rabies (and there have indeed been four since 2000) are of classical rabies and were the result of infections acquired whilst abroad. None of these have been associated with bats.]
- Rabies monitoring – should we send dead bats in?
- If we had an infestation of mice we would clear them out
- Cleaning – Holme Hale £350 for commercial cleaning before a wedding
- Also cost of damage to the fabric and structure of the building, e.g. one church is currently having to pay for temporary roof covering until bat season is over then the real roof can be put on
- Some damage is irreversible such as brass fittings/plaques and stonework
- Droppings stuck on wall as high as ceiling
- Create an unfortunate persona for the church – 'dirty place full of cobwebs and bats'
- I think that only my 'make do and mend' generation will put up with this – cannot see my daughter's generation putting up with it.

- Spring clean took 4 days this year.
- At the other extreme some churches suffer very few problems apart from repetitive cleaning
- A matter of numbers – some years ago it was a small colony, now a large one.
- My church has an estimated 3000 bats

From your personal experience, what do you think about bats in churches?

- I think that they are pests
- We spend 1hr before each service cleaning, even after it has been cleaned the day before
- Default position appears to be that it is acceptable for bats and people to share the same enclosed indoor space. However, I believe that it should not be acceptable for people to share the same indoor space with wildlife.
- My main concern is environmental health – particularly when we are serving food.
- If bats were in a school, restaurant, hotel they would be cleared out – why are churches different?
- At what point did it become acceptable to protect bats?
- Difficulty – want to protect but expected to share space.

Presentation 2: Proposed mitigation methods to be used in the research - Karen Haysom

Q: What does mitigation mean?

A: Generally replacing something and providing an alternative to what is done already. Perhaps we should use the term 'management options'. In the context of this study that could be the provision of an alternative roost in combination with a deterrent

Q: How many bats would use the box?

A: Not sure about this specific one but some churches have a lot of bats and may need to use a couple of boxes. You will be surprised how many can fit in! The aim is to attract enough of the bats to make a difference.

Q: How do we know which type of bat do we have in our church?

A: There are a number of ways of finding out: droppings, bat detectors, licenced person can catch a bat to identify in the hand.

Q: Some of the roosts will require more than an 8ft ladder as the buildings are quite tall.

A: Which churches are invited to participate will depend on accessibility and number of bats. Means that some churches that would really like to be part of the study can't be because the roost is inaccessible.

Q: When will you make a decision on churches to be included in the study?

A: There has been a group Faculty application for all the churches that have been short-listed for participation in the study.

Clarification was provided on the organisation of the research:

Our original research schedule was to conduct nine-day management trials at three churches in summer 2012 and three churches in summer 2013. Two of the three churches originally planned for 2012 (St Andrews, Holme Hale and All Saints, Toftrees) have been selected. However Defra has asked us to fast-track the research to study six churches in summer 2012, requiring a further four churches to be identified. In order to choose churches for the study we draw on existing bat data (e.g. from Philip Parker's Norfolk bats and churches project; previous requests for information and help from churches etc.) but the research team need to visit when the bat colony is present and active in the summer to determine whether the colony is large enough for the study, and whether the bats are roosting in a location sufficiently accessible for bats to be caught for the purpose of attaching radio-tags. Because the bats move the position of their roosts within churches from time to time, and because some of these locations can be difficult or impossible to reach because of the height from the ground, the research team need to check this immediately before the planned studies. The research team will be assessing this during June and early July.]

Q: If bats are keen to be warm could not temperature be used as a deterrent?

A: Range of temperatures in a church, under eaves on south side is probably warm enough for roosting bats, so bats move around. For maternity roosts, bats often select warm locations. At other times, such as hibernation, they may select cooler conditions. Bats naturally move around to select the preferred microclimate for their needs at the time. [It would not be practical or cost-effective to manipulate temperature over a large area as a deterrent, although it could be manipulated in small locations to make alternative roosts more attractive (as in the heated bat boxes).

Discussion 2

Participants were asked to work in 2 groups, each with a facilitator, to answer the following questions:

- *How might the proposed mitigation affect you and how you use the church?*
- *How would you like to be kept informed of the project?*

A record of the discussion was kept by the facilitators:

Group A

How might the proposed mitigation affect you and how you use the church?

Should not affect us at all – church large enough to accommodate study

Concerned that acoustic radar might affect hearing loop

Q: How are boxes heated?

A: Internal heat pad provides a constant 17-20C and costs £20 a year to heat.

When drilling to fix boxes on wall need to stop if coloured dust appears as there could be a hidden wall painting.

Q: Are we likely to have all bats in box in 9 days?

A: Could leave boxes for longer but not deterrents as these need to be carefully monitored.

Q: If deterrents worked would some bats find it difficult to find alternative roosts?

A: Study will look at these animal welfare issues and if they become apparent then research will stop.

Q: What if reverse happens and bats increase?

A: Probably not pull bats in from surrounding area but may move problem onto another church – need to monitor this situation.

Concern about lights – some churches have evening events so before lights go on or off need to think about timing.

Need to keep people informed of the study and its activities perhaps through the following:

- Link from diocesan website to project website
- Ensure that churches are informed before major events such as weddings
- Put literature about bats in the churches

How would you like to be kept informed of the project?

Any church should be able to go on email list so can be kept up to date

Church authorities kept informed

Could volunteers be trained to help churches, e.g. advice on cleaning given through personal visits

Group B

How might the proposed mitigation affect you and how you use the church?

Good. Providing bat boxes are not where we need to do roofing or repair work next year

Tower – question as to when we can use the bells, would be a shame if we could not use them whenever we wanted to.

Heated bat boxes – won't droppings still be the same issue?

Q: Outside – won't the heated bat boxes be outside?

A: They need to be where bats will find them and use them [so it is better for the study to site the boxes internally].

- Could the bat boxes be put ultimately outside – perhaps via a step by step process.
- Outside is definitely best option. Anywhere else inside my church is not acceptable
- Welcome deterrents
- How much time will it take to solve this issue? What are the real chances of excluding from a 600 year old building with lots of holes?
- Cannot exclude bats at the expense of the Parish
- My view – only solution is to create a permanently unfriendly environment
- I don't think that it is practical – hope that I am wrong
- Good that something like this is being done and people are listening
- Welcome this initiative tremendously but I still have a suspicion that Natural England will want to find a way for bats to stay in churches
- I don't want to harm them but I don't want them in the church

Q: If you built a structure for the bats, e.g. small lean-to, – blend in with church – is there a chance you could exclude them permanently?

A: Could technically be an approach, not cheap, hard to plug all gaps in a church, might be better to work with deterrents.

How would you like to be kept informed of the project.

- Do you have the resources to be proactive?
- Website is good but passive
- People desperate for information
- Write for church times/diocese newsletter
- A lot of parishes in this county would love to know what we are doing – perhaps communicate through the 20 Diocese secretaries
- Report back on what found in churches in study
- Invite people to discussions in churches where the study is happening
- Karen - It would be useful to know about events where we could slot in an update session
- Julia – need to recognise constraints of time/ capacity

Summing up

Karen – by bringing a wider number of churches together today we have accessed wider perspectives and ideas. Very valuable and inspiring for us to have these discussions and an incentive to keep trying to find the money for more work, e.g. for volunteer training.

Final point from participants: Anglo catholic churches using incense don't have bats. Incense used less in CoE now.

Thank you

ANNEX 2: Evaluation results

Participants were invited to fill in evaluation forms at the end of meetings. 24 people completed forms.

1. *How successful was today's event for achieving its objectives?*

24 people answered this question. 22 of these considered that the workshop had successfully achieved its objectives while the other 2 people considered that it partially had.

2. *Were your expectations from today's event met?*

23 people answered this question and all felt that the workshop had met their expectations.

3. *How do you use the churches in the study area?*

23 people answered this question. 20 of the workshop participants regularly attended church services, 4 organise or attended groups that used the church and 4 people were involved with the churches in an advisory capacity.

4. *What, if anything did you like about the meeting?*

- To hear about the progress of the research project and the mitigation procedures
- Round table discussions
- Good visuals – clear explanations – succinct summing up.
- Good presentation and discussions
- Hearing the opinions of the other people as it is easy to feel you are the only ones and your problem is put into perspective
- Frank discussion
- The discussions
- The willingness to understand the problems some churches face when they have very large colonies of bats
- Well run, set agenda and schedule kept well
- The positive approach and the very detailed information given
- Discussion session worked well and were given sufficient time

5. *What, if anything, would you change about today?*

- I would have liked to have met the other researchers. It would have been nice to know the 6 churches in which the research is to be conducted
- I would have liked to have seen photos of different species
- Nothing – the discussion was very helpful
- Nothing – it was very good. In Karen's presentation she was going through her points and said 'how can we help bats' when the slide said 'how can we help churches!' (evening session)
- Perhaps more time to share groups thoughts

- Possibly handout with key contacts
- Really cannot think of anything
- Greater consideration to managing church maintenance and repair in relation to bats and their habitats and the cost for parishes for mitigation work
- Not at 1300hrs
- Involvement of the actual researchers – no evidence yet that they actually exist
- Probably about right
- It's a good working model
- More frequent coffee breaks would have aided concentration

6. *Other comments*

- We would enjoy some potential material to take away and digest
- Please share power point presentation for further dissemination to PCC
- As an organ builder working in Norfolk churches I endorse that certain churches have extreme problems with the adverse effects that mean that it is important to address the problem
- Very encouraged by progress to date and hopeful of positive outcome
- Assess the bats in churches issue from a builder's point of view, how they affect project planning and work at the site
- I must admit I was dubious about the meeting – but I have learnt a lot and had my interest awakened
- Excellent
- The researchers were very well informed and understood the problems from the congregations' point of view whilst keeping the welfare of the bats and the need for the study to increase knowledge at the centre of the discussion
- Improvements to the secular planning system to ensure that due care is taken when bat habitats are affected by planning. The removal of habitats may be encouraging bats into churches.
- I was very impressed with the enthusiasm of the group and their wide knowledge

ANNEX 3: Additional anonymous comments

The following comments were supplied by an invited representative of another church, who was unable to attend the meetings, but who was keen to make a contribution. Following the format of the meeting, we have made these comments unattributable.

"I regret that I am unable to attend your meeting but would like to make the following points:-

1. I am a conservationist but have strong views about bats in churches

2. I am the one who opens the church every morning and have to clear up their droppings and try and disperse the strong smell created by their urine.
3. I have to cover our precious brass lectern to prevent it being ruined by the urine
4. I pick up the dead bats
5. At one time they roosted over the very rare terracotta screens and their droppings were over the top of the screens as well as on the floor. I am not sure of the damage this could cause.
6. It was suggested we put a type of umbrella covering over the terracottas - not what visitors from as far away as America and Australia come to see and photograph.
7. There are a number of suitable roosts in and around the church and [the village] in general. Our medieval church is very precious and needs preserving as much as the bats, if not more so. “

APPENDIX 9 – Specifications of deterrents used in churches

1) Acoustic deterrence

Deaton deterrent:

The device consists of a waterproof box (~45 x 45 cm, ~0.9 kg) that houses 16 transducers (Fig. A9.1) that emit continuous broadband ultrasound from 20 to 100 kHz (manufactured by Deaton Engineering, Georgetown, Texas). The transducers in these units have an optimum transmission level at their resonant frequency of 50 kHz and reduced transmission levels at higher and lower frequencies over a broadband range of 20–100 kHz (Table A9.1). This frequency range overlaps with the dominant frequency range of all UK bat species. 50 kHz is also close to the peak sensitivity of Natterer’s bat hearing (40-50 kHz). At 10 metres away, which is approximately equal to the distance that these units were positioned below Natterer’s bat roosts, decibel levels are above the upper target (65 dB; identified as the threshold above which the efficacy of the deterrent is greatest) throughout most of the frequency spectrum (Table A9.1). A spectrogram and power spectrum for the Deaton deterrent are given in Fig. A9.2.

Three factors influence the predicted effective transmitted power at a given distance: the original transmitted power (sound pressure level; SPL), attenuation with distance due to the wave front spreading (inversely proportional to the square of the distance, frequency independent), and the attenuation (absorption) in air of the sound wave (dependent on frequency, humidity and distance).



Figure A9.1 – Deaton (acoustic) deterrent speaker unit housing 16 transducers (left), and mounted on a wind turbine (right). This deterrent was originally designed to deter bats from flying close to wind turbines. Images: Bats and Wind Energy Cooperative (BWEC) (<http://www.batsandwind.org/>)

Relative Humidity	90								
Upper Target (dB)	65								
Lower Target (dB)	35								

Calculated Decibel Level at Distance and Frequency									
(Assumes 20C and 101.325kPa)									
Distance (m)	Frequency (kHz)								
	20	30	40	50	60	70	80	90	100
1	102	107	112	122	122	117	114.5	114.5	117
5	86.6	90.1	93.2	101.4	98.8	92.4	88.1	86.0	86.8
10	78.9	80.5	81.2	87.1	81.3	73.1	66.6	61.8	60.1
15	73.6	73.4	71.7	75.2	66.3	56.3	47.6	40.1	36.1
20	69.3	67.3	63.2	64.4	52.3	40.5	29.6	19.4	13.1
25	65.6	61.7	55.2	54.2	38.8	25.3	12.1	-0.8	-9.4
30	62.3	56.5	47.7	44.3	25.8	10.4	-4.9	-20.5	-31.4
35	59.2	51.6	40.3	34.7	12.9	-4.2	-21.8	-40.1	-53.3
40	56.3	46.8	33.2	25.2	0.3	-18.6	-38.4	-59.4	-74.9
45	53.5	42.2	26.1	15.9	-12.3	-32.9	-55.0	-78.6	-96.5
50	50.9	37.6	19.2	6.7	-24.7	-47.1	-71.4	-97.7	-117.9
55	48.3	33.2	12.4	-2.4	-37.0	-61.2	-87.7	-116.7	-139.2
60	45.8	28.8	5.6	-11.5	-49.3	-75.3	-104.0	-135.7	-160.5

Table A9.1 – Decibel levels of ultrasound emitted by the Deaton deterrent used in experiments to deter Natterer’s bats from roosts inside churches. Reproduced with permission from BWEC (<http://www.batsandwind.org/>)

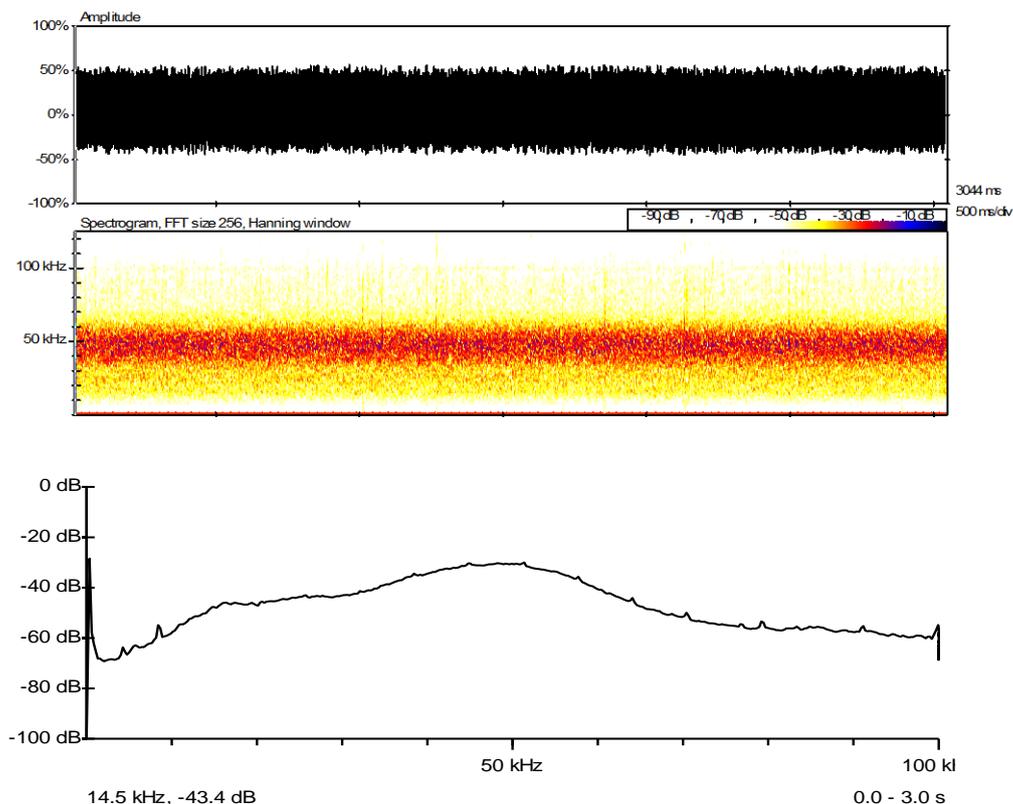


Figure A9.2 – Spectrogram (middle) and power spectrum (bottom) of a recording made from a single Deaton speaker, on axis, in an anechoic room at the University of Bristol.

CR deterrent:

The device, developed in collaboration with Concept Research Ltd (Hertfordshire, England) is considerably smaller and lighter than the Deaton deterrent (Fig. A9.4). The CR deterrent differs from the Deaton deterrent in that it emits a narrowband, rather than a broadband, signal. The unit emits constant frequency signals that cycle between 40 kHz and 60 kHz, with the frequency of sound emitted changing every 4-5 seconds (Fig. A9.3).

We measured the sound pressure levels (SPLs) of sounds emitted by the two speaker designs in an anechoic room at the University of Bristol using a Sanken CO-100K Super Wide Range Microphone (Sanken Microphone Co. Ltd., Tokyo, Japan). On axis, the estimated mean intensity of four Deaton speaker units was 120 dB RMS SPL at one metre. The equivalent mean intensity of three CR speakers was 90 dB RMS SPL. At 45° the sound pressure levels were 94 dB RMS SPL and 83 dB RMS SPL respectively. The Deaton deterrents emit ultrasound at much higher intensities (~30x higher amplitude) than the CR devices, but appear to be more directional.

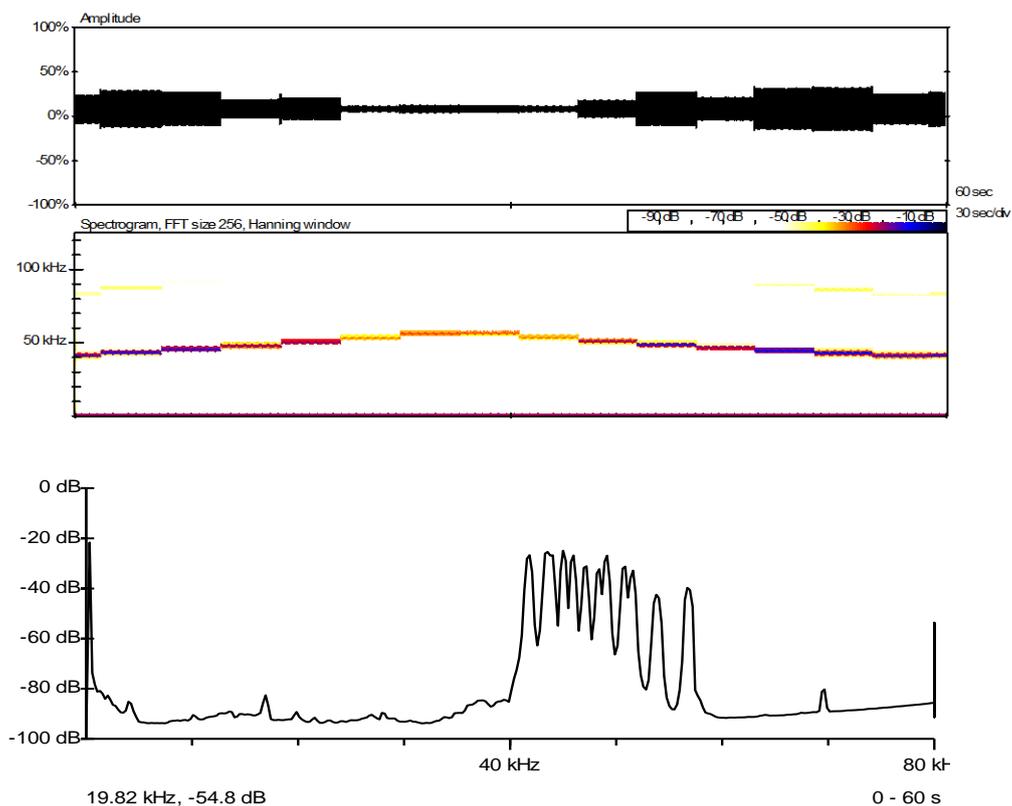


Figure A9.3 – Spectrogram (middle) and power spectrum (bottom) of a recording made from a single Concept Research speaker, on axis, in an anechoic room at the University of Bristol.



Figure A9.4 – Comparison of Deaton (left in each picture) deterrent with CR deterrent (right in each picture). Shows front image (left) and profile image (right). Images: Matt Zeale

2) Artificial lighting

For lighting deterrence, we used a Defender Twin 500W 110V Telescopic Tripod Work Light. At the time of writing the cost of a single tripod with two 400W halogen lamps (Fig. A9.5) is £23.70 (www.tool-net.co.uk).

Specifications:

- 2x 400W pivoting halogen lamps
- 60 cm to 170 cm adjustable tripod
- Quick lock& release height adjustment
- m cable and fitted plug
- IP44 Rated (splash proof)



Figure A9.5 – Lighting rig used in deterrent experiments. One or two units were used at each church depending on the size of church.

3) Radar

The radar model that we trialled during pilot investigations of deterrent types was the Furuno Marine Radar FR-8062 (Furuno Electric Co., Ltd) (Fig. A9.6). At the time of writing, the cost for one of these units is approximately £7000 (Cactus Navigation and Communication)

Specifications:

- Frequency: 9410 ± 30 MHz (X-band)
- Output power: 6 kW
- Length: 4 feet
- Beam width: 4 feet
horizontal = 1.9° , vertical = 22.0°



Figure A9.6 – Radar model used in pilot trials.

APPENDIX 10 – Bat boxes installed at churches during deterrence experiments



Figure A10.1 – Heated bat box (top left) installed at churches to provide alternative roosts for bats during deterrence experiments. Shows box *in situ* at Swanton Morley (top right) and Toftrees (bottom). Images: Matt Zeale

APPENDIX 11 – Response of bats to short-term applications of acoustic deterrence

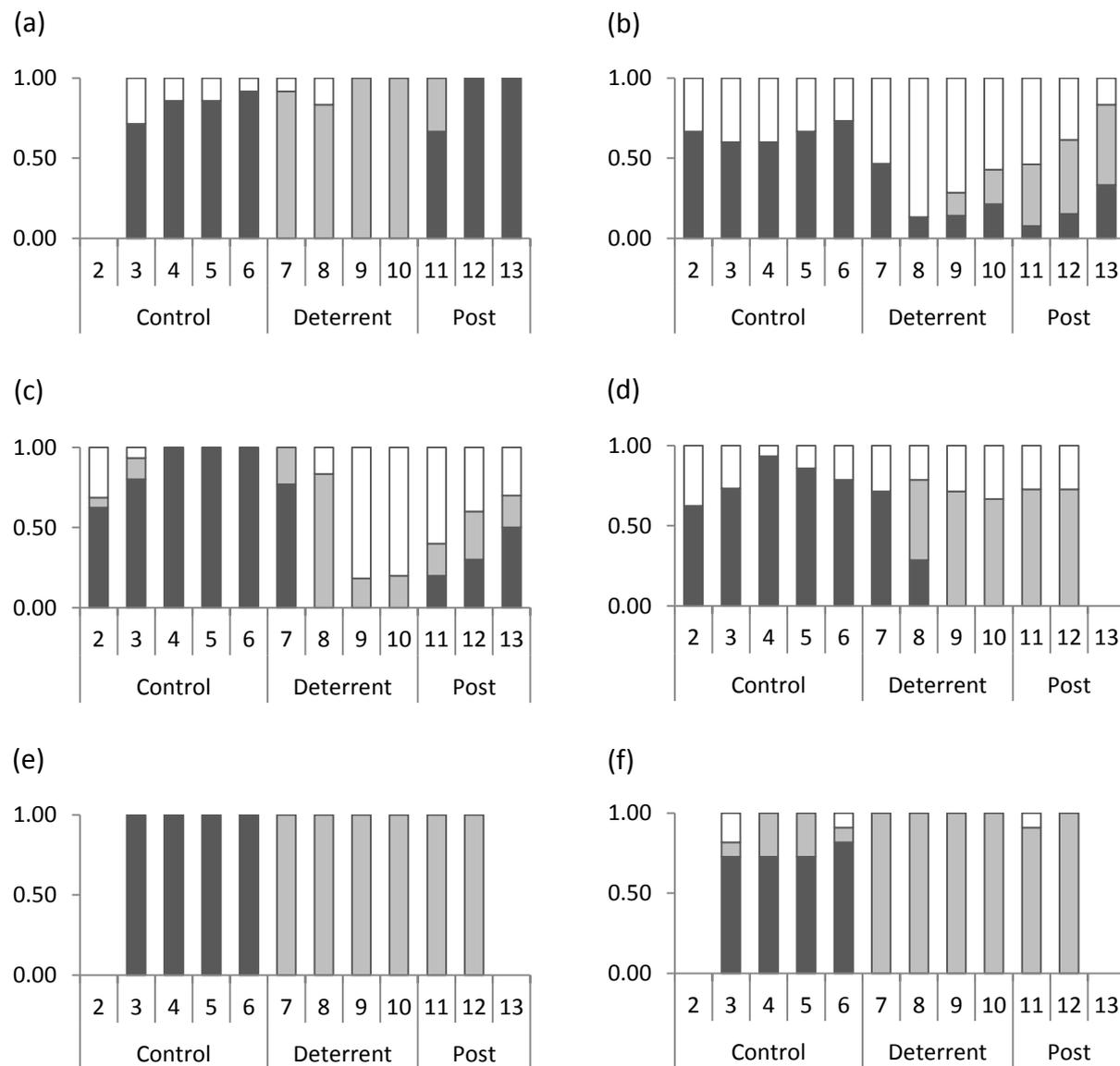


Figure A11.1 – Response of radio-tagged Natterer’s bats to short-term applications of the Deaton (acoustic) deterrent at (a) Guestwick ($n = 14$ bats), (b) Toftrees ($n = 15$ bats), (c) Holme Hale ($n = 16$ bats), (d) Cley ($n = 17$ bats), (e) Swanton Morley ($n = 14$ bats) and (f) Salle ($n = 11$ bats). Shows the proportion of bats roosting in the original roost above the deterrent (dark grey bars), in alternative roosts inside the church (light grey bars) and in alternative roosts outside the church (white bars) during control (deterrent *in situ* and switched off), deterrent (deterrent *in situ* and switched on) and post-deterrent (no deterrent) periods.