Bat Conservation

Global evidence for the effects of interventions

2021 Edition

Anna Berthinussen, Olivia C. Richardson & John D. Altringham

CONSERVATION EVIDENCE SERIES SYNOPSES

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Cover image: Leucistic lesser horseshoe bat *Rhinolophus hipposideros* hibernating in a former water mill, Wales, UK. Credit: Thomas Kitching

Digital material and resources associated with this synopsis are available at https://www.conservationevidence.com/

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Advisory Board

We thank the following people for advising on the scope and content of this synopsis update (2021 edition):

Dr. Fabio Bontadina, SWILD – Urban Ecology & Wildlife Research, Switzerland
Dr. Katherine Boughey & colleagues, Bat Conservation Trust, UK
Dr. Rachel Cooper-Bohannon, Bats Without Borders, Malawi
Dr. Jasja Dekker, Jasja Dekker Dierecologie, Netherlands
Prof. Brock Fenton, University of Western Ontario, Canada
Dr. Neil Furey, Fauna & Flora International, Cambodia
Dr. Winifred Frick & colleagues, Bat Conservation International, USA
Dr. Anita Glover, Vincent Wildlife Trust, UK
Associate Prof. Alice Hughes, Chinese Academy of Sciences, China
Dr. Johnny de Jong, Swedish University of Agricultural Sciences, Sweden
Dr. Javier Juste, Spanish National Research Council, Spain
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Prof. Rodrigo Medellin, National Autonomous University of Mexico, Mexico
Prof. Paul Racey, University of Exeter, UK
Dr. Guido Reiter, Austrian Coordination Centre for Bat Conservation & Research, Austria
Associate Prof. Danilo Russo, University of Naples Federico II, Italy
Dr. Emma Stone, African Bat Conservation, UK/Malawi
Dr. Paul Webala, Maasai Mara University, Kenya

The following people advised on earlier editions:

Associate Prof. David Jacobs, University of Cape Town, South Africa
Prof. Gareth Jones, University of Bristol, UK
Rahul Khanolkar, Indian Bat Research & Conservation Unit, India
Dr. Tigga Kingston, Texas Tech University, US/SE Asia
Dr. Bradley Law, NSW Primary Industries, Australia
Dr. Adrià López-Baucells, University of Lisbon, Portugal
Prof. Kirsty Park, University of Stirling, Scotland, UK
Prof. Stuart Parsons, Queensland University of Technology, Australia/New Zealand
Dr. Orly Razgour, University of Exeter, UK
Dr. Ricardo Rocha, University of Cambridge, UK
Dr. Luísa Rodrigues, Institute for Nature Conservation & Forests, Portugal
Dr. Henry Schofield, Vincent Wildlife Trust, UK

About the authors

Dr. Anna Berthinussen is an ecological consultant and bat specialist at Conservation First, UK.

Dr. Olivia C. Richardson completed a PhD student at the University of Sheffield, UK.

Professor John D. Altringham is Emeritus Professor of Animal Ecology and Conservation in the School of Biology, University of Leeds, UK.

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1. About this book

1.1 The Conservation Evidence project

The Conservation Evidence project has four main parts:

1. The **synopses** of the evidence captured for the conservation of particular species groups or habitats, such as this synopsis. Synopses bring together the evidence for each possible intervention. They are freely available online and, in some cases, available to purchase in printed book form.

2. An ever-expanding **database of summaries** of previously published scientific papers, reports, reviews or systematic reviews that document the effects of interventions. This resource comprises over 6,989 pieces of evidence, all available in a searchable database on the website www.conservationevidence.com.

3. ***What Works in Conservation,*** which is an assessment of the effectiveness of interventions by expert panels, based on the collated evidence for each intervention for each species group or habitat covered by our synopses. This is available as part of the searchable database and is published as an updated book edition each year (www.conservationevidence.com/content/page/79).

4. An online, **open access journal** *Conservation Evidence* publishes new pieces of research on the effects of conservation management interventions. All our papers are written by, or in conjunction with, those who carried out the conservation work and include some monitoring of its effects (www.conservationevidence.com/collection/view).

1.2 The purpose of Conservation Evidence synopses

Conservation Evidence synopses **do**	Conservation Evidence synopses **do not**
• Bring together scientific evidence captured by the Conservation Evidence project (over 6,989 studies so far) on the effects of interventions to conserve biodiversity	• Include evidence on the basic ecology of species or habitats, or threats to them
• List all realistic interventions for the species group or habitat in question, regardless of how much evidence for their effects is available	• Make any attempt to weight or prioritize interventions according to their importance or the size of their effects

• Describe each piece of evidence, including methods, as clearly as possible, allowing readers to assess the quality of evidence	• Weight or numerically evaluate the evidence according to its quality
• Work in partnership with conservation practitioners, policymakers and scientists to develop the list of interventions and ensure we have covered the most important literature	• Provide recommendations for conservation problems, but instead provide scientific information to help with decision-making

1.3 Who this synopsis is for

If you are reading this, we hope you are someone who has to make decisions about how best to support or conserve biodiversity. You might be a land manager, a conservationist in the public or private sector, a farmer, a campaigner, an advisor or consultant, a policymaker, a researcher or someone taking action to protect your own local wildlife. Our synopses summarize scientific evidence relevant to your conservation objectives and the actions you could take to achieve them.

We do not aim to make your decisions for you, but to support your decision-making by telling you what evidence there is (or isn't) about the effects that your planned actions could have.

When decisions have to be made with particularly important consequences, we recommend carrying out a systematic review, as the latter is likely to be more comprehensive than the summary of evidence presented here. Guidance on how to carry out systematic reviews can be found from the Centre for Evidence-Based Conservation at the University of Bangor (www.cebc.bangor.ac.uk).

1.4 Background

Bats represent approximately one fifth of all mammal species with over 1,400 bat species currently known to science (Simmons & Cirranello 2019). They are also the most widely distributed order of terrestrial mammals occupying all areas of the world except the Arctic and Antarctica, although the greatest bat diversity is found in the tropics. Bats provide vital ecosystem services with ecological and economic benefits, such as pest suppression, pollination and seed dispersal (e.g. Boyles *et al.* 2011, Kunz *et al.* 2011). However, the life history of bats (typically low fecundity) makes them particularly vulnerable to extinction, and widespread population declines have been documented over the last few decades (e.g. Frick *et al.* 2019). Many bat species are threatened, particularly by anthropogenic impacts such as logging and deforestation, agriculture, urban and industrial development, pollution, hunting and persecution (e.g. see Voigt & Kingston 2016, Frick *et al.* 2019). Climate change and extreme weather events, such as heat waves and tropical storms, are also a threat to bats (e.g. Sherwin *et al.* 2013).

Five bat species are listed as extinct by the International Union of Conservation for Nature (IUCN) and almost one-fifth of bat species (18%) assessed by the IUCN are considered threatened (Frick *et al.* 2019). However, the actual number may be far greater given that insufficient data are available to assess the conservation status for a further 15% of bat species listed by the IUCN, many newly discovered species are not yet classified or included on the IUCN red list, and there may be many further cryptic species which are yet to be described. Conservation efforts have been successful in reversing population declines for some species, and even preventing species extinctions. For example, the lesser long-nosed bat was recently removed from endangered species lists in both the USA and Mexico after populations recovered following bat-friendly farming initiatives, education programmes and roost protection (US Fish & Wildlife Service 2016).

Evidence-based knowledge is key for planning successful conservation strategies and for the cost-effective allocation of scarce conservation resources. Targeted reviews may be carried out to collate evidence on the effects of a particular conservation intervention, but this approach is labour-intensive, expensive and ill-suited for areas where the data are scarce and patchy. There is a paucity of evidence within the literature for the effectiveness of conservation interventions aimed at bats. As a result, very few targeted reviews exist, and those that do exist are inconclusive or limited in scope.

In 2014, we published the Bat Conservation Synopsis to collate evidence for bat conservation on a global scale (Berthinussen *et al.* 2014). We used a subject-wide evidence synthesis approach (Sutherland *et al.* 2019, Sutherland & Wordley 2018) to simultaneously summarize the evidence for the wide range of interventions dedicated to the conservation of bats. By simultaneously targeting all potential interventions for bats, we were able to review the evidence for each intervention cost-effectively and efficiently. The synopsis is freely available at www.conservationevidence.com and, alongside the *Conservation Evidence* online database, provides a valuable asset to the toolkit of practitioners and policy makers seeking sound information to support bat conservation. We aim to periodically update the synopsis to incorporate new research and to ensure that the most recent evidence is made available to decision-makers. Updates were published in 2019 (Berthinussen *et al.* 2019) and 2020 (Berthinussen *et* *al.* 2020), and so this is the third update. The methods used to update the existing Bat Conservation Synopsis are outlined below.

1.5 Scope of the review

1.5.1 Review subject

This synthesis focuses on updating the evidence for the effectiveness of global interventions for the conservation of bats. New evidence was added to the previous Bat Conservation Synopsis (Berthinussen *et al.* 2020), which was produced using a subject-wide evidence synthesis approach. This is defined as a systematic method of evidence synthesis that covers entire subjects at once, including all closed review topics within that subject at a fine scale and analysing results through study summary and expert assessment, or through meta-analysis; the term can also refer to any product arising from this process (Sutherland *et al.* 2019).

This synthesis covers evidence for the effects of conservation interventions for wild bats (i.e. not in captivity). We have not included evidence from the literature on husbandry of captive bats, such as those kept in zoos. However, where these interventions are relevant to the conservation of wild declining or threatened species, they were included, e.g. captive breeding for the purpose of reintroductions. For this synthesis, conservation interventions include management measures that aim to conserve wild bat populations and ameliorate the deleterious effects of threats. The output of the project is an authoritative, freely accessible evidence-base that will support bat conservation objectives with the latest evidence and help to achieve conservation outcomes.

1.5.2 Advisory board

An advisory board made up of international conservationists and academics with expertise in bat conservation has been formed. These experts inputted into the synopsis update at two key stages: a) updating the comprehensive list of conservation interventions for review, and b) reviewing the updated draft evidence synthesis. The advisory board is listed above and online (www.conservationevidence.com/content/page/119#bat-conservation).

1.5.3 Creating the list of interventions

For previous editions of the Bat Conservation Synopsis (Berthinussen *et al*. 2014, 2019, 2020), a comprehensive list of interventions was developed by searching the literature and in partnership with the advisory board. The list was also checked by Conservation

Evidence to ensure that it followed the standard structure. This list was reviewed by the advisory board for the synopsis update, and edited or additional interventions added if relevant. The aim was to include all interventions that have been carried out or advised to support populations or communities of wild bats, whether evidence for the effectiveness of an intervention is available or not. During the update process further interventions were discovered and integrated into the synopsis structure.

The list of interventions is organized into categories based on the IUCN classifications of direct threats (www.iucnredlist.org/resources/threat-classification-scheme) and conservation actions (www.iucnredlist.org/resources/conservation-actions-classification-scheme).

In total, we found 200 conservation and/or management interventions that could be carried out to conserve bat populations. We found evidence for the effects on bat populations for 81 of these interventions. The evidence was reported as 297 summaries from 232 relevant publications found during our searches (see Methods below).

1.6 Methods

Any new evidence found during the synopsis update was summarised and added to the previous edition of the Bat Conservation Synopsis (Berthinussen *et al*. 2020). Methods for this update followed those used previously, as described below.

1.6.1 Literature searches

Literature was obtained from the Conservation Evidence discipline-wide literature database, and from searches of additional subject-specific literature sources (see Appendices 1–4). The Conservation Evidence discipline-wide literature database is compiled using systematic searches of journals (all titles and abstracts) and report series ('grey literature'); relevant publications describing studies of conservation interventions for all species groups and habitats were saved from each and were added to the database. Final lists of evidence sources searched for this synopsis are published in this synopsis document (see Appendices 1–3), and the full list of journals and report series is published online (www.conservationevidence.com/journal searcher/synopsis).

a) Global evidence

Evidence from all around the world was included.

b) Languages included

The following non-English journals published in Spanish and Portuguese were searched for the previous edition of the Bat Conservation Synopsis (Berthinussen *et al.* 2020) and relevant papers extracted. Due to project constraints, update searches of these journals were not carried out. However, we will aim to update them periodically in the future.

- Therya — Vol. 1, Issue 1 (2010) – Vol. 8, Issue 3 (2018)
- Gamelys — Vol. 1 (2011) – Vol. 7 (2017)
- Boletim da Sociedade Brasileira de Mastozoologia — Vol. 66 (2013) – Vol. 78 (2017)
- Mastozoologia Neotropical — Vol. 1, Issue 1 (1994) – Vol. 24, Issue 1 (2017)
- Chiroptera Neotropical — Vol. 1, Issue 1 (1995) – Vol. 21, Issue 2 (2015)
- Mammalogy Notes — Vol. 1, Issue 1 (2014) – Vol. 4, Issue 1 (2017)
- Revista Mexicana de Mastozoología — Vol. 1 (1995) – Vol. 7, Issue 2 (2017)

Since the last update, 150 additional non-English journals published in Spanish, Portuguese, German, Russian, Japanese and Persian have been searched, and relevant papers added to the Conservation Evidence discipline-wide literature database (see below). All other journals searched are published in English.

c) Journals searched

All journals (and years) listed in Appendix 1 (English journals) and Appendix 2 (non-English journals) were searched prior to or during the completion of this synopsis update by authors of other synopses, and relevant papers added to the Conservation Evidence discipline-wide literature database. An asterisk indicates the journals most relevant to this synopsis. Others are less likely to have included papers relevant to this synopsis, but if they did, those papers were summarised.

The most relevant journals (marked with an asterisk in Appendix 1) were searched up to the end of 2018 for the previous edition of the Bat Conservation Synopsis (Berthinussen *et al.* 2020), and up to the end of 2019 for this update. No new journal searches were undertaken as the specialist journals most likely to yield studies relevant to bat conservation are already included.

d) Reports from specialist websites searched

i) From Conservation Evidence discipline-wide literature database

All report series (and years) listed in Appendix 3 have been systematically searched for the Conservation Evidence project, and relevant studies added to the Conservation Evidence discipline-wide literature database. An asterisk indicates the report series most relevant to this synopsis. Others are less likely to have included reports relevant to this synopsis, but if they did they have been summarised.

ii) Specific searches for the Bat Conservation Synopsis

The following specialist reports/websites relevant to bat conservation had already been searched up to the end of 2018 for the previous edition of the Bat Conservation Synopsis (Berthinussen *et al.* 2020). Searches were carried out either by searching every report title and abstract or summary within each report series or relevant category, or using key words, and any relevant reports were added to the project database. For this update, all specialist reports/websites listed below were searched up to the end of 2019.

- Bat Conservation International (www.batcon.org, resources searched)
- Bat Conservation Trust, UK (www.bats.org.uk, resources searched)
- Rufford Foundation, UK (www.rufford.org, report titles searched for category 'Bats')
- The Vincent Wildlife Trust, UK (www.vwt.org.uk, report titles searched for category 'Bats')
- Scottish Natural Heritage, UK (www.nature.scot/information-library-data-and-research/information-library, database of report titles searched using key word 'bat*')
- Natural England, UK (http://publications.naturalengland.org.uk, database of report titles searched for category 'Species – Mammals – Bats')
- Department for Food, Environment and Rural Affairs (Defra) Science and Research projects, UK (http://sciencesearch.defra.gov.uk, database of report titles searched using key word 'bats')

e) Other literature searches

The online database (www.conservationevidence.com) was searched for relevant publications that have already been summarised. If such summaries existed, they were extracted and added to this synopsis update.

Where a systematic review was found for an intervention, if the intervention had a small literature (<20 papers), all publications including the systematic review were summarised. If the intervention had a large literature (≥20 papers), then only the systematic review and any publications published since the review were summarised. Where a non-systematic review (or editorial, synthesis, preface, introduction etc.) was found for an intervention, all relevant publications referenced within it were included, but the review itself was not summarised. However, if the review also provided new/collective data, then the review itself was also included/summarised (indicating which other summarized publications it included). Relevant publications cited in other publications summarised for the synopsis were not included (due to time restrictions).

f) Supplementary literature identified by advisory board or relevant stakeholders

Additional journal or specialist website searches, and relevant papers or reports suggested by the advisory board or relevant stakeholders were also included, if relevant.

g) Search record database

A database was created of all relevant publications found during searches. Reasons for exclusion were recorded for all studies included during screening but not summarised for the synopsis.

1.6.2 Publication screening and inclusion criteria

A summary of the total number of evidence sources and papers/reports screened is presented in the diagram in Appendix 4.

a) Screening

To ensure consistency/accuracy when screening publications for inclusion in the literature database, an initial test using the Conservation Evidence inclusion criteria (provided below) and a consistent set of references was carried out by authors, compared with the decisions of the experienced core Conservation Evidence team. Results were analysed using Cohen's Kappa test (Cohen 1960). A second Kappa test was used to assess the consistency/accuracy of article screening for the first two years of the first journal searched by each author. Where results did not show 'substantial' (K = 0 .61–0.8) or 'almost perfect' agreement (K = 0.81–1.0), authors received further training before carrying out further searches.

Authors of other synopses who have searched journals and added relevant publications to the Conservation Evidence literature database since 2018, and all other searchers since 2017 have undertaken the initial paper inclusion test described above; searchers prior to that have not. Kappa tests of the first two years searched have been carried out for all new searchers who have contributed to the Conservation Evidence literature database since July 2018.

We acknowledge that the literature search and screening method used by Conservation Evidence, as with any method, results in gaps in the evidence. The Conservation Evidence literature database currently includes relevant papers from over 300 English language journals as well as over 150 non-English journals. Additional journals are frequently added to those searched, and years searched are often updated. It is possible that searchers will have missed relevant papers from those journals searched. Publication bias will not be taken into account, and it is likely that additional biases will result from the evidence that is available, for example there are often geographic biases in study locations.

b) Inclusion criteria

The following Conservation Evidence inclusion criteria were used.

Criteria A: Conservation Evidence includes studies that measure the effect of an intervention that might be done to conserve biodiversity

1. Does this study measure the effect of an intervention that is or was under the control of humans, on wild taxa (including captives), habitats, or invasive/problem taxa? If yes, go to 3. If no, go to 2.

2. Does this study measure the effect of an intervention that is or was under the control of humans, on human behaviour that is relevant to conserving biodiversity? If yes, go to Criteria B. If no, the study will be excluded.

3. Could the intervention be put in place by a conservationist/decision maker to protect, manage, restore or reduce impacts of threats to wild taxa or habitats, or control or mitigate the impact of the invasive/problem taxon on wild taxa or habitats? If yes, the study will be included. If no, the study will be excluded.

Explanation:

1.a. Study must have a measured outcome on wild taxa, habitats or invasive species: excludes studies on domestic/agricultural species, theoretical modelling or opinion pieces. See Criteria B for interventions that have a measured outcome on human behaviour only.

1.b. Intervention must be carried out by people: excludes impacts from natural processes (e.g. tree falls, natural fires), impacts from background variation (e.g. soil type, vegetation, climate change), correlations with habitat types, where there is no test of a specific intervention by humans, or pure ecology (e.g. movement, distribution of species).

2. Study must test an intervention that could be put in place for conservation. This excludes assessing impacts of threats (interventions which remove threats would be included), unless the threat acts as an appropriate control for an intervention. For example, woodland that has been cut down/degraded could be compared with woodland that has been actively retained to test the intervention 'Retain native woodland' (provided that the study states when the intervention was carried out). The test may involve comparisons between sites/factors not originally put in place or modified for conservation but which could be (e.g. mown vs unmown field margins, fenced vs unfenced cave entrances – where the mowing/fencing is as you would do for conservation, even if that was not the original intention in the study).

If the title and/or abstract are suggestive of fulfilling our criteria, but there is not sufficient information to judge whether the intervention was under human control, the intervention could be applied by a conservationist/decision maker or whether there are data quantifying the outcome, then the study will be included for closer inspection by the synopsis authors. If the article has no abstract, but the title is suggestive, then a study will be included.

We sort articles into folders by which taxon/habitat they have an outcome on. If the title/abstract does not specify which species/taxa/habitats are impacted, then the full article will be searched and then assigned to folders accordingly.

The outcome for wild taxa/habitats can be negative, neutral or positive, does not have to be statistically significant but must be quantified (if hard to judge from abstract, then it will be included for closer inspection by the synopsis authors). It could be any outcome that has implications for the health of individuals, populations, species, communities or habitats, including, but not limited to the following:

- Individual health, condition or behaviour, including in captivity: e.g. growth, size, weight, stress, disease levels or immune function, movement, use of natural/artificial habitat/structure, range, predatory or nuisance behaviour that could lead to retaliatory action by humans

- Breeding: egg/sperm production, sperm motility/viability after freezing, artificial fertilization success, mating success, birth rate, pup condition/survival, 'overall recruitment'
- Genetics: genetic diversity, genetic suitability (e.g. adaptation to local conditions, use of flyways for migratory species etc.)
- Life history: age/size at maturity, survival, mortality
- Population measures: number, abundance, density, presence/absence, biomass, movement, cover, age-structure, species distributions (only in response to a human action), disease prevalence, sex ratio
- Community/habitat measures: species richness, diversity measures (including trait/functional diversity), community composition, community structure (e.g. trophic structure), area covered (e.g. by different habitat types), physical habitat structure (e.g. rugosity, height, basal area)

Interventions within the scope of Conservation Evidence include:

- Clear management interventions, e.g. closing a cave to tourism, prescribed burning, mowing, controlling invasive species, creating or restoring habitats
- International or national policies
- Reintroductions or management of wild species in captivity
- Interventions that reduce human-wildlife conflict
- Interventions that change human behaviour, resulting in an impact on wild taxa or habitats

See www.conservationevidence.com/data/index for more examples of interventions.

Note on study types:

Literature reviews, systematic reviews, meta-analyses or short notes that review studies that fulfil these criteria will be included. Theoretical modelling studies will be excluded, as no intervention has been taken. However, studies that use models to analyse real-world data, or compare models to real-world situations will be included (if they otherwise fulfil these criteria).

Criteria B: Conservation Evidence includes studies that measure the effect of an intervention that might be done to change human behaviour for the benefit of biodiversity

1. Does this study measure the effect of an intervention that is or was under human control on human behaviour (actual or intentional) which is likely to protect, manage, restore or reduce threats to wild taxa or habitats? If yes, go to 2. If no, the study will be excluded.

2. Could the intervention be put in place by a conservationist, manager or decision maker to change human behaviour? If yes, the study will be included. If no, the study will be excluded.

Explanation:

1.a. Study must have a measured outcome on <u>actual or intentional human behaviour</u> including self-reported behaviours: excludes outcomes on human psychology (tolerance, knowledge, awareness, attitude, perceptions or beliefs)

1.b. Change in human behaviour must be linked to outcomes for wild taxa and habitats, excludes changes in behaviour linked to outcomes for human benefit, even if these occurred under a conservation programme (e.g. we would exclude a study demonstrating increased school attendance in villages under a community based conservation programme)

1.c. Intervention must be under human control: excludes impacts from climatic or other natural events.

2. Study must test an intervention that could be put in place for conservation: excludes studies with no intervention, e.g. correlating human personality traits with likelihood of conservation-related behaviours.

The human behaviour outcome of the study can be negative, neutral or positive, does not have to be statistically significant but must be quantified (if hard to judge from abstract, then it will be included for closer inspection by the synopsis authors). It could be any behaviour that is likely to have an outcome on wild taxa and habitats (including mitigating the impact of invasive/problem taxon on wild taxa or habitats).

Interventions include, but are not limited to the following:

- Change in adverse behaviours (which directly threaten biodiversity), e.g. unsustainable hunting, burning, grazing, urban encroachment, creating noise, entering sensitive areas, polluting or dumping waste, clearing or habitat destruction, introducing invasive species.
- Change in positive behaviours, e.g. uptake of alternative/sustainable livelihoods, number of households adopting sustainable practices, donations.
- Change in policy or conservation methods, e.g. placement of protected areas, protection of key habitats/species.
- Change in consumer or market behaviour, e.g. purchasing, consuming, buying, willingness to pay, selling, illegal trading, advertising, consumer fraud.
- Behavioural intentions to do any of the above.

Interventions which are particularly likely to have a behaviour change outcome include, but are not limited to the following:

- Enforcement: hunting restrictions, market inspections, increase number of rangers, patrols or frequency of patrols in, around or within protected areas, improve fencing/physical barriers, improve signage.
- Behaviour change: promote alternative/sustainable livelihoods, payment for ecosystem services, ecotourism, poverty reduction, increase appreciation or knowledge, debunking misinformation, altering or re-enforcing local taboos, financial incentives.
- Governance: protect or reward whistle-blowers, increase government transparency, ensure independence of judiciary, provide legal aid.
- Market regulation: trade bans, taxation, supply chain transparency laws.
- Consumer demand reduction: increase awareness or knowledge, fear appeals (negative association with undesirable product), benefit appeal (positive association with desirable behaviour), worldview framing, moral framing, employing decision defaults, providing decision support tools, simplifying advice to consumers, promoting desirable social norms, legislative prohibition.
- Sustainable alternatives: certification schemes, artificial alternatives, sustainable alternatives.
- New policies for conservation/protection.

We allocate studies to folders by their outcome. All studies under Criteria B go in the 'Behaviour change' folder. They are additionally duplicated into a taxon/habitat folder if there is a specific intended final outcome of the behaviour change (if none mentioned, they will be filed only in 'Behaviour change').

c) Relevant subject

Studies relevant to the synopsis subject were those focused on the conservation of wild, native bats.

d) Relevant types of intervention

An intervention has to be one that could be put in place by a manager, conservationist, policy maker, advisor or consultant to protect, manage, restore or reduce the impacts of threats to wild, native bats. Alternatively, interventions may aim to change human behaviour (actual or intentional), which is likely to protect, manage, restore or reduce threats to bat populations. See inclusion criteria above for further details.

If the following two criteria were met, a combined intervention was created within the synopsis, rather than repeating evidence under all the separate interventions: a) there are five or more publications that use the same well-defined combination of interventions, with very clear description of what they were, without separating the effects of each individual intervention, and b) the combined set of interventions is a commonly used conservation strategy.

e) Relevant types of comparator

To determine the effectiveness of interventions, studies must include a comparison, i.e. monitoring change over time (typically before and after the intervention was implemented), or for example at treatment and control sites. Alternatively, a study could compare one specific intervention (or implementation method) against another. For example, this could be comparing the abundance of a bat species before and after woodland is restored, or the reduction in bat mortality at wind turbines with different rotor designs. Exceptions, which may not have a control but were still included, are for example the effectiveness of captive breeding or rehabilitation programmes.

f) Relevant types of outcome

Below we provide a list of included metrics:

- Community response
  - Community composition
  - Richness/diversity
- Population response
  - Abundance: bat activity (relative abundance), number, presence/absence
  - Reproductive success: mating success, birth rate, pup survival

- Survival: survival, mortality
- Condition: body mass, weight, size, forearm length, disease symptoms

– Behaviour
  - Uptake
  - Use
  - Behaviour change: movement, range, timing (e.g. emergence, foraging period)
  - Change in human behaviour

– Other
  - Impact on roost sites
  - Collisions with cave gates
  - Bat box design
  - Bat box position
  - Human-wildlife conflict

g) Relevant types of study design

The table below lists the study designs included. The strongest evidence comes from replicated, randomized, controlled trials with paired-sites and before-and-after monitoring.

Table 1. Study designs

Term	Meaning
Replicated	The intervention was repeated on more than one individual or site. In conservation and ecology, the number of replicates is much smaller than it would be for medical trials (when thousands of individuals are often tested). If the replicates are sites, pragmatism dictates that between five and ten replicates is a reasonable amount of replication, although more would be preferable. We provide the number of replicates wherever possible. Replicates should reflect the number of times an intervention has been independently carried out, from the perspective of the study subject. For example, 10 plots within a mown field might be independent replicates from the perspective of plants with limited dispersal, but not independent replicates for larger motile animals such as birds. In the case of translocations/release of captive bred animals, replicates should be sites, not individuals.
Randomized	The intervention was allocated randomly to individuals or sites. This means that the initial condition of those given the intervention is less likely to bias the outcome.
Paired sites	Sites are considered in pairs, within which one was treated with the intervention and the other was not. Pairs, or blocks, of sites are selected with similar environmental conditions, such as soil type or surrounding landscape. This approach aims to reduce environmental variation and make it easier to detect a true effect of the intervention.
Controlled*	Individuals or sites treated with the intervention are compared with control individuals or sites not treated with the intervention. (The treatment is usually

	allocated by the investigators (randomly or not), such that the treatment or control groups/sites could have received the treatment).
Before-and-after	Monitoring of effects was carried out before and after the intervention was imposed.
Site comparison*	A study that considers the effects of interventions by comparing sites that historically had different interventions (e.g. intervention vs no intervention) or levels of intervention. Unlike controlled studies, it is not clear how the interventions were allocated to sites (i.e. the investigators did not allocate the treatment to some of the sites).
Review	A conventional review of literature. Generally, these have not used an agreed search protocol or quantitative assessments of the evidence.
Systematic review	A systematic review follows structured, predefined methods to comprehensively collate and synthesise existing evidence. It must weight or evaluate studies, in some way, according to the strength of evidence they offer (e.g. sample size and rigour of design). Environmental systematic reviews are available at: www.environmentalevidence.org/index.htm
Study	If none of the above apply, for example a study measuring change over time in only one site or only after an intervention. Or a study measuring use of nest boxes at one site.

* Note that "controlled" is mutually exclusive from "site comparison". A comparison cannot be both controlled and a site comparison. However, one study might contain both controlled and site comparison aspects, e.g. study of fertilized grassland, compared to unfertilized plots (controlled) and natural, target grassland (site comparison).

1.6.3 Study quality assessment & critical appraisal

We did not quantitatively assess the evidence from each publication or weight it according to quality. However, to allow interpretation of the evidence, we made the size and design of each study we reported clear.

We critically appraised each potentially relevant study and excluded those that did not provide data for a comparison to the treatment, did not statistically analyse the results (or if included this was stated in the summary paragraph) or had obvious errors in their design or analysis. A record of the reason for excluding any of the publications included during screening was kept within the synopsis database.

1.6.4 Data extraction

Data on the effectiveness of the relevant intervention (e.g. mean species abundance inside or outside a protected area; reduction in mortality after operational changes to wind turbines) were extracted from, and summarised for, publications that included the relevant subject, types of intervention, comparator and outcomes outlined above. A summary of the total number of evidence sources and papers/reports searched and the total number of publications included following data extraction is presented in Appendix 4.

At the start of each month, authors swapped three summaries with another author to ensure that the correct type of data had been extracted and that the summary followed the Conservation Evidence standard format.

1.6.5 Evidence synthesis

a) Summary protocol

Each publication usually has just one paragraph for each intervention it tested describing the study in (usually) no more than 150 words using plain English. Each summary is in the following format:

A [TYPE OF STUDY] in [YEARS X-Y] in [HOW MANY SITES] in/of [HABITAT] in [REGION and COUNTRY] [REFERENCE] found that [INTERVENTION] [SUMMARY OF ALL KEY RESULTS] for [SPECIES/HABITAT TYPE]. [DETAILS OF KEY RESULTS, INCLUDING DATA]. In addition, [EXTRA RESULTS, IMPLEMENTATION OPTIONS, CONFLICTING RESULTS]. The [DETAILS OF EXPERIMENTAL DESIGN, INTERVENTION METHODS and KEY DETAILS OF SITE CONTEXT]. Data was collected in [DETAILS OF SAMPLING METHODS].

Type of study - see terms and order in Table 1.

Results –only key results relevant to the effects of the intervention are included. Where an overall result for a taxon is given (e.g. total bat activity), the number of species that contributed to the result is also stated (if reported in the original source). Readers are referred to the original source if there are additional or more detailed results for individual species that are not included within the summary.

Site context - for the sake of brevity, only nuances essential to the interpretation of the results are included. The reader is always encouraged to read the original source to get a full understanding of the study site (e.g. history of management, physical conditions, landscape context etc.).

For example:

A replicated study in 1999–2004 in a wetland on an island in Catalonia, Spain (*1*) found that all 69 bat boxes of two different designs were used by soprano pipistrelles *Pipistrellus pygmaeus* with an average occupancy rate of 71%. During at least one of the four breeding seasons recorded, 96% of boxes were occupied and occupation rates by females with pups increased from 15% in 2000 to 53% in 2003. Bat box preferences were detected in the breeding season only, with higher abundance in east-facing bat boxes (average 22 bats/box) compared to west-facing boxes (12 bats/box), boxes with double compartments (average 25 bats/box) compared to single compartments (12 bats/box) and boxes placed on posts (average 18 bats/box) and houses (average 12 bats/box). Abundance was low in bat boxes on trees (average 2 bats/box). A total of 69 wooden bat boxes (10 cm deep x 19 cm wide x 20 cm high) of two types (44 single and 25 double compartment) were placed on three supports (10 trees, 29 buildings and 30 electricity posts) facing east and west. From July 2000 to February 2004, the boxes were checked on 16 occasions. Bats were counted in boxes or upon emergence when numbers were too numerous to count within the box.

(1) Flaquer C., Torre I. & Ruiz-Jarillo R. (2006) The value of bat-boxes in the conservation of *Pipistrellus pygmaeus* in wetland rice paddies. *Biological Conservation*, 128, 223–230.

A replicated, randomized, controlled, before-and-after study in 1993–1999 of five harvested hardwood forests in Virginia, USA (*2*) found that harvesting trees in groups did not result in higher salamander abundances than clearcutting. Abundance was similar between treatments (group cut: 3; clearcut: 1/30 m^2). Abundance was significantly lower compared to unharvested plots (6/30 m^2). Species composition differed before and three years after harvest. There were five sites with 2 ha plots with each treatment: group harvesting (2–3 small area group harvests with selective harvesting between), clearcutting and an unharvested control. Salamanders were monitored on 9–15 transects (2 x 15 m)/plot at night in April–October. One or two years of pre-harvest and 1–4 years of post-harvest data were collected.

(2) Knapp S.M., Haas C.A., Harpole D.N. & Kirkpatrick R.L. (2003) Initial effects of clearcutting and alternative silvicultural practices on terrestrial salamander abundance. *Conservation Biology*, 17, 752–762.

b) Terminology used to describe the evidence

Unless specifically stated otherwise, results reflect statistical tests performed on the data, i.e. we only state that there was a difference if it was a significant difference or state that there was no difference if it was not significant. Table 1 above defines the terms used to describe the study designs.

c) Dealing with multiple interventions within a publication

When separate results are provided for the effects of each of the different interventions tested, separate summaries have been written under each intervention heading. However, when several interventions were carried out at the same time and only the combined effect reported, the results were described with a similar paragraph under all relevant interventions. The first sentence makes it clear that there was a combination of interventions carried out, i.e. '...(REF) found that [x intervention], along with [y] and [z interventions] resulted in [describe effects]'. Within the results section we also added a sentence such as: 'It is not clear whether these effects were a direct result of [x], [y] or [z] interventions', or 'The study does not distinguish between the effects of [x], and other interventions carried out at the same time: [y] and [z].'

d) Dealing with multiple publications reporting the same results

If two publications described results from the same intervention implemented in the same space and at the same time, we only included the most stringently peer-reviewed publication (i.e. journal of the highest impact factor). If one included initial results (e.g. after year one) of another (e.g. after 1–3 years), we only included the publication covering the longest time span. If two publications described at least partially different results, we included both but made it clear they were from the same project in the paragraph, e.g. 'A controlled study... (Gallagher *et al.* 1999; same experimental set-up as Oasis *et al.* 2001)...'.

e) Taxonomy

Taxonomy was not updated but followed that used in the original publication. Where possible, common names and Latin names were both given the first time each species was mentioned within each summary.

f) Key messages

Each intervention for which evidence is found has a set of concise, bulleted key messages at the top, which was written once all the literature had been summarised. These include information such as the number, design and location of studies included.

The first bullet point describes the total number of studies that tested the intervention and the locations of the studies, followed by key information on the relevant metrics presented under the headings and sub-headings shown below (with number of relevant studies in parentheses for each).

- **X studies** examined the effects of [INTERVENTION] on [TARGET POPULATION]. Y studies were in [LOCATION 1][1,2] and Z studies were in [LOCATION 2][3,4].
  Locations will usually be countries, ordered based on chronological order of studies rather than alphabetically, i.e. USA[1], Australia[2] not Australia[2], USA[1]. However, when more than 4-5 separate countries, they may be grouped into regions to make it clearer e.g. Europe, North America. The distribution of studies amongst habitat types may also be added here if relevant.

COMMUNITY RESPONSE (x STUDIES)

- **Community composition (x studies):**
- **Richness/diversity (x studies):**

POPULATION RESPONSE (x STUDIES)

- **Abundance (x studies):**
- **Reproductive success (x studies):**
- **Survival (x studies):**
- **Condition (x studies):**

BEHAVIOUR (x STUDIES)

- **Uptake (x studies):**
- **Use (x studies):**
- **Behaviour change (x studies):**

OTHER (x STUDIES) *(Included only for interventions/chapters where relevant)*

- **[Sub-heading(s) for the metric(s) reported will be created] (x studies):**

If no evidence was found for an intervention, the following text was added in place of the key messages above:

- We found no studies that evaluated the effects of [INTERVENTION] on [TARGET POPULATION].

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

g) Background information

Background information for an intervention is provided to describe the intervention and where we feel recent knowledge is required to interpret the evidence. This is presented before the key messages and relevant references included in the reference list at the end of the intervention section. In some cases, where a body of literature has strong implications for bat conservation, but does not directly test interventions for their effects, we may also refer the reader to this literature in the background sections.

1.6.6 Dissemination/communication of evidence synthesis

The information from this synopsis update will be available in three ways:

- This updated synopsis pdf, downloadable from www.conservationevidence.com, which contains the study summaries, key messages and background information on each intervention.

- The searchable database at www.conservationevidence.com, which contains all the summarized information from the synopsis update, along with updated expert assessment scores.

- A chapter in *What Works in Conservation*, available as a pdf to download and a book from www.conservationevidence.com/content/page/79, which contains the key messages from the synopsis as well as updated expert assessment scores on the effectiveness and certainty of the synopsis, with links to the online database.

1.7 How to use the information provided

The information in this synopsis is freely available to all. It is compiled particularly for those working to support or protect bats, such as land managers, conservationists, farmers, policymakers, researchers, advisors or consultants. However, we would also encourage its use for general fact-finding, such as by students, teachers or anyone wanting to find out more about bat conservation.

This synopsis can be used to guide conservation actions and management plans. <u>However, it does not tell you what to do.</u>

To use the bat synopsis efficiently, we recommend that you search for information relevant to your work, and then assess how applicable the interventions are to your situation. For example, ask yourself:

- Do they deal with the same species or habitats?
- Which studies are the most relevant?
- How dependent are they on local conditions?
- How strong is the evidence one way or another?

Apply the information to your situation and decide on the course of action most likely to succeed. It may be helpful to refer to the original source to gain a full understanding of particular studies.

An expert assessment of the effectiveness of interventions based on the summarized evidence is also available as a chapter in *What Works in Conservation* (www.conservationevidence.com/content/page/79).

IMPORTANT NOTE - Interpreting the evidence

Care must be taken when interpreting some of the evidence provided. Studies do not always measure the most appropriate metric or assess at the population level. For example, a small proportion of bats using a bridge to cross a road is not an effective intervention if a greater proportion are being killed by traffic on the road below, with a negative overall impact on local bat populations. The period of time over which effects have been evaluated must also be considered, given that effects on populations can be delayed and may require long term monitoring to be detected.

Also, a lack of evidence does not mean that interventions are not effective in bat conservation, or that such measures should be abandoned, it simply highlights the need for robust monitoring in these areas to ensure that future conservation efforts will be appropriate and effective.

1.8 How you can help to change conservation practice

If you know of evidence relating to bat conservation that is not included in this synopsis, we invite you to contact us via our website www.conservationevidence.com. If you have new, unpublished evidence, you can submit a paper to the *Conservation Evidence* journal. We particularly welcome papers submitted by conservation practitioners.

1.9 References

Berthinussen A., Richardson O.C. & Altringham J.D. (2014) *Bat Conservation: Global Evidence for the Effects of Interventions*. Synopses of Conservation Evidence Series. University of Cambridge, Cambridge, UK. Available at: https://www.conservationevidence.com/synopsis/download/22

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Kunz T.H., de Torrez E.B., Bauer D., Lobova T., & Fleming T.H. (2011) Ecosystem services provided by bats. *Annals of the New York Academy of Sciences*, 1223, 1–38.

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US Fish & Wildlife Service (2016) *Species status assessment for the lesser long-nosed bat*. December 2016. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, NM. 96 pp.

Voigt C.C. & Kingston T. (2016) *Bats in the Anthropocene: Conservation of Bats in a Changing World*. Springer International Publishing.

2. Threat: Residential and commercial development

Threats from residential and commercial development can include the destruction of habitat, pollution and impacts from transportation and service corridors. Interventions in response to these threats are described in '*Habitat protection*', '*Habitat restoration and creation*', '*Threat: Pollution'* and *'Threat: Transportation and service corridors*'. Interventions that are more specific to development are discussed in this chapter, including the use of bat boxes within building developments. For general interventions relating to bat boxes, which are often used in response to a wide range of threats, see the '*Species management*' chapter.

Residential development can also result in an increase in domestic cats, which can prey on bats. Interventions that involve reducing bat predation by cats are described in '*Threat: Invasive species and disease – Invasive species*'.

2.1. Retain existing bat roosts and access points within developments

- **Three studies** evaluated the effects of retaining existing bat roosts and access points within developments on bat populations. Two studies were in the UK[2,3] and one was in Ireland[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (3 STUDIES)

- **Use (3 studies):** One before-and-after study in Ireland[1] found similar numbers of brown long-eared bats roosting within an attic after existing access points were retained during renovations. One replicated, before-and-after study in the UK[2] found that four of nine bat roosts retained within developments were used as maternity colonies, in two cases by similar or greater numbers of bats after development had taken place. One review in the UK[3] found that bats used two-thirds of retained and modified bat roosts after development, and retained roosts were more likely to be used than newly created roosts.

Background

Many bat species are known to roost in the crevices and roof voids of buildings. Existing roosts and their access points may be conserved during residential or commercial developments, for example by retaining a roof space used as a roost during renovations.

For interventions that involve creating new bat roosts or relocating access points within developments, see '*Create alternative bat roosts within developments*' and '*Relocate access points to bat roosts within developments*'.

A before-and-after study in 2004–2008 of one building renovation in Ireland (*1*) found that retaining four existing bat access points, along with restricting the timing of roofing work, resulted in similar numbers of brown long-eared bats *Plecotus auritus* using a roost within an attic before and after renovations. Fifteen brown long-eared bats were counted roosting in the attic space of the building before the renovation work. After the renovation work, sixteen brown long-eared bats were recorded exiting the roost through the retained access points. The building was an 18th century Georgian house that had the roofing felt and roof slates replaced. Original access points to the roost within the attic of the building were retained by installing four vents in the ridge tiles. The renovations were completed outside of the maternity season (date not reported). The attic was surveyed once in 2004 before the renovations, and once with an emergence survey in September 2008 after the renovations.

A replicated, before-and-after study in 2011–2015 of nine bat maternity roosts retained within building developments across Scotland, UK (*2*) found that four of nine retained roosts were used by maternity colonies after development, and two of the roosts were used by greater or similar numbers of bats. Average roost counts before and after development at the four roosts either remained stable (before: 2 brown long-eared bats *Plecotus auritus*; after: 2 brown long-eared bats), increased by 7% (before: 476 soprano pipistrelles *Pipistrellus pygmaeus*; after 507 soprano pipistrelles), decreased by 39% (before: 341 soprano pipistrelles; after: 208 soprano pipistrelles), or could not be counted (use inferred from brown long-eared bat droppings only). The other five roosts were not used at all (two brown long-eared bat roosts, two common pipistrelle *Pipistrellus pipistrellus* roosts) or had signs of use by bats at a later date (one whiskered bat *Myotis mystacinus* roost). Original roosts were either retained (seven sites) or partially retained (two sites), and original access points were reinstated. The numbers of bats counted before development at each roost were extracted from reports submitted with licence applications. Bats were counted at each roost after development during at least one dusk emergence or dawn re-entry survey between May and September 2015.

A review in 2018 of 283 studies of building developments in the UK (*3*) found that two-thirds of retained and modified bat roosts were used by bats after development, and retained roosts were more likely to be used than new bat lofts or bat boxes installed to replace destroyed roosts. Bats used 67% of roosts that were retained and modified during reroofing work, whereas 52% of newly created bat lofts and 31% of bat boxes were used (the number of bats using roosts and bat lofts/bat boxes before and after development were not reported). Bats were four times more likely to be present in retained roosts than in new bat lofts and bat boxes installed to replace destroyed roosts (data reported as statistical model results). Retained roosts with enhancements, such as timber crevices and squeeze boxes, were six times more likely to be used by pipistrelles *Pipistrellus* spp. than those without enhancements. Retained roosts were also used by brown long-eared bats *Plecotus auritus* and *Myotis* spp. (see original report for data for individual species). The 283 studies (52 for retained and modified roosts, 112 for bat lofts, 119 for bat boxes; dates not reported) were collected from multiple sources, including practitioner reports and licence applications from across the UK, and reviewed in 2018.

(1) Aughney T. (2008) *An investigation of the impact of development projects on bat populations: comparing pre- and post-development bat faunas. Irish Bat Monitoring Programme.* Bat Conservation Ireland.
(2) Mackintosh M. (2016) *Bats and licensing: a report on the success of maternity roost compensation measures*. Scottish Natural Heritage Commissioned Report No. 928.
(3) Lintott P. & Mathews F. (2018) *Reviewing the evidence on mitigation strategies for bats in buildings: informing best-practice for policy makers and practitioners.* Report for the Chartered Institute of Ecology and Environmental Management (CIEEM), UK.

2.2. Relocate access points to bat roosts within developments

- **Two studies** evaluated the effects of relocating access points to bat roosts within building developments on bat populations. One study was in Ireland[1] and one in the UK[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One before-and-after study in Ireland[1] found that fewer brown long-eared bats used a roost after the access points were relocated, and no bats were observed flying through them. One before-and-after study in the UK[2] found that few lesser horseshoe bats used an alternative access point with a 'bend' design to re-enter a roost in a building development, but the number of bats using the roost increased after an access point with a 'straight' design was installed.

Background

This intervention involves relocating the access points to a bat roost within a building development when the original access has been removed or altered. This could involve leaving gaps in brickwork, lead flashing or sofits, or the use of purpose-made ridge and roof tiles, bat bricks, tubes or chutes. For an intervention that involves retaining existing access points, see '*Retain existing bat roosts and access points within developments*'.

A before-and-after study in 2004–2008 of one building renovation in Ireland (*1*) found that after relocating the access points to a bat roost within an attic during renovations, fewer brown long-eared bats *Plecotus auritus* used the roost and no bats were observed flying through the new access points. Before the renovations, 19 and eight brown long-eared bats were recorded exiting the roost through two original access points. After the renovations, no bats were observed exiting through two relocated access points and the number of droppings found inside the attic (<100) indicated that fewer bats were using the roost than before the renovations (number not reported). The building was a 19th century brick house. During renovation work, two bat access points consisting of angled slats (‘louvres’) were installed in the roof in different locations to the original bat access points. Renovations were completed in early 2007. Emergence counts were carried out once in June 2004 before the renovations, and once in August 2008 after the renovations. An internal inspection was carried out in October 2008.

A before-and-after study in 1993–2016 of one building development in the UK (*2*) found that an alternative access point with a ‘straight’ design resulted in an increase in lesser horseshoe bats *Rhinolophus hipposideros* using the basement of the building as a roost, but an access point with a ‘bend’ resulted in a decrease in bats re-entering the roost. Up to 35 bats were counted emerging from the roost prior to the installation of an alternative access point. After installation of the access point with a ‘bend’ in 2000, a similar number of bats exited the roost (data not reported), but only two were observed re-entering. In 2001, the access point was modified to a ‘straight’ design and the number of bats using the roost increased over a 15-year period (2002: 27 bats; 2016: 416 bats). The ‘bend’ design consisted of a 90° turn at the base of a short vertical shaft and was in place for 11 months. The ‘straight’ design consisted of a sloped chute enclosing the original flight route with a clear flight line into the roost. The building was a large manor house converted into a hotel in 2000–2001. Counts of emerging bats were carried out at least once/year between May and July in 1993–2000. Emergence and re-entry counts were carried out three times/year in 2000–2001. Biennial counts were carried out in July in 2002–2016.

(1) Aughney T. (2008) *An investigation of the impact of development projects on bat populations: comparing pre- and post-development bat faunas. Irish Bat Monitoring Programme.* Bat Conservation Ireland.

(2) Reason P.F. (2017) Designing a new access point for lesser horseshoe bats, Gloucestershire, UK. *Conservation Evidence*, 14, 52–57.

2.3. Install sound-proofing insulation between bat roosts and areas occupied by humans within developments

- We found no studies that evaluated the effects of installing sound-proofing insulation between bat roosts and areas occupied by humans within developments on bat populations.

  ‘We found no studies’ means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Sound-proofing insulation installed between bat roosts and areas occupied by humans within developments may reduce the risk of bats being disturbed by noise. This could also reduce the potential for humans to be disturbed by noise from bat roosts and may therefore reduce human-wildlife conflict. For a more general intervention that involves installing sound barriers, see ‘*Threat: Pollution – Noise pollution – Install sound barriers in proximity to bat roosts and habitats*’.

2.4. Create alternative bat roosts within developments

- **Eleven studies** evaluated the effects of creating alternative bat roosts within developments on bat populations. Nine studies were in Europe[3,4a,4b,5,6,7,8a,8b,9] and two were in the USA[1,2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (11 STUDIES)

- **Use: (11 studies):** Two replicated studies in the USA[1] and UK[8b] found that bats did not use any of the alternative roosts provided in bat houses[1] or a purpose-built bat wall[8b] after exclusion from buildings. Three studies (two replicated) in the USA[2] and UK[5,6] and one review in the UK[9] found that bat boxes[2,5,9] or bat lofts/barns[5,6,9] were used by bats at 13–74% of development sites, and bat lofts/barns were used by maternity colonies at one of 19 development sites[6]. Three of five before-and-after studies in Portugal[4a], Ireland[4b], Spain[7] and the UK[3,8a] found that bat colonies used purpose-built roosts in higher[7] or similar numbers[4b,8a] after the original roosts were destroyed. The other two studies[3,4a] found that bats used purpose-built roosts in lower numbers than the original roost. One review in the UK[9] found that new bat boxes/lofts built to replace destroyed roosts were four times less likely to be used by returning bats than roosts retained during development.

Background

New alternative bat roosts are often created within developments to replace original roosts that have been destroyed. This can include purpose-built bat barns, lofts or houses, bat boxes, or features created within existing buildings such as specially designed crevices and bat bricks.

For an intervention that involves retaining existing bat roosts within developments, see '*Retain existing bat roosts and access points within developments*'. For general interventions relating to bat boxes, see the '*Species management*' chapter.

A replicated study in 1988–1990 at an urban institute in New York, USA (*1*) found that displaced little brown bats *Myotis lucifugus* did not use any of 43 bat houses of four different designs and sizes. The four designs tested were 20 very small bat houses (longest dimension <0.4 m, volume 0.002 m^2, installed 3–4 m high on trees), eight small bat houses (20 x 15 x 15 cm with partitioned spaces, installed 2–7 m high on building walls), 11 Bat Conservation International (BCI) style bat houses (50 x 20 x 15 cm, installed 2–7 m high on building walls) and four large "Missouri" style bat houses (2.3 x 1 x 1 m with partitioned spaces below and an attic-like space above, installed on building roofs). Bats were excluded from five buildings in 1988–1990 due to renovations. Bats were captured and confined to bat houses overnight on 1–4 occasions/year between May and August in 1988–1990 with the aim of increasing use of the bat houses. Thirty-nine of 43 bat houses were regularly checked for bats between May and August 1988–1990.

A replicated study in 1991–1993 in an urban area of Pennsylvania, USA (*2*) found that maternity colonies of big brown bats *Eptesicus fuscus* and little brown bats *Myotis lucifugus* used pairs of bat boxes at five of nine sites after they had been excluded from buildings. At the four sites where boxes were not used, bats either re-entered the building, found new roosts nearby or were not seen again. All occupied bat boxes faced a southeastern or southwestern aspect and received at least seven hours of direct sunlight. Unoccupied bat boxes received less than five hours of direct sunlight. Each of nine sites had a maternity colony of >30 bats that were excluded from buildings in 1991–1992. Homeowners installed pairs of wooden bat boxes (76 x 30 x 18 cm), one horizontally (30 cm tall) and one vertically (76 cm tall) side by side on the building close to the original roost. Emerging bats were counted on two nights in May–June and June–August in 1992 or 1993.

A replicated, before-and-after study in 1991–2001 of nine buildings across Scotland, UK (*3*) found that five of nine roosting spaces installed within the roofs of the buildings were used by soprano pipistrelles *Pipistrellus pygmaeus*, but the number of bats declined at four of the five roosts. Of the nine bat boxes, four were not used by bats, four were used by bats in lower numbers than the original roost (original roost vs roosting space: 546 vs 455 bats; 769 vs 277 bats; 1,963 vs 1,174 bats; 3,500 vs 740 bats), and one was used by bats in greater numbers than the original roost (original roost: 280 bats; roosting space: 682 bats). Seven of the nine roosting spaces were designed for soprano pipistrelles. Two of the nine roosting spaces were designed for other bat species (common pipistrelles *Pipistrellus pipistrellus* and brown long-eared bats *Plecotus auritus*) and neither were used by bats. The roosting spaces were built into the roofs of residential buildings or offices to contain bats roosting within them. They were installed during renovations or to prevent conflict between roosting bats and human inhabitants. The size and design of the roosting spaces varied (see original report for details). Emergence counts and/or internal inspections were carried out 1–5 times/year over 1–10 years before construction and over 1–4 years after construction at each site between 1991 and 2001.

A before-and-after study in 2000–2007 of a residential development in Portugal (*4a*) found that an alternative roost was used by fewer European free-tailed bats *Tadarida teniotis* than the original roost in a nearby 15-storey building. In 2000, the original roost was used by 100 European free-tailed bats. Following demolition of the original roost, 22 European free-tailed bats were counted in the alternative roost in 2006, and 11 in 2007. Small numbers of serotine bats *Eptesicus serotinus* (2006: 12 bats; 2007: 11 bats) and soprano pipistrelles *Pipistrellus pygmaeus* (2006: 4 bats; 2007: 7 bats) were also found in the alternative roost (numbers in original roost not reported). Original roosts were in crevices on a 15-storey building, which was demolished in 2005. In 2003, an alternative roost (12 m high) was built 150 m from the original roost. Concrete plates from the original building were used on the alternative roost to recreate roosting crevices with similar temperatures. Fifty bats were captured and released at the alternative roost to encourage use of the structure. Bats were counted in the original roost in 2000 and in the alternative roost in 2006 and 2007.

A before-and-after study in 2003–2007 of a building development in southwest Ireland (*4b*) found that an alternative roost in a loft within an outbuilding was used by a similar number of lesser horseshoe bats *Rhinolophus hipposideros* as the original roost in a nearby cottage. In 2003, 150 lesser horseshoe bats were counted in the original roost. Following renovation work, 120 lesser horseshoe bats were counted in the alternative roost in 2005, and 150 in 2007. The original roost was converted for residential use in 2004, and the original bat access points were sealed. An alternative roost was created in an outbuilding (10 x 5 m) located 10 m from the original roost. The outbuilding was roofed with felt and slate, and a loft was created with an access point in one of the gables. Bats were counted at the original roost in 2003 and at the alternative roost in 2005 and 2007.

A review of 389 bat mitigation licences issued in 2003–2005 in England, UK (*5*) found that 26 of 35 bat lofts and barns and three of 24 bat boxes were used by bats after development. Bats were found to be present in 26 of 35 (74%) bat lofts or barns after development, and in 3 of 24 (13%) bat boxes. The roost status, bat species and number of bats using the roosts before and after development were not reported. Most licensees (67%) failed to submit post-development reports, and post-development monitoring was conducted at only 35 of 374 (9%) bat lofts/barns, and 24 of 1,690 (1%) bat boxes. The licences analysed were submitted to Natural England between 2003 and 2005 and were issued for three types of development (renovation, conversion and demolition).

A replicated, before-and-after study in 2011–2015 of 19 building developments with alternative bat maternity roosts across Scotland, UK (*6*) found that three bat boxes provided at one site were used by a maternity colony, but bat boxes and lofts at 18 other sites were not used by maternity colonies. At one site, a group of three bat boxes (Schwegler design 1FFH) was used by a maternity colony of soprano pipistrelles *Pipistrellus pygmaeus* after development, but fewer bats used them than the original roost (average count in original roost: 62 bats; average count in bat boxes after development: 20 bats). Alternative roosts at 18 other sites (16 with heated or unheated bat boxes, two with bat lofts) were not used by maternity colonies, but some (two bat boxes, one bat loft) were used by 2–5 individual bats. Bat boxes were mounted internally or externally on developed buildings, or on nearby trees, either singly or in groups (2–15 bat boxes). Bat lofts were purpose-built structures with internal flight spaces. The numbers of bats counted before development at each roost were extracted from reports submitted with licence applications. Bats were counted at each roost after development during at least one dusk emergence or dawn re-entry survey between May and September 2015.

A before-and-after study in 2014–2016 in one agricultural site in Navarra, Spain (*7*) found that four bat species colonized two artificial roosts and a bat box after the original roost was destroyed. Numbers of at least three of the four species were higher two years after the construction of the artificial roosts than in previous counts in the destroyed roost (417 vs 90–200 Geoffroy's bats *Myotis emarginatus*, 93 vs 50 greater horseshoe bats *Rhinolophus ferrumequinum*, 44 vs 33 lesser horseshoe bats *Rhinolophus hipposideros*). Additionally, 36 common pipistrelles *Pipistrellus pipistrellus* roosted in one bat box placed on one of the artificial bat roost buildings (an unknown number roosted in the destroyed roost). In July 2014, two buildings (2.6 x 2.6 x 3.2–4 m), 100 m apart, were constructed as artificial roosts for bats roosting in a building destroyed in 2013. A bat box was placed inside one of the artificial roosts. Bats were counted weekly from mid-April to mid-July 2015 and 2016 using an infrared light.

A before-and-after study in 2010–2017 of one residential building development in the Cotswold Hills, UK (*8a*) found that a purpose-built bat house was used by a brown long-eared bat *Plecotus auritus* maternity colony after the original roost in a farmhouse loft was demolished. In 2010 (the year before demolition), the original roost was used by 8–12 bats. In 2013 (two years after construction), 20–22 bats were recorded in the new bat house, although no juveniles were counted, and numbers were lower in 2014–2017 (range 1–11 bats). Small numbers of common pipistrelle bats *Pipistrellus pipistrellus* were also observed using roost features on the bat house (data not reported). The bat house was constructed in an 'L-shape' 30 m from the original roost and included features such as bat tiles, ridge beam access points, wall-integrated bat boxes (Schwegler design 2FR), hanging tiles, and wall mounted climber planting. The original roost was demolished in late winter 2010 and the bat house was completed in early spring 2011. Surveys were carried out every year in 2010–2017 including daytime inspections and evening emergence counts on 1–3 separate occasions/year.

A before-and-after study in 2010–2017 of one residential building development in the Cotswold Hills, UK (*8b*) found that a purpose-built bat wall was not used by a common pipistrelle *Pipistrellus pipistrellus* maternity colony six years after the original roost in a stone cottage wall was demolished. In 2010 (the year before demolition), the original roost was used by >76 bats. During the six years after construction, the new bat wall was used by low numbers of individual bats (0–3 bats/year) and was not used as a maternity roost. The bat wall was constructed on the east-facing gable wall of an existing hay barn 30 m from the original roost. It included multiple stone crevices leading to internal cavities and five wall-integrated bat boxes (Schwegler design 1FR). The original roost was demolished in late winter 2010 and the bat wall was completed in early spring 2011. Surveys were carried out every year in 2010–2017 including daytime inspections and evening emergence counts on 1–3 separate occasions/year.

A review in 2018 of 283 studies of building developments in the UK (*9*) found that just over half of newly created bat lofts and a third of bat boxes were used by bats, and new roosts built to replace destroyed roosts were less likely to be used than existing roosts that were retained and modified. Bats were present in 52% of newly created bat lofts after development, and in 31% of bat boxes (the number of bats using roosts and bat lofts/bat boxes before and after development were not reported). New bat lofts and bat boxes built to replace destroyed roosts were four times less likely to be used by bats than roosts retained and modified during reroofing work (data reported as statistical model results). Bat lofts and bat boxes were used by common pipistrelles *Pipistrellus pipistrellus*, soprano pipistrelles *Pipistrellus pygmaeus*, brown long-eared bats *Plecotus auritus* and *Myotis* spp. (see original report for data for individual species). The 283 studies (112 for bat lofts, 119 for bat boxes, 52 for retained and modified roosts; dates not reported) were collected from multiple sources, including practitioner reports and licence applications from across the UK, and reviewed in 2018.

(1) Neilson A.L. & Fenton M.B. (1994) Response of little brown *Myotis* to exclusion and to bat houses. *Wildlife Society Bulletin*, 22, 8–14.

(2) Brittingham M.C. & Williams L.M. (2000) Bat boxes as alternative roosts for displaced bat maternity colonies. *Wildlife Society Bulletin*, 28, 197–207.

(3) Bat Conservation Trust (2006) *A review of the success of bat boxes in houses*. Scottish Natural Heritage Commissioned Report No. 160.

(4) Marnell F. & Presetnik P. (2010) *Protection of overground roosts for bats (particularly roosts in buildings of cultural heritage importance)*. EUROBATS Publication Series No. 4 (English version). UNEP / EUROBATS Secretariat, Bonn, Germany.

(5) Stone E.L., Jones G. & Harris S. (2013) Mitigating the effect of development on bats in England with derogation licensing. *Conservation Biology*, 27, 1324–1334.

(6) Mackintosh M. (2016) *Bats and licensing: a report on the success of maternity roost compensation measures*. Scottish Natural Heritage Commissioned Report No. 928.

(7) Alcalde J.T., Martínez I., Zaldua A., & Antón I. (2017) Conservation of breeding colonies of cave-dwelling bats using man-made roosts. Conservación de colonias reproductoras de murciélagos cavernícolas mediante refugios artificiales. *Journal of Bat Research & Conservation*, 10.

(8) Garland L., Wells M. & Markham S. (2017) Performance of artificial maternity bat roost structures near Bath, UK. *Conservation Evidence*, 14, 44–51.

(9) Lintott P. & Mathews F. (2018) *Reviewing the evidence on mitigation strategies for bats in buildings: informing best-practice for policy makers and practitioners*. Report for the the Chartered Institute of Ecology and Environmental Management (CIEEM), UK.

2.5. Change timing of building work

- **One study** evaluated the effects of changing the timing of building work on bat populations. The study was in Ireland[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One before-and-after study in Ireland[1] found that carrying out roofing work outside of the bat maternity season, along with retaining bat access points, resulted in a similar number of brown long-eared bats continuing to use a roost within an attic.

Background

To reduce disturbance to bats, building work may be avoided at times of year when they are most vulnerable, such as during hibernation and the maternity season.

A before-and-after study in 2004–2008 of one building renovation in Ireland (*1*) found that carrying out roofing work outside of the maternity season, along with retaining existing bat access points, resulted in a similar number of brown long-eared bats *Plecotus auritus* using a roost within an attic before and after renovations. Fifteen brown long-eared bats were counted roosting in the attic space of the building before renovation work. After the renovation work, sixteen brown long-eared bats were recorded exiting the roost through the retained access points. The building was an 18th century Georgian house that had the roofing felt and roof slates replaced. Original access points to the roost within the attic of the building were retained by installing four vents in the ridge tiles. The renovations were completed outside of the maternity season (date not reported). The attic was surveyed once in 2004 before the renovations, and once with an emergence survey in September 2008 after the renovations.

(1) Aughney T. (2008) *An investigation of the impact of development projects on bat populations: comparing pre- and post-development bat faunas. Irish Bat Monitoring Programme.* Bat Conservation Ireland.

2.6. Exclude bats from roosts during building work

- **One study** evaluated the effects of excluding bats from roosts during building work on bat populations. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One replicated, before-and-after study in the UK[1] found that excluding bats from roosts within buildings did not change roost switching frequency, core foraging areas or foraging preferences of soprano pipistrelle colonies.

Background

This intervention involves excluding bats from roosts within buildings during building work. Although this may prevent injury or death as a direct result of the building work itself, it is important to consider both the short-term and long-term impacts of exclusion on the survival and productivity of bat populations.

A replicated, before-and-after study in 2012–2013 of five buildings across England, UK (*1*) found that excluding bats from roosts within buildings resulted in no difference in roost switching frequency, core foraging areas or foraging preferences of soprano pipistrelle *Pipistrellus pygmaeus* colonies. All five bat colonies established in alternative roosts within three days of exclusion in other buildings within 1.5 km of the original roost. Bats switched roosts at a similar frequency before (average every 2.1 days) and after exclusion (average 2 days). Bats also foraged in similar sized core areas (before: average 44 ha; after: average 47 ha), travelled similar distances to foraging sites (before: average 1.5 km, after: average 1.5 km), and had the same foraging habitat preferences (data reported as statistical model results) before and after exclusion. Exclusion experiments were carried out in the spring of 2012 and 2013. Temporary one-way exclusion measures were installed at roost exits. The five sites had 150–300 bats present before exclusion, and four sites were known maternity roosts. Bats were radio-tracked for up to 4 h after sunset for 4–7 days before and after exclusion.

(1) Stone E., Zeale M.R.K., Newson S.E., Browne W.J., Harris S. & Jones G. (2015) Managing conflict between bats and humans: The response of soprano pipistrelles (*Pipistrellus pygmaeus*) to exclusion from roosts in houses. *PLOS ONE,* 10, e0131825.

2.7. Educate homeowners about building and planning laws relating to bats to reduce disturbance to bat roosts

- We found no studies that evaluated the effects of educating homeowners and planning authorities about building and planning laws relating to bats to reduce disturbance to bat roosts.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

This intervention involves making homeowners aware of building and planning laws and providing them with relevant information so that they may take appropriate action when bats are found or are present in their homes. Information resources are available for homeowners in some countries.

2.8. Plant gardens with night-scented flowers

- We found no studies that evaluated the effects of planting gardens with night-scented flowers on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Planting night-scented flowers may attract night-flying insects providing a foraging resource for insect-eating bats.

2.9. Increase semi-natural habitat within gardens

- We found no studies that evaluated the effects of increasing the amount of semi-natural habitat within gardens on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Increasing the amount of semi-natural habitat, such as hedges, trees, ponds, and wild areas, in gardens may provide bats with additional foraging and roosting opportunities within urban areas.

2.10. Protect brownfield or ex-industrial sites

- **One study** evaluated the effects of protecting brownfield or ex-industrial sites on bat populations. The study was in the USA[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One study in the USA[1] found that five bat species were recorded within a protected urban wildlife refuge on an abandoned manufacturing site.

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

Background

'Brownfield sites' are previous industrial or commercial sites that have been abandoned and are available for reuse. These sites may be targeted for redevelopment in urban areas. Some sites can support a high diversity of wildlife making them important sites for biodiversity and conservation. High insect numbers can provide important foraging habitat for bats, and derelict buildings may provide roosting opportunities.

A study in 1997–1998 in an urban wildlife refuge on the grounds of a former weapons manufacturing facility near Denver, USA (*1*) found that five bat species were recorded at the site. Three tree-roosting species and two species known to roost in buildings were captured or recorded, with big brown bats *Eptesicus fuscus* making up 86% of the captures. In total, 176 bats were captured, and 955 bat passes were recorded. Big brown bats commuted further from roosts in buildings within surrounding urban areas to the refuge (9–19 km) than typically reported for the species elsewhere (1–2 km). The manufacturing facility was active until 1985 and was designated as a wildlife refuge in 1992. The refuge covered 6,900 ha of grassland, woodland, and wetlands within an urban area. At 18 locations within the refuge, bats were captured with mist nets on a total of 53 nights between May and August in 1997 and 1998. Twelve big brown bats were captured and radio-tagged in 1998. At each of eight locations within the refuge, bat detectors recorded bat activity for 90 minutes on 3–4 nights in June–August 1997.

(1) Everette A.L., O'Shea T.J., Ellison L.E., Stone, L.A. & McCance J. L. (2001) Bat use of a high plains urban wildlife refuge. *Wildlife Society Bulletin,* 29, 967–973.

2.11. Protect greenfield sites or undeveloped land in urban areas

- We found no studies that evaluated the effects of protecting greenfield sites or undeveloped land in urban areas on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

'Greenfield sites' are areas of previously undeveloped land within urban areas, such as agricultural and amenity land, forests, parks and gardens. Such sites may provide important habitat for wildlife and act as wildlife corridors. However, greenfield sites are frequently built upon with the growing pressure for urban development. See also '*Create or restore bat foraging habitat in urban areas*'.

2.12. Create or restore bat foraging habitat in urban areas

- **Three studies** evaluated the effects of creating or restoring bat foraging habitat in urban areas on bat populations. One study in each of the UK[2] and USA[3] evaluated green roofs and one study in the USA[1] evaluated restored forest fragments.

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, controlled, site comparison study in the USA[3] found no difference in species richness over green roofs and conventional unvegetated roofs.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** One site comparison study in the USA[1] found higher bat activity (relative abundance) in two of seven restored forest fragments in urban areas than in two unrestored forest fragments. One replicated, controlled, site comparison study in the UK[2] found greater bat activity over 'biodiverse' green roofs than conventional unvegetated roofs, but not over 'sedum' green roofs. One replicated, controlled, site comparison study in the USA[3] found greater bat activity for three of five bat species over green roofs than over conventional unvegetated roofs.

BEHAVIOUR (0 STUDIES)

Background

Providing foraging habitat for bats in urban areas may reduce the impact of residential and commercial development. Existing foraging sites may be protected, or be replaced with suitable alternatives such as parks, woodland and wetlands. Bat activity was found to be higher in large parks in Mexico City than in natural forest or other urban habitats, although the number of species was higher in natural forest (Avila-Flores & Fenton 2005). Habitats should also be appropriately managed for bats, for example a study in Australia found more bat species in urban green spaces with a higher density of large trees and native plants (Threlfall *et al*. 2016). See also '*Protect greenfield sites or undeveloped land in urban areas*'.

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.

Threlfall C.G., Williams N.S.G., Hahs A.K. & Livesley S.J. (2016) Approaches to urban vegetation management and the impacts on urban bird and bat assemblages. *Landscape and Urban Planning,* 153, 28–39.

A site comparison study in 2004–2005 in nine forest fragments within the Chicago metropolitan area, USA (*1*) found that two of seven restored forest fragments had higher bat activity than two unrestored forest fragments. Bat activity was higher in two forest fragments that had been restored with multiple prescribed burns, invasive plant species removal and snag recruitment (average 7–19 bat passes/survey) than in two control sites with no restoration (average 1–4 bat passes/survey). Bat activity was similar between control sites and five other forest fragments that had been restored with multiple prescribed burns and various combinations of invasive species removal, snag recruitment and deer population control (1–6 bat passes/survey). Six bat species were recorded in total (see original paper for data for individual species). Fire suppression over the last 100 years had altered the structure of the nine forest fragments (10–260 ha in size). Seven of the nine forest fragments were being restored to open the canopy, reduce tree density and remove invasive plant species. At each of nine sites, four bat detectors recorded bat activity for 4 h from sunset for five nights/year in June–September 2004 and May–August 2005.

A replicated, controlled, site comparison study in 2010 of 39 green roofs in Greater London, UK (*2*) found that 'biodiverse' green roofs had higher bat activity than conventional roofs, but 'sedum' green roofs had similar or lower bat activity than conventional roofs. When a small amount (<33%) of natural foraging habitat was located within 100 m of roofs, bat activity was higher over 'biodiverse' green roofs (average 7 bat passes/night) than conventional roofs (average 1.3 bat passes/night), and similar over 'sedum' green roofs (average 1 bat pass/night) and conventional roofs. However, when higher amounts of natural habitat cover were located within 100 m of roofs (33–66%), bat activity was similar between 'biodiverse' green roofs (average 10 bat passes/night) and conventional roofs (average 12 bat passes/night), and lower over 'sedum' green roofs (average 4 bat passes/night). Four bat species or species groups were recorded in total (see original paper for data for individual species). All green roofs had shallow substrate (20–200 mm). 'Biodiverse' roofs were planted with a variety of wild flowers, herbs, sedums, mosses, and grasses. 'Sedum' roofs were planted with low-growing succulent plants. Conventional roofs were flat or shallow pitched with bitumen felt or paving slabs. Bat activity was recorded over each of 13 biodiverse, nine sedum and 17 conventional roofs for seven full nights in May–September 2010.

A replicated, controlled, paired sites study in 2013 of four paired roofs in New York City, USA (*3*) found higher activity over green roofs than conventional roofs for three of five bat species, but no difference in species richness. Five bat species were recorded over both green and conventional roofs. The average number of bat passes/night was higher over green roofs than conventional roofs for the eastern red bat *Lasiurus borealis* (green: 253; conventional: 128), big brown bat *Eptesicus fuscus* (green: 11; conventional: 0.6), and tricoloured bat *Perimyotis subflavus* (green: 12; conventional: 2). The average number of bat passes/night was similar over green and conventional roofs for the hoary bat *Lasiurus cinereus* (green: 56; conventional: 57) and silver-haired bat *Lasionycteris noctivagans* (green: 33; conventional: 24). Paired roofs were six or eight stories high and were located within one block of each other. One of each pair was a green roof with a waterproof membrane with growing substrate covered in vegetation. The other of each pair was a conventional roof with a 'blacktop' or concrete roofing material with no vegetation. Bat activity was recorded between May and September in 2013 with a bat detector deployed in the centre of each roof.

(1) Smith D.A. & Gehrt S.D. (2010) Bat response to woodland restoration within urban forest fragments. *Restoration Ecology* 18, 914–923.

(2) Pearce H. & Walters C. (2012) Do green roofs provide habitat for bats in urban areas? *Acta Chiropterologica*, 14, 469–478.

(3) Parkins K.L. & Clark J.A. (2015) Green roofs provide habitat for urban bats. *Global Ecology and Conservation*, 4, 349–357.

2.13. Legally protect bats during development

- **Four studies** evaluated the effects of legally protecting bats by issuing licences during development on bat populations. The four studies were in the UK[1,2a,2b,3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (2 STUDIES)

- **Change in human behaviour (2 studies):** One review in the UK[2b] found that the number of development licences for bats more than doubled over three years in Scotland. One review in the UK[1] found that 81% of licensees did not carry out post-development monitoring to assess whether bats used the roost structures installed.

OTHER (3 STUDIES)

- **Impact on bat roost sites (3 studies):** One review in the UK[1] found that licenced activities during building developments had a negative impact on bat roosts, with 68% of roosts being destroyed. One replicated, before-and-after study in the UK[2a] found that five of 28 compensation roosts provided under licence were used, and two by similar or greater numbers of bats after development. One review in the UK[3] found that 31–67% of compensation roosts provided under licence were used by bats.

Background

Bats are protected by national and/or international law in many countries. This typically includes protection against killing, injuring, capturing, disturbing or trading bats, or damaging, destroying, or obstructing access to their roosts. Activities such as development that are likely to affect bats in these ways may be against the law and require licences from a government licensing authority.

The studies discussed here relate specifically to protecting bats during development. Other studies that discuss legal protection are included in '*Habitat protection – Legally protect bat habitats*' and '*Species management – Legally protect bat species*'.

A review of 389 bat mitigation licences issued in 2003–2005 in England, UK (*1*) found that overall the effect of licenced activities on bat roosts was negative and the majority of roosts for which licenses were issued were destroyed during development. Overall, bat roosts were more likely to be destroyed (68%) than damaged (20%) or disturbed (12%). Most licensees (67%) failed to submit post-development reports, and post-development monitoring was conducted at only 19% of sites. The licences analysed related to 1,776 roosts of 15 bat species and were issued for three types of development (renovation, conversion, and demolition). A total of 2,536 structures for bats, of 10 types, were installed under the licences including bat boxes (1,690), bat lofts (362), bat barns (12), bat houses (10), bat towers (2), cellars/caves (18), building enhancements for bats, e.g. crevices and cavities in roofs and walls (437), a covered shed (2), a light sampling canopy (1) and a grille (1).

A replicated, before-and-after study in 2011–2015 of 28 bat maternity roosts subject to licenced building developments across Scotland, UK (*2a*) found that five of 28 compensation roosts provided were used as maternity roosts by the target bat species after development, and two of the five roosts were used by a similar or greater number of bats as before the development. Average roost counts before and after development at the four roosts either remained stable (before: 2 brown long-eared bats *Plecotus auritus*; after: 2 brown long-eared bats), increased by 7% (before: 476 soprano pipistrelles *Pipistrellus pygmaeus*; after 507 soprano pipistrelles), decreased by 39% (before: 341 soprano pipistrelles; after: 208 soprano pipistrelles), or could not be counted (use inferred from brown long-eared bat droppings only). Four of five sites retained the original bat roost and access points within the development, and one site had bat boxes installed (3 x Schwegler design 1FFH) on an external wall near the original roost location. Compensation roosts followed the designs in Species Protection Plans. The numbers of bats counted before development at each roost were extracted from reports submitted with licence applications. Bats were counted at each roost after development during at least one dusk emergence or dawn re-entry survey between May and September 2015.

A review in 2015 of development licences affecting bats across Scotland, UK (*2b*) found that the number of licences issued had increased from 2012 to 2014. Licences issued increased over three years from 80 in 2012 to 180 in 2014. A total of 437 development licences were issued for bats between July 2011 and December 2014, 67 of which related to maternity roost sites. All UK bat species are protected by UK and European law. Licences are therefore issued for certain activities that involve mitigation and/or compensation for the impacts of development. Licensing information collected by the governmental licensing authority, Scottish Natural Heritage, was analysed.

A review in 2018 of 283 studies of bat roosts subject to licenced building developments in the UK (*3*) found that 31–67% of compensation roosts were used by bats after development. Bats used 67% of roosts retained and modified during reroofing work, 52% of newly created bat lofts, and 31% of bat boxes after development (the number of bats using roosts and bat lofts/bat boxes before and after development were not reported). The roosts were used by common pipistrelles *Pipistrellus pipistrellus*, soprano pipistrelles *Pipistrellus pygmaeus*, brown long-eared bats *Plecotus auritus* and *Myotis* spp. (see original report for data for individual species). The 283 studies (52 for retained and modified roosts, 112 for bat lofts, 119 for bat boxes; dates not reported) were collected from multiple sources, including practitioner reports and licence applications from across the UK, and reviewed in 2018.

(1) Stone E.L., Jones G. & Harris S. (2013) Mitigating the effect of development on bats in England with derogation licensing. *Conservation Biology*, 27, 1324–1334.

(2) Mackintosh M. (2016) *Bats and licensing: a report on the success of maternity roost compensation measures*. Scottish Natural Heritage Commissioned Report No. 928.

(3) Lintott P. & Mathews F. (2018) *Reviewing the evidence on mitigation strategies for bats in buildings: informing best-practice for policy makers and practitioners.* Report for the Chartered Institute of Ecology and Environmental Management (CIEEM), UK.

3. Threat: Agriculture

In many parts of the world, much of the conservation effort is directed at reducing the impacts of agricultural intensification on biodiversity on farmland and in the wider countryside. Several of the interventions that we have captured reflect this. However, the two greatest threats from agriculture tend to be loss of habitat and pollution (e.g. from fertilizer and pesticide use). Interventions in response to these threats are described in '*Habitat protection*', '*Habitat restoration and creation*', and '*Threat: Pollution*'.

For evidence relating to the use of bat boxes on farmland, see '*Species management – Provide bat boxes for roosting bats*'.

All farming systems

3.1. Use organic farming instead of conventional farming

- **Twelve studies** evaluated the effects of using organic farming instead of conventional farming on bat populations. Eight studies were in Europe[1–5,7–9], two in the USA[6,10], one in Canada[11] and one in Chile[12].

COMMUNITY RESPONSE (7 STUDIES)

- **Community composition (1 study):** One replicated, paired sites study in the USA[10] found that the composition of bat species did not differ between organic and non-organic farms.
- **Richness/diversity (7 studies):** Five of seven replicated, paired sites or site comparison studies in Europe[1,2,7], the USA[6,10], Canada[11] and Chile[12] found that the number of bat species did not differ between organic and non-organic farms[1,6,7,10,11]. The other two studies[2,12] found more bat species on organic farms than non-organic farms.

POPULATION RESPONSE (12 STUDIES)

- **Abundance (12 studies):** Five of nine replicated, paired sites or site comparison studies in Europe[2–4,7,8], the USA[6,10], Canada[11] and Chile[12] found that overall bat activity (relative abundance)[3,6,7,10] and common pipistrelle activity[4] did not differ between organic and non-organic farms. The other four studies[2,8,11,12] found higher overall bat activity[2,8,11], bat feeding activity[8], Brazilian free-tailed bat activity[12], and activity of four of seven bat species[11] on organic farms than non-organic farms. Two replicated, paired sites and site comparison studies in the UK[1,5] found higher activity of *Myotis* species over water and rivers on organic farms than non-organic farms, but no differences were found for other species or habitats. One replicated, site comparison study in France[9] found higher activity for two of three bat species over organic fields than two of three types of conventionally managed fields.

BEHAVIOUR (0 STUDIES)

Background

Organic farming is an agricultural system that excludes the use of synthetic fertilizers and pesticides and relies on techniques such as crop rotation, compost, and biological pest control. Organic standards are strictly regulated in many countries prohibiting the use of chemicals and providing recommendations for management to conserve biodiversity. Organic farming may include combinations of several separate interventions (as discussed separately in this chapter). The studies below examine the effects of organic farming overall.

For an intervention that relates specifically to organic pest control, see '*Threat: Pollution – Agricultural and forestry effluents – Use organic pest control instead of synthetic pesticides*'. For an intervention that involves reducing the use of synthetic pesticides and fertilisers, see '*Threat: Pollution – Agricultural and forestry effluents – Reduce pesticide, herbicide or fertiliser use*'.

A replicated, paired sites study in 2000–2002 on 24 pairs of farms in southern England and Wales, UK (*1*) found that water habitats on organic farms had higher activity for two of 11 bat species than on conventional farms, but bat activity did not differ in pasture, arable or woodland habitats, and a similar number of bat species was recorded on both farm types. The activity of Brandt's bats *Myotis brandtii* and Bechstein's bats *Myotis bechsteinii* was higher over water habitats on organic farms (Brandt's bat: 66 bat passes; Bechstein's bat: 7 bat passes) than on conventional farms (Brandt's bat: 2 bat passes; Bechstein's bat: 0 bat passes). Brandt's and Bechstein's bat activity did not differ in pasture, arable or woodland habitats, or for any other bat species, between organic and conventional farms (see original paper for detailed results). A similar number of species was recorded on organic (14 species) and conventional farms (11 species). Certified organic farms (established 1–2 years) were paired with nearby conventional farms with similar habitats (pasture, arable, water and woodland), size and type of business. No details were reported about the type or origin of water habitats; water may have originated from outside of the farms. Each of 48 farms was surveyed with bat detectors rotated between three random points for 1.5 h from 1 h after sunset. Two farms within a pair were sampled on consecutive nights in June–September 2000 or 2002.

A replicated, paired sites study in 2002–2003 on 65 pairs of farms in England, UK (*2*) found that organic farms had higher bat activity and a greater number of bat species than conventional farms. A greater number of bat passes and bat species were recorded on organic farms (abundance index 6–75% higher; species density 8–65% higher) than conventional farms (numbers not reported). Organic farms with >30 ha of arable land were paired with nearby conventional farms matched by crop type and cropping season. Habitat data collected across all 130 farms showed that organic farms had a higher density of hedgerows, a greater proportion of grassland than crops, smaller fields, and wider, taller hedgerows with fewer gaps than conventional farms. Each of 130 farms was surveyed using bat detectors along a 3 km triangular transect in June–August in 2002 and 2003.

A replicated, paired sites and site comparison study in 2005 in six pairs of olive *Olea europea* groves and six native woodlands on Zakynthos island, Greece (*3*) found that organic olive groves had similar bat activity and foraging activity to non-organic olive groves. Overall bat activity and foraging activity did not differ between organic (average 0.8 bat passes/min, 0.04 feeding buzzes/min) and non-organic olive groves (1.1. bat passes/min, 0.06 feeding buzzes/min). Bat activity in organic and non-organic olive groves also did not differ significantly to that in three native oak *Quercus* spp. woodland patches (1.5 bat passes/min) and three native pine *Pinus halipensis* woodland patches (2.5 bat passes/min). Eleven bat species were recorded in total (see original paper for data for individual species). Six organic olive groves were paired with six non-organic olive groves similar in size, age, density of trees and altitude. Organic olive groves used organic pest control (scent and sticky traps) and no chemicals. Non-organic groves were treated with a yearly insecticide spray. Six native, untreated woodland patches were also surveyed (three oak, three pine). Each of 18 sites was surveyed with bat detectors rotated between four random points for 1.5 h from dusk. Surveys were repeated on three nights/site in June–August 2006.

A replicated, paired sites study in 2003 on eight paired farms near Bristol, UK (*4*) found that organic cereal fields had similar common pipistrelle *Pipistrellus pipistrellus* activity to nearby conventionally farmed fields. Common pipistrelle activity did not differ significantly between organic cereal fields (total 96 bat passes) and nearby conventionally farmed fields (total 152 bat passes). Pairs of fields were matched to control for habitat variables and were sampled simultaneously during one night in May–August 2003. At each of 16 sites, bat detectors recorded bat activity from 45 minutes after sunset for 20 minutes at each of four points along a transect (two points within fields, two along field boundaries).

A replicated, site comparison study in 2009–2011 of 5–13 organic and 10–30 non-organic farms in Wales, UK (*5*) found that rivers on organic farms had higher activity of Daubenton's bats *Myotis daubentonii* than rivers on non-organic farms, but the activity of five other bat species in fields and along hedgerows did not differ between organic and non-organic farms. The average number of bat passes for Daubenton's bats was higher over rivers on organic farms than non-organic farms (data reported as statistical model results). However, a similar number of bat passes/year were recorded on organic and non-organic farms for common pipistrelles *Pipistrellus pipistrellus*, soprano pipistrelles *Pipistrellus pygmaeus*, common noctules *Nyctalus noctula*, greater horseshoe bats *Rhinolophus ferrumequinum* and lesser horseshoe bats *Rhinolophus hipposideros* (data reported as statistical model results). Organic farms were part of an organic farming scheme. The number of farms included in the analysis varied for each bat species from 5–13 for organic and 10–30 for non-organic farms. Some farms (organic and non-organic) were also part of agri-environment schemes. No details were reported about the origin of the rivers; water may have originated from outside of the farms. Transects or static detector surveys were carried out at each farm once or twice/year between June and September in 2009, 2010 and 2011.

A replicated, site comparison study in 2009–2010 at four organic and four conventional apple orchards in Michigan, USA (*6*) found that organic orchards had similar bat activity, number of bat captures and species diversity as conventional orchards. The average number of bat passes recorded did not differ significantly between organic (37 bat passes/night) and conventional orchards (51 bat passes/night). The number of bats captured also did not differ significantly between organic (1.5 captures/night) and conventional orchards (2.2 captures/night). The same was true for species diversity (data reported as the Simpson's Index). Four bat species were recorded in total (see original paper for data for individual species). Four organic and four conventional apple orchards (small dwarf or semi-dwarf varieties, 6–24 ha in size) were surveyed between June and August 2009, and May and August 2010. One bat detector/orchard recorded nightly bat activity and was moved to random locations within each orchard each week. Mist netting was carried out 3–5 times/week at one orchard/night for 4 h from sunset.

A replicated, paired sites study in 2015 at 21 pairs of organic and conventional vineyards in the south of France (*7*) found that organic farms had similar bat activity and species richness to conventional farms. Bat activity for the most abundant group of bat species (mid-range echolocating bats) did not differ significantly on organic (average 35 bat passes/site) and conventional farms (47 bat passes/site). Numbers for other groups of bat species were too low for statistical analysis. Species richness was also similar between organic and conventional farms (average 5 species/site for both). Ten bat species were recorded in total (see original paper for data for individual species). Twenty-one pairs of organic and conventional vineyards were matched according to local and landscape scale criteria, such as altitude, slope, aspect, presence of linear habitat features, vineyard area and proportion of semi-natural habitats. Conventional vineyards were assumed by the authors to have high pesticide use, although details were not reported. Each of 21 pairs of sites were sampled simultaneously with two bat detectors for one full night in August–September 2015.

A replicated, site comparison study in 2015–2016 at three organic and three conventional rice farms near Vercelli, Italy (*8*) found that organic farms had higher overall bat activity and bat feeding activity than conventional farms. The average number of bat passes was higher on organic rice farms (178 bat passes/hour) than conventional rice farms (50 bat passes/hour). The same was true for the average number of feeding buzzes (organic farms: 27 buzzes/hour; conventional farms: 1 buzz/hour). Twelve bat species were recorded in total although 95% of the recordings were *Pipistrellus* spp. (see original paper for data for individual species). Surveys were carried out on three organic rice farms (rice paddies certified organic and not treated with synthetic pesticides) and three conventional rice farms (rice paddies regularly treated with pesticides and chemical fertilizers). Bat activity was recorded with a bat detector at one sampling point/farm for three nights in May–September 2015 or 2016.

A replicated, site comparison study in 2016 of 19 wheat fields in the Île-de-France region, France (*9*) found that organic fields had higher activity for two of three bat species than two of three types of conventionally managed fields. Activity of Kuhl's pipistrelle *Pipistrellus kuhlii* and common pipistrelle *Pipistrellus pipistrellus* was higher over organic tillage fields than conventional tillage fields with two herbicide applications and conventional 'conservation tillage' fields with three herbicide applications, but not over conventional 'conservation tillage' fields with two herbicide applications (data reported as statistical model results). The activity of Nathusius' pipistrelle *Pipistrellus nathusii* did not differ significantly between organic fields and any of the three conventional field types. Surveys were carried out at 12 sites in two organic fields (tillage to 30 cm depth and no herbicides) and 13–18 sites in 5–7 of each of the three types of conventionally managed fields (tillage with two herbicide applications, or superficial 'conservation tillage' with two or three herbicide applications). Bat detectors were used to simultaneously survey 1–4 sites/treatment on each of eight nights in June 2016.

A replicated, paired sites study in 2014 at 18 pairs of farms in California, USA (*10*) found that organic farms had similar bat activity, species richness, diversity, and species composition to conventional farms. Overall bat activity did not differ significantly between organic (average 45 bat passes/night) and conventional farms (average 40 bat passes/night). The same was true for the activity of bat species adapted to cluttered habitats (organic: average 10 bat passes/night; conventional: 4 bat passes/night) and open habitats (organic: average 31 bat passes/night; conventional: 33 bat passes/night). Bat species richness, bat diversity and species composition also did not differ significantly between organic and conventional farms (data reported as statistical indices). Eleven bat species were recorded in total (see original paper for data for individual species). Each of 18 pairs of fields in certified organic farms and conventional farms was surveyed simultaneously with one bat detector/field for 6–7 nights in June–September 2014.

A replicated, paired sites study in 2017 of 16 pairs of soybean *Glycine max* fields in Canada (*11*) found that organic fields had higher overall bat activity and activity of four of seven bat species than conventional fields, but the number of bat species did not differ. Overall bat activity (bat passes) and the activity of four bat species (big brown bat *Eptesicus fuscus*, hoary bat *Lasiurus cinereus*, little brown bat *Myotis lucifugus*, silver-haired bat *Lasionycteris noctivagans*) was higher over organic fields than conventional fields (data reported as statistical model results). The activity of three other bat species (eastern red bat *Lasiurus borealis*, northern long-eared bat *Myotis septentrionalis*, tri-coloured bat *Perimyotis subflavus*) and the number of bat species recorded did not differ over organic and conventional fields (data reported as statistical model results). Sixteen soybean fields on certified organic farms were paired with 16 soybean fields on conventional farms (fields treated with neonicotinoid pesticides) according to field size, local habitat, and surrounding landscape. Two locations at the edge of each of 32 fields were surveyed with bat detectors for two nights in June–July 2017.

A replicated, paired sites study in 2016–2017 at 11 paired plots on organic and conventional vineyards in Buin and Paine, Chile (*12*) found that organic vineyards had more bat species and greater activity of Brazilian free-tailed bats *Tadarida brasiliensis* than conventional vineyards. A higher number of bat species were recorded on organic (average 2 bat species/sampling point) than conventional vineyards (average 1 bat species/sampling point). Organic vineyards had greater activity of Brazilian free-tailed bats (average 24 bat passes/sampling point) than conventional vineyards (average 10 bat passes/sampling point). Eleven pairs of plots on organic and conventional vineyards were matched by adjacent habitats and surrounding land cover types. Organic vineyards had been certified for 15–20 years, did not use agrochemical treatments (except fungicides) and had cover crops, flowers, and weeds between rows. Two sampling points/plot (edge and interior) were surveyed simultaneously using bat detectors for 30 minutes on each of three nights in January–March 2016 and 2017.

(1) Wickramasinghe L.P., Harris S., Jones G. & Vaughan, N. (2003) Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. *Journal of Applied Ecology,* 40, 984–993.

(2) Fuller R.J., Norton L.R., Feber R.E., Johnson P.J., Chamberlain D.E., Joys A.C., Mathews F., Stuart R.C., Townsend M.C., Manley W.J., Wolfe M.S., Macdonald D.W. & Firbank L.G. (2005) Benefits of organic farming to biodiversity vary among taxa. *Biology Letters,* 1, 431–434.

(3) Davy, C.M., Russo D. & Fenton M.B. (2007) Use of native woodlands and traditional olive groves by foraging bats on a Mediterranean island: consequences for conservation*. Journal of Zoology*, 273, 397–405.

(4) Pocock M.J.O. & Jennings N. (2008) Testing biotic indicator taxa: the sensitivity of insectivorous mammals and their prey to the intensification of lowland agriculture. *Journal of Applied Ecology*, 45, 151–160.

(5) MacDonald M.A., Morris A.J., Dodd S., Johnstone I., Beresford A., Angell R., Haysom K., Langton S., Tordoff G., Brereton T., Hobson R., Shellswell C., Hutchinson N., Dines T., Wilberforce E.M., Parry R. & Matthews V. (2012) *Welsh Assembly Government Contract 183/2007/08 to Undertake Agri-environment Monitoring and Services. Lot 2 – Species Monitoring. Final report: October 2012.*

(6) Long B.L. & Kurta A. (2014) Activity and diet of bats in conventional versus organic apple orchards in southern Michigan. *Canadian Field-Naturalist*, 128, 158 –164.

(7) Froidevaux J.S.P., Louboutin B. & Jones G. (2017) Does organic farming enhance biodiversity in Mediterranean vineyards? A case study with bats and arachnids. *Agriculture, Ecosystems & Environment*, 249, 112–122.

(8) Toffoli R. & Rughetti M. (2017) Bat activity in rice paddies: organic and conventional farms compared to unmanaged habitat. *Agriculture, Ecosystems & Environment*, 249, 123–129.

(9) Barré K., Le Viol I., Julliard R., Chiron F. & Kerbiriou C. (2018) Tillage and herbicide reduction mitigate the gap between conventional and organic farming effects on foraging activity of insectivorous bats. *Ecology and Evolution*, 8, 1496–1506.

(10) Olimpi E.M. & Philpott S.M. (2018) Agroecological farming practices promote bats. *Agriculture, Ecosystems & Environment*, 265, 282–291.

(11) Put J.E., Mitchell G.W. & Fahrig L. (2018) Higher bat and prey abundance at organic than conventional soybean fields. *Biological Conservation*, 226, 177–185.

(12) Rodríguez-San Pedro A., Chaperon P.N., Beltrán C.A., Allendes J.L., Ávila F.I. & Grez A.A. (2018) Influence of agricultural management on bat activity and species richness in vineyards of central Chile. *Journal of Mammalogy*, 99, 1495–1502.

3.2. Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)

- **Three studies** evaluated the effects of agri-environment schemes on bat populations. The three studies were in the UK[1–3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** Two of three replicated, paired sites studies in the UK[1–3] found that overall bat activity (relative abundance)[2] or the occurrence of six bat species[3] did not differ significantly between farms managed under agri-environment schemes and those managed conventionally. One of the studies[3] found that agri-environment scheme farms had similar activity of five bat species, and lower activity of one bat species, compared to conventional farms. The other study[1] found lower overall bat activity and activity of pipistrelle species on agri-environment scheme farms than conventional farms.

BEHAVIOUR (0 STUDIES)

Background

This action involves compensating farmers financially for changing agricultural practices to be more favourable to biodiversity and the landscape, usually through government or inter-governmental schemes. Such schemes exist around the world, although the terminology used may differ. For example, agri-environment schemes are used in the UK and Europe. In the USA, there are incentive programs such as The Environmental Quality Incentives Program and the Conservation Stewardship Program.

In the UK, agri-environment schemes use many different specific interventions which may be beneficial to bats such as the protection and maintenance of archaeological features, traditional farm buildings and stone walls; the restoration and enhancement of key habitats such as woodland, wetlands and hedgerows; and improvements to air and water quality. Three studies that evaluated the overall effects of agri-environment schemes are discussed here. Relevant individual interventions are also discussed in this chapter. See also '*Threat: Pollution – Agricultural and forestry effluents – Reduce pesticide, herbicide and fertiliser use*'.

For more general interventions relating to protecting and conserving important habitats, see '*Habitat protection*', '*Habitat restoration and protection*' and '*Threat: Pollution*'.

A replicated, paired sites study in 2008 on 18 pairs of farms in Scotland, UK (*1*) found that agri-environment scheme farms had lower overall bat activity and foraging activity than non-participating conventional farms. Overall bat activity and foraging activity were lower on agri-environment scheme farms (total 790 bat passes, 37 feeding buzzes) than conventional farms (total 1,175 bat passes, 85 feeding buzzes). The same was true for activity of the two most frequently recorded bat species: common pipistrelle *Pipistrellus pipistrellus* (agri-environment scheme farms: 159 bat passes; conventional farms: 312 bat passes) and soprano pipistrelle *Pipistrellus pygmaeus* (agri-environment scheme farms: 537 bat passes; conventional farms: 734 bat passes). Eighteen farms participating in the Scottish Rural Stewardship Scheme since 2004 were paired with nearby conventionally managed farms of a similar size and with similar farming activities. Each of 18 pairs of farms was sampled once on the same night in June–September 2008. Bat activity was recorded along transects (2.5–3.7 km long) from 45 minutes after sunset using bat detectors.

A replicated, site comparison study in 2008 of 18 paired pasture fields in Devon, UK (*2*) found that fields under agri-environment scheme management had similar bat activity as fields under conventional management. There was no significant difference in the overall number of bat passes recorded over agri-environment scheme fields (average 3 passes/night) and conventionally managed fields (1 pass/night). Seven bat species were recorded in total (see original paper for data for individual species). Paired agri-environment scheme fields and conventionally managed fields were matched where possible by topography, size and landscape context. Agri-environment scheme fields were managed with no pesticide or fertiliser inputs. Conventionally managed fields had no management restrictions. Bat activity was recorded using bat detectors at each pair of fields for 1–2 full nights in May, July, or August 2008.

A replicated, paired sites study in 2009–2011 of 40–60 pairs of commercial farms in south Wales, UK (*3*) found that agri-environment scheme farms had a similar occurrence and similar or lower activity of six bat species compared to conventional farms. Overall occurrence (proportion of transect sections with species present) and echolocation activity (counts of bat passes) did not differ significantly between agri-environment scheme farms and conventional farms for five of six bat species: common pipistrelles *Pipistrellus pipistrellus*, soprano pipistrelles *Pipistrellus pygmaeus*, Daubenton's bats *Myotis daubentonii*, greater horseshoe bats *Rhinolophus ferrumequinum* and lesser horseshoe bats *Rhinolophus hipposideros* (data reported as statistical model results). For common noctules *Nyctalus noctula*, occurrence was similar on agri-environment scheme and conventional farms, but echolocation activity was 33% lower on agri-environment scheme farms. Pairs of agri-environment scheme farms (under scheme management for 3–11 years) and conventional farms were 2–26 km apart and matched by area, altitude, farm type and proximity to towns. Field transects were carried out at 60 pairs of farms, waterway transects at 40 pairs of farms, and static hedgerow surveys at 45 pairs of farms. Surveys were carried out twice/year between June and September in 2009, 2010 and 2011.

(1) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) Pipistrelle bats and their prey do not benefit from four widely applied agri-environment management prescriptions. *Biological Conservation*, 144, 2233–2246.

(2) MacDonald M.A., Cobbold G., Mathews F., Denny M.J.H., Walker L.K., Grice P.V. & Anderson G.Q.A. (2012) Effects of agri-environment management for cirl buntings on other biodiversity. *Biodiversity and Conservation*, 21, 1477–1492.

(3) Angell R.L., Langton S.D., MacDonald M.A., Skates J. & Haysom K.A. (2019) The effect of a Welsh agri-environment scheme on bat activity: a large-scale study. *Agriculture, Ecosystems & Environment*, 275, 32–41.

3.3. Engage farmers and landowners to manage land for bats

- **One study** evaluated the effects of engaging farmers and landowners to manage land for bats on bat populations. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One study in the UK[1] found that during a five-year project to engage farmers and landowners to manage land for bats, the overall population of greater horseshoe bats at four maternity roosts in the area increased (but see summary below).

BEHAVIOUR (1 STUDY)

- **Change in human behaviour (1 study):** One study in the UK[1] found that a landowner engagement project resulted in 77 bat-related management agreements covering approximately 6,536 ha of land.

Background

Only 14.7% of the world's land surface is currently protected (UNEP-WCMC & IUCN 2016). Therefore, it is vital to engage effectively with landowners, such as farmers, so that they manage their land in ways that help to maintain bat populations. This may be done by providing advice and support to farmers on how to manage their land specifically for bats.

For an intervention that uses financial incentives to encourage environmentally friendly farming practices that may benefit bats, see '*Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)*'. For an intervention that involves providing education, see '*Education and awareness raising – Educate farmers, land managers and local communities about the benefits of bats to improve management of bat habitats*'.

UNEP-WCMC and IUCN (2016) *Protected Planet Report 2016*. UNEP-WCMC and IUCN: Cambridge UK and Gland, Switzerland.

A study in 1995–2003 of the greater horseshoe bat project in England, UK (*1*) found that the landowner engagement project resulted in 77 bat-related management agreements covering approximately 6,536 ha of land in Devon, Cornwall, and Somerset. This included 80 km of new/restored hedgerow and 400 ha of grassland within key areas surrounding greater horseshoe bat *Rhinolophus ferrumequinum* maternity roosts. The overall population of greater horseshoe bats at four maternity roosts in Devon was found to increase by 58% in 1995–2003, although the authors note that it is difficult to directly attribute this increase to the project. Advice was provided to 163 landowners and five organisations during farm visits, training seminars and farm walks. Support was also provided with grant applications. The project was widely publicised in the press (24 articles) and TV/radio (five programmes).

(1) Longley M. (2003) *Greater horseshoe bat project (1998-2003)*. English Nature Research Report No. 532.

3.4. Provide or retain set-aside areas in farmland

- We found no studies that evaluated the effects of providing or retaining set-aside areas in farmland on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Allocation of some farmland to 'set-aside' (fields taken out of production) was compulsory under European agricultural policy from 1992 until 2008. Originally intended as a method of reducing production, set-aside has also been promoted as a way of protecting on-field biodiversity. Set-aside fields that are left to naturally regenerate may provide important foraging habitat for bats within the farmed landscape. For studies that may carry out this intervention alongside other interventions to benefit bats on farmland, see '*Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)*'.

3.5. Increase the proportion of semi-natural habitat in the farmed landscape

- We found no studies that evaluated the effects of increasing the proportion of semi-natural habitat in the farmed landscape on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

This intervention is concerned with general increases in the proportion of natural or semi-natural habitat in the landscape. Studies describing the effects of creating or restoring specific habitat types are discussed in 'Habitat restoration and creation'. For studies that may carry out this intervention alongside other interventions to benefit bats on farmland, see '*Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)*'.

3.6. Reduce field size (or maintain small fields)

- **One study** evaluated the effects of maintaining small fields on bat populations. The study was in Canada[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Canada[1] found that agricultural landscapes with smaller fields had higher activity (relative abundance) of six of seven bat species than landscapes with larger fields.

BEHAVIOUR (0 STUDIES)

Background

Reducing field size (or maintaining small fields) means having a greater number of smaller fields, with boundaries and field margins between them. This would provide heterogeneity within the farmed landscape and may also increase the density of linear habitat features, such as treelines and hedgerows, which are important for commuting, foraging and roosting bats.

A replicated, site comparison study in 2012 of 46 agricultural sites in Ontario, Canada (*1*) found that agricultural landscapes with smaller fields had higher activity for six of seven bat species than those with larger fields. Six bat species (hoary bat *Lasiurus cinereus*, big brown bat *Eptesicus fuscus*, little brown bat *Myotis lucifugus*, tricolored bat *Perimyotis subflavus*, northern myotis *Myotis septentrionalis*) had higher activity in agricultural landscapes with smaller average field sizes than those with larger average field sizes (data reported as statistical model results). The opposite was true for silver-haired bat *Lasionycteris noctivagans* which had higher activity in landscapes with larger average field sizes. Forty-six agricultural landscapes (3 x 3 km) with crop fields (including hay, corn, soybean, cereals, legumes, pasture, fallow) of different sizes (number of each not reported) were surveyed during 1–5 nights in May–August 2012. Bat detectors recorded bat activity for 3 h from sunset in two locations along field boundaries within the centre (1 x 1 km) of each landscape.

(1) Monck-Whipp L., Martin A.E., Francis C.M. & Fahrig L. (2018) Farmland heterogeneity benefits bats in agricultural landscapes. *Agriculture, Ecosystems & Environment*, 253, 131–139.

3.7. Retain unmown field margins

- **One study** evaluated the effects of retaining unmown field margins on bats populations. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, paired sites study in the UK[1] found that pipistrelle activity (relative abundance) did not differ between unmown field margins managed for wildlife on agri-environment scheme farms and field margins on conventional farms.

BEHAVIOUR (0 STUDIES)

Background

Field margins can provide foraging habitat for bats. Leaving field margins unmown and allowing them to regenerate naturally can increase the abundance and diversity of plants and invertebrate prey. Unmown field margins are likely to be particularly beneficial when close to other bat habitats, such as woodland or tall field boundaries with trees (McHugh *et al.* 2019).

See also '*Plant field margins with a diverse mix of plant species*'. For studies that may carry out this intervention alongside other interventions to benefit bats on farmland, see '*Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)*'.

McHugh N.M., Bown B.L., Hemsley J.A. & Holland J.M. (2019) Relationships between agri-environment scheme habitat characteristics and insectivorous bats on arable farmland. *Basic and Applied Ecology*, 40, 55–66.

A replicated, paired sites study in 2008 on 15 pairs of farms in Scotland, UK (*1*) found that unmown field margins on agri-environment scheme farms had similar activity of *Pipistrellus* species as field margins on conventional farms. The activity of common pipistrelles *Pipistrellus pipistrellus* and soprano pipistrelles *Pipistrellus pygmaeus* was similar along unmown and conventionally managed field margins (data reported as statistical model results). On agri-environment scheme farms, field margins were planted with a mix of grass seeds and had restrictions on fertiliser, pesticides, and grazing. Each of 15 field margins on agri-environment scheme farms was paired with 15 field margins on conventional farms with similar farming activities and surrounding habitats. Field margins (measured on five pairs of farms) were wider and had taller vegetation on agri-environment scheme farms (average 6 m wide, 2.4 m tall) than conventional farms (average 2 m wide, 2 m tall). Each of 15 pairs of farms was sampled once on the same night in June–September 2008. Bat activity was recorded along transects (2.5–3.7 km long) from 45 minutes after sunset using bat detectors.

(1) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) Pipistrelle bats and their prey do not benefit from four widely applied agri-environment management prescriptions. *Biological Conservation*, 144, 2233–2246.

3.8. Plant field margins with a diverse mix of plant species

- **One study** evaluated the effects of planting field margins with a diverse mix of plant species on bats populations. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in the UK[1] found that the activity (relative abundance) of soprano pipistrelles and barbastelle bats increased with a greater diversity of plant species within field margins, but there was no effect on common pipistrelle activity nor on the occurrence of any of the six bat species studied.

BEHAVIOUR (0 STUDIES)

Background

Planting field margins with a diverse mix of plant species can increase the abundance and diversity of invertebrate prey for bats. See also '*Retain unmown field margins*'. For studies that may carry out this intervention alongside other interventions to benefit bats on farmland, see '*Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)*'.

A replicated, site comparison study in 2017 on 15 farms in south west England, UK (*1*) found that field margins planted with a greater diversity of plant species were associated with higher activity of two of three bat species but there was no effect on bat occurrence. Activity of soprano pipistrelles *Pipistrellus pygmaeus* and barbastelle bats *Barbastella barbastellus* increased with plant diversity within field margins, but there was no effect on the occurrence of either species (data reported as statistical model results). There was no effect on the activity or occurrence of common pipistrelles *Pipistrellus pipistrellus*, nor on the occurrence of three other bat species or species groups (serotine bats *Eptesicus serotinus*, noctule bats *Nyctalus noctula*, *Myotis* spp.). Dicot cover and flowering plant abundance had positive effects on bat activity and occurrence (see original paper for details). Four types of field margins were surveyed on agri-environment scheme farms: grass margins (14 farms), wildflower margins (eight farms), wild bird seed plots (15 farms), pollen and nectar plots (11 farms). Each of the 48 field margins was surveyed with bat detectors for three consecutive nights on three occasions in April–September 2017.

(1) McHugh N.M., Bown B.L., Hemsley J.A. & Holland J.M. (2019) Relationships between agri-environment scheme habitat characteristics and insectivorous bats on arable farmland. *Basic and Applied Ecology*, 40, 55–66.

3.9. Plant new hedges

- We found no studies that evaluated the effects of planting new hedges on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Hedgerows provide important commuting and foraging habitats for bats within open agricultural landscapes. Frey-Ehrenbold *et al.* (2013) found bat activity to be 1.4–2.8 times higher along linear features such as hedgerows than in open farmland areas, and one study in the UK found bats to be highly sensitive to the loss of hedgerows (Pocock & Jennings 2008). Planting new hedges within farmland may benefit bats. However, it will take a considerable amount of time for hedgerows to become established and sufficiently mature. Existing hedges should therefore be retained where possible. See '*Manage hedges to benefit bats*'. For studies that may carry out this intervention alongside other interventions to benefit bats on farmland, see '*Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)*'.

Frey-Ehrenbold A., Bontadina F., Arlettaz R. & Obrist M.K. (2013) Landscape connectivity, habitat structure and activity of bat guilds in farmland-dominated matrices. *Journal of Applied Ecology,* 50, 252–261.

Pocock M.J.O. & Jennings N. (2008) Testing biotic indicator taxa: the sensitivity of insectivorous mammals and their prey to the intensification of lowland agriculture. *Journal of Applied Ecology*, 45, 151–160.

3.10. Manage hedges to benefit bats

- **Two studies** evaluated the effects of managing hedges to benefit bat populations. Both studies were in the UK[1,2].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, site comparison study in the UK[2] found that hedges trimmed ≥3 years prior had more bat species recorded along them than hedges trimmed during the previous winter.

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** One replicated, paired sites study in the UK[1] found that pipistrelle activity (relative abundance) did not differ between hedges managed for wildlife on agri-environment scheme farms and hedges on conventional farms. One replicated, site comparison study in the UK[2] found that hedges trimmed ≥3 years prior had higher activity of two of eight bat species/species groups than hedges trimmed during the previous winter.

BEHAVIOUR (0 STUDIES)

Background

Hedgerows on farms may be subject to various management practices, including cutting. However, there is evidence that bats prefer taller, wider, structurally diverse hedgerows and those with emergent trees (e.g. Boughey *et al.* 2011, Lacoeuilhe *et al.* 2016). Reducing the cutting frequency of hedges, planting trees within hedges, retaining and maintaining existing emergent trees, minimising pesticide use and filling gaps within hedges are all likely to benefit bats. For studies that may carry out this intervention alongside other interventions to benefit bats on farmland, see '*Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)*'.

Boughey K.L., Lake I.R., Haysom K.A. & Dolman P.M. (2011) Improving the biodiversity benefits of hedgerows: how physical characteristics and the proximity of foraging habitat affect the use of linear features by bats. *Biological Conservation,* 144, 1790–1798.

Lacoeuilhe A., Machon N., Julien J.-F. & Kerbiriou C. (2016) Effects of hedgerows on bats and bush crickets at different spatial scales. *Acta Oecologica,* 71, 61–72.

A replicated, paired sites study in 2008 on 13 pairs of farms in Scotland, UK (*1*) found that hedges managed for wildlife on agri-environment scheme farms had similar activity of *Pipistrellus* species as hedges on conventional farms. The activity of common pipistrelles *Pipistrellus pipistrellus* and soprano pipistrelles *Pipistrellus pygmaeus* was similar along hedges managed for wildlife and along conventionally managed hedges (data reported as statistical model results). On agri-environment scheme farms, hedges had gaps filled, hedge bottoms were left unmown, and pesticide use and cutting was restricted (cut once every three years). Each of 13 hedges on agri-environment scheme farms were paired with 13 hedges on conventional farms with similar farming activities and surrounding habitats. No details were reported about the management of hedges on conventional farms. Each of 13 paired sites was sampled once on the same night in June–September 2008. Bat activity was recorded along transects (2.5–3.7 km long) from 45 minutes after sunset using bat detectors.

A replicated, site comparison study in 2016 on 20 farms in southwest England, UK (*2*) found that hedges that had not been trimmed for at least three years had more bat species and greater activity of two of eight bat species/species groups than hedges trimmed during the previous winter. Hedges trimmed ≥3 years prior had more bat species and greater activity of greater horseshoe bats *Rhinolophus ferrumequinum* and *Plecotus* spp. than hedges trimmed during the previous winter (data reported as statistical model results). Lesser horseshoe bats *Rhinolophus hipposideros* were more likely to be recorded along hedges trimmed ≥3 years prior, but activity did not differ significantly. Activity also did not differ significantly for five other bat species/species groups (see original paper for details). There were no significant differences between hedges trimmed two years prior vs. those trimmed during the previous winter. Sixty-four hedges were surveyed on 20 farms (2–4 hedges/farm). Nineteen hedges (under agri-environment scheme management since 2005) had not been trimmed for ≥3 consecutive winters. Twenty-eight hedges were trimmed during the previous winter (four agri-environment scheme, 24 conventionally managed), 17 were trimmed two winters prior (seven agri-environment scheme, 10 conventionally managed). All hedges were mechanically top trimmed. Bats were recorded with a bat detector along each of 64 hedges during one full night in June–August 2016.

(1) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) Pipistrelle bats and their prey do not benefit from four widely applied agri-environment management prescriptions. *Biological Conservation*, 144, 2233–2246.

(2) Froidevaux J.S.P., Boughey K.L., Hawkins C.L., Broyles M. & Jones G. (2019) Managing hedgerows for nocturnal wildlife: do bats and their insect prey benefit from targeted agri-environment schemes? *Journal of Applied Ecology*, 56, 1610–1623.

3.11. Manage ditches to benefit bats

- We found no studies that evaluated the effects of managing ditches to benefit bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Ditches, particularly those with still water, may provide foraging habitats for bats within farmed landscapes. Intensive agriculture can result in loss of ditch biodiversity through activities such as mowing, grazing and the use of fertilizer and pesticides. Management practices that maintain and increase the diversity of invertebrate species within ditches may benefit bats. For studies that may carry out this intervention alongside other interventions to benefit bats on farmland, see '*Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)*'.

3.12. Retain existing in-field trees

- We found no studies that evaluated the effects of retaining existing in-field trees on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Single or scattered trees, particularly mature or veteran trees, may provide important roosting and foraging habitat for bats in open agricultural landscapes. Two studies in Australia found greater total bat activity and more bat species over pastures with scattered trees than open pastures without trees (Lumsden & Bennett 2005, Fischer *et al.* 2010). A study in Sweden found that tree density (up to 120–130 trees/ha) had a positive effect on total bat activity and foraging activity, activity of cluttered and edge habitat adapted bat species, and species richness in wood-pastures (Wood *et al.* 2017). A study in the USA found greater activity of edge habitat adapted bat species around remnant mature oak trees (*Quercus* spp.) than in treeless, open areas within vineyards (Polyakov *et al.* 2019).

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared areas where existing in-field trees have been retained with areas where they have been removed. There must have been an active decision (i.e. intervention) to retain the in-field trees and the study must state when the intervention was carried out.

For studies that may carry out this intervention alongside other interventions to benefit bats on farmland, see '*Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)*'. For studies that relate to retaining remnant forest or woodland, see '*Retain remnant forest or woodland on agricultural land*'.

Fischer J., Stott J. & Law B.S. (2010) The disproportionate value of scattered trees. *Biological Conservation,* 143, 1564–1567.

Lumsden L.F. & Bennett A.F. (2005) Scattered trees in rural landscapes: foraging habitat for insectivorous bats in south-eastern Australia. *Biological Conservation,* 122, 205–222.

Polyakov A.Y., Weller T.J. & Tietje W.D. (2019) Remnant trees increase bat activity and facilitate the use of vineyards by edge-space bats. *Agriculture Ecosystems & Environment*, 281, 56–63.

Wood H., Lindborg R. & Jakobsson S. (2017) European Union tree density limits do not reflect bat diversity in wood-pastures. *Biological Conservation*, 210, 60–71.

3.13. Plant in-field trees

- We found no studies that evaluated the effects of planting in-field trees on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Single or scattered trees may be planted within fields to provide roosting and foraging habitat for bats in open agricultural landscapes. However, it will take a considerable amount of time for trees to become established and sufficiently mature. Existing in-field trees should therefore be retained where possible. See '*Retain existing in-field trees*'.

For studies that may carry out this intervention alongside other interventions to benefit bats on farmland, see '*Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)*'. For other interventions that involve planting trees on agricultural land, see '*Create tree plantations on agricultural land*' and '*Retain or plant native trees and shrubs amongst crops (agroforestry)*'.

3.14. Create tree plantations on agricultural land

- **Three studies** evaluated the effects of creating tree plantations on agricultural land on bat populations. The three studies were in Australia[1-3].

COMMUNITY RESPONSE (3 STUDIES)

- **Richness/diversity (3 studies):** Three replicated, site comparison studies in Australia[1–3] found no difference in the number of bat species in agricultural areas with and without plantations of native trees.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** Two of three replicated, site comparison studies in Australia[1–3] found no difference in bat activity (relative abundance) in agricultural areas with and without plantations of native trees[2,3]. The other study[1] found higher bat activity in plantations next to remnant native vegetation than in isolated plantations or over grazing land. In all three studies, bat activity was lower in plantations compared to original forest and woodland remnants.

BEHAVIOUR (0 STUDIES)

Background

Creating tree plantations on agricultural land may replace lost roosting and foraging habitat for bats. For evidence relating to planting single or scattered trees, see '*Plant in-field trees*'. For an intervention relating to planting trees to shade crops as part of agroforestry farming systems, see '*Retain or plant native trees and shrubs amongst crops (agroforestry)*'. For studies that may carry out this intervention alongside other interventions to benefit bats on farmland, see '*Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)*'.

A replicated, site comparison study in 1999 of four agricultural sites planted with native bluegum *Eucalyptus globulus* in Western Australia (*1*) found that tree plantations next to remnant vegetation had higher overall bat activity than isolated plantations or agricultural grazing land, but the number of bat species was similar. More bat passes were recorded in plantations next to remnant vegetation (52 bat passes) than in plantations isolated from remnant vegetation (4 bat passes) or over agricultural grazing land (14 bat passes), although no statistical tests were carried out. Bat activity was highest in remnants of original vegetation (75 bat passes). Similar numbers of bat species (2–4) were recorded in plantations and grazing land. Eight bat species were recorded in total (see original paper for data for individual species). All four sites had farm forestry plantations (4–6 years old), remnants of original native vegetation, and open grazing land. At each of four sites, one location within each of four habitats (plantations next to remnants, isolated plantations, grazing land, and remnant vegetation) was sampled with a bat detector for one full night in October 1999.

A replicated, site comparison study in 2002 of 120 sites in an agricultural area in New South Wales and Victoria, Australia (*2*) found that sites planted with native eucalypt trees had similar overall bat activity and a similar number of bat species as treeless grazed paddocks. Bat activity and the number of bat species did not differ significantly between plantations (average 87 bat passes/night, 5–7 species) and treeless grazed paddocks (50 bat passes/night, 5 species). Bat activity was lower in plantations than in remnants of original forest (302 bat passes/night), but the number of bat species was similar (7 species in remnants). Eleven bat species were recorded in total (see original paper for data for individual species). Grazing land with small remnants of forest had been planted with native tree species from the mid-1970s to 1991. Twelve treatments were sampled including different shapes or sizes (narrow, small, medium, large, very large) and ages (<10 or >10 years old) of plantations and remnant forest, and grazed paddocks with and without trees. For each of 12 treatments, 10 points were sampled with bat detectors for one full night in November–December 2002.

A replicated, site comparison study in 2006–2007 at 14 farms in New South Wales, Australia (*3*) found that tree plantations on agricultural land had similar bat activity and species richness as treeless paddocks, and lower bat activity, species richness and numbers of roosts than remnant native woodlands. Bat activity and the number of bat species recorded was similar between plantations (87 bat passes/night, 6–8 species) and paddocks (40 passes/night, 7 species), but higher in remnant woodland (650 bat passes/night, 10 species), although no statistical tests were carried out. Species composition was also similar in plantations and paddocks but differed in remnant woodland (data reported as statistical model results). Twenty-eight bat roosts were identified in remnant trees, but none in plantations. Twelve bat species were recorded in total (see original paper for data for individual species). Forty-four sites were surveyed across 14 farms (11 in remnant woodland, 27 in plantations, six in treeless paddocks). Plantations (2–40 ha) consisted of 1–4 *Eucalyptus* spp. and were 4–5 or 10 years old. Each of 44 sites was surveyed for two consecutive nights/site in September 2006 and February 2007. Ten bats were caught in harp traps and radio-tracked in late summer and spring 2008 at three farms.

(1) Hobbs R., Catling P.C., Wombey J.C., Clayton M., Atkins L. & Reid A. (2003) Faunal use of bluegum (*Eucalyptus globulus*) plantations in southwestern Australia. *Agroforestry Systems,* 58, 195–212.

(2) Law B.S. & Chidel M. (2006) Eucalypt plantings on farms: use by insectivorous bats in south-eastern Australia. *Biological Conservation*, 133, 236–249.

(3) Law B.S., Chidel M. & Penman T. (2011) Do young eucalypt plantations benefit bats in an intensive agricultural landscape? *Wildlife Research*, 38, 173–187.

3.15. Retain remnant forest or woodland on agricultural land

- We found no studies that evaluated the effects of retaining remnant forest or woodland on agricultural land on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Remnant forest or woodland fragments may provide important habitat for bats in agricultural landscapes. Remnants of forest or woodland have been found to support greater bat activity and/or more bat species than surrounding pasture, arable land or plantations (e.g. Hobbs *et al.* 2003, Law *et al.* 2011, Lentini *et al*. 2012, Fuentes-Montemayor *et al.* 2013, Pina *et al.* 2013). A study in Southeast Asia found that larger forest fragments in areas of plantation agriculture supported similar or higher bat abundance and diversity to undisturbed continuous forest (Struebig *et al.* 2008).

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared remnant forest or woodland that has been kept intact with similar/nearby areas where remnants have been cut down or otherwise degraded. There must have been an active decision (i.e. intervention) to retain the remnant forest or woodlands and the study must state when the intervention was carried out.

For studies that may carry out this intervention alongside other interventions to benefit bats on farmland, see '*Pay farmers to cover the costs of conservation measures (e.g. agri-environment schemes)*'. For a general intervention that involves retaining remnant habitats, see '*Habitat protection – Retain remnant habitat patches*'.

Fuentes-Montemayor E., Goulson D., Cavin L., Wallace J.M. & Park K.J. (2013) Fragmented woodlands in agricultural landscapes: The influence of woodland character and landscape context on bats and their insect prey. *Agriculture, Ecosystems & Environment*, 172, 6–15.

Hobbs R., Catling P.C., Wombey J.C., Clayton M., Atkins L. & Reid A. (2003) Faunal use of bluegum (*Eucalyptus globulus*) plantations in southwestern Australia. *Agroforestry Systems,* 58, 195–212.

Law B.S., Chidel M. & Penman T. (2011) Do young eucalypt plantations benefit bats in an intensive agricultural landscape? *Wildlife Research*, 38, 173–187.

Lentini P.E., Gibbons P., Fischer J., Law B., Hanspach J. & Martin T.G. (2012) Bats in a farming landscape benefit from linear remnants and unimproved pastures. *PLoS ONE,* 7, e48201.

Pina S.M.S., Meyer C. & Zortéa M. (2013) A comparison of habitat use by bats in natural forest fragments and Eucalyptus plantations in Brazilian Savanna. *Chiroptera Neotropical*, 19, 14–30

Struebig M.J., Kingston T., Zubaid A., Mohd-Adnan A. & Rossiter S.J. (2008) Conservation value of forest fragments to Palaeotropical bats. *Biological Conservation,* 141, 2112–2126.

3.16. Retain riparian buffers on agricultural land

- **One study** evaluated the effects of retaining riparian buffers on agricultural land on bat populations. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, paired sites study in the UK[1] found that pipistrelle activity (relative abundance) did not differ along waterways with buffers of vegetation on agri-environment scheme farms and waterways on conventional farms.

BEHAVIOUR (0 STUDIES)

Background

This intervention involves retaining buffers of woodland, forest or other vegetation along streams and rivers (riparian buffers or corridors) in agricultural areas. This may provide foraging and roosting opportunities for bats and maintain connectivity in disturbed landscapes.

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared agricultural areas where riparian buffers have been kept intact with similar/nearby areas where riparian vegetation has been cut down or otherwise degraded. There must have been an active decision (i.e. intervention) to retain the riparian buffer and the study must state when the intervention was carried out.

For a similar intervention relevant to logging, see '*Threat: Biological resource use – Logging and wood harvesting – Retain riparian buffers in logged areas*'. For an intervention that involves planting riparian buffers to reduce pollution, see '*Threat: Pollution – Agricultural and forestry effluents – Plant riparian buffer strips*'.

A replicated, paired sites study in 2008 on 17 pairs of farms in Scotland, UK (*1*) found that buffer strips along waterways on agri-environment scheme farms had similar activity of *Pipistrellus* species as the edges of waterways on conventional farms. The activity of common pipistrelles *Pipistrellus pipistrellus* and soprano pipistrelles *Pipistrellus pygmaeus* was similar along waterways with buffer strips and conventionally managed waterways (data reported as statistical model results). On agri-environment scheme farms, waterways had buffers with tall, waterside vegetation and restrictions on fertiliser, pesticides, mowing and grazing. Each of 17 waterways with buffers on agri-environment scheme farms was paired with 17 waterways on conventional farms with similar farming activities and surrounding habitats. No details were reported about waterway edges on conventional farms. Each of 13 pairs of farms was sampled once on the same night in June–September 2008. On each of 26 farms, bat activity was recorded continuously from 45 minutes after sunset using bat detectors along transects 2.5–3.7 km in length.

(1) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) Pipistrelle bats and their prey do not benefit from four widely applied agri-environment management prescriptions. *Biological Conservation*, 144, 2233–2246.

3.17. Retain or plant native trees and shrubs amongst crops (agroforestry)

- **Eight studies** evaluated the effects of retaining or planting native trees and shrubs amongst crops on bat populations. Four studies were in Mexico[2,4,5,6], three were in South America[1,3,8] and one was in Tanzania[7].

COMMUNITY RESPONSE (7 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in Tanzania[7] found different compositions of bat species in coffee plantations with different amounts and types of shade cover.

- **Richness/diversity (7 studies):** Four of six replicated, site comparison studies in Columbia[1], Mexico[2,4,5,6] and Costa Rica[3] found a similar number of bat species in shaded and unshaded coffee plantations[1], and in coffee plantations with different amounts and types of shade cover[2,4,5]. The two other studies[3,6] found more bat species[3,6] and higher bat diversity[3] in coffee, cacao and banana plantations with varied shade cover, than in plantations with a single shade species[6] or no shade[3]. One replicated, site comparison study in Tanzania[7] found more bat species in shaded coffee plantations than in traditional mixed agroforestry systems with natural forest vegetation.

POPULATION RESPONSE (6 STUDIES)

- **Abundance (5 studies):** Two replicated, site comparison studies in Mexico[4,6] captured more bats in coffee plantations with varied shade cover than in plantations with a single shade species. One replicated, site comparison study in Mexico[5] found higher activity (relative abundance) of forest bat species in plantations with a varied shade cover than in plantations with a single shade species, but the opposite was true for open habitat bat species. One replicated, site comparison study in Costa Rica[3] found no difference in the number of bats captured between cacao and banana shade plantations and unshaded monocultures. One replicated, site comparison study in Tanzania[7] found greater bat occurrence in shaded coffee plantations than in traditional mixed agroforestry systems with natural forest vegetation.
- **Condition (1 study):** One replicated, site comparison study in Columbia[8] found that great fruit-eating bats captured in 'silvopastoral' areas that used agroforestry, along with no chemicals, had higher body weights and body condition scores than those in conventional farming areas.

BEHAVIOUR (0 STUDIES)

Background

This intervention involves growing crops under shade trees that are either native tree species that are remnants from cleared vegetation, or other crop trees (often referred to as 'agroforestry'). This approach provides a more complex habitat than conventional monoculture farming and can support higher levels of biodiversity.

A replicated, site comparison study in 1999–2000 of 18 sites in coffee plantations and forest fragments in the Central Andes, Columbia (*1*) found that there was no significant difference in bat species richness in shaded and unshaded coffee plantations. Bat species richness overall was similar in shaded coffee (14 species) and unshaded coffee plantations (12 species). In landscapes dominated by shaded coffee, there was no significant difference in bat species richness between shaded (9.4 species) or unshaded coffee plantations (9.8 species) and native forest fragments (9.9 species). However, in landscapes dominated by unshaded coffee plantations, bat species richness was higher in native forest fragments (14.6 species) than in shaded (9.4 species) or unshaded coffee plantations (7.9 species). Six sites of each habitat type were surveyed (shaded coffee, unshaded coffee, and native forest fragments). Shaded coffee plantations had native shade trees. Unshaded plantations were coffee monocultures with no trees or containing just isolated trees. Bats were sampled with 50–80 m of mist nets for three consecutive nights/site between October 1999 and February 2000.

A site comparison study in 2004–2005 in five agroforestry plantations and one montane rainforest in southeastern Chiapas, Mexico (*2*) found that coffee agroforestry plantations with different amounts and types of shade cover had a similar number of bat species. The number of bat species captured (23–26) did not differ significantly between five coffee agroforestry plantations with different amounts and types of shade cover. However, the number of bat species captured across all sites was found to be positively correlated with the number of vegetation layers, and the height and cover of trees (data reported as statistical model results). More bat species were recorded in native rainforest (37 species) than in any of the five coffee agroforestry plantations. One native rainforest site was sampled, and five coffee agroforestry plantations with different heights (6–25 m), layers (2–3 strata), types (native rainforest trees, shimbillo *Inga* spp. or banana *Musa* spp.) and amounts (40–90%) of shade cover. Management intensity (pruning, weeding, and use of chemicals) also varied between sites. At each of six sites, bats were captured with six mist nets placed along a 150 m transect for 6 h from sunset on two nights. Surveys were repeated every 50 days from March 2004 to June 2005.

A replicated, site comparison study in 2002–2003 in 28 agroforestry plantations and seven tropical lowland forest sites in Talamanca, Costa Rica (*3*) found that banana and cacao agroforestry plantations had higher bat diversity and more bat species than unshaded plantain monocultures, but the total number of bats captured did not differ. Bat diversity (reported as diversity indices) and the number of bat species was higher in banana (14 bat species) and cacao (15 bat species) agroforestry plantations than in unshaded plantain monocultures (10 bat species). A similar number of bats were captured in banana (76 bats) and cacao (89 bats) agroforestry plantations and in unshaded plantain monocultures (83 bats). Banana and cacao agroforestry plantations had similar or higher bat diversity, number of bat species and bat captures as native forest (13 bat species, 47 bats captured). Banana and cacao agroforestry plantations were grown organically with a shade canopy of native trees or planted fruit and timber trees. Plantain monocultures were grown without shade and with the use of chemicals such as insecticides. Thirty-five sites were sampled including seven replicates each of native forest, plantain monoculture and banana agroforestry, and 14 replicates of cacao agroforestry. At each of 35 sites, bats were captured with four mist nets for 5 h on one night in May–November 2002/2003 and one night in February–November 2003.

A replicated, site comparison study in 2006–2007 of 44 sites in coffee agroforestry plantations and native rainforest fragments in Chiapas, Mexico (*4*) found that traditional agroforestry plantations had a similar number of leaf-nosed *Phyllostomidae* bat species to more intensively managed agroforestry plantations, but species composition differed and more bats were captured in traditional plantations. A similar number of bat species but more bats were captured in traditional agroforestry plantations (24 species, average 2.5 bats/mist net/hour) than in plantations with moderate (22 species, 1.6 bats/mist net/hour) or high intensity management (22 species, 1.4 bats/mist net/hour). A similar number of bat species were also captured in native forest (24 bat species). The proportion of bat species in all feeding groups decreased as management intensity increased, except for large fruit-eating bat species which increased in proportion (from 30% in native forest and traditional plantations to 48% in high intensity plantations). Bats were sampled in traditional agroforestry coffee plantations (coffee and other plants grown under original forest trees, 12 sites), moderate intensity coffee plantations (coffee grown under a variety of fruit and timber trees, 11 sites), high intensity coffee plantations (coffee grown under shimbillo *Inga* spp. trees, 10 sites) and native forest fragments (11 sites). At each of 44 sites, bats were captured with mist nets for 8–10 h during one night between November 2006 and August 2007.

A replicated, site comparison study in 2006–2007 of 44 sites in coffee agroforestry plantations and tropical rainforest in Chiapas, Mexico (*5*) found that traditional agroforestry plantations had a similar number of insect-eating bat species to more intensively managed agroforestry plantations, but species composition differed. The number of insect-eating bat species did not differ significantly between traditional agroforestry plantations (18 species) and plantations with moderate (23 bat species) or high intensity management (21 bat species). Activity of forest bat species was lower in high intensity plantations (average 6 bat passes/night) than moderate intensity (14 bat passes/night) or traditional plantations (21 bat passes/night). The opposite was true for open habitat bat species (high intensity plantations: average 3 bat passes/night; low intensity and traditional plantations: 1 bat pass/night). Native forest had a similar number of bat species (19) to all three types of plantations. Bats were sampled in traditional agroforestry coffee plantations (coffee and other plants grown under original forest trees, 12 sites), moderate intensity coffee plantations (coffee grown under a variety of fruit and timber trees, 11 sites), high intensity coffee plantations (coffee grown under shimbillo *Inga* spp. trees, 10 sites) and native forest fragments (11 sites). At each of 44 sites, sampling was carried out with mist nets and bat detectors for 8–10 h during one night between November 2006 and August 2007.

A replicated, site comparison study in 2008–2009 of nine farms in Veracruz, Mexico (*6*) found that coffee plantations with a mix of shade species had more bats and bat species captured within them than coffee plantations with few shade species and little understorey or pastures. More fruit and nectar-eating bats and bat species were captured in coffee plantations with a mix of shade species (378 bats, 20 bat species) than in coffee plantations with few shade species and little understorey (64 bats, 10 bat species) or pastures (26 bats, 8 bat species). Three coffee plantations had a varied shade layer including fruit trees and native tree species. Three coffee plantations were shaded only by mainly shimbillo *Inga* spp. trees with few understorey species. Three pastures were cattle-grazed with introduced grass species and isolated trees. Nine farms (three of each type) were surveyed eight times across three different seasons between April 2008 and September 2009. Bats were captured using 10 mist nets/site placed end to end at ground level for 4 h from sunset.

A replicated, site comparison study in 2010–2011 in 19 plantation, forest and grassland sites on the southern slopes of Mount Kilimanjaro, Tanzania (*7*) found that shaded coffee plantations had greater overall bat occurrence and species richness than traditional agroforestry systems, grasslands or natural forests, and species composition also differed. Overall bat occurrence was greater in shaded coffee plantations (average 49 occurrences) than traditional agroforestry systems (34 occurrences), grasslands (29 occurrences) or natural forests (15 occurrences). Species richness was higher in shaded coffee plantations (10 different types of bat echolocation call) than traditional agroforestry systems (8 types of bat call), grasslands (7 types of bat call) or natural forests (6 types of bat call). Species composition also differed between habitat types (data reported as statistical model results). Surveys were conducted in 4–5 plots (0.5 ha) within each of four habitat types: shaded coffee plantations (coffee plants with native or non-native tree species), traditional agroforestry systems (mixed agricultural plants with natural forest vegetation and large shade trees), grasslands (frequently cut to feed livestock) and natural forests. Four points/plot were surveyed from sunset for 4 x 5-minute intervals. Each plot was surveyed on one night in December–March 2010/2011 and June–September 2011.

A replicated, site comparison study in 2011–2012 of four tropical forest fragments in livestock farming areas in Córdoba, Columbia (*8*) found that great fruit-eating bats *Artibeus lituratus* captured in 'silvopastoral' areas that used agroforestry, along with no chemicals, had higher body weights and body condition scores than those within conventional farming areas. Great fruit-eating bats captured in 'silvopastoral' areas had a higher average body weight (64 g) and body condition score (0.93) than those captured in conventional farming areas (59.5 g; 0.86). In August 2011–July 2012, great fruit-eating bats were captured at forest fragments within each of two 'silvopastoral' areas (total 260 bats) and two conventional farming areas (total 69 bats). 'Silvopastoral' areas grazed livestock amongst trees, shrubs, and crops, without chemicals. Conventional areas grazed livestock in monocultures with little tree or shrub cover, and used agrochemicals, pesticides, and herbicides. Each of four sites was sampled 15 times for three consecutive nights with mist nets (6 x 3 m) deployed within the forest fragment (nine nets) and surrounding area (five nets). Nets were deployed for 12 h/night (18:00–06:00 h) and checked every 45 minutes. Each captured bat was weighed, forearm length was measured, and body condition calculated (body weight/forearm length). Bats were marked before release.

(1) Numa C., Verdú J.R. & Sánchez-Palomino P. (2005) Phyllostomid bat diversity in a variegated coffee landscape. *Biological Conservation*, 122, 151–158.

(2) Estrada C.G., Damon A., Hernández C.S., Pinto S.L. & Núñez G.I. (2006) Bat diversity in montane rainforest and shaded coffee under different management regimes in southeastern Chiapas, Mexico. *Biological Conservation,* 132, 351–361.

(3) Harvey C.A. & González Villalobos J.A. (2007) Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. *Biodiversity and Conservation,* 16, 2257–2292.
(4) Williams-Guillén K. & Perfecto I. (2010) Effects of agricultural intensification on the assemblage of leaf-nosed bats (Phyllostomidae) in a coffee landscape in Chiapas, Mexico. *Biotropica*, 42, 605–613.
(5) Williams-Guillén K. & Perfecto I. (2011) Ensemble composition and activity levels of insectivorous bats in response to management intensification in coffee agroforestry systems. *PLoS ONE,* 6, e16502.
(6) Castro-Luna A.A. & Galindo-González J. (2012) Enriching agroecosystems with fruit-producing tree species favors the abundance and richness of frugivorous and nectarivorous bats in Veracruz, Mexico. *Mammalian Biology,* 77, 32–40.
(7) Helbig-Bonitz M., Ferger S.W., Bohning-Gaese K., Tschapka M., Howell K. & Kalko E.K.V. (2015) Bats are not birds - different responses to human land-use on a tropical mountain. *Biotropica*, 47, 497–508.
(8) Chacón-Pacheco J.J. & Ballesteros-Correa J. (2019) Better body condition of *Artibeus lituratus* in fragments of tropical dry forest associated with silvopastoral systems than in conventional livestock systems in Córdoba, Colombia. Mejor condición corporal de *Artibeus lituratus* en fragmentos de bosque seco asociados a sistemas silvopastoriles que en sistemas convencionales de ganadería en Córdoba, Colombia. *Oecologia Australis,* 23, 589–605.

Livestock farming

3.18. Avoid the use of antiparasitic drugs for livestock

- We found no studies that evaluated the effects of avoiding the use of antiparasitic drugs for livestock on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

In some countries, livestock are treated with antiparasitic drugs to control parasites. These drugs may persist in livestock dung and have a negative impact on dung-eating invertebrates, which are an important food source for some insect-eating bat species (e.g. see EUROBATS 2010). This action is often carried out as part of an organic farming approach. See '*Use organic farming instead of conventional farming*' for studies that examine the effects of organic farming overall.

EUROBATS (2010) *Report of the Intersessional Working Group on impact on bat populations of the use of antiparasitic drugs for livestock*. Doc. EUROBATS.StC4-AC15.29. Rev1.

3.19. Manage grazing regimes to increase invertebrate prey

- We found no studies that evaluated the effects of managing grazing regimes to increase invertebrate prey on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Grazing regimes can be designed to maintain pasture in good condition and increase the abundance of invertebrate prey for bats. Bats may also forage over herds of grazing livestock, particularly at moderate stocking densities (e.g. Ancillotto *et al*. 2017).

Ancillotto L., Ariano A., Nardone V., Budinski I., Rydell J. & Russo D. (2017) Effects of free-ranging cattle and landscape complexity on bat foraging: implications for bat conservation and livestock management. *Agriculture, Ecosystems & Environment,* 241, 54–61.

3.20. Replace culling of bats with non-lethal methods of preventing vampire bats from spreading rabies to livestock

- We found no studies that evaluated the effects of replacing culling of bats with non-lethal methods of preventing vampire bats from spreading rabies to livestock on vampire bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Vampire bats have been extensively culled in Latin America to prevent the spread of rabies to livestock. However, research shows that culling is ineffective and may increase the spread of rabies (e.g. Streicker *et al.* 2012). Non-lethal measures of disease control have been suggested as alternatives, such as vaccinating livestock against rabies (e.g. Benavides *et al*. 2017).

For an intervention relating to the spread of rabies to humans, see '*Threat: Hunting – Replace culling of bats with non-lethal methods of preventing vampire bats from spreading rabies to humans*'.

Benavides J.A., Rojas Paniagua E., Hampson K., Valderrama W. & Streicker D.G. (2017) Quantifying the burden of vampire bat rabies in Peruvian livestock. *PLOS Neglected Tropical Diseases,* 11, e0006105.

Streicker D.G., Recuenco S., Valderrama W., Gomez Benavides J., Vargas I., Pacheco V., Condori Condori R.E., Montgomery J., Rupprecht C.E., Rohani P. & Altizer S. (2012) Ecological and anthropogenic drivers of rabies exposure in vampire bats: implications for transmission and control. *Proceedings of the Royal Society B: Biological Sciences,* 279, 3384–3392.

3.21. Manage livestock water troughs as a drinking resource for bats

- **Two studies** evaluated the effects of managing livestock water troughs as a drinking resource for bats. Both studies were in the USA[1,2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One replicated, paired sites study in the USA[1] found that removing livestock modifications from water troughs resulted in bats drinking from them more frequently. One paired sites study in the USA[2] found that livestock water tanks that were larger, full of water or surrounded by sparse vegetation had more bats drinking from them than smaller, half full tanks surrounded by no or dense vegetation.
- **Behaviour change (1 study):** One replicated, paired sites study in the USA[1] found that when livestock modifications were removed from water troughs, bats approached troughs fewer times before successfully drinking from them.

Background

Livestock water troughs can provide water sources for bats, particularly in arid areas. Modifications to water troughs that prevent livestock from damaging or entering them, such as wires and braces across the water surface, may injure bats or prevent them from drinking. Removing livestock modifications, keeping water troughs full and managing surrounding vegetation may increase the use of troughs by bats. Carefully designed escape structures may also prevent downed bats from drowning (e.g. see Taylor & Tuttle 2012).

For studies that avoid illuminating livestock water troughs, see '*Threat: Pollution – Avoid illumination of bat foraging, drinking, and swarming sites*'. For studies that create water sources on farmland and in other habitats, see '*Habitat restoration and creation – Create artificial water sources*'.

Taylor D.A.R & Tuttle M.D. (2012) *Water for Wildlife: A handbook for ranchers and range managers*. Bat Conservation International, Austin, Texas, USA.

A replicated, paired sites study in 2004 of four pairs of water troughs in northern Arizona, USA (*1*) found that removing livestock modifications from water troughs resulted in bats drinking from them more frequently. More bats reached the water surface at unmodified troughs than modified troughs during both single approaches (unmodified: 71% of bats; modified: 25%) and multiple approaches (unmodified: 97%; modified: 61%). Bats also approached unmodified troughs fewer times before successfully drinking than at modified troughs (unmodified: average 0.3 times; modified: 1.8 times). Three experiments were carried out at a pair of rectangular troughs (surface area 7.5 m^2) and one experiment at a pair of circular troughs (surface area 4.7 m^2). One trough in each pair had modifications installed with either a 3-strand barbed wire fence across the centre or boards at 100 cm intervals, the other was left unmodified. Troughs were filmed simultaneously for 1–5 nights in May–August 2004. Modifications were then switched to the unmodified trough and filming was repeated.

A paired sites study in 2008 in a semi-arid area of Texas, USA (*2*) found that livestock water tanks that were larger, full of water or surrounded by sparse vegetation had more bats drinking from them than smaller, half full tanks surrounded by no or dense vegetation. More bats drank from tanks that were larger (30 bats), full of water (20 bats) or surrounded by sparse vegetation (15 bats) compared to tanks that were smaller (0 bats), half full of water (0 bats) or surrounded by no vegetation (2 bats) or dense vegetation (0 bats). Four pairs of galvanized livestock water tanks (1.2, 1.8 or 3 m diameter, 0.6 m high) were deployed (spaced 80 m apart) for two nights each. Each pair tested one of four treatments: tank size (3-m diameter tank vs 1.2-m diameter tank), water level (full tank vs half full tank), sparse vegetation (one tank with salt cedar *Tamarix* spp. branches tied around the perimeter with some gaps, the other with no vegetation), dense vegetation (one tank with dense salt cedar branches tied around the perimeter, the other with no vegetation). Treatments were switched within each pair between the two nights. Bat activity was recorded using night-vision video cameras and infra-red lights for 160 minutes/night after sunset at each of the eight tanks in June–August 2008. Bats were not identified to species.

(1) Tuttle S.R., Chambers C.L. & Theimer T.C. (2006) Potential effects of livestock water-trough modifications on bats in northern Arizona. *Wildlife Society Bulletin*, 34, 602–608.
(2) Jackrel S.L. & Matlack R.S. (2010) Influence of surface area, water level and adjacent vegetation on bat use of artificial water sources. *The American Midland Naturalist,* 164, 74–79.

Perennial, non-timber crops

3.22. Prevent culling of bats around fruit orchards

- We found no studies that evaluated the effects of preventing culling of bats around fruit orchards on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Bats are frequently shot, persecuted, and even legally culled around fruit orchards to prevent damage to or loss of fruit crops. This is likely to have a significant impact on the survival of fruit bat populations. For example, the Mauritius fruit bat *Pteropus niger* has undergone an estimated population decline of 50% since government-implemented culling took place in 2015 and 2016 (Vincenot *et al.* 2017).

Vincenot C.E., Florens F.B.V. & Kingston T. (2017) Can we protect island flying foxes? *Science,* 355, 1368–1370.

3.23. Use non-lethal measures to prevent bats from accessing fruit in orchards to reduce human-wildlife conflict

- **Two studies** evaluated the effects of using non-lethal measures to prevent bats from accessing fruit in orchards to reduce human-wildlife conflict. The studies were in Madagascar[1] and Mauritius[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (0 STUDIES)

OTHER (2 STUDIES)

- **Human-wildlife conflict (2 studies):** Two replicated, controlled studies (including one randomized study) in Madagascar[1] and Mauritius[2] found that using an organic deterrent spray[1], hanging plastic flags in trees[1], or covering individual tree branches with nylon net bags[2] reduced damage to lychees caused by Madagascan flying foxes[1] or Mauritius fruit bats[2]. One of the studies[1] found that ringing bells in lychee trees deterred most Madagascan flying foxes.

Background

Bats may be culled by farmers or injured/killed by entanglement with inappropriately installed nets at fruit orchards. Various non-lethal alternatives have been suggested to prevent bats from accessing fruit in orchards to reduce human-wildlife conflict. These include using fixed nets (that prevent entanglement), netting individual trees or branches, planting decoy crops, picking fruit before peak ripeness and deterring bats with light, noise or unpleasant smells and tastes (see Aziz *et al*. 2016).

Aziz S.A., Olival K.J., Bumrungsri S., Richards G.C. & Racey P.A. (2016) The conflict between Pteropodid bats and fruit growers: species, legislation and mitigation. Pages 377–426 in*:* Voigt C.C. & Kingston T. (eds.) *Bats in the Anthropocene: Conservation of Bats in a Changing World.* Springer International Publishing, Cham.

A replicated, randomized, controlled study in 2012–2013 at two lychee *Litchi chinensis* growing sites in Madagascar (*1*) found that using an organic deterrent or plastic flags reduced lychee damage caused by Madagascan flying foxes *Pteropus rufus*, and ringing bells caused most bats to fly away. At both sites, the average proportion or number of lychees damaged by flying foxes/fruit cluster was lower with an organic deterrent (Site 1 = 5%; Site 2: two fruit/fruit cluster) or plastic flags (Site 1 = 32%; Site 2 = 0.5 fruit/fruit cluster) than with no deterrent (Site 1 = 62%; Site 2 = 11 fruit/fruit cluster). Across both sites, ringing bells resulted in 35 of 44 (80%) flying foxes flying away. Three deterrents were tested at two sites in 2012 and 2013. An organic deterrent ('Plantskydd') made from dried blood and vegetable oil was mixed with water and sprayed onto 19–27 lychee clusters/site (each with 60–125 fruit), 15 days before lychees ripened. Bright pink plastic flags (1 x 0.5 m) were hung 1 m from 18–20 randomly selected lychee clusters/site (each with 100–150 fruit). Controls were 21–32 lychee clusters/site with no deterrents. On three occasions, six bells (12-cm diameter) were hung in two lychee trees for four consecutive nights. Bells were rung using a string between 18:00 and 22:00 h when flying foxes attempted to feed on lychees. Lychee damage caused by flying foxes (identified from teeth marks) was monitored daily until lychees were collected by farmers.

A replicated, controlled study in 2016–2017 of 18 lychee *Litchi chinensis* trees in three towns in central Mauritius (*2*) found that covering individual branches with nylon net bags reduced damage to lychees, mostly caused by Mauritius fruit bats *Pteropus niger*. Lychee yield from panicles that were covered with net bags was 33% greater than that from uncovered panicles (data reported as statistical model results) due to reduced damage by Mauritius fruit bats, birds, or other causes. Bats were estimated to damage 42% of lychees, birds 13% and unknown causes or splitting 21%. Up to six individual panicles on each of 18 'backyard' lychee trees were covered with nylon net bags and six were left uncovered (total 75 covered, 81 uncovered). The number of lychees on each panicle and damaged/fallen lychees were counted every 2–3 days over an average of 18 days in November–January 2016/2017. Damage by bats was identified from bite marks or discarded seeds.

(1) Raharimihaja T.E.A., Rakotoarison J.L.M., Racey P.A. & Andrianaivoarivelo R.A. (2016) A comparison of the effectiveness of methods of deterring Pteropodid bats from feeding on commercial fruit in Madagascar. *Journal of Threatened Taxa,* 8, 9512–9524.
(2) Tollington S., Kareemun Z., Augustin A., Lallchand K., Tatayah V. & Zimmermann A. (2019) Quantifying the damage caused by fruit bats to backyard lychee trees in Mauritius and evaluating the benefits of protective netting. *PLOS ONE*, 14, e0220955.

3.24. Restore and manage abandoned orchards for bats

- We found no studies that evaluated the effects of restoring and managing abandoned orchards for bats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Restoring and managing traditional orchards (e.g. by pruning and removing undergrowth) may provide a suitable habitat for foraging and roosting bats. For example, a study in Switzerland found more bat species and greater bat foraging activity in traditionally managed sweet chestnut *Castanea sativa* orchards with a more open structure than in abandoned and unmanaged orchards that had become overgrown with dense vegetation (Obrist *et al*. 2011).

Obrist M.K., Rathey E., Bontadina F., Martinoli A., Conedera M., Christe P. & Moretti M. (2011) Response of bat species to sylvo-pastoral abandonment. *Forest Ecology and Management,* 261, 789–798.

3.25. Introduce certification for bat-friendly crop harvesting regimes

- We found no studies that evaluated the effects of introducing certification for bat-friendly crop harvesting regimes on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Certification schemes can encourage bat-friendly crop harvesting regimes and raise awareness of bat conservation. An example is the Tequila Interchange Project, which awards tequila producers a 'bat-friendly' tequila label if they use farming practices that benefit bats (www.tequilainterchangeproject.org).

4. Threat: Energy production and mining

Energy production (renewable and non-renewable) and mining can have significant impacts on bat populations through the destruction and pollution of habitats. General interventions in response to these threats are discussed in '*Habitat protection*', '*Habitat restoration and creation*' and '*Threat: Pollution*'. Interventions that are more specific to wind turbines and mining are discussed in this chapter.

Wind turbines

Renewable energy sources, such as wind power, have increased dramatically over the last few decades. Most wind energy development has been on commercial wind farms that have multiple large wind turbines with rotor diameters up to and over 100 m, each generating up to 2.3 Mega Watts. Studies indicate that large numbers of bats are killed by large-scale wind farms across the world, raising concerns about the cumulative impacts of wind energy on bat populations (e.g. Frick *et al*. 2017). The evidence provided in this chapter relates to large commercial wind turbines.

Smaller 'micro' wind turbines (which typically generate up to 50–100 kW) have also become increasingly popular, usually installed singly or in small groups by homeowners on private land. We found no studies that evaluated the effects of interventions relating to small 'micro' wind turbines. However, bat fatalities have been reported at small wind turbines. For example, one study estimated that 161–3,363 bats may be killed per year across 20,000 small wind turbines in the UK (Minderman *et al.* 2015). It has been suggested that the moving blades of small wind turbines interfere with bat echolocation calls, which may make them difficult to detect (Long *et al.* 2010). Small wind turbines may also affect habitat use by bats. Some bat species have been found to avoid small wind turbines, with adverse effects on bat activity recorded up to 100 m away (Minderman *et al.* 2012, 2017).

Frick W.F., Baerwald E.F., Pollock J.F., Barclay R.M.R., Szymanski J.A., Weller T.J., Russell A.L., Loeb S.C., Medellin R.A. & McGuire L.P. (2017) Fatalities at wind turbines may threaten population viability of a migratory bat. *Biological Conservation,* 209, 172–177.

Long C.V., Flint J.A. & Lepper P.A. (2010) Wind turbines and bat mortality: doppler shift profiles and ultrasonic bat-like pulse reflection from moving turbine blades. *The Journal of the Acoustical Society of America,* 128, 2238–2245.

Minderman J., Pendlebury C.J., Pearce-Higgins J.W. & Park K.J. (2012) Experimental evidence for the effect of small wind turbine proximity and operation on bird and bat activity. *PLOS ONE,* 7, e41177.

Minderman J., Fuentes-Montemayor E., Pearce-Higgins J.W., Pendlebury C.J. & Park K.J. (2015) Estimates and correlates of bird and bat mortality at small wind turbine sites. *Biodiversity and Conservation,* 24, 467–482.

Minderman J., Gillis M.H., Daly H.F. & Park K.J. (2017) Landscape-scale effects of single- and multiple small wind turbines on bat activity. *Animal Conservation,* 20, 455–462.

4.1. Apply textured coating to turbines

- **One study** evaluated the effects of applying a textured coating to turbines on bat populations. The study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One paired sites study in the USA[1] found that applying a textured coating to a turbine did not reduce the activity of four bat species or the number of bats observed.

BEHAVIOUR (0 STUDIES)

Background

It has been suggested that smooth surfaces, such as those found on wind turbine towers, may be misidentified by bats as water or clear flight paths due to their acoustic mirror properties (Russo *et al.* 2012, McAlexander 2013, Greif *et al*. 2017). Applying a textured coating could reduce bat collisions and fatalities. Behavioural experiments in flight rooms found that bats did not make contact with textured surfaces and approached them less often than smooth surfaces (Greif & Siemers 2010, Bienz 2015).

Bienz C. (2015) *Surface texture discrimination by bats: implications for reducing bat mortality at wind turbines.* MSc Thesis. Texas Christian University.

Greif S. & Siemers B.M. (2010) Innate recognition of water bodies in echolocating bats. *Nature Communications,* 1, 107.

Greif S., Zsebők S., Schmieder D. & Siemers B.M. (2017) Acoustic mirrors as sensory traps for bats. *Science,* 357, 1045–1047.

McAlexander C. (2013) *Evidence that bats perceive wind turbine surfaces to be water.* MSc Thesis. Texas Christian University.

Russo D., Cistrone L. & Jones G. (2012) Sensory ecology of water detection by bats: A field experiment. *PLOS ONE,* 7, e48144.

A paired sites study in 2017 at a wind farm in an agricultural and wooded area in Texas, USA (*1*) found that applying a textured coating to a turbine did not reduce the activity of four bat species or the number of bats observed compared to a conventional smooth turbine. Average hoary bat activity was greater at a textured turbine than a smooth turbine in one trial (textured: 2.7 calls/h; smooth: 0.3 calls/h) but did not differ significantly in the other (textured: 0.3 calls/h; smooth: 0.7 calls/h). Activity did not differ significantly between textured and smooth turbines in either trial for eastern red bats *Lasiurus borealis* (textured: 1.5–1.8 calls/h; smooth: 1.3–1.9 calls/h), tricolored bats *Perimyotis subflavus* (textured: 0.8–1.1 calls/h; smooth: 0.9–1.0 calls/h), or evening bats *Nycticeius humeralis* (textured: 1.0–1.5 calls/h; smooth: 1.5–1.6 calls/h). The average number of bats observed also did not differ significantly (textured: 5–7 bats/h; smooth: 6–9 bats/h). A textured coating was applied to one turbine (around the entire turbine from 10–43 m above ground) in each of two pairs in June 2017. The other turbine in each pair was left smooth. Paired turbines (1 ha apart) had similar bat activity during previous surveys. Bats were surveyed on 27 nights at each turbine using night-vision, thermal imaging cameras and bat detectors in June–September 2017.

(1) Huzzen B. (2019) *Does a textured coating alter bat activity and behaviour in proximity to wind turbines*. MSc thesis. Texas Christian University.

4.2. Deter bats from turbines using radar

- We found no studies that evaluated the effects of deterring bats from wind turbines using radar on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

It has been suggested that bats may avoid the radio frequency radiation associated with radar installations. During experimental trials in the UK, bats were less active at wetland and woodland foraging sites when pulses of radar signals were emitted from antennas (Nicholls & Racey 2009). However, the authors state that the thermal effects of exposure to electromagnetic radiation may be harmful to bats and other organisms.

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.

4.3. Deter bats from turbines using ultrasound

- **Four studies** evaluated the effects of deterring bats from wind turbines using ultrasound on bat populations. The four studies were in the USA[1–4].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (3 STUDIES)

- **Survival (3 studies):** Three replicated, randomized, controlled studies (one with a before-and-after trial in the second year) in the USA[2–4] found mixed results. In the first year of one study[2], 21-51% fewer bats were killed at turbines with an ultrasonic deterrent fitted than at control turbines, but in the second year, from 2% more to 64% fewer bats were killed at turbines with ultrasonic deterrents fitted. One study[3] found that using an ultrasonic deterrent emitting a constant or pulsed signal had mixed effects on the fatality rates of three bat species. One study[4] found that using ultrasonic deterrents resulted in fewer fatalities for two of three bat species.

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One paired sites study in the USA[1] found fewer bats flying near one of two wind turbines with an ultrasonic deterrent compared to turbines without, but the effect of the deterrent overall was not significant.

Background

Bats rely on ultrasound to echolocate for foraging and navigation. Broadcasting ultrasonic sounds at the frequency range which bats use for echolocation may act as a deterrent by interfering with their ability to perceive echoes. Three studies in the USA found reduced bat activity at pond sites when ultrasonic deterrents were used (Szewczak & Arnett 2006, Szewczak & Arnett 2008, Johnson *et al.* 2012). For a similar intervention relating to roads and rail, see '*Threat: Transportation and service corridors – Deter bats from roads/railways using ultrasound*'.

Johnson J.B., Ford W.M., Rodrigue J.L. & Edwards J.W. (2012) *Effects of acoustic deterrents on foraging bats.* Research Note NRS-129. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.

Szewczak J.M. & Arnett E. (2006) *Preliminary field test results of an acoustic deterrent with the potential to reduce bat mortality from wind turbines. An investigative report submitted to the Bats and Wind Energy Cooperative*. Bat Conservation International, Austin, Texas, USA.

Szewczak J.M. & Arnett E.B. (2008) *Field test results of a potential acoustic deterrent to reduce bat mortality from wind turbines. An investigative report submitted to the Bats and Wind Energy Cooperative*. Bat Conservation International, Austin, Texas, USA.

A paired sites study in 2007 on a wind farm in an agricultural area of New York, USA (*1*) found mixed effects on bat activity during two trials with an ultrasonic deterrent, and the deterrent did not have a significant effect overall. Fewer bats were observed over 10 consecutive nights at a turbine with an ultrasonic deterrent fitted (average 13 bat passes/night) than at a matched control turbine without a deterrent (average 24 bat passes/night). No significant difference was found in bat activity when this was repeated with a second matched pair (average 10 bat passes/night at both). The ultrasonic deterrent did not have a significant effect on the number of bats observed when results from both trials were combined (data reported as statistical model results). The deterrent broadcast random pulses of broadband ultrasound from 20–80 kHz. For both trials, bat activity was observed simultaneously at treatment and control turbines for 3.6 h after sunset for 10 consecutive nights in August 2007 using thermal infrared imaging cameras. Bats were not identified to species.

A replicated, randomized, controlled study in 2009–2010, with a before-and-after trial in the second year, at a wind farm in a forested area of Pennsylvania, USA (*2*) found that an ultrasonic deterrent had mixed effects on bat mortality. In 2009, 21–51% fewer bats overall were killed per deterrent turbine (average 6 bats killed/turbine) than control turbine (average 9 bats killed/turbine). The difference in mortality was significant for hoary bats *Lasiurus cinereus* (deterrent: average 4 bats killed/turbine; control: 2 bats killed/turbine), but not for five other bat species (see original paper for data). In the 2010 before-and-after trial, between 2% more and 64% fewer bats were killed overall at deterrent turbines than at control turbines when accounting for differences found between control and deterrent turbines in the 'before' trial. Differences for individual species were not tested for statistical significance due to low numbers (see original paper for data). In 2009 and 2010, 10 randomly selected wind turbines were fitted with deterrent devices, and 15 randomly selected turbines without the device were used as controls. The deterrent emitted continuous ultrasonic broadband noise at 20–100 kHz. In 2009, daily carcass searches were conducted in August–October. In 2010, the before-and-after trial was conducted with daily carcass searches in May–July before the deterrent was used, followed by daily searches in July–October with the deterrent active. Carcass counts were adjusted to account for searcher efficiency and removal by scavengers.

A replicated, randomized, controlled study in 2014–2016 at a wind farm in a forested area of Illinois, USA (*3*) found that turbines with ultrasonic deterrents emitting a constant or pulsed signal had mixed effects on bat mortality. Turbines with ultrasonic deterrents emitting a constant signal had 26–36% fewer hoary bat *Lasiurus cinereus* fatalities compared to turbines with no deterrent (data reported as statistical model results). For silver-haired bats *Lasionycteris noctivagans* and eastern red bats *Lasiurus borealis*, there were significantly fewer fatalities (57% and 39% respectively) during one of two years of the study with the constant signal deterrent. Turbines with deterrents emitting a pulsed signal had 73% fewer fatalities of silver-haired bats, but the difference was not significant for hoary bats or eastern red bats. Five other bat species or species groups were identified during carcass searches, although numbers were too low for statistical analysis (see original paper for data). In each of three years, nine or 10 six-day trials were carried out at 12–16 randomly selected turbines (half with deterrents fitted). Deterrents were switched between turbines halfway through each trial. Air-jet ultrasonic deterrents emitted sounds at 30–100 kHz between 1800 and 0630 h. Constant signals were used in 2014 and 2015 and pulsed signals in 2016 (5–8 second duration at 3 second intervals). Transects within a 60-m radius around each turbine were searched daily for bat carcasses during each trial in August–October 2014–2016. Carcass counts were adjusted to account for searcher efficiency and removal by scavengers.

A replicated, randomized, controlled study in 2017–2018 at a wind energy facility in an area of dry shrubland in Texas, USA (*4*) found that using ultrasonic deterrents on turbines reduced the number of fatalities of hoary bats *Lasiurus cinereus* and Brazilian free-tailed bats *Tadarida brasiliensis* but not northern yellow bats *Lasiurus intermedius*. On average, fewer bat carcasses were found at turbines with active ultrasonic deterrents than at those with inactive deterrents for hoary bats (active: 0.006 carcasses/night; inactive: 0.029 carcasses/night) and Brazilian free-tailed bats (active: 0.119 carcasses/night; inactive: 0.261 carcasses/night). The difference was not significant for northern yellow bats (active: 0.016 carcasses/night; inactive: 0.020 carcasses/night). Ultrasonic deterrents (arrays of 5–6 speakers emitting continuous sounds at 20–50 kHz) were installed on the nacelles of 16 wind turbines. During each night in July–October 2017 and 2018, eight randomly selected turbines had 'active' ultrasonic deterrents (turned on), and eight control turbines had 'inactive' deterrents (turned off). Carcass searches were conducted daily along transects in circular plots (100-m radius) around each of the 16 turbines.

(1) Horn J.W., Arnett E.B., Jensen M. & Kunz T.H. (2008) *Testing the effectiveness of an experimental bat deterrent at the Maple Ridge wind farm. A report submitted to The Bats and Wind Energy Cooperative*. Bat Conservation International, Austin, Texas, USA.
(2) 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,* 8, e65794.
(3) Romano W.B., Skalski J.R., Townsend R.L., Kinzie K.W., Coppinger K.D. & Miller M.F. (2019) Evaluation of an acoustic deterrent to reduce bat mortalities at an Illinois wind farm. *Wildlife Society Bulletin*, 43, 608–618.
(4) Weaver S.P. (2019) *Understanding wind energy impacts on bats and testing reduction strategies in South Texas*. PhD thesis. Texas State University.

4.4. Deter bats from turbines using low-level ultraviolet light

- We found no studies that evaluated the effects of deterring bats from turbines using low-level ultraviolet light on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

It has been suggested that bats may approach wind turbines because they misidentify them as trees (Cryan *et al*. 2014). Illuminating turbines with ultraviolet light may help bats to differentiate between wind turbines and trees. A study in the USA found that the activity of Hawaiian hoary bats *Lasiurus cinereus semotus* was lower at trees lit with dim flickering ultraviolet lights than at unlit trees (Gorresen *et al.* 2015). However, this has yet to be tested at wind turbines.

Cryan P.M., Gorresen P.M., Hein C.D., Schirmacher M.R., Diehl R.H., Huso M.M., Hayman D.T.S., Fricker P.D., Bonaccorso F.J., Johnson D.H., Heist K. & Dalton D.C. (2014) Behavior of bats at wind turbines. *Proceedings of the National Academy of Sciences,* 111, 15126–15131.
Gorresen P.M., Cryan P.M., Dalton D.C., Wolf S., Johnson J.A., Todd C.M. & Bonaccorso F.J. (2015) Dim ultraviolet light as a means of deterring activity by the Hawaiian hoary bat *Lasiurus cinereus semotus*. *Endangered Species Research,* 28, 249–257.

4.5. Remove turbine lighting to reduce bat and insect attraction

- We found no studies that evaluated the effects of removing turbine lighting to reduce bat and insect attraction on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Lights placed on wind turbines may attract insects and foraging bats, increasing the risk of collision. However, one study in the USA found fewer bat fatalities at turbines lit with flashing red aviation lights than at unlit turbines (Bennett & Hale 2014), and three other studies in the USA found no difference (Johnson *et al.* 2004, Jain *et al.* 2010, Baerwald & Barclay 2011).

Baerwald E.F. & Barclay R.M.R. (2011) Patterns of activity and fatality of migratory bats at a wind energy facility in Alberta, Canada. *The Journal of Wildlife Management,* 75, 1103–1114.

Bennett V.J. & Hale A.M. (2014) Red aviation lights on wind turbines do not increase bat-turbine collisions. *Animal Conservation*, 17, 354–358.

Jain A.A., Koford R.R., Hancock A.W. & Zenner G.G. (2010) Bat mortality and activity at a northern Iowa wind resource area. *The American Midland Naturalist,* 165, 185–200.

Johnson G.D., Perlik M.K., Erickson W.P. & Strickland M.D. (2004) Bat activity, composition, and collision mortality at a large wind plant in Minnesota. *Wildlife Society Bulletin,* 32, 1278–1288.

4.6. Paint turbines to reduce insect attraction

- We found no studies that evaluated the effects of painting turbines to reduce insect attraction on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

There is evidence that bats actively feed on insects around wind turbines (e.g. Foo *et al*. 2017). Common turbine colours (white and grey) have been found to attract more insects than other colours, such as purple (Long *et al.* 2011). Painting turbines in colours that are less attractive to insects could reduce bat foraging activity and subsequent fatalities.

Foo C.F., Bennett V.J., Hale A.M., Korstian J.M., Schildt A.J. & Williams D.A. (2017) Increasing evidence that bats actively forage at wind turbines. *PeerJ,* 5, e3985.

Long C.V., Flint J.A. & Lepper P.A. (2011) Insect attraction to wind turbines: does colour play a role? *European Journal of Wildlife Research,* 57, 323–331.

4.7. Close off potential access points on turbines to prevent roosting bats

- We found no studies that evaluated the effects of closing off potential access points on turbines to prevent roosting bats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Bats have been observed roosting in the nacelles of wind turbines (Ahlén *et al*. 2009), as well as in turbine door slats, stairwells and between the gills of the transformer (Bennett *et al*. 2017). Closing off potential access points on wind turbines to prevent bats from roosting may reduce the risk of bat collisions with turbine blades.

Ahlén I., Baagøe H.J. & Bach L. (2009) Behavior of Scandinavian bats during migration and foraging at sea. *Journal of Mammalogy,* 90, 1318–1323.

Bennett V.J., Hale A.M. & Williams D.A. (2017) When the excrement hits the fan: fecal surveys reveal species-specific bat activity at wind turbines. *Mammalian Biology,* 87, 125–129.

4.8. Modify turbine placement to reduce bat fatalities

- We found no studies that evaluated the effects of modifying turbine placement to reduce bat fatalities.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Positioning wind turbines away from bat roosts, foraging areas and commuting or migration routes may reduce bat mortality. At wind farms in the USA, bat fatalities are often dominated by migratory species and are higher during autumn migration periods (e.g. Arnett *et al.* 2008, Baerwald & Barclay 2009, Piorkowski & O'Connell 2010). A review of reports in northwest Europe found higher fatality rates at wind farms located on forested hills than in flat, open farmland (Rydell *et al.* 2010). Spatial patterns of bat fatalities within wind farms in Europe and the USA have been found in some studies (Arnett *et al.* 2008, Baerwald & Barclay 2011, Georgiakakis *et al.* 2012) but not others (Arnett *et al.* 2008, Piorkowski & O'Connell 2010).

Arnett E.B., Brown W.K., Erickson W.P., Fiedler J.K., Hamilton B.L., Henry T.H., Jain A., Johnson G.D., Kerns J., Koford R.R., Nicholson C.P., O'Connell T.J., Piorkowski M.D. & Tankersley R.D. (2008) Patterns of bat fatalities at wind energy facilities in North America. *The Journal of Wildlife Management,* 72, 61–78.

Baerwald E.F. & Barclay R.M.R. (2009) Geographic variation in activity and fatality of migratory bats at wind energy facilities. *Journal of Mammalogy,* 90, 1341–1349.

Baerwald E.F. & Barclay R.M.R. (2011) Patterns of activity and fatality of migratory bats at a wind energy facility in Alberta, Canada. *The Journal of Wildlife Management,* 75, 1103–1114.

Georgiakakis P., Kret E., Carcamo B., Doutau B., Kafkaletou-Diez A., Vasilakis D. & Papadatou E. (2012) Bat fatalities at wind farms in north-eastern Greece. *Acta Chiropterologica,* 14, 459–468.

Piorkowski M.D. & O'Connell T.J. (2010) Spatial pattern of summer bat mortality from collisions with wind turbines in mixed-grass prairie. *The American Midland Naturalist,* 164, 260–269.

Rydell J., Bach L., Dubourg-Savage M.-J., Green M., Rodrigues L. & Hedenström A. (2010) Bat mortality at wind turbines in northwestern Europe. *Acta Chiropterologica,* 12, 261–274.

4.9. Retain a buffer between turbines and habitat features used by bats

- We found no studies that evaluated the effects of retaining a buffer between turbines and habitat features used by bats on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

This intervention involves leaving a minimum distance between wind turbines and bat roosts or habitat features to create a buffer zone. The EUROBAT guidance on bats and wind turbines recommends a minimum distance of 200 m between wind turbines and important bat habitats (Rodrigues *et al*. 2014). Natural England, UK recommends a minimum distance of 50 m from the turbine blade tip to the nearest bat habitat feature (Mitchell-Jones & Carlin 2012), and for micro turbines a minimum distance of 20 m has been recommended (Minderman *et al.* 2012). However, reduced bat activity has been recorded up to 1,000 m from wind turbines (Barré *et al.* 2018). This action may not protect migratory bat species. Bennet & Hale (2018) found high fatalities of migratory bats at wind turbines without bat habitat features nearby (e.g. in open grazed fields).

Barré K., Le Viol I., Bas Y., Julliard R. & Kerbiriou C. (2018) Estimating habitat loss due to wind turbine avoidance by bats: implications for European siting guidance. *Biological Conservation,* 226, 205–214.

Bennett V.J. & Hale A.M. (2018) Resource availability may not be a useful predictor of migratory bat fatalities or activity at wind turbines. *Diversity,* 10, 44.

Minderman J., Pendlebury C.J., Pearce-Higgins J.W. & Park K.J. (2012) Experimental evidence for the effect of small wind turbine proximity and operation on bird and bat activity. *PLoS ONE,* 7, e41177.

Mitchell-Jones T. & Carlin C. (2012) *Bats and onshore wind turbines interim guidance*. Natural England Technical Information Note TIN051.

Rodrigues L., Bach L., Dubourg-Savage M., Karapandža B., Kovač D., Kervyn T., Dekker J., Kepel A., Bach P., Collins J., Harbusch C., Park K., Micevski B. & Minderman J. (2015) *Guidelines for Consideration of Bats in Wind Farm Projects - Revision 2014*. EUROBATS Publication Series No. 6 (English version). UNEP/EUROBATS Secretariat, Bonn, Germany.

4.10. Prevent turbine blades from turning at low wind speeds ('feathering')

- **Six studies** evaluated the effects of preventing turbine blades from turning at low wind speeds on bat populations. Five studies were in the USA[2–6] and one was in Canada[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (6 STUDIES)

- **Survival (6 studies):** Five of six studies (including five replicated, controlled studies and one before-and-after study) in the USA[2–6] and Canada[1] found that preventing turbine blades from turning at low wind speeds ('feathering')[1,2], or feathering along with increasing the wind speed at which turbines become operational ('cut-in speed')[3,5,6] resulted in fewer bat fatalities than at conventionally operated turbines. The other study[4] found that automatically feathering turbine blades at low wind speeds did not reduce bat fatalities.

BEHAVIOUR (0 STUDIES)

Background

Most wind turbines operate by a 'cut-in' wind speed at which the turbine begins to generate electricity and the blades can move at a maximum rotation speed. However, the blades can still rotate below cut-in speeds when electricity is not being generated. Preventing wind turbine blades from turning when they are not operational (known as 'feathering') may reduce bat fatalities, which have been found to be higher at low wind speeds (e.g. Horn *et al.* 2008, Rydell *et al.* 2010, Wellig *et al.* 2018). Turbine blades may be locked or the angle of the blades may be changed to be parallel to the wind. In some cases, the blades may still move a minimal amount (e.g. 1–2 rotations/minute). The cut-in speed of wind turbines is often increased in combination with this intervention. See '*Increase the wind speed at which turbines become operational ('cut-in speed')*'.

Horn J.W., Arnett E.B. & Kunz T.H. (2008) Behavioral responses of bats to operating wind turbines. *The Journal of Wildlife Management,* 72, 123–132.

Rydell J., Bach L., Dubourg-Savage M.-J., Green M., Rodrigues L. & Hedenström A. (2010) Bat mortality at wind turbines in northwestern Europe. *Acta Chiropterologica,* 12, 261–274.

Wellig S.D., Nusslé S., Miltner D., Kohle O., Glaizot O., Braunisch V., Obrist M.K. & Arlettaz R. (2018) Mitigating the negative impacts of tall wind turbines on bats: vertical activity profiles and relationships to wind speed. *PLOS ONE,* 13, e0192493.

A replicated, controlled study in 2005 at a wind farm in an agricultural area of Alberta, Canada (*1*) found that preventing turbine blades from turning at low wind speeds ('feathering') resulted in fewer bat fatalities than at conventional turbines. The total number of bat carcasses recovered by searchers was lower at experimental turbines shut down at low wind speeds (64 bats, 40% of total) than at conventional control turbines (95 bats, 60% of total). The number of bat carcasses did not differ significantly between turbines before the experiment ('experimental' turbines: 157 bats, 49% of total; 'control' turbines: 164 bats, 51% of total). Five bat species were found, although 97% of bat carcasses were hoary bats *Lasiurus cinereus* and silver-haired bats *Lasionycteris noctivagans* (see original report for data). In August 2005, all of 39 turbines were operated using conventional methods (blades rotated freely at wind speeds <4 m/s). In September 2005, odd numbered turbines (20 of 39) were braked and locked to prevent them from turning at wind speeds <4 m/s. Nineteen control turbines were left unaltered. Carcass searches were conducted weekly along transects in circular plots (40-m radius) around each turbine in August–September 2005.

A replicated, randomized, controlled study in 2010 at a wind energy facility in a forested area of West Virginia, USA (*2*; same site as *4*) found that preventing turbine blades from turning at low wind speeds ('feathering') in the first or second half of the night resulted in fewer bat fatalities than at conventional turbines. Average bat fatality estimates were lower when turbine blades were feathered in the first half of the night (0.05 bats/turbine) or the second half (0.09 bats/turbine) compared to conventional control turbines (0.18 bats/turbine). Fatality estimates for turbines feathered in the first vs second half of the night did not differ significantly. Six bat species were found, although 86% of bat carcasses were hoary bats *Lasiurus cinereus* and eastern red bats *Lasiurus borealis* (see original report for data). On nights when wind speeds were forecasted to be low, two treatments (blades feathered at wind speeds <4 m/s for 5 h after sunset or 5 h before sunrise) and a control (blades rotated freely at wind speeds <4 m/s) were each randomly assigned to three groups of eight turbines. Treatments were rotated between turbine groups weekly over 12 weeks in July–October 2010. Daily carcass searches were conducted along transects in plots up to 100 m around each of the 24 turbines. Carcass counts were corrected to account for searcher efficiency, removal by scavengers, and unsearchable areas within plots.

A replicated, randomized, controlled study in 2011 at a wind farm in an agricultural area of Indiana, USA (*3*) found that preventing turbine blades from turning at low wind speeds ('feathering'), and feathering along with increasing the speed at which turbines become operational ('cut-in speed'), resulted in fewer bat fatalities than at conventional control turbines. Total bat fatalities were 36% lower when turbine blades were feathered below the conventional cut-in speed (66 fatalities) compared to control turbines without feathering (105 fatalities). Total bat fatalities were 59% and 75% lower when blades were feathered and cut-in speeds increased to 4.5 and 5.5 m/s respectively (42 and 25 fatalities). Differences in total bat fatalities between treatments were significant. Seven bat species were found, although 81% of bat carcasses were eastern red bats *Lasiurus borealis* and hoary bats *Lasiurus cinereus* (see original report for data). Three treatments (turbine blades feathered below cut-in speeds of 3.5, 4.5 and 5.5 m/s) were each randomly assigned to a group of 42 turbines. Two control groups of nine and 42 turbines were left unaltered (blades rotated freely below cut-in speed of 3.5 m/s). Treatments were rotated between turbine groups nightly in July–October 2011. Carcass searches were conducted every 1–2 days along transects in circular plots (80-m radius) around each of the 177 turbines.

A replicated, randomized, controlled study in 2011 at a wind energy facility in a forested area of West Virginia, USA (*4*; same site as *2*) found that automatically preventing turbine blades from turning at low wind speeds ('feathering') did not result in fewer bat fatalities than at conventional turbines. Average bat fatality estimates did not differ significantly between turbines with automatically feathered blades (6.5 bats/turbine) and conventional control turbines (7.4 bats/turbine). Five bat species were found across the site (see original report for details). Twelve turbines were assigned with the treatment (blades automatically feathered when wind speeds dropped below 4 m/s for at least 6 minutes). Twelve control turbines were left unaltered (blades rotated freely at wind speeds <4 m/s). The treatment was rotated between turbines weekly for 12 weeks in July–October 2011. Daily carcass searches were conducted along transects in plots up to 100 m around each of the 24 turbines. Carcass counts were corrected to account for searcher efficiency, removal by scavengers, and unsearchable areas within plots.

A before-and-after study in 2011–2012 at a wind energy facility in a forested area of Maryland, USA (*5*) found that preventing turbine blades from turning at low wind speeds ('feathering'), along with increasing the speed at which turbines become operational ('cut-in speed'), resulted in fewer bat fatalities than before the operational changes. Average bat fatality estimates were 62% lower after turbine blades were feathered below an increased cut-in speed of 5 m/s (11 bats/turbine) compared to the previous year without operational changes (29 bats/turbine). The difference was not tested for statistical significance. Five bat species were found across the site (see original report for details). In July–October 2012, all of 28 turbines at the facility were operated with feathering below an increased cut-in speed of 5 m/s. Weekly carcass searches were conducted along transects in circular plots (40-m radius) around 14 of the 28 turbines. Data for before the operational changes (blades rotated freely below a cut-in speed of 4 m/s) were collected in a previous study in July–October 2011. Carcass counts in both years were corrected to account for searcher efficiency and removal by scavengers.

A replicated, randomized, controlled study in 2012–2013 at a wind farm in a forested area in Vermont, USA (*6*) found that preventing turbine blades from turning at low wind speeds ('feathering'), along with increasing the wind speed at which turbines become operational ('cut-in speed') at temperatures above 9.5°C, resulted in fewer bat fatalities than at conventional turbines. The average number of bat fatalities was 62% lower at wind turbines when cut-in speeds were increased to 6 m/s at temperatures >9.5°C and the blades were feathered below this speed (0.5 bats/turbine) compared to conventional control turbines (1.4 bats/turbine). Three bat species were found (see original paper for details). In June–September 2012 and 2013, eight of 16 turbines were randomly assigned the treatment (cut-in speed increased to 6 m/s at temperatures >9.5°C and blades feathered below this speed) for a total of 60 nights. The other eight turbines were unaltered (cut-in speed of 4 m/s without feathering). Daily carcass searches were conducted along transects in rectangular plots (3,629–5,746 m^2) centred on each of the 16 turbines. If applied to all turbines, it was estimated that the operational changes would result in annual energy losses of 1%.

(1) Brown W.K. & Hamilton B.L. (2006) *Monitoring of bird and bat collisions with wind turbines at the Summerview Wind Power Project, Alberta, 2005–2006*. Vision Quest Windelectric. Calgary, Alberta, Canada.

(2) Young D.P. Jr., Nomani S., Tidhar W.L & Bay K. (2011) *NedPower Mount Storm Wind Energy Facility post-construction avian and bat monitoring: July–October 2010*. Report prepared for NedPower Mount Storm LLC by Western EcoSystems Technology, Inc. (WEST), Cheyenne, Wyoming.

(3) Good R.E., Erickson W., Merrill A., Simon S., Murray K., Bay K., & Fritchman C. (2012) *Bat monitoring studies at the Fowler Ridge Wind Energy Facility, Benton County, Indiana: April 1 – October 31, 2011*. Report prepared for Fowler Ridge Wind Farm by Western EcoSystems Technology, Inc. (WEST), Cheyenne, Wyoming.

(4) Young D., Nomani S., Courage Z. & Bay K. (2012) *NedPower Mount Storm Wind Energy Facility post-construction avian and bat monitoring: July–October 2011*. Report prepared for NedPower Mount Storm LLC by Western EcoSystems Technology, Inc. (WEST), Cheyenne, Wyoming.

(5) Young D.P. Jr., Nations C., Lout M. & Bay K. (2013) *Post-construction monitoring study, Criterion Wind Project, Garrett County, Maryland: April–November 2012*. Report prepared for Criterion Power Partners LLC by Western EcoSystems Technology, Inc. (WEST), Cheyenne, Wyoming.

(6) Martin C.M., Arnett E.B., Stevens R.D. & Wallace M.C. (2017) Reducing bat fatalities at wind facilities while improving the economic efficiency of operational mitigation. *Journal of Mammalogy,* 98, 378–385.

4.11. Slow rotation of turbine blades at low wind speeds

- **One study** evaluated the effects of slowing the rotation of turbine blades at low wind speeds on bat populations. The study was in Canada[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, randomized, controlled study in Canada[1] found that bat fatalities were reduced when turbine blades were slowed at low wind speeds.

BEHAVIOUR (0 STUDIES)

Background

Most wind turbines operate by a 'cut-in' wind speed at which the turbine begins to generate electricity and the blades can move at a maximum rotation speed. However, the blades can still rotate below cut-in speeds when electricity is not being generated. Slowing the rotation of turbine blades below the cut-in speed may reduce bat fatalities, which have been found to be higher at low wind speeds (e.g. Horn *et al.* 2008, Rydell *et al.* 2010, Wellig *et al.* 2018).

For studies that prevent turbine blades from turning below the cut-in speed, see '*Prevent turbine blades from turning at low wind speeds ('feathering')*'. Cut-in speeds may also be increased in combination with this intervention. See '*Increase the wind speed at which turbines become operational ('cut-in speed')*'.

Horn J.W., Arnett E.B. & Kunz T.H. (2008) Behavioral responses of bats to operating wind turbines. *The Journal of Wildlife Management,* 72, 123–132.

Rydell J., Bach L., Dubourg-Savage M.-J., Green M., Rodrigues L. & Hedenström A. (2010) Bat mortality at wind turbines in northwestern Europe. *Acta Chiropterologica,* 12, 261–274.

Wellig S.D., Nusslé S., Miltner D., Kohle O., Glaizot O., Braunisch V., Obrist M.K. & Arlettaz R. (2018) Mitigating the negative impacts of tall wind turbines on bats: vertical activity profiles and relationships to wind speed. *PLOS ONE,* 13, e0192493.

A replicated, randomized, controlled study in 2006–2007 at a wind farm in an agricultural area of Alberta, Canada (*1*) found that slowing the rotation of turbine blades at low wind speeds resulted in fewer bat fatalities than at conventional turbines. Average bat fatality estimates were lower at experimental turbines with altered blade angles (8 bats/turbine) than at conventional control turbines (19 bats/turbine). Average bat fatality estimates did not differ significantly between turbines before the experiment ('experimental' turbines: 19 bats/turbine; 'control' turbines: 24 bats/turbine). Most bats identified during carcass searches were hoary bats *Lasiurus cinerus* and silver-haired bats *Lasionycteris noctivagans* (see original paper for data). In 2006, all of 14 turbines were operated using conventional methods (blades rotated freely at low wind speeds). In 2007, six randomly chosen turbines were altered by changing the pitch angle of the rotor blades to slow rotation at low wind speeds (<4 m/s). Eight control turbines were left unaltered. Carcass searches were conducted weekly along spiral transects up to 52 m around each of the 14 turbines in July–September 2006 and 2007. Carcass counts were corrected to account for searcher efficiency and removal by scavengers.

(1) 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. *The Journal of Wildlife Management*, 73, 1077–1081.

4.12. Increase the wind speed at which turbines become operational ('cut-in speed')

- **Twelve studies** evaluated the effects of increasing the wind speed at which turbines become operational ('cut-in speed') on bat populations. Ten studies were in the USA[2–5,7–11] and two were in Canada[1,6].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (12 STUDIES)

- **Survival (12 studies):** Ten of 12 studies (including 10 replicated, randomized, controlled studies and one before-and-after study) in the USA[2–5,7–11] and Canada[1,6] found that increasing the wind speed at which turbines become operational ('cut-in speed')[1,2,3a,4,6,9,11], or increasing the cut-in speed along with preventing turbine blades from turning at low wind speeds ('feathering')[5,8,10] resulted in fewer bat fatalities than at conventionally operated turbines. The other two studies[3b,7] found that increasing cut-in speeds did not reduce bat fatalities, but sample sizes were small[3a] or treatments were applied for short periods only[7].

BEHAVIOUR (0 STUDIES)

Background

Most wind turbines operate by a 'cut-in' wind speed at which the turbine begins to generate electricity and the blades can move at a maximum rotation speed. Increasing turbine cut-in speeds (known as 'curtailment') may reduce bat fatalities, which have been found to be high at low wind speeds (e.g. Horn *et al.* 2008, Rydell *et al.* 2010, Wellig *et al.* 2018). Wind turbines may also be slowed or prevented from turning below the cut-in speed. See '*Slow rotation of turbine blades at low wind speeds*' and '*Prevent turbine blades from turning at low wind speeds ('feathering')*'.

Horn J.W., Arnett E.B. & Kunz T.H. (2008) Behavioral responses of bats to operating wind turbines. *The Journal of Wildlife Management,* 72, 123–132.

Rydell J., Bach L., Dubourg-Savage M.-J., Green M., Rodrigues L. & Hedenström A. (2010) Bat mortality at wind turbines in northwestern Europe. *Acta Chiropterologica,* 12, 261–274.

Wellig S.D., Nusslé S., Miltner D., Kohle O., Glaizot O., Braunisch V., Obrist M.K. & Arlettaz R. (2018) Mitigating the negative impacts of tall wind turbines on bats: vertical activity profiles and relationships to wind speed. *PLOS ONE,* 13, e0192493.

A replicated, randomized, controlled study in 2006–2007 at a wind farm in an agricultural area of Alberta, Canada (*1*) found that increasing the wind speed at which turbines become operational ('cut-in speed') resulted in fewer bat fatalities than at conventional turbines. Average bat fatality estimates were lower at experimental turbines with increased cut-in speeds (8 bats/turbine) than at conventional control turbines (19 bats/turbine). Average bat fatality estimates did not differ significantly between turbines before the experiment ('experimental' turbines: 23 bats/turbine; 'control' turbines: 24 bats/turbine). Most bats identified during carcass searches were hoary bats *Lasiurus cinerus* and silver-haired bats *Lasionycteris noctivagans* (see original paper for data). In 2006, all of 23 turbines were operated using conventional methods. In 2007, fifteen randomly chosen turbines were altered by increasing the cut-in wind speed to 5.5 m/s. Eight control turbines were left unaltered (cut-in speed of 4 m/s). Carcass searches were conducted weekly along spiral transects up to 52 m around each of the 23 turbines in July–September 2006 and 2007. Carcass counts were corrected to account for searcher efficiency and removal by scavengers.

A replicated, randomized, controlled study in 2008–2009 at a wind farm in a forested area of Pennsylvania, USA (*2*) found that increasing the wind speed at which turbines become operational ('cut-in speed') resulted in fewer bat fatalities than at conventional turbines. Average bat fatality estimates were lower at turbines with cut-in speeds increased to 5 m/s (0.3–0.7 bats/turbine) and 6.5 m/s (0.5–0.6 bats/turbine) than at turbines with conventional cut-in speeds (3.5 m/s: 2.0–2.3 bats/turbine). Fatality estimates did not differ significantly between the two treatments. In July–October 2008 and 2009, two treatments (cut-in speed increased to 5 or 6 m/s) and one control (cut-in speed of 3.5 m/s) were each randomly assigned to three groups of four turbines for 25 nights/treatment. All 12 turbines were prevented from turning ('feathered') below cut-in wind speeds. Daily carcass searches were conducted along transects in plots (126 x 120 m) centred on each of the 12 turbines. Carcass counts were corrected to account for unsearchable areas within plots. If applied to the entire wind farm (23 turbines), annual power output losses were projected to be 0.3% with cut-in speeds increased to 5 m/s, and 1% with cut-in speeds increased to 6.5 m/s.

A replicated, randomized, controlled study in 2010 at a wind energy facility in an agricultural area in the Midwest region, USA (*3a*) found that increasing the wind speed at which turbines become operational ('cut-in speed') resulted in fewer bat fatalities than at conventional turbines. Bat fatalities were estimated to be 47% and 72% lower at turbines with cut-in speeds increased to 4.5 and 5.5 m/s respectively compared to control turbines with conventional cut-in speeds (data reported as statistical model results). A total of 25 and 14 bat carcasses were found at turbines with cut-in speeds of 4.5 and 5.5 m/s respectively, whereas 53 carcasses were found at control turbines. Two treatments (cut-in speed increased to 4.5 and 5.5 m/s from 1 h before sunset to 1 h after sunrise) and a control (conventional cut-in speed of 3.5 m/s) were each randomly assigned to four turbines. Treatments were rotated weekly between turbines over nine weeks in

August–October 2010. Daily carcass searches were conducted in plots (80 x 80 m) centred on each of the 12 turbines.

A replicated, randomized, controlled study in 2012 at a wind energy facility in a desert scrub area in the Pacific Southwest region, USA (*3b*) found that increasing the wind speed at which turbines become operational ('cut-in speed') did not result in fewer bat fatalities compared to conventional turbines. Total numbers of bat fatalities were reported to be 20–38% lower for four different treatments with increased cut-in speeds than at conventional turbines, but none of the differences were significant. The authors report that sample sizes were small (numbers not reported). Three bat species were found, although 74% of bat carcasses were Brazilian free-tailed bats *Tadarida brasiliensis* (see original paper for details). Four treatments (cut-in speed increased to 4, 5 or 6 m/s for 4 h after sunset, or cut-in speed increased to 5 m/s all night) and a control (conventional cut-in speed of 3 m/s) were randomly rotated each night between four groups of 10 turbines in August–September 2012. Daily carcass searches were conducted along transects in plots (126 x 126 m) centred on each of the 40 turbines.

A replicated, randomized, controlled study in 2010 at a wind farm in an agricultural area of Indiana, USA (*4*; same site as *5*) found that increasing the wind speed at which turbines become operational ('cut-in speed') resulted in fewer bat fatalities than at conventional turbines. Average bat fatality estimates were 50% and 78% lower when cut-in speeds were increased to 5 and 6.5 m/s respectively (7 and 3 bats/turbine) compared to conventional control turbines (14 bats/turbine). Six bat species were found, although 72% of bat carcasses were eastern red bats *Lasiurus borealis* (see original report for data). Two treatments (cut-in speed increased to 5 or 6 m/s) and a control (conventional cut-in speed of 3.5 m/s) were each randomly assigned to a group of nine turbines. Treatments were rotated between the three turbine groups weekly in August–October 2010. Nine control turbines were left unaltered. Daily carcass searches were conducted along transects in plots (80 x 80 m) centred on each of the 36 turbines. Carcass counts were corrected for searcher efficiency and removal by scavengers.

A replicated, randomized, controlled study in 2011 at a wind farm in an agricultural area of Indiana, USA (*5*; same site as *4*) found that increasing the wind speed at which turbines become operational ('cut-in speed'), along with preventing turbine blades from turning at low wind speeds ('feathering'), resulted in fewer bat fatalities compared to conventional turbines. Total bat fatalities were 59% and 75% lower (42 and 25 fatalities) when cut-in speeds were increased to 4.5 and 5.5 m/s respectively, and blades were feathered below these speeds, compared to conventional control turbines (105 fatalities). Differences in total fatalities between the two treatments were significant. Six bat species were found, although 80% of bat carcasses were eastern red bats *Lasiurus borealis* and hoary bats *Lasiurus cinereus* (see original report for data). Two treatments (cut-in speeds increased to 4.5 and 5.5 m/s and blades feathered below these speeds) were each assigned to a group of 42 turbines. Two control groups of nine and 42 turbines were left unaltered (blades rotated freely below cut-in speed of 3.5 m/s).

Treatments were rotated between turbine groups nightly in July–October 2011. Carcass searches were conducted every 1–2 days along transects in circular plots (80-m radius) around each of the 135 turbines.

A replicated, randomized, controlled study in 2011 at a wind farm on an island in Ontario, Canada (*6*) found that increasing the wind speed at which turbines become operational ('cut-in speed') resulted in fewer bat fatalities than at conventional turbines. Average bat fatality estimates were lower at turbines with cut-in speeds increased to 4.5 m/s (2.7 bats/turbines) or 5.5 m/s (2.1 bats/turbine) than at conventional control turbines (5.3 bats/turbine). The differences were not tested for statistical significance. Four bat species were found (see original report for details). In July–September 2011, fourteen turbines were randomly assigned to each of two treatments (increased cut-in speed of 4.5 or 5.5 m/s from sunset to sunrise) or as controls (conventional cut-in speed of 4 m/s). Carcass searches were carried out twice weekly along transects within circular plots (50-m radius) around each of the 42 turbines. Carcass counts were corrected to account for searcher efficiency, removal by scavengers, and the percentage of plot areas searched.

A replicated, randomized, controlled study in 2012 at a wind farm in a forested area of West Virginia, USA (*7*; same site as *9*) found that increasing the wind speed at which turbines become operational ('cut-in speed') for all or part of the night did not result in fewer bat fatalities than at conventional turbines. Overall, average nightly bat fatality rates did not differ significantly between turbines with the cut-in speed increased to 5 m/s for all or part of the night and conventional control turbines (data reported as statistical model results). The authors report that wind speeds of 3–5 m/s (i.e. when the treatments were in effect) only occurred for 17% of the time during the study. Six species were found across the site (see original report for details). Each of 12 turbines was randomly assigned to one of two treatments (cut-in speed increased to 5 m/s from sunset to sunrise or for the first 4 h after sunset) or as a control (conventional cut-in speed of 3 m/s). Treatments were rotated between turbines nightly over 75 nights in July–September 2012. All 12 turbines were prevented from turning ('feathered') below the cut-in speed. Daily carcass searches were conducted along transects in plots (126 x 120 m) centred on each of the 12 turbines.

A before-and-after study in 2011–2012 at a wind energy facility in a forested area of Maryland, USA (*8*) found that increasing the speed at which turbines become operational ('cut-in speed'), along with preventing turbine blades from turning at low wind speeds ('feathering'), resulted in fewer bat fatalities than before the operational changes. Average bat fatality estimates were 62% lower after the cut-in speed was increased to 5 m/s and turbine blades were feathered below this speed (11 bats/turbine) compared to the previous year without operational changes (29 bats/turbine). The difference was not tested for statistical significance. Five bat species were found across the site (see original report for details). In July–October 2012, all of 28 turbines at the facility were operated with an increased cut-in speed of 5 m/s with blades feathered below this speed. Weekly carcass searches were conducted along transects in circular plots (40-m radius) around 14 of the 28 turbines. Data for before the operational changes (blades rotated freely below a cut-in speed of 4 m/s) were collected in a previous study in July–October 2011. Carcass counts in both years were corrected to account for searcher efficiency and removal by scavengers.

A replicated, randomized, controlled study in 2013 at a wind farm in a forested area of West Virginia, USA (*9*; same site as *7*) found that increasing the wind speed at which turbines become operational ('cut-in speed') resulted in fewer bat fatalities than at conventional turbines. Average bat fatality estimates were 54% and 76% lower when cut-in speeds were increased to 5 and 6.5 m/s respectively (0.5 and 0.3 bats/turbine/night) than at conventional control turbines (1.3 bats/turbine/night). The difference in fatality rates between the two treatments was not significant. Five bat species were found (see original report for data). Each of 12 turbines was randomly assigned to one of two treatments (cut-in speed increased to 5 or 6.5 m/s) or as a control (conventional cut-in speed of 3 m/s). Treatments were rotated between turbines nightly over 72 nights in July–September 2013. Turbines started/stopped operating when the average wind speed over 10 minutes (measured at a weather tower) was above or below the cut-in speed. All turbines were prevented from turning ('feathered') below the cut-in speed. Daily carcass searches were conducted along transects in plots (126 x 120 m) centred on each of the 12 turbines. Carcass counts were corrected to account for searcher efficiency, removal by scavengers, and unsearchable areas within plots.

A replicated, randomized, controlled study in 2012–2013 at a wind farm in a forested area in Vermont USA (*10*) found that increasing the wind speed at which turbines become operational ('cut-in speed') at temperatures above 9.5°C, along with preventing turbine blades from turning at low wind speeds ('feathering'), resulted in fewer bat fatalities than at conventional turbines. The average number of bat fatalities was 62% lower at wind turbines when cut-in speeds were increased to 6 m/s at temperatures >9.5°C and the blades were feathered below this speed (0.5 bats/turbine) compared to conventional control turbines (1.4 bats/turbine). Three bat species were found (see original paper for details). In June–September 2012 and 2013, eight of 16 turbines were randomly assigned the treatment (cut-in speed increased to 6 m/s at temperatures >9.5°C and blades feathered below this speed) for a total of 60 nights. The other eight turbines were unaltered (cut-in speed of 4 m/s without feathering). Daily carcass searches were conducted along transects in rectangular plots (3,629–5,746 m^2) centred on each of the 16 turbines. If applied to all turbines, it was estimated that the operational changes would result in annual energy losses of 1%.

A study in 2013–2017 at a wind farm in an agricultural area of Indiana, USA (*11*) found that increasing the wind speed at which turbines become operational ('cut-in speed') resulted in fewer bat fatalities in both the spring and autumn migration periods. During spring, average bat fatality estimates were lower during one year in which the cut-in speed was increased to 5 m/s (0.3 bats/turbine) compared to three years in which the manufacturer's cut-in speed was used (3.5 m/s; 0.7–1.4 bats/turbine). During autumn, average bat fatality estimates were lower during three years with an increased cut-in speed of 6.9 m/s (0.7–1.5 bats/turbine) compared to one year with a cut-in speed of 5 m/s (2.2. bats/turbine). The differences were not tested for statistical significance. Five bat species were found across the site (see original report for details). During spring (April–May), all of 125 turbines were operated at a cut-in speed of 5 m/s for one year (2016) and 3.5 m/s for four years (2013–2015, 2017). During autumn (August–October), all of 125 turbines were operated at a cut-in speed of 6.9 m/s for three years (2013–2015) and 5 m/s for one year (2017). Carcass searches were conducted 1–2 times/week along transects up to 80 m around each of the 125 turbines in April–May and August–October 2017. Data for 2013–2016 were collected during previous studies. All carcass counts were corrected for searcher efficiency, removal by scavengers, and unsearchable areas within plots.

(1) 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. *The Journal of Wildlife Management*, 73, 1077–1081.

(2) Arnett E.B., Huso M.M.P., 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.

(3) Arnett E.B., Johnson G.D., Erickson W.P. & Hein C.D. (2013) *A synthesis of operational mitigation studies to reduce bat fatalities at wind energy facilities in North America*. *A report submitted to the National Renewable Energy Laboratory*. Bat Conservation International. Austin, Texas, USA.

(4) Good R.E., Erickson W., Merrill A., Simon S., Murray K., Bay K. & Fritchman C. (2011) *Bat monitoring studies at the Fowler Ridge Wind Energy Facility, Benton County, Indiana: April 13 – October 15, 2010*. Report prepared for Fowler Ridge Wind Farm by Western EcoSystems Technology, Inc. (WEST), Cheyenne, Wyoming.

(5) Good R.E., Erickson W., Merrill A., Simon S., Murray K., Bay K., & Fritchman C. (2012) *Bat monitoring studies at the Fowler Ridge Wind Energy Facility, Benton County, Indiana: April 1 – October 31, 2011*. Report prepared for Fowler Ridge Wind Farm by Western EcoSystems Technology, Inc. (WEST), Cheyenne, Wyoming.

(6) Stantec Consulting Ltd. (2012) *Wolfe Island Wind Plant post-construction follow-up plan bird and bat resources monitoring report No. 6, July–December 2011*. Prepared for TransAlta Corporation's wholly owned subsidiary Canadian Renewable Energy Corporation by Stantec Consulting Ltd., Guelph, Ontario.

(7) Hein C.D., Prichard A., Mabee T. & Schirmacher M.R. (2013) *Effectiveness of an operational mitigation experiment to reduce bat fatalities at the Pinnacle Wind Farm, Mineral County, West Virginia, 2012.* An annual report submitted to Edison Mission Energy and the Bats and Wind Energy Cooperative. Bat Conservation International, Austin, Texas.

(8) Young D.P. Jr., Nations C., Lout M. & Bay K. (2013) *Post-construction monitoring study, Criterion Wind Project, Garrett County, Maryland: April–November 2012*. Report prepared for Criterion Power Partners LLC by Western EcoSystems Technology, Inc. (WEST), Cheyenne, Wyoming.

(9) Hein C.D., Prichard A., Mabee T. & Schirmacher M.R. (2014) *Efficacy of an operational minimization experiment to reduce bat fatalities at the Pinnacle Wind Farm, Mineral County, West Virginia, 2013. An annual report submitted to Edison Mission Energy and the Bats and Wind Energy Cooperative*. Bat Conservation International, Austin, Texas.

(10) Martin C.M., Arnett E.B., Stevens R.D. & Wallace M.C. (2017) Reducing bat fatalities at wind facilities while improving the economic efficiency of operational mitigation. *Journal of Mammalogy,* 98, 378–385.

(11) Stantec Consulting Services Inc. (2018) *Post-construction bat mortality monitoring report Wildcat Wind Farm, Madison and Tipton Counties, Indiana 2017*. Report prepared for Wildcat Wind Farm LLC by Stantec Consulting Services Inc. Independence, Iowa.

4.13. Automatically reduce turbine blade rotation when bat activity is high

- **Two studies** evaluated the effects of automatically reducing turbine blade rotation when bat activity is high on bat populations. One study was in Germany[1] and one in the USA[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Survival (2 studies):** Two replicated studies (one randomized, controlled and one paired sites study) in Germany[1] and the USA[2] found that automatically reducing the rotation speed of wind turbine blades when bat activity is predicted to be high resulted in fewer bat fatalities for all bat species combined[1] and for five bat species[2].

BEHAVIOUR (0 STUDIES)

Background

This intervention involves the use of automatic bat registration systems to monitor bat activity and shut down operation of wind turbines when bat activity reaches a predetermined 'high' level.

A replicated, paired sites study in 2012 at eight pairs of wind turbines in Germany (*1*) found that using automated 'bat-friendly' operating systems that reduced turbine blade rotation speed resulted in fewer bat fatalities than at conventionally operated wind turbines. Total bat fatalities and average collision rates were lower at automated turbines (total 2 bat fatalities, 0.01 fatalities/turbine/night) than at conventionally operated turbines (total 21 bat fatalities, 0.06 fatalities/turbine/night). At automated turbines, predictive models identified periods of high fatality risk and low energy yield from bat activity and wind speed data. During these periods, rotor blades were moved parallel to the wind to reduce rotation speed according to a target bat fatality rate (0.012 fatalities/turbine/night). Conventionally operated turbines rotated freely. At each of eight sites, automated and conventional operating modes were alternated weekly between two paired turbines over 14 weeks in July–October 2012. Carcass searches were carried out daily. Carcass counts were corrected to account for searcher efficiency and removal by scavengers. If applied to all turbines, it was estimated that automated operation would result in annual energy losses of 2.1%.

A replicated, randomized, controlled study in 2015 at a wind energy facility in an agricultural area of Wisconsin, USA (*2*) found that using automated 'Smart Curtailment' operating systems that reduced turbine blade rotation speed resulted in 74–91% fewer fatalities of five bat species compared to conventionally operated turbines. Total fatality estimates were lower at automated turbines than conventionally operated turbines for eastern red bats *Lasiurus borealis* (automated: 34 fatalities; conventional: 220 fatalities); hoary bats *Lasiurus cinereus* (automated: 11; conventional: 59); silver-haired bats *Lasionycteris noctivagans* (automated: 5; conventional: 55); big brown bats *Eptesicus fuscus* (automated: 8; conventional: 31); and little brown bats *Myotis lucifugus* (automated: 3; conventional: 35). Twenty turbines were randomly selected (10 operated by automated systems, 10 conventionally operated). At automated turbines, fatality risk was calculated by a predictive model using real-time bat activity and wind speed data every 10 minutes. If fatality risk was high (wind speed <8 m/s and >1 bat call detected in the previous 10 minutes), rotor blades were rotated out of the wind and slowed (to ≤1 rpm) for 30 minutes. Conventionally operated turbines were 'feathered' to rotate slowly below a cut-in speed of 3.5 m/s. Daily carcass searches were conducted along transects in plots (80 x 80 m) centred on each of the 20 turbines in July–September 2015. Carcass counts were corrected to account for searcher efficiency and removal by scavengers. Electricity generation was reduced by 90 MWh/turbine at automated turbines during the study period.

(1) Behr O., Brinkmann R., Korner-Nievergelt F., Nagy M., Niermann I., Reich M. & Simon R. (2016) *Reducing the Collision Risk for Bats at Onshore Wind Turbines (RENEBAT II). Reduktion des Kollisionsrisikos von Fledermäusen an Onshore-Windenergieanlagen (RENEBAT II)*. Umwelt und Raum Bd. 7, 368 S., Institut für Umweltplanung, Hannover.

(2) Hayes M.A., Hooton L.A., Gilland K.L., Grandgent C., Smith R.L., Lindsay S.R., Collins J.D., Schumacher S.M., Rabie P.A., Gruver J.C. & Goodrich-Mahoney J. (2019) A smart curtailment approach for reducing bat fatalities and curtailment time at wind energy facilities. *Ecological Applications,* 29, e01881.

Mining

Abandoned mines are often used as roosting sites for cave-dwelling bats as they provide stable microclimates and shelter. However, abandoned mines can be hazardous to members of the public and are often closed and reclaimed by filling in, sealing, blasting or gating.

4.14. Provide artificial subterranean bat roosts to replace roosts in reclaimed mines

- We found no studies that evaluated the effects of providing artificial subterranean bat roosts to replace roosts in reclaimed mines on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Artificial subterranean bat roosts may be provided in proximity to reclaimed mines to replace lost roosts. Similar interventions are described in '*Threat: Human* *intrusions and disturbance – Caving and tourism – Provide artificial subterranean bat roosts to replace roosts in disturbed caves*' and '*Habitat restoration and creation – Create artificial caves or hibernacula for bats*'.

4.15. Exclude bats from roosts prior to mine reclamation

- We found no studies that evaluated the effects of excluding bats from roosts prior to mine reclamation on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Excluding bats from roosts within mines prior to reclamation may prevent injury or death. However, it is important to also consider the short-term and long-term impacts of exclusion from roosts on the survival and productivity of bat populations.

4.16. Relocate bats from reclaimed mines to alternative subterranean roost sites

- We found no studies that evaluated the effects of relocating bats from reclaimed mines to alternative subterranean roost sites on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

It may be possible to relocate bats roosting in reclaimed mines to nearby alternative subterranean roosts, if conditions are suitable.

4.17. Retain access points for bats following mine closures

- We found no studies that evaluated the effects of retaining access points for bats following mine closures on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Access points for bats may be retained following mine closures to prevent entombment and to allow continued use by roosting bats. For a similar intervention, see '*Threat: Human intrusions and disturbance – Caving and tourism – Retain bat access points to caves*'.

4.18. Install and maintain gates at mine entrances to restrict public access

- **Nine studies** evaluated the effects of installing gates at mine entrances on bat populations. Eight studies were in the USA[1–3,5–7c] and one in Australia[4].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, before-and-after study in the USA[5] found that fewer bat species entered mines after gates were installed.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** Two replicated, site comparison or before-and-after studies in the USA[3] and Australia[4] found fewer bats in mines[4] or at mine entrances[3] after gates were installed. One replicated, controlled, before-and-after study in the USA[7a] found that bat activity (relative abundance) remained stable or increased at five of seven gated mines, and decreased at two gated mines.

BEHAVIOUR (6 STUDIES)

- **Use (2 studies):** One before-and-after study in the USA[1] found that 43 of 47 mines continued to be used 12 years after gates were installed, however bats abandoned four mines with 'ladder' design gates. One replicated study in the USA[7c] found that gate design and time since gate installation had varied effects on the presence of four bat species.
- **Behaviour change (4 studies):** Four replicated, before-and-after or site comparison studies in the USA[2,6,7b] and Australia[4] found that bats at mine entrances circled more[2,4,6,7b] and entered mines less[2,6] after gates were installed.

OTHER (2 STUDIES)

- **Collisions with gates (1 study):** One replicated, controlled, before-and-after study in the USA[6] found that up to 7% of bats at mine entrances collided with mine gates.

Background

Gates may be installed at mine entrances to restrict public access and reduce human disturbance. However, gates can also impede access by bats and early installation attempts from the 1950s to the 1970s often resulted in roost abandonment (Tuttle 1977). For evidence relating to cave gates, see '*Threat: Human intrusions and disturbance – Caving and tourism – Install and maintain cave gates to restrict public access*'.

Tuttle M.D. (1977) Gating as a means of protecting cave dwelling bats. Pages 77–82 in: T. Aley & D. Rhodes (eds.) *1976 National Cave Management Symposium Proceedings*, Speleobooks, Albuquerque, USA.

A before-and-after study in 1991–2004 at 47 gated abandoned mines in forested areas of Colorado, USA (*1*) found that 43 of 47 mines with gates of various designs continued to be used by eight bat species up to 12 years after installation. None of 43 mines with full gates with or without culverts were abandoned by bats. Three mines with ladder gates and one mine with a culvert ladder gate were abandoned by bats. Four types of gate were evaluated, all with bar spacings of 150 mm. Traditional gates allowed access to bats across the whole gate, ladder gates allowed access to bats at the centre only, and both types of gate were also constructed in metal culverts where mine entrances were too unstable to anchor the gate itself. Each of 47 mines were surveyed 2–10 times in 1991–2004 using multiple methods (catching, visual counts and infrared motion detectors).

A replicated, controlled, before-and-after and site comparison study in 2003 at 28 mine and cave sites between Ontario, Canada and Tennessee, USA (*2*) found that at mine and cave entrances with gates, bats circled, retreated more and passed through less often than at ungated entrances. Bats circled and retreated more and passed through less at entrances with existing mine or cave gates (37% of bats circled and retreated, 50% passed through) or newly installed mock gates (60% circled and retreated, 25% passed through) than at ungated entrances (23% circled and retreated, 68% passed through). Separate results for mines and caves were not provided. Seven mines or caves had existing gates (of various designs), twelve mines or caves were ungated and had mock wooden gates installed (horizontal bars 25 mm diameter with 146 mm spacing). Ungated entrances were surveyed before and after mock gates were installed. At each of 28 sites, observations of behaviour were made during 3–4 x 5-minute periods during 1–2 nights in July–October 2003.

A replicated, site comparison study in 2002 of 24 gated and 23 ungated abandoned mines in West Virginia, USA (*3*) found that mines with gates had fewer bats captured of nine species than ungated mines, but other mine features were more important than gates for predicting bat presence. The number of bats captured was lower for nine bat species at mine entrances with gates than at mine entrances without gates (data reported as statistical model results). However, mine entrance size, shape and distance to other entrances were more important than gates for predicting the presence of bats (see original paper for detailed results). Twenty-four mine entrances were gated (one had a 'bat-friendly' angle-iron design, 23 had a round-bar design with 1.5 cm bars spaced 500 cm horizontally and 200 cm vertically). Twenty-three mine entrances had no gates installed. Bats were captured with harp traps and/or mist nets for one night at 36 of 47 mines in June–July 2002 and at all 47 mines in August–September 2002.

A replicated, controlled, before-and-after study in 2003 at four derelict mines in a forested area of south-eastern Australia (*4*) found that installing gates with 125 mm horizontal spacing resulted in fewer eastern horseshoe bats *Rhinolophus megaphyllus* and Schreiber's bats *Miniopterus schreibersii* using the mines and more bats aborted exit and entry flights, whereas gates with horizontal spacings of 450 mm and 300 mm did not affect bat numbers or behaviour. Fewer bats used two mines after gates with a 125 mm horizontal spacing were installed (before: 120 and 540 bats; after: 30 and 290 bats). The number of bats aborting exit and entry flights also increased (data reported as standardized results). Gates with horizontal spacings of 450 mm and 300 mm did not affect bat numbers or behaviour. Bat numbers at two similar control mines either remained constant or increased. Two mines were fitted with gates (made from 20 mm plastic tubing), and two were left ungated (controls). In March–April 2003, bat activity at the two experimental mines was observed in four stages of 11 days each: before gating followed by the successive addition of horizontal gate bars to reduce the spacing size (to 400, 300 and 125 mm). Bats were logged automatically using infrared beams, and night-vision video cameras recorded flight behaviour for 30 minutes at dusk and dawn.

A replicated, before-and-after study in 2002–2004 at five pairs of abandoned mines in northern Idaho, USA (*5*) found that installing gates resulted in fewer bats and fewer bat species entering the mines. Fewer bats entered mines after gates were installed with an overall decrease of 65% across all gated mines (before: average 29 bat entries; after: 10 bat entries). The number of bats entering five ungated mines increased by 45% over the same period ('before': 20 bat entries; 'after' 32 bat entries). Fewer bat species entered the mines after gates were installed (before: average 2.3 bat species; after: 1 bat species), but no change was observed at ungated mines ('before': 2 bat species; 'after': 1.8 bat species). Gates were installed at five of 10 mines in 2002 and 2003. Gates had vertical supports (10 x 10 x 1 cm iron) and horizontal bars (10 x 10 cm angle iron) with gaps of <14.6 cm. Each of five pairs of mines was surveyed twice in July–August in two consecutive years in 2002–2004 (before and after gating). One mist net survey and one video survey were carried out at the mine entrance of each site/year.

A replicated, controlled, before-and-after study in 2003–2004 at four abandoned mines in western Utah, USA (*6*) found that gated mines had more Townsend's big-eared bats *Corynorhinus townsendii* circling at entrances than entering or exiting them, and 2–7% of bats flying through the entrances collided with the gates. More Townsend's big-eared bats circled at gated mine entrances than flew through them (data not reported). However, there was no difference in the number of bats circling and entering/exiting at ungated mines. Bats were observed colliding with gates at all four gated mines (2–7 % of bats entering or exiting/night, total <5–50 bats/gate). All of four mines had maternity colonies of Townsend's big-eared bats (average 84–112 bats). Two mines were gated before the study in 1998 and 2000 and two had gates installed during the study in 2004. All gate designs were 'bat-compatible' (round steel bars with horizontal bars spaced 10–14 cm apart). Each of the four mines was surveyed with infrared video cameras at the entrances during two consecutive mornings and a single night each month in May–July 2003 (before gating) and in May and July–September 2004 (after gating).

A replicated, controlled, before-and-after study in 2014–2015 at 11 abandoned mines in southern Arizona and New Mexico, USA (*7a*) found that after gates were installed bat activity levels remained stable or increased at five of seven gated mines and three of four ungated control mines. After gating, bat activity levels decreased at two of seven gated mines and one of four ungated control mines (data reported as bat logger voltage measures). Seven bat species were recorded within the mines (data not reported for individual species). Eleven mines (4–200 m long) with similar characteristics (bat use, mine features, number of entrances) were surveyed. Seven mines had gates (standard square-tube bar gates or corrugated metal culverts with rectangle-tube bar gates, both with 14.6 cm horizontal spacing) installed in winter 2014 or spring 2015. Four control mines were left ungated. Visual observations and bat logger surveys were carried out in June–September 2014 (before gating) and 2015 (after gating).

A replicated, before-and-after study in 2015 at two abandoned mines in Arizona, USA (*7b*) found that bats performed more flight manoeuvres at mine entrances after mock gates were installed than before, but gate material and height had no effect on bat behaviour. Bats performed more energetically demanding flight manoeuvres at mine entrances after mock gates were installed (data not reported). There was no significant difference in bat behaviour between two types of gate material (corrugated metal and non-corrugated high-density polyethylene) or two gate heights (0.15 m and 1.15 m above the ground). Both mines (60–80 m long) had single ungated entrances and were occupied by winter colonies (>100 individuals) of California leaf-nosed bats *Macrotus californicus*. Round bar gates (14.6 cm horizontal bar spacing) were installed within culverts (76 cm diameter, 1.2 m length) at each of two mine entrances. In March–April 2015, bats were filmed with infrared cameras for three nights before gates were installed, followed by three nights with one randomly chosen gate material/height installed and three nights with the other.

A replicated study in 2015 at 41 abandoned gated mines in Arizona, Colorado, Nevada, New Mexico and Utah, USA (*7c*) found that gate age and design had varied effects on the presence of four bat species, but mine features were more important than gates for predicting presence. Townsend's big-eared bats *Corynorhinus townsendii* were found more often in mines with narrower horizontal bar spacing (12–15 cm) than wider spacing (18 cm; data reported as statistical model results). California myotis *Myotis californicus* and western small-footed myotis *Myotis ciliolabrum* were found more often in mines with older gates (>10 years old) and less often in mines with angle-iron bar gates than mines with four other gate designs. Cave myotis *Myotis velifer* were found more often in mines with newer gates (<9 years old) and less often in mines with culvert gates than mines with four other gate designs. Fringed myotis *Myotis thysanodes* were found more often in mines with gates closer to the entrance (<2 m) with smaller gate areas (<2.5 m^2) and wider vertical bar spacing (>0.9 m). Mine features (e.g. elevation, number of levels or entrances) were more important than gate age, location, or design for predicting the presence of all four bat species. Each of 41 mines had one of five gate designs installed: standard round bar (8 mines); standard angle-iron bar (15 mines); standard square-tube bar (7 mines); corrugated metal culvert with square-tube bar (7 mines); ladder gate (4 mines). Fresh guano samples were collected from the mines in June–December 2015 for DNA analysis, and mine features were recorded.

(1) Navo K.W. & Krabacher P. (2005) The use of bat gates at abandoned mines in Colorado. *Bat Research News*, 46, 1–8.
(2) Spanjer G.R. & Fenton M.B. (2005) Behavioral responses of bats to gates at caves and mines. *Wildlife Society Bulletin,* 33, 1101–1112.
(3) Johnson J.B., Wood P.B. & Edwards J.W. (2006) Are external mine entrance characteristics related to bat use? *Wildlife Society Bulletin*, 34, 1368–1375.
(4) Slade C. & Law B. (2008) An experimental test of gating derelict mines to conserve bat roost habitat in southeastern Australia. *Acta Chiropterologica*, 10, 367–376.
(5) Derusseau S.N. & Huntly N.J. (2012) Effects of gates on the nighttime use of mines by bats in northern Idaho. *Northwestern Naturalist*, 93, 60–66.
(6) Diamond G.F. & Diamond J.M. (2014) Bats and mines: evaluating Townsend's big-eared bat (*Corynorhinus townsendii*) maternity colony behavioral response to gating. *Western North American Naturalist*, 74, 416–426.
(7) Tobin A., Corbett R.J.M., Walker F.M. & Chambers C.L. (2018) Acceptance of bats to gates at abandoned mines. *The Journal of Wildlife Management*, 82, 1345–1358.

4.19. Maintain microclimate in closed/abandoned mines

- **One study** evaluated the effects of maintaining the microclimate in an abandoned mine on bat populations. The study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One before-and-after study in the USA[1] found that modifying the microclimate of an abandoned mine by closing a human-made entrance resulted in a greater number of bats hibernating within the mine.

BEHAVIOUR (0 STUDIES)

Background

Closing mines and physically obstructing mine entrances can alter the internal microclimate and make conditions unsuitable for roosting bats. Adverse impacts on airflow and water drainage should be avoided. For a similar intervention, see '*Threat: Human intrusions and disturbance – Caving and tourism – Restore and maintain microclimate in modified caves*'. See also '*Threat: Human intrusions and disturbance – Caving and tourism – Install and maintain cave gates to restrict public access*' for a study in which a stone wall and gate influenced the microclimate of a cave with an effect on hibernating bats.

A before-and-after study in 2004–2007 at one mine in Southern Illinois, USA (*1*) found that modifying the microclimate within an abandoned mine by closing a human-made entrance resulted in an increase in the number of hibernating bats, including Indiana bats *Myotis sodalis*. Before the entrance was closed, <500 bats were counted hibernating in the mine and internal temperatures varied widely during the hibernation period (-2–18°C). After the entrance was closed, internal temperatures were more stable (11-13°C), and more bats hibernated within the mine (one year after: 1,500 bats; two years after: 2,500 bats). In summer 2005, a culvert with a door (1.2 m wide) was built into the horizontal human-made entrance shaft and the rest of the entrance was filled in. Three other entrances to the mine were left open. Hibernating bats were counted within the mine in 2004 before the entrance was closed, and in 2006 and 2007 after the entrance was closed.

(1) Carter T.C. & Steffen B.J. (2010) Converting abandoned mines to suitable hibernacula for endangered Indiana bats. Pages 205–213 in: Vories K.C., Caswell A.H. & Price T.M. (eds.) *Protecting threatened bats at coal mines: A technical interactive forum.* Department of Interior, Office of Surface Mining, Coal Research Center, Southern Illinois University Carbondale.

4.20. Reopen entrances to closed mines and make suitable for roosting bats

- We found no studies that evaluated the effects of reopening entrances to closed mines and making them suitable for roosting bats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Mines that have previously been closed and sealed may be reopened to provide roosting sites for bats. Modifications may be required to create access points and a suitable microclimate for bats.

4.21. Restore bat foraging habitat at ex-quarry sites

- **One study** evaluated the effects of restoring bat foraging habitat at ex-quarry sites on bat populations. The study was in France[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in France[1] found that gravel-sand pits had higher overall bat activity (relative abundance) 10 years after restoration than gravel-sand pit sites before or during quarrying.

BEHAVIOUR (0 STUDIES)

Background

Abandoned mining sites, such as quarries, may be rehabilitated to provide foraging habitat for bats, e.g. through the restoration of grassland, trees, and wetlands.

For general interventions relating to the restoration of specific habitat types, see the '*Habitat restoration & creation*' chapter.

A replicated, site comparison study in 2009–2013 of 21 gravel-sand pit sites in France (*1*) found that restored gravel-sand pits had higher overall bat activity 10 years after restoration than gravel-sand pit sites before or during quarrying, but there was no difference for gravel-sand pits less than 10 years after restoration. Overall bat activity was higher at gravel-sand pits that had been restored more than 10 years previously (average 0.8 bat passes/six minute interval) than at gravel-sand pit sites before or during quarrying (both 0.3 bat passes). However, there was no significant difference between gravel-sand pits restored 5–10 years previously (0.5 bat passes) or less than five years previously (0.4 bat passes) and gravel-sand pit sites before or during quarrying. Twelve bat species were recorded in total (see original paper for data for individual species). Gravel-sand pit sites (average 4 ha) consisted of bare soil and were restored to water, wooded vegetation and meadows after quarrying ceased. At each of 21 sites, 1–5 points (18–37 points/treatment in total across all sites) were sampled with bat detectors during two visits/year in June–September 2009–2013.

(1) Kerbiriou C., Parisot-Laprun M. & Julien J.F. (2018) Potential of restoration of gravel-sand pits for bats. *Ecological Engineering*, 110, 137–145.

5. Threat: Transportation and service corridors

Threats from transportation and service corridors tend to be from the destruction of habitat and pollution. Interventions in response to these threats are described in '*Habitat protection*', '*Habitat restoration and creation*' and '*Threat: Pollution*'.

For interventions relating to bat boxes, which are often used in response to a wide range of threats, see the '*Species management*' chapter.

Roads have been shown to have a negative impact on bats, acting as a barrier to movement and causing direct mortality due to collisions with vehicles (e.g. see Altringham & Kerth 2016, Fensome & Mathews 2016). The habitat surrounding roads may also become unsuitable for bats due to light, noise, and chemical pollution. Railways could have similar effects, although there has been little research in this area. One study found that some bat species avoided railways, whereas others used railway verges for foraging (Vandevelde *et al*. 2014). Utility and service corridors (e.g. carrying power lines, pipelines, or seismic exploration lines) also have the potential to have negative impacts on bats. These corridors are typically cleared of vegetat resulting in disturbance, habitat loss and fragmentation.

Several interventions involve providing safe passage for bats over or under roads/railways, with the ultimate aim of increasing road/rail permeability and reducing mortality so as to maintain bat populations. We found no evidence to show that crossing structures either increase permeability or maintain bat populations in proximity to roads or railways. We found evidence that some crossing structures over and under roads are used by bats. However, few crossing structures were used by a sufficient proportion of crossing bats to suggest they would be effective at maintaining bat populations, e.g. Berthinussen & Altringham (2015) suggest >90% of bats must cross safely for structures to be considered effective.

Altringham J. & Kerth G. (2016) Bats and roads. Pages 35–62 in: Voigt C.C. & Kingston T. (eds.) *Bats in the Anthropocene: Conservation of Bats in a Changing World.* Springer International Publishing, Cham.

Berthinussen A. & Altringham J.D. (2015) *WC1060: Development of a cost-effective method for monitoring the effectiveness of mitigation for bats crossing linear transport infrastructure*. Report for Department for Environment, Food and Rural Affairs (Defra), UK.

Fensome A.G. & Mathews F. (2016) Roads and bats: a meta-analysis and review of the evidence on vehicle collisions and barrier effects. *Mammal Review,* 46, 311–323.

Vandevelde J.-C., Bouhours A., Julien J.-F., Couvet D. & Kerbiriou C. (2014) Activity of European common bats along railway verges. *Ecological Engineering,* 64, 49–56.

Roads & Railroads

5.1. Install underpasses or culverts as road/railway crossing structures for bats

- **Eight studies** evaluated the effects of installing underpasses or culverts as road crossing structures for bats. Seven studies were in Europe[1–5,7,8] and one in Australia[6].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (8 STUDIES)

- **Use (8 studies):** Eight studies (including six replicated studies) in Germany[1], Ireland[2,3], the UK[4,5,7], Australia[6] and France[8] found that bats used underpasses and culverts below roads, and crossed over the roads above them, in varying proportions. One replicated, site comparison study in Australia[6] found that bat species adapted to cluttered habitats used small culverts and underpasses more than bat species adapted to open or edge habitats[6]. One replicated, site comparison study in France[8] found that the use of underpasses by five bat species was influenced by underpass type and height, road width, and the amount of forest and hedgerows in the surrounding landscape.

Background

Underpasses may guide bats safely under roads or railways. They have the potential to reduce the number of bats killed by traffic and increase the permeability of roads/railways for bats to maintain connectivity across the landscape. There is evidence that an unknown proportion of bats of various species use underpasses below roads (e.g. Bach *et al.* 2004, Boonman 2011, Barros 2014). However, these studies have not been summarised here as they do not provide data that can be used to assess effectiveness, such as a control or the proportion of bats that are or are not using the underpasses. The studies described below report the proportion of bats that are either using underpasses to cross roads safely, or are crossing the road above them at risk of collisions with traffic. We did not find any studies that assessed underpasses below railways as crossing structures for bats.

Bach L., Burkhardt P. & Limpens H. (2004) Tunnels as a possibility to connect bat habitats. *Mammalia,* 68, 411–420.

Barros P. (2014) Agricultural underpasses: their importance for bats as roosts and role in facilitating movement across roads. Pasos agrícolas inferiores de carreteras: su importancia para los murciélagos como refugio y lugar para cruzar la vía. *Barbastella, Journal of Bat Research & Conservation,* 7, 22–31.

Boonman M. (2011) Factors determining the use of culverts underneath highways and railway tracks by bats in lowland areas. *Lutra,* 54, 3–16.

A study in 2004–2007 of an underpass below a motorway in a forested area of northern Bavaria, Germany (*1*) found that a cluttered habitat bat species rarely crossed the motorway and only crossed through the underpass, whereas an open habitat bat species crossed the motorway frequently and flew over the road more often than through the underpass. Only three of 34 radio-tracked Bechstein's bats *Myotis bechsteinii* crossed the motorway, all using the underpass (36 crossings). Five of six radio-tracked barbastelle bats *Barbastella barbastellus* crossed the motorway but flew over the road (21 crossings at six different sites) more often than through the underpass (16 crossings). The motorway had four to five lanes carrying an average of 84,000 vehicles/day. The underpass (5 m wide x 4.5 m high x 30 m long) was located within a motorway section surrounded by forest. Mist netting was carried out for 153 nights at 12 sites within the forest in May–September 2004–2007. Each of 40 adult female bats was radio-tracked for at least three full consecutive nights.

A replicated, site comparison study in 2008 at 13 under-motorway crossing routes in agricultural and woodland habitat in southern Ireland (*2*) recorded more bat activity in under-motorway routes (underpasses or rivers bridged over by the road) than over the road above them, or in adjacent habitats. More bats were recorded in under-motorway routes (underpasses: 662 bat passes; river bridges: 4,692 bat passes) than over the road above them (above underpasses: 45 bat passes; above river bridges: 96 bat passes). Bat activity was also greater (by >10%) at under-motorway crossing routes than in adjacent habitats (data reported as statistical measures). Six bat species or species groups were recorded in total (see original paper for data for individual species). The motorway (65–70 m wide) had four lanes carrying an average of 20,000 vehicles/day. Seven underpasses (5–17 m wide x 4–10 m high x 26–63 m long) and six river bridges (6–420 m wide x 3–19 m high x 23–39 m long) were surveyed. Bat detectors recorded bat activity above and below each of the 13 structures and simultaneously at two adjacent linear features on two nights in May–September 2008.

A study in 2009 at an underpass below a motorway in an agricultural area of Ennis, west Ireland (*3*) found that a large underpass was used by five of six bat species although 2–18% of bat passes were recorded over the road above the underpass. Two edge habitat adapted bat species (soprano pipistrelle *Pipistrellus pygmaeus,* common pipistrelle *Pipistrellus pipistrellus*) were recorded most frequently in the underpass (soprano pipistrelle: 770 bat passes; common pipistrelle: total 469 bat passes) but 18% of bat passes were recorded over the road above (soprano pipistrelle: 174 bat passes; common pipistrelle: 103 bat passes). The underpass was also used by cluttered habitat adapted brown long-eared bats *Plecotus auritus* (60 bat passes), lesser horseshoe bats *Rhinolophus hipposideros* (58 bat passes) and *Myotis* spp. (30 bat passes), with only a small number of bats recorded over the road above (1–3 bat passes, 2–5%). One open habitat adapted bat species, Leisler's bat *Nyctalus leisleri,* was only recorded flying over the road above the underpass (56 bat passes). The motorway had four lanes carrying an average of 11,000 vehicles/day. The underpass (17 m wide x 6 m high x 26 m long) had a minor road through it. Simultaneous recordings were made with bat detectors above and below the underpass for 16 full nights in May 2009.

A replicated study in 2010 at three underpasses below two roads in an agricultural area of Cumbria, UK (*4*) found that one of three underpasses had a greater proportion of bats flying through it than crossing over the road above at traffic height. At one underpass (6 m wide x 5 m high x 30 m long) located on an original bat commuting route, 96% of bats (864 of 904) flew through it to cross the road and 4% (32 of 904) flew over the road above at traffic height. At two underpasses (5 m wide x 2.5 m high x 15 m long; 6 m wide x 3 m high x 30 m long), 4% (39 of 1,117) and 31% of bats (11 of 36) flew through them and 67% (751 of 1,117) and 61% (22 of 36) crossed the road above at traffic height. Both underpasses were not located on original bat commuting routes, but attempts had been made to divert bats towards them with planting. The two roads had 2–3 lanes of traffic carrying an average of 12,000–17,000 vehicles/day. At each of three underpasses, crossing bats were observed and recorded with bat detectors during 10 x 90-minute surveys at dusk or dawn in June–July 2010.

A replicated study in 2013 at three underpasses below two roads in the UK (*5*) found that more bats crossed through the underpasses than over the road above, but at two underpasses up to a third of bats still crossed the road above at traffic height. At one underpass (4.5 m wide and high x 45 m long), 95% of bats (608 of 639) flew through it to cross the road, and 5% (31 of 639) flew over the road above at traffic height. At two underpasses (2.5 m wide and high x 70 m long; 2.5 m wide and high x 45 m long), 70% (199 of 283) and 66% of bats (129 of 196) flew through them to cross the road, but 29% of bats (82 of 283 and 57 of 196) crossed the road above them at traffic height. Seven bat species or species groups were recorded in total (see original report for data for individual species). All three underpasses were installed for bats. Observations of crossing bats and recordings of bat calls were made during 6–10 x 60-minute surveys at dusk or dawn at each underpass in June–August 2013.

A replicated, site comparison study in 2013–2015 of six culverts and six open-span underpasses under a road in Victoria, Australia (*6*) found that culverts and underpasses were used more frequently to cross the road by bat species adapted to cluttered habitats, but results were mixed for bat species adapted to open and edge habitats. Bat species adapted to cluttered habitats crossed the road more often through culverts (average 5 times/night) and underpasses (10 times/night) than over the road above (2 times/night above both). Bat species adapted to edge habitats crossed less often through culverts (1 time/night) than over the road above (13 times/night), but more often through underpasses (29 times/night) than over the road above (4 times/night). Bat species adapted to open habitats crossed more often over the road above culverts (31 times/night) and underpasses (19 times/night) than through culverts (1 time/night) or underpasses (12 times/night). Culverts were box culverts (3–3.6 m wide and high x 24–67 m long) with a concrete floor. Underpasses were large, open structures (10–90 m wide x 3–15 m high x 30–54 m long) with natural vegetation below. The road was a four-lane divided highway carrying an average of 8,000–14,000 vehicles/day. Six bat detectors were deployed/site to record crossing bats for a total of four full nights in December–January in 2013/2014 and 2014/2015.

A replicated, site comparison study in 2011–2013 and 2015 of eight structures under a road in Wales, UK (*7*) found that larger underpasses and a 'box' culvert had higher activity of greater horseshoe bats *Rhinolophus ferrumequinum* within them than over the road above, but smaller 'pipe' culverts did not. Higher greater horseshoe bat activity was recorded within three large underpasses (68–97% of bat passes) and a 'box' culvert (88%) than over the road above (underpasses: 3–32%; box culvert: 12%), although the results were not tested for statistical significance. Three smaller 'pipe' culverts had lower greater horseshoe bat activity within them (15–40% of bat passes) than over the road above (60–85%). Three 'pipe' culverts (0.75, 1 and 1.5 m diameter), a 'box' culvert (1.8 x 3 m) and three underpasses (one for cattle: 2.7 x 2.4 m; two for horses: 3.5 x 4 m; one open-span: 8.95 x 3.5 m) were installed under a new road in 2011. All were on/near bat commuting routes or foraging habitat and 4.3–6.5 km from a greater horseshoe bat roost. In May–September, bat detectors within and above each structure recorded bat activity for one night/month (2011, 2012 and 2015) or on three occasions (2013). Surveyors using night-vision equipment confirmed bats were flying through or over the structures.

A replicated, site comparison study in 2018 of 24 underpasses along four roads in the Occitanie region, France (*8*) found that underpasses were used by five bat species or species groups in varying proportions, and use was influenced by underpass type and height, road width, and the amount of forest and hedgerows in the surrounding landscape. *Myotis*, *Rhinolophus* and *Pipistrellus*/*Miniopterus* spp. had greater activity in underpasses that bridged rivers than in culverts with rivers or roads through them (data reported as statistical model results). Taller underpasses were used less (compared to flying over road sections above or adjacent to them) than shorter ones by *Rhinolophus* spp., and *Plecotus* spp. were more likely to use underpasses under roads with more lanes (see original paper for details). Greater proportions of bats also used underpasses in landscapes with greater forest cover (*Myotis* spp. and barbastelle bats *Barbastella barbastellus*), fewer hedgerows (*Myotis* spp.) or that were closer to forest patches (*Rhinolophus* spp.). The 24 underpasses varied in width (2.5–15 m), height (2.5–6 m), length (5–100 m) and type (five river bridges, seven river culverts, 12 road or track culverts). The four roads were surrounded by a mixed landscape of woodland, hedgerows, grassland, and agricultural land. Bat detectors recorded bat activity within, above, and 200 m along the road from, each underpass for three consecutive full nights in July–August 2018.

(1) Kerth G. & Melber M. (2009) Species-specific barrier effects of a motorway on the habitat use of two threatened forest-living bat species. *Biological Conservation* 142, 270–279.

(2) Abbott I.M., Butler F. & Harrison S. (2012) When flyways meet highways - the relative permeability of different motorway crossing sites to functionally diverse bat species. *Landscape and Urban Planning,* 106, 293–302.

(3) Abbott I.M., Harrison S. & Butler F. (2012) Clutter-adaptation of bat species predicts their use of under-motorway passageways of contrasting sizes - a natural experiment. *Journal of Zoology*, 287, 124–132.

(4) Berthinussen A. & Altringham J. (2012) Do bat gantries and underpasses help bats cross roads safely? *PLoS ONE,* 7, e38775.

(5) Berthinussen A. & Altringham J.D. (2015) *WC1060: Development of a cost-effective method for monitoring the effectiveness of mitigation for bats crossing linear transport infrastructure*. Report for Department for Environment, Food and Rural Affairs (Defra), UK.
(6) Bhardwaj M., Soanes K., Straka T.M., Lahoz-Monfort J.J., Lumsden L.F. & van der Ree R. (2017) Differential use of highway underpasses by bats. *Biological Conservation,* 212, 22–28.
(7) Davies J.G. (2019) Effectiveness of mitigation of the impacts of a new road on horseshoe bats *Rhinolophus ferrumequinum* in Wales, UK. *Conservation Evidence*, 16, 17–23.
(8) Laforge A., Archaux F., Bas Y., Gouix N., Calatayud F., Latge T. & Barbaro L. (2019) Landscape context matters for attractiveness and effective use of road underpasses by bats. *Biological Conservation*, 237, 409–422.

5.2. Install overpasses as road/railway crossing structures for bats

- **Four studies** evaluated the effects of installing overpasses as road crossing structures for bats. Three studies were in Europe[1,2,4] and one in Australia[3].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One site comparison study in Australia[3] found that the same number of bat species were recorded at an overpass and in nearby forest and bushland.

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (3 STUDIES)

- **Use (3 studies):** Two replicated studies (including one site comparison) in Ireland[1] and France[4] found that two[4] or three[1] bat species/species groups used overpasses but up to three-quarters of bats crossed the road below at traffic height[1] or crossed at other nearby locations[4]. One study in the UK[2] found that an overpass with planters was used by two-thirds of crossing bats, and an unvegetated overpass with a paved road over it was not used by crossing bats.

Background

Overpasses (solid structures such as bridges built for pedestrians, vehicles or specifically for wildlife) may help to guide bats safely over roads or railways. This would both reduce the number of bats killed and increase the permeability of roads/railways for bats to maintain connectivity across the landscape. Studies have been summarised below if they provide data that can be used to assess effectiveness, such as a control or the proportion of bats that are or are not using overpasses.

For evidence relating to bat gantries/bridges (wire or mesh structures), see '*Install bat gantries or bat bridges as road/railway crossing structures for bats*'.

A replicated, site comparison study in 2008 at six overpasses over a road in agricultural and woodland habitat in southern Ireland (*1*) found that three bat species or species groups flew over overpasses but 39–75% of activity was recorded over the road below them, and lower activity was recorded on overpasses than in adjacent habitats. Overpasses were used by three bat species or species groups (common pipistrelle *Pipistrellus pipistrellus*, soprano pipistrelle *Pipistrellus pygmaeus*, *Myotis* spp.), but 39% of common pipistrelle passes, 49% of soprano pipistrelle passes, and 75% of *Myotis* spp. passes were recorded over the road below overpasses. Bat activity was lower (by >10%) on overpasses than in adjacent habitats (data reported as statistical measures). The overpasses (8–11 m wide x 6–11 m high x 58–76 m long) had minor roads over them. The motorway (65–70 m wide) had four lanes carrying an average of 20,000 vehicles/day. Bat detectors recorded bat activity above and below each of the six overpasses and simultaneously at two adjacent linear features on two nights in May–September 2008.

A study in 2013 at two overpasses over two roads in the UK (*2*) found that an 'environmental' bridge was used by almost two-thirds of crossing bats, but an unvegetated overpass carrying a paved road was not used by crossing bats and only three bats crossed the road nearby. A greater number of bats used an 'environmental' bridge (62%, 118 of 192 bats) than crossed the road below at traffic height (19%, 36 of 192 bats). Six bat species or species groups were recorded in total (see original report for data for individual species). An unvegetated overpass was not used by crossing bats and only three bats were observed crossing the road nearby (12–20 m away) at heights of 2–20 m. Both overpasses were designed as crossing structures for bats, alongside other purposes. The 'environmental' bridge (30 m long x 5 m wide x 6 m high) had solid vertical sides (2 m high) and was covered with deadwood and planters of hawthorn *Crataegus monogyna*. The overpass (40 m long x 15 m wide x 8 m high) had a paved road over it and no vegetation. It was designed to carry traffic and provide a crossing structure for bats. Observations of crossing bats and recordings of bat calls were made during 6 x 60-minute surveys at dusk or dawn at each overpass and the road below in June–August 2013.

A site comparison study in 2014–2015 of one vegetated overpass over a road within a forest reserve in Brisbane, Australia (*3*) found that the overpass had higher bat activity but the same number of bat species as adjoining forest and bushland. More bat passes were recorded on the overpass (average 52 bat passes) than in the adjoining forest (27 bat passes) or bushland (29 bat passes), although no statistical tests were carried out. Nine bat species were recorded on the overpass and in the adjoining forest and bushland (see original paper for data for individual species). The overpass was hourglass shaped (70 m long x 15 m wide at the midpoint and 20 m wide at the ends) and was planted with natural vegetation and mature saplings (70 shrubs and six trees/100 m^2). It was built over two dual lanes of a major urban road bisecting forest and bushland. Bat activity was recorded using bat detectors over two consecutive nights/month between December 2014 and July 2015 at two stationary points on the overpass and along eight 75 m transects perpendicular to the road.

A replicated study in 2016 of two overpasses over a road near Lyon, France (*4*) found that both 'U-shaped' metal overpasses were used by two bat species or species groups, although 51–65% of bats crossed the road at other locations. One overpass, installed within a bat commuting corridor, was used by 39% (26 of 67) of crossing bats, whereas 51% (34 of 67) crossed the road at other locations within the corridor. The other overpass, installed 325 m from a bat commuting corridor, was used by 19% (7 of 37) of crossing bats, whereas 65% (24 of 37) crossed the road within the original commuting corridor. Crossing heights were not reported. Two bat species/species groups (all *Pipistrellus* spp.) used the overpasses and 4–6 bat species/species groups crossed at other locations (see original paper for details). Both overpasses (40 m long x 4.8 m wide, <10 m high) were installed (2.5 km apart) over a new four-lane highway in November 2012. At each site, six pairs of bat detectors on opposite sides of the road (one pair at the overpass, five pairs within the commuting corridor or adjacent habitats) simultaneously recorded crossing bats over five consecutive nights in July or September 2016.

(1) Abbott I.M., Butler F. & Harrison S. (2012) When flyways meet highways – the relative permeability of different motorway crossing sites to functionally diverse bat species. *Landscape and Urban Planning,* 106, 293–302.

(2) Berthinussen A. & Altringham J.D. (2015) *WC1060: Development of a cost-effective method for monitoring the effectiveness of mitigation for bats crossing linear transport infrastructure*. Report for Department for Environment, Food and Rural Affairs (Defra), UK.

(3) McGregor M., Matthews K. & Jones D. (2017) Vegetated fauna overpass disguises road presence and facilitates permeability for forest microbats in Brisbane, Australia. *Frontiers in Ecology and Evolution,* 5, 153.

(4) Claireau F., Bas Y., Puechmaille S.J., Julien J.-F., Allegrini B. & Kerbiriou C. (2019) Bat overpasses: An insufficient solution to restore habitat connectivity across roads. *Journal of Applied Ecology*, 56, 573–584.

5.3. Install bat gantries or bat bridges as road/railway crossing structures for bats

- **Three studies** evaluated the effects of installing bat gantries as road crossing structures for bats. Two studies were in the UK[1,2] and one in France[3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (3 STUDIES)

- **Use (3 studies):** Two replicated studies (including one site comparison) in the UK[1,2] found that fewer bats used bat gantries than crossed the road below at traffic height, and one bat gantry was not used at all[2]. One replicated study in France[3] found that a temporary bat gantry was used by three bat species/species groups, but almost half of crossing bats flew over the road at other locations.

Background

Bat gantries, or bat bridges, are purpose-built structures designed to act as linear features that will guide echolocating bats over roads at a safe height above traffic. They typically consist of wood or metal pylons erected on either side of the road with wires or mesh over the road between them. The aim is to both reduce the number of bats killed on roads and increase the permeability of roads to maintain connectivity for bats across the landscape. Studies have been summarised below if they provide data that can be used to assess effectiveness, such as a control or the proportion of bats that are or are not using bat gantries.

Bat gantries, or bat bridges, may also be built over railways, although we found no studies that assessed this. For evidence relating to overpasses (solid structures such as bridges built for pedestrians or vehicles), see '*Install overpasses as road/railway crossing structures for bats*'.

A replicated, site comparison study in 2010 at four bat gantries (or bat bridges) on four roads within agricultural areas of northern England, UK (*1*) found fewer bats using bat gantries to safely cross roads than crossing below them at traffic height. The number of bats using gantries to safely cross roads was lower (2–24 bats, <1–11% of crossing bats) than the number of bats crossing roads at traffic height below gantries (10–751 bats, 17–84%). The four bat gantries were of a similar design (height 6–9 m, width 2 m) with two or three pairs of wires spanning the road (20–30 m) with plastic spheres attached. All four roads had 2–3 lanes of traffic carrying an average of 12,000–17,000 vehicles/day. At each of four gantries, crossing bats were observed and recorded with bat detectors during 10 x 90-minute surveys at dusk or dawn in June–July 2010. Bats were counted as 'using' gantries when flying within 2 m of the wires above traffic height (>5 m above the road).

A replicated study in 2014 at two bat gantries (or bat bridges) over a road in the UK (*2*) found that one bat gantry (or bat bridge) was used by 3% of crossings bats and another was not used at all. At one gantry, fewer bats used the bat gantry (3%, 1 of 35 bats) than crossed the road below at traffic height (80%, 28 of 35 bats). At the other gantry, no bats used the bat gantry to cross the road, but 4 bats crossed the road below at traffic height. Four bat species or species groups were recorded in total (see original report for data for individual species). Both bat gantries (30 m long x 2 m wide x 7 m high) had wire mesh spanning a four-lane road between two vertical poles on each side. At each of two gantries, crossing bats were observed and recorded with bat detectors during 7–9 x 60-minute surveys at dusk or dawn in June–August 2014. Bats were counted as 'using' gantries when flying within 2 m of the wires above traffic height (>5 m above the road).

A study in 2016 of a bat gantry (or bat bridge) at a road construction site near Beauvais, France (*3*) found that the temporary wire bat gantry was used by three bat species or species groups, although 46% of bats crossed the road at other locations. The gantry, installed within a bat commuting corridor, was used by 54% (97 of 180) of crossing bats, whereas 43% (77 of 180) crossed the road at other locations within the corridor and 3% (6 of 180) crossed at other locations outside the corridor. Crossing heights were not reported. Three bat species/species groups used the gantry (nearly all *Pipistrellus* spp.) and five bat species/species groups crossed at other locations (see original paper for details). The gantry (80 m long, <2 m high) was temporarily installed within a bat commuting corridor during the construction of a four-lane highway in 2015–2016. Two parallel wires (1.2 m apart) were strung across the road, each with 29 reflective polystyrene spheres (23-cm diameter) attached. Six pairs of bat detectors on opposite sides of the road (one pair at the gantry, five pairs within the commuting corridor or adjacent habitats) simultaneously recorded crossing bats over four consecutive nights in May 2016.

(1) Berthinussen A. & Altringham J. (2012) Do bat gantries and underpasses help bats cross roads safely? *PLoS ONE,* 7, e38775.

(2) Berthinussen A. & Altringham J.D. (2015) *WC1060: Development of a cost-effective method for monitoring the effectiveness of mitigation for bats crossing linear transport infrastructure*. Report for Department for Environment, Food and Rural Affairs (Defra), UK.

(3) Claireau F., Bas Y., Puechmaille S.J., Julien J.-F., Allegrini B. & Kerbiriou C. (2019) Bat overpasses: An insufficient solution to restore habitat connectivity across roads. *Journal of Applied Ecology*, 56, 573–584.

5.4. Install green bridges as road/railway crossing structures for bats

- **One study** evaluated the effects of installing green bridges as road crossing structures for bats. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One study in the UK[1] found that a green bridge was used by 97% of bats crossing a road.

Background

Green bridges are bridges over roads/railways that are covered in vegetation and usually planted with hedgerows and trees. They have been built as mitigation measures usually to guide larger mammals, such as deer, safely across wide roads or railways. A study in Germany found 10 bat species using eight green bridges to fly over a road and also to forage (Bach & Müller-Stiess 2005). However, the study has not been summarised here as it did not provide data that can be used to assess effectiveness, such as a control, or the proportion of bats not using the green bridges. The study described below reports the proportion of bats that are either using a green bridge to cross the road safely or are crossing the road below at risk of collisions with traffic.

Bach L. & Müller-Stiess H. (2005) Technical article bats on selected green bridges. Efficiency of wildlife passages in Baden-Württemberg. Fachbeitrag Fledermäuse an ausgewählten Grünbrücken. Effizienzkontrolle von Wildtierpassagen in Baden-Württemberg (FE 02.220/2002/LR) In: Georgii B., Peters-Ostenberg E., Henneberg M., Herman M., Müller-Stiess H. & Bach L. (2007) *Nutzung von Grünbrücken und anderen Querungsbauwerken durch Säugetiere*. Gesamtbericht zum Forschungs- und Entwicklungsvorhaben 02.247/2002LR.

A study in 2014 at one green bridge over a road in the UK (*1*) found that the green bridge was used by 97% of bats that crossed the road. A greater number of bats crossed the road using the green bridge (97%, 121 of 125 bats) than crossed the road below at traffic height (2.4%, 3 of 125 bats) or above traffic height (0.8%, 1 of 125 bats). Four bat species were recorded using the green bridge for crossing and foraging: common pipistrelle *Pipistrellus pipistrellus* (92 bats), soprano pipistrelle *Pipistrellus pygmaeus* (22 bats), Natterer's bats *Myotis nattereri* (2 bats), and a whiskered or Brandt's bat *Myotis mystacinus* or *Myotis brandtii* (1 bat). Four bats using the green bridge could not be identified to species. One common pipistrelle and two unidentified bats were recorded crossing the road below the green bridge at traffic height. One common pipistrelle crossed the road below above traffic height. The green bridge was built over a four-lane road in 2005 to maintain access to a historic property and provide a wildlife crossing. The bridge (50 m long x 30 m wide x 6–8 m high) had a paved road over it with grass verges, shrubs, and trees (2–3 m high) on each side. Observations of crossing bats and recordings of bat calls were made during 10 x 60-minute surveys at dusk or dawn in June–August 2014.

(1) Berthinussen A. & Altringham J.D. (2015) *WC1060: Development of a cost-effective method for monitoring the effectiveness of mitigation for bats crossing linear transport infrastructure*. Report for Department for Environment, Food and Rural Affairs (Defra), UK.

5.5. Install hop-overs as road/railway crossing structures for bats

- We found no studies that evaluated the effects of hop-overs as road/railway crossing structures for bats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

A 'hop-over' typically consists of tall vegetation planted on either side of a road/railway with overhanging branches that create a continuous canopy over the gap. The aim is to guide bats across roads/railways at a safe height above traffic. There is evidence that bats will cross roads at greater heights in the presence of high canopy cover or roadside embankments (Russell *et al.* 2009, Berthinussen & Altringham 2012). However, experiments using two parallel screens at natural gaps in bat flight paths in Denmark had mixed results, with some bats continuing to fly at hazardous heights or abandoning their commuting routes (Christensen *et al.* 2016).

Berthinussen A. & Altringham J. (2012) Do bat gantries and underpasses help bats cross roads safely? *PLoS ONE,* 7, e38775.

Christensen M., Fjederholt E.T., Baagøe H.J. & Elmeros M. (2016) *Hop-overs and their effects on flight heights and patterns of commuting bats – a field experiment*. SafeBatPaths Technical Report. Conference of European Directors of Roads (CEDR), Brussels.

Russell A.L., Butchkoski C.M., Saidak L. & McCracken G.F. (2009) Road-killed bats, highway design, and the commuting ecology of bats. *Endangered Species Research,* 8, 49–60.

5.6. Divert bats to safe crossing points over or under roads/railways with plantings or fencing

- **One study** evaluated the effects of diverting bats using an artificial hedgerow on bat populations. The study was in Switzerland[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One controlled, before-and-after study in Switzerland[1] found that up to one fifth of lesser horseshoe bats within a colony flew along an artificial hedgerow to commute.

Background

Linear features such as hedgerows and treelines provide important commuting routes for bats (e.g. Limpens & Kapteyn 1991, Verboom & Huitema 1997, Downs & Racey 2006). Roads or railways can fragment these commuting routes cutting off important habitat. Attempts may be made to divert bats from their original commuting routes to crossing structures or safe crossing places along roads/railways, by planting tree lines or hedgerows, or installing fences. Berthinussen & Altringham (2012) found that although diverted bats were not recorded directly, very few bats used two underpasses below roads where attempts had been made to divert bats to them with plantings. Conversely, high numbers of bats were found using an underpass constructed on an original flight path.

For general interventions that involve creating or retaining bat commuting routes, see '*Habitat restoration and creation – Create new unlit bat commuting routes using planting*' and '*Habitat protection – Retain existing bat commuting routes*'.

Berthinussen A. & Altringham J. (2012) Do bat gantries and underpasses help bats cross roads safely? *PLoS ONE,* 7,e38775.
Downs N.C. & Racey P.A. (2006) The use by bats of habitat features in mixed farmland in Scotland. *Acta Chiropterologica,* 8, 169–185.
Limpens H.J. & Kapteyn K. (1991) Bats, their behaviour and linear landscape elements. *Myotis,* 29, 39–48.
Verboom B. & Huitema H. (1997) The importance of linear landscape elements for the pipistrelle *Pipistrellus pipistrellus* and the serotine bat *Eptesicus serotinus*. *Landscape Ecology,* 12, 117–125.

A controlled, before-and-after study in 2003 of a bat roost in an agricultural area of Giswil, Switzerland (*1*) found that more lesser horseshoe bats *Rhinolophus hipposideros* exiting from the roost from one side flew in a particular direction after an artificial hedgerow was installed. The number of bats flying in a particular direction increased after an artificial hedgerow had been installed for over two weeks (before: average 3% of bats; after: 10% of bats). Bats flying along the artificial hedgerow were found to emerge earlier from the roost and return later than bats using other flight routes and were out of the roost for longer (up to 4 minutes more). The artificial hedgerow (1 m wide x 1.5–2 m high x 200 m long) consisted of native hedgerow plants in containers. It was placed through open farmland to connect the bat roost with a foraging habitat within forest. The experiment was split into phases of 4–5 nights, with one phase each for before and after control periods, and 6 experimental phases with the artificial hedgerow in place. Bat activity was monitored with bat detectors and infrared video cameras for >50 minutes at sunset and sunrise for 39 nights in July–September 2003.

(1) Britschgi A., Theiler A. & Bontadina F. (2004) *Checking the effectiveness of connectivity structures. Partial report within the special investigation into the nursery of the lesser horseshoe bat in Friedrichswalde-Ottendorf / Saxony. Wirkungskontrolle von Verbindungsstrukturen. Teilbericht innerhalb der Sonderuntersuchung zur Wochenstube der Kleinen Hufeisennase in Friedrichswalde-Ottendorf / Sachsen*. Unveröffentlichter Bericht, ausgeführt von BMS GbR, Erfurt & SWILD, Zürich im Auftrage der DEGES, Berlin.

5.7. Maintain bat roosts in road/railway bridges and culverts

- **Two studies** evaluated the effects of maintaining bat roosts within road bridges on bat populations. One study was in Ireland[1] and one in the USA[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One before-and-after study in Ireland[1] found that a maternity colony of Daubenton's bats continued to roost in a road bridge over a river in similar numbers after crevices were retained during repair work. One review in the USA[2] found that when bat roosts were maintained during bridge replacement works, Yuma myotis and Mexican free-tailed bats recolonised most roosts in similar numbers to before the works, but pallid bats did not return.

Background

Bats can roost in gaps, cracks or between beams within road or railway bridges and culverts (e.g. Feldhamer *et al.* 2003, Celuch & Sevcík 2008, Geluso & Mink 2009). A study in the USA found over four million bats of 24 species roosting in 211 road bridges and culverts (Keeley & Tuttle 1999). Maintenance, repairs, or bridge/culvert replacement work may result in the loss of potential roost sites, entombment or injury of roosting bats, and abandonment of roosts and/or young.

For a similar intervention see '*Create spaces for roosting bats in road/railway bridges and culverts*'.

Celuch M. & Sevcík M. (2008) Road bridges as roosts for noctules (*Nyctalus noctula*) and other bat species in Slovakia (Chiroptera: Vespertilionidae). *Lynx,* 39, 47–54.

Feldhamer G.A., Carter T.C., Morzillo A.T. & Nicholson E.H. (2003) Use of bridges as day roosts by bats in Southern Illinois. *Transactions of the Illinois State Academy of Science,* 96, 107–112.
Geluso K. & Mink J.N. (2009) Use of bridges by bats (Mammalia: Chiroptera) in the Rio Grande Valley, New Mexico. *The Southwestern Naturalist,* 54, 421–429.
Keeley B.W. & Tuttle M. (1999) *Bats in American bridges*. Bat Conservation International, Austin, Texas, USA.

A before-and-after study in 1988–2005 of a road bridge over a river in northwest Ireland (*1*) found that after crevices were retained during strengthening work and repairs to the bridge, a Daubenton's bat *Myotis daubentonii* maternity colony continued to roost in the bridge in similar numbers as before the work. A maternity colony of approximately 25 Daubenton's bats was first recorded roosting in the bridge in 1988 (no more recent data provided). After the repair work was complete, four bats were recorded in the original roost crevice in 2004, and 25 bats were recorded in 2005. Strengthening works (including laying cement, pointing, and grouting) were carried out on the five-arch masonry bridge in September–October 2003. Roosting crevices were marked and temporarily filled with polystyrene to prevent them from being filled. Bats were counted in the bridge in July 2004 and 2005.

A review in 2017–2018 of case studies at five road bridges in California, USA (*2*) found that when bat roosts were maintained during bridge replacement works, Yuma myotis bats *Myotis yumanensis* recolonised two of three roosts and Mexican free-tailed bats *Tadarida brasiliensis* recolonised three of four roosts in similar numbers to before the works, but pallid bats *Antrozous pallidus* did not return to either of two roosts. Yuma myotis bats recolonised two roosts in similar numbers to before the works (before: 220, 100; after: 220, 100), whereas numbers declined at a third roost (before: 40; after: 20). Mexican free-tailed bats recolonised three roosts in similar numbers to before the works (before: 200, 3,000, 994; after: 200, 3,000, 1,010), whereas numbers declined at a fourth roost (before: 2,000; after: 600). Pallid bats did not return to either of two roosts used by 18–20 bats. At all of five sites, the original bat roost structures (abutments: one site; hinges and expansion joints: four sites) were retained during bridge replacement works (dates not reported; see original report for details). Bats were temporarily excluded from roosts in hinges and expansion joints. Counts of bats before and after the works were taken from questionnaires completed by the California Department of Transportation. Field surveys (including daytime inspections, colony and emergence counts) were conducted by the authors in spring and summer 2017 and 2018 after bridge works were complete.

(1) Marnell F. & Presetnik P. (2010) *Protection of overground roosts for bats (particularly roosts in buildings of cultural heritage importance)*. EUROBATS Publication Series No. 4 (English version). UNEP / EUROBATS Secretariat, Bonn, Germany.
(2) H.T. Harvey & Associates (2019) *Caltrans bat mitigation: a guide to developing feasible and effective solutions.* Report prepared for California Department of Transportation by H.T. Harvey Associates in collaboration with HDR Inc., Sacramento, California.

5.8. Create spaces for roosting bats in road/railway bridges and culverts

- **One study** evaluated the effects of creating spaces for roosting bats in road bridges. The study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One review in the USA[1] found that spaces created in road bridges for roosting bats to replace those lost during bridge works were recolonized by bats in similar or greater numbers to the original roosts at four of eight sites.

Background

Bridges and culverts can provide roosting opportunities for bats. Suitable roosting spaces, such as crevices or chambers, can be incorporated into the design of new bridges and culverts, or can be retrofitted to existing structures (e.g. by adding wood strips or panels; see Keeley & Tuttle 1999).

For a similar intervention see '*Maintain bat roosts in road/railway bridges and culverts*'. For evidence relating to the use of bat boxes under bridges, see '*Species management – Provide bat boxes for roosting bats*'.

Keeley B.W. & Tuttle M. (1999) *Bats in American bridges*. Bat Conservation International, Austin, Texas, USA.

A review in 2017–2018 of case studies at eight road bridges in California, USA (*1*) found that spaces created for roosting bats to replace those lost during bridge works were recolonized by bats in similar or greater numbers to the original roosts at half of the sites. At two sites, 'add-on' hanging roost boxes were used by Yuma myotis bats *Myotis yumanensis* in greater numbers (300 and 1,200 bats) than the original roosts (700 and 4,000 bats). At one site, recessed 'cast-in place' elongated roost boxes were used by Mexican free-tailed bats *Tadarida brasiliensis* in greater numbers (total 82,052 bats) than the original roost (40,000 bats). At another site, concrete 'Oregon wedge' panels were used by Mexican free-tailed bats in similar numbers (500 bats) to the original roost (400 bats). At four other sites, roosting spaces (including concrete slabs, concrete or plywood 'Oregon wedge' panels, and recessed 'cast-in place' elongated roost boxes) were used by 75–99% fewer Mexican free-tailed bats than the original roosts (see original report for details). At all eight sites, roosting spaces were created to replace those lost during bridge works. Counts of bats before and after the works were taken from questionnaires completed by the California Department of Transportation. Field surveys (including daytime inspections, colony and emergence counts) were conducted by the authors in spring and summer 2017 and 2018 after bridge works were complete. Twenty-seven other case studies were reviewed in the report, but numbers of bats before and/or after bridge works were not reported.

(1) H.T. Harvey & Associates (2019) *Caltrans bat mitigation: a guide to developing feasible and effective solutions.* Report prepared for California Department of Transportation by H.T. Harvey Associates in collaboration with HDR Inc., Sacramento, California.

5.9. Change timing of maintenance work at road/railway bridges and culverts

- We found no studies that evaluated the effects of changing the timing of maintenance work at road/railway bridges and culverts on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

To reduce disturbance to bats roosting within road/railway bridges or culverts, maintenance work may be avoided at times of year when they are most vulnerable, such as during hibernation and the maternity season.

5.10. Exclude bats from roosts during maintenance work at road/railway bridges and culverts

- We found no studies that evaluated the effects of excluding bats from roosts during maintenance work at road/railway bridges and culverts on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Temporarily excluding bats from roosts within bridges or culverts during maintenance work may prevent injury or death. However, it is important to also consider the short-term and long-term impacts of exclusion from roosts on the survival and productivity of bat populations. It may be necessary to provide alternative roosting locations during exclusion. See '*Provide alternative bat roosts during maintenance work at road/railway bridges and culverts*'.

5.11. Provide alternative bat roosts during maintenance work at road/railway bridges and culverts

- **One study** evaluated the effects of providing alternative bat roosts during maintenance work at road bridges. The study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One review in the USA[1] found that bat houses provided as alternative roosts during bridge replacement works were used by fewer Mexican free-tailed bats than the original roost at one site and were not used by bats at all at three sites.

Background

Bats may be temporarily excluded from their roosts in bridges or culverts during maintenance work to prevent injury or death. Alternative structures, such as bat houses, may be provided as temporary roosts until the work is complete.

For the effects of excluding bats, see '*Exclude bats from roosts during maintenance work at road/railway bridges and culverts*'.

A review in 2017–2018 of case studies at four road bridges in California, USA (*1*) found that bat houses provided as alternative roosts during bridge replacement works were used by fewer bats than the original roost or were not used at all. At one site, seven bat houses built to replace a roost for four years during bridge replacement works were used by fewer Mexican free-tailed bats *Tadarida brasiliensis* (2,000 bats) than the original roost (40,000 bats). At three other sites, bat houses built to replace roosts used by pallid bats *Antrozous pallidus* (18 bats), Yuma myotis bats *Myotis yumanensis* (40–100 bats), and/or Mexican free-tailed bats (994 bats) during bridge replacement works were not used at all. At all four sites, bat houses (or 'condominiums') were built as temporary roosts while bats were excluded from their original roosts during bridge replacement works (dates not reported). Counts of bats before and after the works were taken from questionnaires completed by the California Department of Transportation.

(1) H.T. Harvey & Associates (2019) *Caltrans bat mitigation: a guide to developing feasible and effective solutions.* Report prepared for California Department of Transportation by H.T. Harvey Associates in collaboration with HDR Inc., Sacramento, California.

5.12. Deter bats from roads/railways using lighting

- We found no studies that evaluated the effects of deterring bats from roads/railways using lighting on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Strategically placed lighting around roads or railways may be used to deter bat species that avoid lights from unsafe crossing points and divert them to safe crossing points. Other relevant interventions involving lighting are discussed in '*Threat: Pollution – Light pollution*'.

5.13. Deter bats from roads/railways using ultrasound

- We found no studies that evaluated the effects of deterring bats from roads/railways using ultrasound on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

It has been suggested that bats could be deterred from roads or railways using ultrasound. For a similar intervention relating to wind turbines, see '*Threat: Energy production and mining – Wind turbines – Deter bats from turbines using ultrasound*'.

5.14. Minimize road lighting to reduce insect attraction

- We found no studies that evaluated the effects of minimizing road lighting to reduce insect attraction on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Insect-eating bats may be attracted to lighting along roads to feed on insects, bringing them into contact with traffic and increasing the risk of collisions. Minimizing road lighting may reduce insect densities and bat foraging activity in proximity to roads.

Other relevant interventions involving lighting are discussed in '*Threat: Pollution – Light pollution*'.

5.15. Avoid planting fruit trees alongside roads/railways in areas with fruit bats

- We found no studies that evaluated the effects of avoiding planting fruit trees alongside roads/railways in areas with fruit bats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Planting fruit trees alongside roads or railways may attract fruit bats, bringing them into contact with traffic and increasing the risk of collisions.

5.16. Replace or improve habitat for bats around roads/railways

- We found no studies that evaluated the effects of replacing or improving habitat around roads/railways on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

There is evidence that the effect of a road on bat diversity is reduced in better quality bat habitat (Berthinussen & Altringham 2012). Replacing lost habitat and improving habitat quality (for example by planting trees, hedges, woodland or creating wetlands) around roads or railways may reduce the negative impact on bats.

For interventions relating to more general habitat improvements, see '*Habitat restoration and creation*'.

Berthinussen A. & Altringham J. (2012) The effect of a major road on bat activity and diversity. *Journal of Applied Ecology,* 49, 82–89.

Utility & Service Lines

5.17. Replace or improve roosting habitat for bats along utility and service line corridors

- We found no studies that evaluated the effects of replacing or improving roosting habitat for bats along utility and service line corridors on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

The construction of utility and service line corridors may result in the loss of bat roosts, e.g. in trees. Replacing or improving roosting habitat for bats along utility and service line corridors may help to compensate for the loss of roosts.

5.18. Manage vegetation along utility and service line corridors to increase foraging habitat for bats

- We found no studies that evaluated the effects of managing vegetation along utility and service line corridors to increase forgaing habitat for bats on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Vegetation along utility or service line corridors could be managed to increase foraging habitat for bats, e.g. by creating scalloped woodland or forest edges, planting a diverse mix of native plant species, retaining shrubs and low-growing trees, avoiding the use of chemicals, such as herbicides etc.

6. Threat: Biological resource use

Biological resource use (as defined in this synopsis) includes the killing of bats for food and medicinal purposes, the harvesting of bat droppings (guano), as well as logging and wood harvesting. While hunting has a direct effect on bat survival, logging and wood harvesting indirectly threaten bats through habitat destruction and fragmentation.

For general interventions that may help reduce exploitation of bat species, see also '*Education and awareness raising*'. For interventions relating to legal protection, see: '*Species management – Legally protect bat species' and 'Habitat protection – Legally protect bat habitats*'.

Hunting

Background

Mostly fruit bat species, but also some insect-eating species, are hunted for bushmeat for both local and commercial consumption. Bats are also hunted for medicine or sport and are culled as pests. There is evidence that hunting of bats is having a significant impact on bat populations in the Old World tropics (Mildenstein *et al*. 2016).

Mildenstein T., Tanshi I. & Racey P.A. (2016) Exploitation of bats for bushmeat and medicine. Pages 325–375 in*:* Voigt C.C. & Kingston T. (eds.) *Bats in the Anthropocene: Conservation of Bats in a Changing World.* Springer International Publishing, Cham.

6.1. Introduce and enforce legislation to control hunting of bats

- We found no studies that evaluated the effects of introducing and enforcing legislation to control the hunting of bats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

This intervention involves the introduction of legislation to protect bats from hunting. This may include measures such as hunting regulations, issue of hunting licences or permits, prohibition of export, and the control of guns and ammunition. Subsequent enforcement of legislation is also important to prevent illegal hunting.

6.2. Enforce regulations to prevent trafficking and trade of bats

- We found no studies that evaluated the effects of enforcing regulations to prevent trafficking and trade of bats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Bat species threatened by trade are protected under the CITES agreement (Convention on International Trade in Endangered Species of Wild Fauna and Flora), which aims to regulate the international trade of endangered species. However, it is the responsibility of each participating country to adopt its own national legislation to ensure the regulations are implemented, and in some countries illegal trade continues.

6.3. Strengthen cultural traditions that discourage bat harvesting

- We found no studies that evaluated the effects of strengthening cultural traditions that discourage bat harvesting on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Species that provide an important cultural resource can be highly revered. For example, a study in the Solomon Islands found that bat teeth are used traditionally as currency, and the authors suggest that this tradition could be used to highlight the cultural value of bats and encourage sustainable hunting and conservation (Lavery & Fasi 2017).

Lavery T.H. & Fasi J. (2017) Buying through your teeth: traditional currency and conservation of flying foxes *Pteropus* spp. in Solomon Islands. *Oryx*, 1–8.

6.4. Inform local communities about the negative impacts of bat hunting to reduce killing of bats

- **One study** evaluated the effects of informing local communities about the negative impacts of bat hunting to reduce killing of bats on bat populations. The study was in Ghana[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One before-and-after study in Ghana[1] found that after providing education about the ecological roles of bats fewer hunters intended to hunt bats in the future.

Background

Education programmes that emphasize the negative impacts of bat hunting and the role of bats in providing ecosystem services are being implemented in some countries, and may benefit bats (e.g. Entwistle 2001, Trewellha *et al*. 2005). However, there are many factors that influence human behaviour, and it may be necessary to collaborate with social scientists to design appropriate education programmes (e.g. see Kingston 2016). See also '*Inform local communities about disease risks from hunting and eating bat meat to reduce killing of bats*'.

Entwistle A. (2001) Community-based protection successful for the Pemba flying fox. *Oryx,* 35, 355–356.

Kingston T. (2016) Cute, creepy, or crispy – How values, attitudes, and norms shape human behavior toward bats. Pages 571–595 in: Voigt C.C. & Kingston T. (eds.) *Bats in the Anthropocene: Conservation of Bats in a Changing World.* Springer International Publishing, Cham.

Trewhella W.J., Rodriguez-Clark K.M., Corp N., Entwistle A., Garrett S.R.T., Granek E., Lengel K.L., Raboude M.J., Reason P.F. & Sewall B.J. (2005) Environmental education as a component of multidisciplinary conservation programs: lessons from conservation initiatives for critically endangered fruit bats in the western Indian Ocean. *Conservation Biology,* 19, 75–85.

A before-and-after study in 2009–2011 in a rural region of southern Ghana (*1*) found that after education about the negative impacts of bat hunting, fewer hunters intended to hunt bats in the future than before the education was provided. In response to a questionnaire, fewer hunters (2 of 4) stated they intended to hunt bats in the future after they were given education about the negative impacts of bat hunting than before (all 4 of the hunters), although sample sizes were small and the difference was not tested for statistical significance. In 2009–2011, each of four bat hunters was interviewed with the same set of questions before and after a brief education piece was provided including verbal explanations of the important ecological roles of bats.

(1) Kamins A.O., Rowcliffe J.M., Ntiamoa-Baidu Y., Cunningham A.A., Wood J.L.N. & Restif O. (2015) Characteristics and risk perceptions of Ghanaians potentially exposed to bat-borne zoonoses through bushmeat. *EcoHealth*, 12, 104–120.

6.5. Inform local communities about disease risks from hunting and eating bat meat to reduce killing of bats

- **One study** evaluated the effects of informing local communities about disease risks from hunting and eating bat meat to reduce killing of bats on bat populations. The study was in Ghana[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One before-and-after study in Ghana[1] found that fewer hunters intended to hunt bats in future after they were provided with education about the risks of diseases carried by bats.

Background

Infectious diseases can be transmitted through the handling, preparation, and consumption of bats. However, hunters and vendors are often unaware of these risks (Harrison *et al*. 2011). Informing local communities about disease risks may discourage people from hunting and eating bats. However, this would need to be implemented with caution as it may also encourage negative attitudes and increase the intentional killing of bats to reduce the risk of exposure. See also '*Inform local communities about the negative impacts of bat hunting to reduce killing of bats*'.

Harrison M.E., Cheyne S.M., Darma F., Ribowo D.A., Limin S.H. & Struebig M.J. (2011) Hunting of flying foxes and perception of disease risk in Indonesian Borneo. *Biological Conservation,* 144, 2441–2449.

A before-and-after study in 2009–2011 in a rural region of southern Ghana (*1*) found that after education about the disease risks from hunting and eating bat meat, fewer hunters intended to hunt bats in the future than before the education was provided. In response to a questionnaire, fewer hunters (1 of 4) stated they intended to hunt bats in the future after they were given education about the risks of diseases carried by bats than before (all 4 of the hunters), although sample sizes were small and the difference was not tested for statistical significance. In 2009–2011, each of four bat hunters was interviewed with the same set of questions before and after a brief education piece was provided including verbal explanations of the risks of contracting diseases carried by bats.

(1) Kamins A.O., Rowcliffe J.M., Ntiamoa-Baidu Y., Cunningham A.A., Wood J.L.N. & Restif O. (2015) Characteristics and risk perceptions of Ghanaians potentially exposed to bat-borne zoonoses through bushmeat. *EcoHealth*, 12, 104–120.

6.6. Introduce alternative treatments to reduce the use of bats in traditional medicine

- We found no studies that evaluated the effects of introducing alternative treatments to reduce the use of bats in traditional medecine on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Bats may be hunted for their perceived medicinal properties. Introducing alternative treatments and dispelling myths about the health benefits of using bats as medicine may reduce hunting pressure.

6.7. Introduce other food sources to replace bat meat

- We found no studies that evaluated the effects of introducing other food sources to replace bat meat on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Bat meat may provide a source of protein during food shortages or in countries where the cost of meat is high. Introducing other food sources to replace bat meat may reduce hunting pressure. This could include introducing new husbandry practices, such as chicken or fish farming.

6.8. Introduce other income sources to replace bat trade

- We found no studies that evaluated the effects of introducing other income sources to replace bat trade on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Introducing alternative income sources to replace bat trade may reduce hunting pressure. This could include cultivating crops or rearing domestic animals.

6.9. Encourage online vendors to remove bat specimens for sale

- We found no studies that evaluated the effects of encouraging online vendors to remove bat specimens for sale on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Vendors, such as online selling platforms, could be encouraged to sign up to a code of practice to remove illegal bat specimens for sale.

6.10. Replace culling of bats with non-lethal methods of preventing vampire bats from spreading rabies to humans

- We found no studies that evaluated the effects of replacing culling of bats with non-lethal methods of preventing vampire bats from spreading rabies to humans on vampire bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Vampire bats have been extensively culled in Latin America to prevent the spread of rabies to humans. However, research shows that culling is ineffective and may increase the spread of rabies (e.g. Streicker *et al.* 2012). Non-lethal measures of disease control have been suggested as alternatives, such as vaccinating humans against rabies, placing netting over doorways in dwellings, and avoiding sudden removal of established livestock from villages (e.g. Stoner-Duncan *et al.* 2014).

For an intervention relating to the spread of rabies to livestock, see '*Threat: Agriculture – Livestock Farming – Replace culling of bats with non-lethal methods of preventing vampire bats from spreading rabies to livestock*'.

Stoner-Duncan B., Streicker D.G. & Tedeschi C.M. (2014) Vampire bats and rabies: toward an ecological solution to a public health problem. *PLOS Neglected Tropical Diseases,* 8, e2867.

Streicker D.G., Recuenco S., Valderrama W., Gomez Benavides J., Vargas I., Pacheco V., Condori Condori R.E., Montgomery J., Rupprecht C. E., Rohani P. & Altizer S. (2012) Ecological and anthropogenic drivers of rabies exposure in vampire bats: implications for transmission and control. *Proceedings of the Royal Society B: Biological Sciences,* 279, 3384–3392.

6.11. Restrict the collection of bat specimens for research

- We found no studies that evaluated the effects of restricting the collection of bat specimens for research on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Both ethical and conservation concerns have been raised over the unnecessary collection of bat specimens for research (e.g. Russo *et al*. 2017). It has been suggested that there should be stricter regulation and the use of alternatives, such as collecting tissue or fur samples for molecular analysis, should be encouraged.

Russo D., Ancillotto L., Hughes A.C., Galimberti A. & Mori E. (2017) Collection of voucher specimens for bat research: conservation, ethical implications, reduction, and alternatives. *Mammal Review,* 47, 237–246.

Guano harvesting

Bat guano has a high concentration of nitrates and has been harvested from caves for centuries for a variety of uses. Modern day use is typically for fertilizer, both for commercial production and subsistence farming. Guano harvesting can cause serious disturbance to bat colonies causing arousal from hibernation, the abandonment of pups or total abandonment of caves as roosting sites.

6.12. Introduce and enforce legislation to regulate harvesting of bat guano

- We found no studies that evaluated the effects of introducing and enforcing legislation to regulate the harvesting of bat guano on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Guidelines for the sustainable harvesting of bat guano have been drawn up by the IUCN (International Union for Conservation of Nature, IUCN SSC 2014). Introducing and enforcing legislation informed by such guidelines may help to reduce the negative impact of guano harvesting on bat populations.

IUCN SSC (2014) *IUCN SSC Guidelines for minimizing the negative impact to bats and other cave organisms from guano harvesting*. Ver. 1.0. IUCN, Gland.

Logging and wood harvesting

Background

Logging and wood harvesting causes habitat destruction, fragmentation, and disturbance, and is a significant threat to bats (e.g. see Law *et al*. 2016, Meyer *et al*. 2016, Webala *et al.* 2019). The interventions below describe management practices that may reduce the impact of logging or wood harvesting. Interventions that relate to protecting forest and woodland can be found in the chapter '*Habitat protection*'.

Law B., Park K.J. & Lacki M.J. (2016) Insectivorous bats and silviculture: balancing timber production and bat conservation. Pages 105–150 in: Voigt C.C. & Kingston T. (eds.) *Bats in the Anthropocene: Conservation of Bats in a Changing World.* Springer International Publishing, Cham.

Meyer C.F.J., Struebig M.J. & Willig M.R. (2016) Responses of tropical bats to habitat fragmentation, logging, and deforestation. Pages 63–103 in: Voigt C.C. & Kingston T. (eds.) *Bats in the Anthropocene: Conservation of Bats in a Changing World.* Springer International Publishing, Cham.

Webala P.W., Mwaura J., Mware J.M., Ndiritu G.G. & Patterson B.D. (2019) Effects of habitat fragmentation on the bats of Kakamega Forest, western Kenya. *Journal of Tropical Ecology,* 35, 260–269.

6.13. Thin trees within forest and woodland

- **Eleven studies** evaluated the effects of thinning trees within forest and woodland on bat populations. Six studies were in the USA[1,2,4,5,7,8], four were in Australia[6,9–11] and one was in Canada[3].

COMMUNITY RESPONSE (2 STUDIES)

- **Richness/diversity (2 studies):** One replicated, site comparison study in Australia[6] recorded the same bat species in thinned and unthinned forest, except for the chocolate wattled bat, which was not recorded in forests with unthinned regrowth. One replicated, site comparison study in Australia[10] found that forest thinned up to 20 years previously had higher bat diversity than unthinned forest, but sites thinned more than 20 years previously did not differ.

POPULATION RESPONSE (11 STUDIES)

- **Abundance (11 studies):** Five of six replicated, site comparison studies (including two paired sites studies and one controlled study) in the USA[1,2,4,5,8] and Australia[6] found higher overall bat activity (relative abundance) in thinned[1,2,5,6] or thinned and burned forest[8] than unthinned forest. The other study[4] found similar overall bat activity in thinned and unthinned stands. One replicated, randomized, site comparison study in the USA[7] found higher overall bat activity for three of four types of thinning and burning treatments. One replicated, site comparison study in Australia[10] found that forest thinned up to eight years previously or more than 20 years previously had higher bat activity than unthinned forest, but sites thinned 8–20 years previously did not differ. Three replicated, controlled studies (including one site comparison and one before-and-after study) in Canada[3] and Australia[9,11] found that thinning increased the activity of some bat species but not others.

BEHAVIOUR (0 STUDIES)

Background

Thinning is a forestry practice that involves the selective removal of trees to reduce tree density and improve the growth rate and health of remaining trees. Thinning has been done historically to maximize timber production but may have ecological benefits. The retention of large old trees may provide roosting sites for bats and opening the canopy may provide favourable foraging habitats.

For studies that used thinning as part of selective logging methods, see the intervention '*Use selective or reduced impact logging instead of conventional logging*'.

A replicated, site comparison study in 1993–1994 of 24 forest sites in the Cascade mountains, USA (*1*) found that thinned tree stands of two different ages had higher bat activity than young unthinned tree stands, but lower bat activity than clearcut stands. A greater number of bat passes were recorded in 10–13-year-old thinned stands (average 2 bat passes/night) and mature thinned stands (4 bat passes/night) than in young unthinned stands (no bat passes). However, fewer bat passes were recorded in both thinned stands than in clearcut stands (8 bat passes/night). At least five bat species were recorded (see original paper for data for individual species). Six replicates of tree stands in four post-harvest stages were sampled: thinned stands (10–13 year old Douglas fir *Pseudotsuga menziesii*), mature thinned stands (51–62 year old Douglas fir or western hemlock *Tsuga heterophylla*), young unthinned stands (30–40 years old, high tree density with varied tree diameter), clearcut stands (2–3 years post-harvest, 1–2 m high Douglas fir seedlings). At each of 24 sites, bat detectors recorded bat activity for six nights in July–September 1993 and 1994.

A replicated, paired sites and site comparison study in 1994–1995 in 11 pairs of forest stands and nine old growth forests in the Oregon Coast range, USA (*2*) found that thinned tree stands had higher bat activity than unthinned tree stands, and there was no difference in bat activity between thinned stands and old growth forest. Overall bat activity (of at least nine bat species) was higher in thinned (average 10 bat passes/night) than unthinned stands (6 bat passes/night). There was no significant difference in bat activity between thinned stands and old growth forest (average 13 bat passes/night). Surveys were carried out in 11 pairs of stands (10–63 ha, 50–100 years old) that were thinned (in 1971–1985, average 184 trees/ha) or unthinned (average 418 trees/ha), and in nine old growth forest stands (20–70 ha, >200 years old, average 155 trees/ha). All 31 tree stands were dominated by Douglas fir *Pseudotsuga menziesii*. Bat detectors recorded bat activity at one random location in each of 11 pairs of tree stands and in a nearby old growth forest stand simultaneously for two consecutive nights on four occasions in June–September 1994 or May–September 1995.

A replicated, controlled, site comparison study in 1998–2000 of 36 deciduous, coniferous and mixed forest sites in Alberta, Canada (*3*) found that thinned tree stands had similar activity for three bat species to unthinned tree stands, but one bat species was recorded less often in thinned stands than in clearcut patches. The activity (bat passes/hour) of little brown bats *Myotis lucifugus,* northern long-eared bats *Myotis septentrionalis* and silver haired bats *Lasionycteris noctivagans* did not differ significantly between thinned and unthinned tree stands in any of the three types of forest (data reported as statistical model results). In all three types of forest, silver-haired bat activity was lower in thinned tree stands than in clearcut patches. Experimental forest patches (10 ha, average 974–1,210 stems/ha) were created in winter 1998–1999 with three replicates of four treatments (clearcut with no trees retained, thinned with 20% or 50% of trees retained, unthinned with 100% of trees retained) in each of the three forest types (all >50 years old). At each of 36 sites, bat activity was recorded with bat detectors at the centre and edge of each patch in June–July 1999 and June–August 2000 for a total of 33–42 nights/site.

A replicated, paired sites study in 2001 in 13 managed red pine *Pinus resinosa* forests in Lower Michigan, USA (*4*) found that thinned tree stands had similar bat activity to unthinned stands. Overall bat activity (of at least five bat species) did not differ significantly between thinned (16 bat passes, 0.3 feeding buzzes) and unthinned stands (8 bat passes, 0.5 feeding buzzes). At all sites, bat activity was higher in nearby openings within the forests (thinned: 788 bat passes, 5 feeding buzzes; unthinned: 725 bat passes, 5 feeding buzzes) than within tree stands. Thirteen paired tree stands (one thinned: 12 stems/100 m^2: one unthinned: 22 stems/100 m^2) were surveyed on two occasions. All stands were >10 ha and 52 years old on average. Thinned stands had been thinned 5–11 years prior to the study. Openings in stands were either cleared for wildlife or sites used by loggers. Bat surveys were carried out simultaneously at groups of four sites (interior and openings in a pair of thinned and unthinned stands). Bat detectors recorded bat activity for one full night/site in May–June and July–August 2001. Bats were captured using mist nets during six nights in May–August 2001 at half of the thinned sites and half of the unthinned sites.

A replicated, controlled, site comparison study in 2001–2002 of nine pine forest sites in South Carolina, USA (*5*) found that thinned tree stands had higher activity for two of three bat species than unthinned control tree stands. Activity of big brown bats *Eptesicus fuscus* and eastern red bats *Lasiurus borealis* was higher in thinned tree stands (big brown bats: average 1.2 bat passes/night; eastern red bats: 0.7 bat passes/night) than in unthinned control stands (big brown bats: 0.1 bat passes/night; eastern red bats: 0.5 bat passes/night) or burned stands (big brown bats: 0.3 bat passes/night; eastern red bats: 0.3 bat passes/night). Activity of eastern pipistrelles *Perimyotis subflavus* did not differ significantly between thinned (0.4 bat passes/night), unthinned (0.1 bat passes/night) or burned stands (0.1 bat passes/night). Nine 14 ha stands (loblolly pine *Pinus taeda* and shortleaf pine *Pinus echinata*) were surveyed with three replicates of three treatment types: thinning to an average of 576 live trees/ha (in winter 2000–2001), prescribed burning (burned in April 2001 with strip head fire and flanking fires, average 532 live trees/ha), and a control with no treatment (average 755 live trees/ha). Bat activity was sampled with two bat detectors at random points in each of 12 stands for two full nights/month in May–August 2001 and 2002.

A replicated, site comparison study in 2012–2013 at 24 eucalypt forest sites in southeastern Australia (*6*) found that thinned forests had greater overall bat activity than forests with unthinned regrowth, but bat activity was similar between thinned and natural forests, and 10 of 11 bat species were recorded in all forest types. Overall bat activity was lowest in unthinned regrowth (average 140 bat passes/night) and similar in forest thinned 0–4 years previously (318 bat passes/night), forest thinned 5–10 years previously (344 passes/night) and natural forest (350 bat passes/night). The same 10 bat species were recorded in all four types of forest, except for the chocolate wattled bat *Chalinolobus morio*, which was not recorded in forests with unthinned regrowth (see original paper for data for individual species). Six sites were surveyed for each of four thinning categories: unthinned regrowth (even-aged, average 1,253 stems/ha), thinned 0–4 years previously (even-aged, average 280 stems/ha), thinned 5–10 years previously (patchy structure, average 419 stems/ha), natural forest (mature, open forest with mixed-age, large trees, average 295 stems/ha). Bat activity was recorded with bat detectors at two locations/site for 2–6 full nights between December 2012 and January 2013.

A replicated, randomized, site comparison study in 2013–2014 of 10 hardwood tree stands in Tennessee, USA (*7*) found that thinned and burned tree stands had higher overall bat activity for three of four treatment types than untreated tree stands. Overall bat activity was higher in tree stands thinned to $14 m^2$/ha and burned in the spring (average 656 bat passes) or autumn (292 bat passes) than untreated control stands (95 bat passes). However, tree stands thinned to $7 m^2$/ha had higher bat activity than control stands when burned in the autumn (280 bat passes) but not in the spring (123 bat passes). Six groups of bat species were recorded (see original paper for data for individual species groups). The study does not distinguish between the effects of thinning and burning. Each of four treatments (thinning to 7 or 14 m^2/ha with burning in the autumn or spring) was randomly applied to two tree stands (20 ha, 80–100 years old). Two tree stands were untreated controls (average 20 m^2/ha). Overstorey thinning was carried out in June 2008 and prescribed fires in October 2010 and 2012 (autumn) and March 2011 and 2013 (spring). Each of 10 stands was surveyed with a bat detector for seven full nights on three occasions in May–July 2013 and 2014.

A replicated, site comparison study in 2006–2010 of 12 tree stands in two upland hardwood forests in Ohio, USA (*8*) found that overall bat activity was higher in thinned and burned tree stands than in untreated tree stands. Overall bat activity was higher in tree stands thinned with 50% of the overstorey retained and burned (average 16–30 bat passes/night) and tree stands thinned with 70% of the overstorey retained and burned (14–24 bat passes/night) than in untreated control stands (3–4 bat passes/night). Four bat species or species groups were recorded (see original paper for data for individual species). The study does not distinguish between the effects of thinning and burning. In each of two forests, four tree stands (10 ha) were treated with thinning (commercially thinned between June 2005 and March 2006 with 50% or 70% overstorey retained) and prescribed fire (backing and strip fires in autumn 2009 or spring 2010) and two tree stands were untreated controls (tree density not reported). In each of 12 tree stands, eight points were sampled with bat detectors for 3 h/night over a total of six nights in May–August 2006 and June–September 2009 and 2010.

A replicated, controlled, before-and-after study in 2012–2015 of 10 forest sites in south-eastern Australia (*9*) found that thinning increased the activity of six of nine bat species/species groups. For six bat species/species groups (Gould's wattled bat *Chalinolobus gouldii*, free-tailed bats *Mormopterus* spp., inland broad-nosed bat *Scotorepens balstoni*, large forest bat *Vespadelus darlingtoni*, southern forest bat *Vespadelus regulus*, little forest bat *Vespadelus vulturnus*), activity was higher after thinning than before (data reported as statistical model results), whereas activity in control plots was either similar (five species) or decreased (one species). For two bat species/species groups (long-eared bats *Nystophilus* spp., yellow-bellied sheath-tailed bat *Saccolaimus flaviventris*), activity was similar before and after thinning, but decreased at control plots. For one bat species (white-striped free-tailed bat *Austronomous australis*), activity decreased after thinning and in control plots. Two plots (0.1 ha) were sampled in each of 10 forest sites (dominated by river red gum *Eucaluptus camaldulensis*). Five treatment sites were thinned in 2012–2015 (average 434 stems/ha). Five control sites were left unthinned (average 1,150–1,300 stems/ha). One bat detector recorded bat activity at the centre of each of 20 plots for three consecutive nights in December 2012 (before thinning) and December 2015 (after thinning).

A replicated, site comparison study in 2015 of six forest sites in New South Wales, Australia (*10*) found that recently thinned sites had higher bat activity and diversity than unthinned sites, but results varied for sites thinned more than eight years previously. Overall bat activity and diversity were higher in sites recently thinned (<8 years previously) than in unthinned sites (data reported as statistical model results). Sites thinned 8–20 years previously had similar bat activity to unthinned sites, but higher bat diversity. Sites thinned >20 years previously had higher bat activity than unthinned sites, but similar bat diversity. Bat activity did not differ significantly between thinned sites and undisturbed forest but was lower at unthinned sites than undisturbed forest. Twelve bat species were recorded in total (see original paper for data for individual species). Five treatments were sampled at each of six forest sites (20–30 ha, dominated by white cypress pine *Callitris glaucophylla*): unthinned (~6,500 stems/ha); recently thinned (<8 years previously); thinned 8–20 years previously; thinned >20 years previously; undisturbed forest. All thinned sites had a similar density of stems (~1,600 stems/ha). One bat detector recorded bat activity for 2–3 nights at each of 30 sites in November 2015.

A replicated, controlled study in 2016–2017 at eight forest sites in New South Wales, Australia (*11*) found that thinned tree stands had higher overall bat activity and activity of little forest bats *Vespadelus vulturnus* than unthinned tree stands, and long-eared bats *Nyctophilus* spp. had higher activity in thinned tree stands in the spring but not in the autumn. Overall nightly bat activity (of 10 species/species groups) was higher in thinned (183 bat passes) than unthinned tree stands (97 bat passes) as was the activity of little forest bats (data not reported). Average nightly activity of long-eared bats was higher during spring in thinned (7 bat passes) than unthinned tree stands (1 bat pass), but the reverse was true in autumn (thinned: 3 bat passes; unthinned: 6 bat passes). All eight sites (12 ha) were dense white cypress pine *Callitris glaucophylla* regrowth separated by ≤200 m. Four sites were thinned in June–July 2016 (average 358 stems/ha) and four sites were left unthinned (average 463 stems/ha). Each pair was surveyed simultaneously with 1–2 bat detectors/stand for two nights in November 2016 (spring) and March 2017 (autumn).

(1) Erickson, J.L. & West S.D. (1996) Managed forests in the western Cascades: the effects of seral stage on bat habitat use patterns. Pages 215–227 in: R. M. R. Barclay and R. M. Brigham (eds.) *Bats and Forests Symposium*. British Columbia Ministry of Forests, Victoria, Canada.

(2) Humes M.L., Hayes J.P. & Collopy M.W. (1999) Bat activity in thinned, unthinned, and old-growth forests in western Oregon. *The Journal of Wildlife Management*, 63, 553–561.

(3) Patriquin K.J. & Barclay R.M.R. (2003) Foraging by bats in cleared, thinned and unharvested boreal forest. *Journal of Applied Ecology*, 40, 646–657.

(4) Tibbels A.E. & Kurta A. (2003) Bat activity is low in thinned and unthinned stands of red pine. *Canadian Journal of Forest Research*, 33, 2436–2442.

(5) Loeb S.C. & Waldrop T.A. (2008) Bat activity in relation to fire and fire surrogate treatments in southern pine stands. *Forest Ecology and Management,* 255, 3185–3192.

(6) Blakey R.V., Law B.S., Kingsford R.T., Stoklosa J., Tap P. & Williamson K. (2016) Bat communities respond positively to large-scale thinning of forest regrowth. *Journal of Applied Ecology*, 53, 1694–1703.

(7) Cox M.R., Willcox E.V., Keyser P.D. & Vander Yacht A.L. (2016) Bat response to prescribed fire and overstory thinning in hardwood forest on the Cumberland Plateau, Tennessee. *Forest Ecology and Management*, 359, 221–231.

(8) Silvis A., Gehrt S.D. & Williams R.A. (2016) Effects of shelterwood harvest and prescribed fire in upland Appalachian hardwood forests on bat activity. *Forest Ecology and Management*, 360, 205–212.

(9) Gonsalves L., Law B. & Blakey R. (2018) Experimental evaluation of the initial effects of large-scale thinning on structure and biodiversity of river red gum (*Eucalyptus camaldulensis*) forests. *Wildlife Research*, 45, 397–410.

(10) Gonsalves L., Law B., Brassil T., Waters C., Toole I. & Tap P. (2018) Ecological outcomes for multiple taxa from silvicultural thinning of regrowth forest. *Forest Ecology and Management*, 425, 177–188.

(11) Law B., Gonsalves L., Brassil T. & Hill D. (2018) Does thinning homogenous and dense regrowth benefit bats? Radio-tracking, ultrasonic detection and trapping. *Diversity*, 10, 45.

6.14. Use selective or reduced impact logging instead of conventional logging

- **Four studies** evaluated the effects of using selective or reduced impact logging instead of conventional logging on bat populations. Two studies were in the Neotropics[1,2], one study was in Italy[3] and one in Germany[4].

COMMUNITY RESPONSE (1 STUDY)

- **Community composition (1 study):** One replicated, controlled, site comparison study in Trinidad[1] found that the composition of bat species differed between selectively logged and conventionally logged forest.
- **Richness/diversity (1 study):** One replicated, site comparison study in Germany[4] found similar bat diversity in selectively logged and conventionally logged forest.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** One replicated, site comparison study in Germany[4] found similar overall bat activity (relative abundance) in selectively logged and conventionally logged forest. One review of 41 studies in the Neotropics[2] found that reduced impact logging had a smaller effect on bat abundance than conventional logging. One replicated, site comparison study in Italy[3] found greater bat activity at two of three sites that used selective logging techniques to open up the forest canopy rather than leaving the canopy intact.

BEHAVIOUR (0 STUDIES)

Background

Selective logging is the removal of selected trees within a forest based on criteria such as diameter, height, or species. Remaining trees are left in the stand, as opposed to clearcutting where all trees are felled.

Reduced impact logging is a sustainable harvesting and management method that aims to minimize ecological disturbance. It involves selective logging as well as other practices such as directional tree felling, stream buffer zones, constructing roads, trails and landings to minimum widths, and methods to extract timber with minimal damage. One study on reduced impact logging has been included but the effects of selective logging cannot be separated from the other interventions used.

A replicated, controlled, site comparison study in 2001–2002 of six tropical forest sites in Victoria-Mayaro Forest Reserve, Trinidad (*1*) found that the composition of bat species differed between selectively logged forest, continuously logged forest and undisturbed forest. Fewer fruit-eating and gleaning animal-eating bat species were captured in selectively logged forest (fruit-eating: 352 bats of nine species; animal-eating: 25 bats of seven species) than in continuously logged forest (fruit-eating: 958 bats of 13 species; animal-eating: 52 bats of eight species). In undisturbed forest, fewer fruit-eating bats (282 bats of 10 species) and more animal-eating bats (71 bats of nine species) were captured than in either type of logged forest. In total, 38 bat species were captured (see original paper for data for individual species). Two sites were surveyed in each of three forest types: selectively logged forest (4–8 selected trees/ha felled in blocks of 150–300 ha), continuously logged forest (trees continuously felled creating an open canopy with fruit plants growing below) and undisturbed forest. At each of six sites, bats were captured at five sampling points using mist nets and harp traps for 6 h from sunset on two nights in 2001–2002.

A review in 2014 of 41 logging studies in the Neotropics (*2*) found that reduced impact logging had a smaller effect on bat abundance than conventional logging, even when conventional logging used similar harvesting intensities as reduced impact logging (≤30 m^3/ha). The average effect sizes were lower for reduced impact logging than for conventional logging (data reported as statistical model results). Effect sizes were calculated from a meta-analysis of all available studies (n = 41) and included multiple species-level comparisons for each logging method (reduced impact logging: 88 comparisons, all conventional logging: 139 comparisons; conventional logging with harvesting intensity ≤30 m^3/ha; 84 comparisons). All 41 studies used selective logging alongside other interventions typical of reduced-impact logging such as directional felling, winching of logs and careful planning of logging roads.

A replicated, site comparison study in 2014 in three mixed forest sites across Italy (*3*) found that 'innovative' selective logging resulted in greater bat activity than 'traditional' selective logging at two of three sites. Two sites had greater bat activity in 'innovatively' logged forest than 'traditionally' logged and unlogged forest (data reported as statistical model results). One site had similar bat activity in 'innovatively' and 'traditionally' logged forest but lower bat activity in unlogged forest (data reported as statistical model results). Nine bat species were recorded in total (see original paper for data for individual species). In the 'innovatively' logged forest, trees were selectively retained (40–80 trees/ha) according to their shape, dominance, position and quality, and adjacent trees were cut to create openings. In the 'traditionally' logged forest, understorey trees were selectively thinned every 20–30 years and the canopy left intact. Unlogged forest had not been logged for >20 years. At each of three sites, three plots (3–6 ha) were surveyed for each of three treatments ('innovatively' logged, 'traditionally' logged, unlogged). Each plot was surveyed three times in June–September 2014 for two consecutive nights. Bat detectors recorded bat activity for 8 h from 30 minutes before sunset.

A replicated, site comparison study in 2009–2010 of 43 forest sites in central Germany (*4*) found that selectively logged sites had similar overall bat activity and diversity to conventionally logged sites and unmanaged forest. There was no significant difference in overall bat activity (data reported as statistical model results) and bat diversity (data reported as diversity indices) between selectively logged sites, conventionally logged sites, and unmanaged forest. Surveys were carried out in 13 selectively logged sites (uneven-aged forest with large diameter overstorey trees harvested every five years), 17 conventionally logged sites (even-aged forest stands of 4–8 ha harvested in rotation) and 13 forest sites unmanaged for 20–70 years. All sites were European beech *Fagus sylvatica* forest. Bats were monitored in 2009 and 2010 (details of methods not reported).

(1) Clarke F.M., Pio D.V. & Racey P.A. (2005) A comparison of logging systems and bat diversity in the Neotropics. *Conservation Biology*, 19, 1194–1204.

(2) Bicknell J.E., Struebig M.J., Edwards D.P. & Davies Z.G. (2014) Improved timber harvest techniques maintain biodiversity in tropical forests. *Current Biology*, 24, R1119–R1120.

(3) Cistrone L., Altea T., Matteucci G., Posillico M., De Cinti B. & Russo D. (2015) The effect of thinning on bat activity in Italian high forests: the LIFE+ "ManFor C.BD." experience. *Hystrix-Italian Journal of Mammalogy,* 26, 125–131.

(4) Schall P., Gossner M.M., Heinrichs S., Fischer M., Boch S., Prati D., Jung K., Baumgartner V., Blaser S., Böhm S., Buscot F., Daniel R., Goldmann K., Kaiser K., Kahl T., Lange M., Müller J., Overmann J., Renner S.C., Schulze E.-D., Sikorski J., Tschapka M., Türke M., Weisser W.W., Wemheuer B., Wubet T. & Ammer C. (2018) The impact of even-aged and uneven-aged forest management on regional biodiversity of multiple taxa in European beech forests. *Journal of Applied Ecology*, 55, 267–278.

6.15. Use shelterwood cutting instead of clearcutting

- **One study** evaluated the effects of using shelterwood cutting instead of 'gap release' cutting on bat populations. The study was in Australia[1]. We found no studies that evaluated the effects of shelterwood cutting instead of clearcutting.

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One site comparison study in Australia[1] found more Gould's long-eared bats roosting in remnant trees within forests that had been shelterwood harvested than in forests harvested using gap release methods. Comparisons were not made with clearcutting.

Background

There are several different shelterwood systems. The basic process is the selective removal of overstorey trees to allow enough light through to the forest floor to create new, even-aged stands below. The remaining mature overstorey trees provide seeds for regeneration and create shelter for the younger trees. Harvesting is done in a series of cuts and may also involve thinning of the lower forest canopies.

A replicated, site comparison study in 2009 of 21 radio-tracked bats in jarrah *Eucalyptus marginata* forest in south-western Australia (*1*) found that shelterwood harvested forests had more Gould's long-eared bat *Nyctophilus gouldi* and southern forest bat *Vespadelus regulus* roosts than gap release forests. More Gould's long-eared bat roosts were in remnant trees in shelterwood forests (10 roosts, 37%) than in gap release forests (one roost, 3%). The remainder of tracked Gould's long-eared bats roosted in mature forest (eight roosts, 30%) and riparian buffers (eight roosts, 30%). Only one southern forest bat roost was found in shelterwoods, and none in gap release forests. Most southern forest bat roosts were in mature unlogged forest (15 roosts, 71%) and riparian buffers (five roosts, 24%). Shelterwood forest had retention levels of 40–60%. Gap release forest had 95% of the mature overstory removed. Riparian buffers and mature forest areas had been undisturbed for >30 years. Eleven Gould's long-eared bats and 10 southern forest bats were caught with harp traps at two water holes and radio-tracked for 3–8 days in February–March 2009.

(1) Webala P.W, Craig M.D., Law B.S., Wayne A.F. & Bradley J.S. (2010) Roost site selection by southern forest bat *Vespadelus regulus* and Gould's long-eared bat *Nyctophilius gouldi* in logged jarrah forests; south-western Australia. *Forest Ecology and Management*, 260, 1780–1790.

6.16. Train arborists and forestry operatives to identify potential bat roosts

- We found no studies that evaluated the effects of training arborists and forestry operatives to identify potential bat roosts on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Bat roosts within trees can be difficult to identify. Arborists and forestry operatives may be trained to identify potential roost features and the signs associated with bat use, such as droppings, staining, smells and substrate changes.

6.17. Protect roost trees during forest operations

- We found no studies that evaluated the effects of protecting roost trees during forest operations on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Trees with bat roosts, or potential bat roosts, should be retained during forest operations and protected from damage.

6.18. Retain buffers around roost trees in logged areas

- We found no studies that evaluated the effects of retaining buffers around roost trees in logged areas on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Buffers of vegetation may be retained around trees with bat roosts, or potential bat roosts, to avoid disturbance and to maintain the microclimate and light levels within the roost.

6.19. Change timing of forestry operations

- We found no studies that evaluated the effects of changing the timing of forestry operations on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

To reduce disturbance to bats, forestry operations may be avoided at times of year when they are most vulnerable such as during hibernation and the maternity season.

6.20. Retain forested corridors in logged areas

- **Three studies** evaluated the effects of retaining forested corridors in logged areas on bat populations. The three studies were in the USA[1–3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 studies):** One replicated, site comparison study in the USA[3] found that bat activity (relative abundance) was higher along the edges of forested corridors than in corridor interiors or in adjacent logged stands, which had similar activity levels.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One replicated, site comparison study in the USA[1] found more Seminole bats roosting in forested corridors than logged stands or mature forest. One replicated, site comparison study in the USA[2] found more male but fewer female evening bats roosting in forested corridors than logged stands.

Background

This intervention involves retaining corridors of unlogged mature forest within logged areas. This may provide foraging and roosting opportunities for bats and maintain connectivity in disturbed landscapes. See also '*Retain riparian buffers in logged areas*'.

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared logged areas where forested corridors have been kept intact with similar/nearby logged areas where forested corridors have not been kept. There must have been an active decision (i.e. intervention) to retain the forested corridors and the study must state when the intervention was carried out.

A replicated, site comparison study in 2003–2006 of 27 radio-tracked Seminole bats *Lasiurus seminolus* in loblolly pine *Pinus taeda* plantations in South Carolina, USA (*1*) found that forested corridors had more Seminole bat roosts than logged mid-rotation tree stands or mature forest. More male and female Seminole bat roosts were in forested corridors (male bats: 25 roosts, 61%; female bats: 31 roosts, 63%) than in logged mid-rotation stands (male bats: 14 roosts, 34%; female bats: 14 roosts, 29%) or mature forest (male bats: 2 roosts, 5%; female bats: 4 roosts, 8%). Distance to the nearest forested corridor was also negatively related to roost site selection (data reported as statistical model results). The study area (41,365 ha) was intensively managed for pine production. Mid-rotation logged stands were 12–22 years old. Forested corridors (100–200 m wide) consisted of mature pine (>23 years old) and/or mixed hardwood (>50 years old). Bats were caught with mist nets at nine ponds in open habitat from May–August in 2003–2006. Twenty-seven adult Seminole bats (10 males, 17 females) were tracked to 90 day roosts in the canopy of live pine trees.

A replicated, site comparison study in 2003–2006 of 53 radio-tracked evening bats *Nycticeius humeralis* in loblolly pine *Pinus taeda* plantations in South Carolina, USA (*2*) found that forested corridors had more male but fewer female evening bat roosts than logged mid-rotation tree stands. More male but fewer female evening bat roosts were in forested corridors (male: 12 roosts, 39%; female: eight roosts, 18%) than in logged mid-rotation stands (male: six roosts, 19%; female: nine roosts, 21%). The greatest number of roosts were in mature forest (male: 13 roosts, 42%; female: 27 roosts, 61%). Distance to the nearest forested corridor was negatively related to roost site selection in male bats but not females (data reported as statistical model results). The study area (41,365 ha) was intensively managed for pine production. Mid-rotation logged stands were 12–22 years old. Forested corridors (100–200 m wide) consisted of mature pine (>23 years old) and/or mixed hardwood (>50 years old). Bats were caught with mist nets at nine ponds in open habitat from May–August in 2003–2006. Fifty-three adult evening bats (26 males, 27 females) were tracked to 75 day roosts in trees.

A replicated, paired sites study in 2004–2005 in 32 pairs of forested corridors and logged loblolly pine *Pinus taeda* stands in South Carolina, USA (*3*) found that forested corridor edges had higher overall bat activity than corridor interiors or adjacent logged tree stands. Higher bat activity was recorded along forested corridor edges (54 bat passes/detector/night) than in corridor interiors (7 bat passes/detector/night) or in adjacent logged stands (12 bat passes/detector/night). Six bat species were recorded in total (see original paper for data for individual species). The study area (41,365 ha) was intensively managed for pine production. Thirty-two forested corridors (100–200 m wide) were paired with adjacent logged stands of a similar age. At each of 32 pairs of sites, bat activity was simultaneously recorded with five bat detectors (one on each corridor edge, one in the corridor interior, and two in adjacent logged stands) from two full consecutive nights in June–August 2004 or 2005.

(1) Hein C.D., Castleberry S.B. & Miller K.V. (2008) Sex-specific summer roost-site selection by Seminole bats in response to landscape-level forest management. *Journal of Mammalogy*, 89, 964–972.

(2) Hein C.D., Miller K.V. & Castleberry S.B. (2009) Evening bat summer roost-site selection on a managed pine landscape. *The Journal of Wildlife Management*, 73, 511–517.

(3) Hein C.D., Castleberry S.B. & Miller K.V. (2009) Site-occupancy of bats in relation to forested corridors. *Forest Ecology and Management,* 257, 1200–1207.

6.21. Retain residual tree patches in logged areas

- **Three studies** evaluated the effects of retaining residual tree patches in logged areas on bat populations. The three studies were in Canada[1–3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** Two replicated, site comparison studies in Canada[1,2] found no difference in bat activity (relative abundance) along the edges of residual tree patches and the edges of clearcut blocks. One replicated, site comparison study in Canada[2] found that the activity of smaller bat species was higher along the edge of residual tree patches than in the centre of clearcut blocks, but the activity of larger bat species did not differ. One replicated, controlled study in Canada[3] found that residual tree patches had similar activity of little brown bats and northern long-eared bats and lower activity of silver-haired bats compared to clearcut forest patches.

BEHAVIOUR (0 STUDIES)

Background

Logging by clearcutting results in large open, cleared areas in forests (clearcut blocks). Residual tree patches may be left uncut within these areas.

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared residual tree patches that have been kept intact with similar/nearby areas where tree patches have been cut down or otherwise degraded. There must have been an active decision (i.e. intervention) to retain the residual tree patches and the study must state when the intervention was carried out.

A replicated, site comparison study in 2000 of six sites in logged forest in central British Columbia, Canada (*1*) found that the edges of residual tree patches had similar bat activity to clearcut forest edges. Overall bat activity along residual tree patch edges (49 total bat passes) did not differ significantly to that along clearcut forest edges (110 bat passes). Six residual tree patches (0.5–2 ha) were sampled in six clearcut blocks (105–180 ha, <5 years old) in logged forest (dominated by lodgepole pine *Pinus contorta*). At each of six sites, bat activity was recorded with bat detectors simultaneously along residual tree patch edges and clearcut edges for one night in July–August 2000.

A replicated, site comparison study in 2000 at nine sites in an experimental forest in Alberta Canada (*2*) found that the edges of residual tree patches had higher activity of smaller bat species than the centre of open clearcut blocks, but the activity of larger bat species did not differ. More bat passes of smaller bat species (calls detected at 45 kHz) were recorded along the edges of residual tree patches (average 4 bat passes/hour) and forest edges (5 bat passes/hour) than in the centre of open clearcut blocks (2 bat passes/hour). A similar number of passes of larger bat species (calls detected at 25 kHz) were recorded along residual tree patch edges, forest edges and in the centre of clearcut blocks (data not reported). Residual tree patches were oval (60 x 90 m). At each of nine clearcut blocks (8–10 ha, 1–2 years old), three locations were sampled (forest edge, residual patch edge, centre of clearcut block). Each of three locations within nine clearcut blocks was sampled for 15 minutes 2–3 times in a randomized order during one night in June–July 2000.

A replicated, controlled study in 1998–2000 of 18 deciduous, coniferous and mixed forest sites in Alberta, Canada (*3*) found that residual tree patches had similar activity of two bat species and lower activity of one bat species compared to forest patches that had been cleared. The activity (bat passes/hour) of little brown bats *Myotis lucifugus* and northern long-eared bats *Myotis septentrionalis* was similar within residual tree patches and clearcut patches in all three types of forest (data reported as statistical model results). The activity of silver-haired bats *Lasionycteris noctivagans* was lower within residual tree patches than clearcut patches in all three types of forest. In winter 1998–1999, three patches of forest were left intact (average 974–1,210 stems/ha) and three were cleared in each of three forest types (deciduous, coniferous, mixed). Each of the 18 x 10 ha patches was surrounded by a buffer of intact forest (59–471 m wide). At each of 18 sites, bat activity was recorded with bat detectors at the centre and edge of each patch in June–July 1999 and June–August 2000 for a total of 33–42 nights/site.

(1) Swystun M.B, Syllakis J.M & Brigham R.M. (2001) The influence of residual tree patch isolation on habitat use by bats in central British Columbia. *Acta Chiropterologica,* 3, 197–201.

(2) Hogberg L.K., Patriquin K.J. & Barclay R.M.R. (2002) Use by bats of patches of residual trees in logged areas of the boreal forest. *American Midland Naturalist*, 148, 282–288.

(3) Patriquin K.J. & Barclay R.M.R. (2003) Foraging by bats in cleared, thinned and unharvested boreal forest. *Journal of Applied Ecology*, 40, 646–657.

6.22. Retain riparian buffers in logged areas

- We found no studies that evaluated the effects of retaining riparian buffers in logged areas on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

This intervention involves retaining unlogged buffers along streams and rivers in logged areas. This may provide foraging and roosting opportunities for bats and maintain connectivity in disturbed landscapes. A study in Australia found that riparian buffers in logged areas had similar overall bat activity and species richness to unlogged mature forest (Lloyd *et al.* 2006). See also '*Retain forested corridors in logged areas*'.

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared logged areas where riparian buffers have been kept intact with similar/nearby logged areas where riparian buffers have not been kept. There must have been an active decision (i.e. intervention) to retain the riparian buffer and the study must state when the intervention was carried out.

For a similar intervention relevant to agriculture, see '*Threat: Agriculture – All farming systems – Retain riparian buffers in agricultural areas*'. For an intervention that involves planting riparian buffers to reduce pollution, see '*Threat: Pollution – Agricultural and forestry effluents – Plant riparian buffer strips*'.

Lloyd A., Law B. & Goldingay R. (2006) Bat activity on riparian zones and upper slopes in Australian timber production forests and the effectiveness of riparian buffers. *Biological Conservation,* 129, 207–220.

6.23. Maintain forest and woodland edges for foraging bats

- We found no studies that evaluated the effects of maintaining forest and woodland edges for foraging bats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Edge habitats are important for foraging bats. A study in North America found higher activity of six bat species along forest edges than forest interiors in both unmanaged and thinned forest (Morris *et al*. 2010).

Morris A.D., Miller D.A. & Kalcounis-Rueppell M.C. (2010) Use of forest edges by bats in a managed pine forest landscape. *The Journal of Wildlife Management,* 74, 26–34.

6.24. Manage forest and woodland to encourage understorey growth

- **One study** evaluated the effects of managing forest and woodland to encourage understorey growth on bat populations. The study was in Germany[1].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One paired sites study in Germany[1] found more bat species and higher bat diversity in a forest managed to encourage understorey growth than in a managed forest without understorey growth.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One paired sites study in Germany[1] found higher overall bat activity (relative abundance) in a forest managed to encourage understorey growth than in a managed forest without understorey growth.

BEHAVIOUR (0 STUDIES)

Background

The amount of understorey vegetation within forests and woodland has an influence on insect abundance, predation risk and the ability of bats to access the stand interior. Different bat species have been found to prefer different amounts of understorey vegetation, depending on their wing morphology and foraging strategy (e.g. Jung *et al*. 2012).

Jung K., Kaiser S., Böhm S., Nieschulze J. & Kalko E.K.V. (2012) Moving in three dimensions: effects of structural complexity on occurrence and activity of insectivorous bats in managed forest stands. *Journal of Applied Ecology,* 49, 523–531.

A site comparison study in 2012–2013 of two forest sites in Brandenburg, Germany (*1*) found that a forest managed to encourage understorey growth had higher overall bat activity and more bat species than a managed forest without understorey growth. Overall bat activity (of 11 bat species), the number of bat species recorded and bat diversity (reported as diversity indices) were higher in the forest with understorey growth (average 1.2 bat passes/hour, 3 bat species/night) than the forest without understorey growth (average 0.3 bat passes/hour, 2 bat species/night). One site (1 ha) was sampled in each of two managed forests, a Scots pine *Pinus sylvestris* monoculture stand without understorey, and a Scots pine stand with pedunculate oak *Quercus robur* in the understorey. Sites were selected to ensure they were a similar distance to settlements, water bodies and other land use types. At each of two sites, two bat detectors recorded bat activity simultaneously over a total of 37 nights in May–October 2012 and April–October 2013.

(1) Starik N., Göttert T., Heitlinger E. & Zeller U. (2018) Bat community responses to structural habitat complexity resulting from management practices within different land use types - a case study from north-eastern Germany. *Acta Chiropterologica*, 20, 387–405.

6.25. Coppice woodland

- We found no studies that evaluated the effects of coppicing woodland on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Coppicing involves repeatedly felling trees at the base and allowing them to regrow. The effects on bats are likely to be mixed. Temporarily removing tree cover may be beneficial for bat species that forage in open spaces or along edge habitats. However, coppice with dense regrowth may only be suitable for some bat species that are adapted to cluttered habitats. Older trees retained within coppice may provide roosting opportunities.

6.26. Replant native trees in logged areas

- We found no studies that evaluated the effects of replanting native trees in logged areas on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Replanting native trees in logged areas is likely to provide both foraging and roosting opportunities for bats.

6.27. Encourage natural regeneration in former plantations

- We found no studies that evaluated the effects of encouraging natural regeneration in former plantations on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Encouraging logged plantations to naturally regenerate may provide habitat for bats. Regenerating secondary forests has been found to provide important habitats for some bat species in fragmented landscapes, although it may take many years for bat assemblages to recover to levels found in undisturbed forest (e.g. Farneda *et al.* 2018, Rocha *et al.* 2018).

Farneda F.Z., Rocha R., López-Baucells A., Sampaio E.M., Palmeirim J.M., Bobrowiec P.E.D., Grelle C.E.V. & Meyer C.F.J. (2018) Functional recovery of Amazonian bat assemblages following secondary forest succession. *Biological Conservation,* 218, 192–199.

Rocha R., Ovaskainen O., López-Baucells A., Farneda F.Z., Sampaio E.M., Bobrowiec P.E.D., Cabeza M., Palmeirim J.M. & Meyer C.F.J. (2018) Secondary forest regeneration benefits old-growth specialist bats in a fragmented tropical landscape. *Scientific Reports,* 8, 3819.

6.28. Strengthen cultural traditions such as sacred groves that prevent timber harvesting

- We found no studies that evaluated the effects of strengthening cultural traditions such as sacred groves that prevent timber harvesting on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Strengthening cultural traditions such as protecting sacred groves may help to prevent timber harvesting and protect important bat habitats.

7. Threat: Human intrusions and disturbance

In addition to large-scale disturbances from activities such as agriculture, building developments, energy production and biological resource use, disturbance of bat populations can come from smaller scale human intrusions, such as caving activities and tourism.

For general interventions that may help reduce disturbance to bats, see also '*Habitat protection*' and '*Education and awareness raising*'.

Caving and tourism

7.1. Retain bat access points to caves

- We found no studies that evaluated the effects of retaining bat access points to caves on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Access points may be retained within caves to allow continued use by roosting bats. For a similar intervention, see '*Threat: Energy production and mining – Mining – Retain access points for bats following mine closures*'.

7.2. Install and maintain cave gates to restrict public access

- **Eleven studies** evaluated the effects of installing cave gates on bat populations. Six studies were in the USA[2–5,7,10] and five were in Europe[1,6,8,9,11].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (7 STUDIES)

- **Abundance (7 studies):** Three of four before-and-after studies (including one replicated study and one controlled study) in the Netherlands[1], the USA[5], Spain[8] and Turkey[9] found more[1,5,9] or similar numbers[5] of bats in caves and a bunker[1] after gates were installed to restrict public access. The other study[8] found fewer bats in caves after gates were installed. Two before-and-after studies in the USA[3] and Spain[8] found more bats within two caves after the size of the gated entrances were increased. One replicated, before-and-after study in the USA[10] found that installing cave gates resulted in population increases or decreased rates of decline for 13 of 20 colonies of Indiana bat. One replicated, site comparison study in Spain[11] found no difference in the population growth rates of bats roosting in caves with and without cave gates.

- **Condition (1 study):** One site comparison study in the USA[3] found that bats hibernating in a cave with a wall and gate over the entrance lost more body mass than bats in a nearby unmodified cave.

BEHAVIOUR (5 STUDIES)

- **Use (1 study):** One replicated, site comparison study in Spain[11] found no difference in the occupancy rates of bats roosting in caves with and without cave gates.
- **Behaviour change (4 studies):** One replicated, controlled, before-and-after and site comparison study in the USA[7] found that bats at cave entrances circled more and entered caves less after gates were installed. One replicated study in the USA[2] found that bats flew through gates with a funnel design more frequently than gates with a round bar or angle iron design. One randomized, controlled, before-and-after study in the UK[6] found that fewer bats flew through cave gates when the spacing between horizontal bars was reduced. One before-and-after study in the USA[4] found that fewer bats emerged from a cave with a gate installed compared with a cave with a fence.

Background

Recreational users of caves can disturb both nursing and hibernating colonies of bats causing abandonment of young or arousal from hibernation. Gates have been installed at cave entrances to restrict public access and reduce human disturbance. However, cave gating can also impede access by bats and early installation attempts from the 1950s to the 1970s often resulted in roost abandonment (Tuttle 1977). For evidence relating to gates at mines, see '*Threat: Energy production and mining – Mining – Install and maintain gates at mine entrances to restrict public access*'.

Tuttle M.D. (1977) Gating as a means of protecting cave dwelling bats. Pages 77–82 in: T. Aley & D. Rhodes (eds.) *1976 National Cave Management Symposium Proceedings*, Speleobooks, Albuquerque, USA.

A controlled, before-and-after and site comparison study in 1976–1984 in four abandoned underground war bunkers in the Netherlands (*1*) found that the number of hibernating bats at three bunkers increased after human access had been restricted by installing grilles or sealing entrances, and the number of bats in one unmodified bunker remained constant. The number of hibernating bats in three bunkers increased over one and a half years after grilles were installed or entrances were sealed (before: 15–35 bats; after: 30–115 bats). Bat numbers at a fourth bunker with no restrictions in place remained constant (1976: 12 bats; 1984: 13 bats). At least five bat species were counted (see original paper for data for individual species). Bunker entrances were either sealed completely or grilles of vertical bars were installed in 1977 or 1980. Sand and debris were also removed from one of the bunkers. The individual effects of each intervention were not reported. At each of four bunkers, annual winter counts were conducted from 1976 or 1978 until 1984.

A small replicated study in 1985 at two caves in Alabama and West Virginia, USA (*2*) found that Townsend's big-eared bats *Plecotus townsendii* and gray myotis bats *Myotis grisescens* flew more frequently through test frames at gated cave entrances with a round bar design or angle iron design than a funnel design. A greater proportion of Townsend's big-eared bats and gray myotis bats flew through test frames with a round bar design (average 40% of big-eared bats and 20% of gray myotis bats exiting through the cave entrance), or angle iron design (21% of big-eared bats and 16% of gray myotis) than a funnel design (7% of big-eared bats, 2% of gray myotis). At one entrance at each of two caves, a 1 m^2 test frame was installed in front of an existing gate with a round bar design. Inserts of three different designs were installed in the frames: round bar (19 mm round steel bars in a 615 x 154 mm pattern), angle iron (103 mm angle iron welded 154 mm apart in a horizontal pattern) and funnel (a 1 m^2 one-way metal funnel narrowing to an exit hole of 230 x 230 mm). Each of three designs was tested for a total of 25 nights/cave in May–August 1985. At dusk, bats were counted emerging through the frame and the remainder of the cave entrance.

A before-and-after and site comparison study in 1976–1991 in two caves in Indiana, USA (*3*) found that Indiana bats *Myotis sodalis* hibernating within a cave modified with a stone wall and gate constructed at the entrance entered hibernation at a 5% higher body mass and lost 42% more body mass than bats in an unmodified cave 4 km away. The stone wall and gate in the modified cave restricted the cave opening by 62% reducing airflow and resulting in average winter temperatures 5°C higher than in the unmodified cave. In 1977, the stone wall was removed and replaced with steel bars. From 1977 to 1991, the population of Indiana bats in the cave increased from 2,000 to 13,000 bats. In each of two caves, temperatures were measured near to hibernation sites every other week, and bats were counted and weighed in early winter (October–November 1976) and late winter (March 1977). Bats were monitored with a biannual census from 1977 to 1991 (no other details reported).

A before-and-after study in 1994–1996 at one cave on a forested limestone ridge in north Florida, USA (*4*) found that a steel bar gate across the cave entrance resulted in fewer southeastern myotis bats *Myotis austroriparius* and gray myotis bats *Myotis grisescens* emerging than when the gate was replaced with a fence. Fewer bats emerged from the cave entrance when it had a steel bar gate across it (average 306 bats/month, 8% of total bats emerging from cave) than when the gate was replaced with a fence (average 1,517 bats/month, 48% of total bats emerging). The number of bats emerging from a second un-gated entrance to the cave decreased after the gate was replaced with a fence (from 3,609 to 1,651 bats/month). The cave gate consisted of steel bars 13 mm in diameter spaced 100 mm apart in one direction and 465 mm in the other. Before removal of the gate a 2.2 m high chain-link fence was erected 6–8 m from the cave entrance. Emerging bats were counted monthly at the open entrance and gated entrance for one year before and one year after the cave gate was removed (August 1994 to July 1996).

A replicated, before-and-after study in 1981–2001 at five caves in a limestone plateau in northeastern Oklahoma, USA (*5*) found that after cave gates were installed the number of gray myotis bats *Myotis grisescens* increased at two caves and remained similar at three caves. After cave gates were installed, the number of gray myotis bats was estimated to increase at two caves (before: 3,031–15,047 bats; after: 12,500–32,136 bats) and remain similar at three caves (before: 3,693–18,031 bats; after: 3,721–9,533 bats). At each of six caves, gates were installed (horizontal angle-iron bars and 150 mm spacing) in different years between 1981 and 2000. Numbers of gray myotis bats in each of six caves were estimated during the summers of 1981–1983, 1991, 1999 and 2001 from the size of guano accumulation.

A randomized, controlled, before-and-after study in 2004 at a cave in a wooded limestone valley in northern England, UK (*6*) found that cave gates with horizontal bar spacings of 130 mm and 100 mm caused more bats to abort attempts to enter the cave through the gate, but gates with spacings of 150 mm had no effect on bat behaviour. The proportion of bats entering the cave decreased after gates were installed with horizontal spacings of 130 mm (without gate: 0.20–0.28 bats/30 min; with gate: 0.07 bats/30 min) and 100 mm (without gate: 0.20 bats/30 min; with gate: 0.08 bats/30 min). Gates with horizontal spacings of 150 mm had no significant effect (without gate: 0.14–0.16 bats/30 min; with gate: 0.10 bats/30 min). Bat behaviour was similar before the gates were installed and after they were removed. One cave entrance was used for the experiments (1.5 m diameter) with custom made gates (made with 15 mm diameter plastic tubing) of each of three horizontal spacings (100, 130 and 150 mm) positioned over it. Bats were recorded for 3 x 30-minute periods with the gate open ('before'), closed, and open again ('after'). The behaviour of swarming bats (mostly Natterer's bats *Myotis nattereri*) was observed on 6–10 nights for each of three gate designs using night video recording, with gate size randomized between nights.

A replicated, controlled, before-and-after and site comparison study in 2003 at 28 cave and mine sites between Ontario, Canada and Tennessee, USA (*7*) found that at cave and mine entrances with gates, bats circled, retreated more and passed through less often than at ungated entrances. Bats circled and retreated more and passed through less at entrances with existing cave gates (37% of bats circled and retreated, 50% passed through) or newly installed mock gates (60% circled and retreated, 25% passed through) than at ungated entrances (23% circled and retreated, 68% passed through). Separate results for caves and mines were not provided. Seven caves or mines had existing gates (of various designs), twelve caves or mines were ungated and had mock wooden gates installed (horizontal bars 25 mm diameter with 146 mm spacing). Ungated entrances were surveyed before and after mock gates were installed. At each of 28 sites, observations of behaviour were made during 3–4 x 5-minute periods during 1–2 nights in July–October 2003.

A before-and-after study in 1998–2009 and 2010 in one cave in Castile and León, Spain (*8*) found fewer bent-wing bats *Miniopterus schreibersii* using a cave after the installation of a cave gate with a narrow entrance. Between six and nine years after the installation of a cave gate with a narrow entrance, fewer bent-wing bats were counted using the cave than before the installation of the gate (before: 600–700 bats; after: 200–280 bats), but statistical tests were not carried out. However, >450 bent-wing bats were counted seven months after the gated opening was enlarged. In 2001, a cave gate covering 75% of the cave entrance was fitted to a small cave. In March 2010, the cave gate opening was enlarged from 3.5 x 1 m to 7 x 2 m. Bats were counted approximately once/month in 2010 using infrared lights. Data were compared to previously published bat counts at the cave from 1998–2009.

A before-and-after study in 2002–2008 at a cave system in forested mountains of Turkey (*9*) found that installing cave gates, along with other restrictions to reduce human disturbance, resulted in an increase in the number of 15 bat species using two caves in the system. Maximum counts of bats in the two caves were higher after the cave system was opened to tourism and cave gates and other restrictions were put in place (before: 42,800 hibernating and 7,900 breeding bats; after: 54,600 hibernating and 11,000 breeding bats). The study does not distinguish between the effects of cave gating and other interventions carried out at the same time. A third cave in the system, which remained ungated and closed to tourism, had similar numbers of bats throughout the study period. Before opening to tourism, recreational users had made frequent uncontrolled visits to the caves. After opening for tourism in 2003, gates were installed on two cave entrances (horizontal iron bars with 200 mm spacing), daily and seasonal timing of tourist visits were controlled, information signs were erected, and lights were switched off outside of visiting times. Bat colonies were counted every 40 days with 15 surveys before (2002–2004) and 38 surveys after opening to tourism (2004–2008). Update 2018: The findings of this study have been challenged, see Furman *et al.* 2012.

Furman A., Çoraman E. & Bilgin R. (2012) Bats and tourism: a response to Paksuz & Özkan. *Oryx,* 46, 330–330.

A replicated, before-and-after study in 1979–2009 of 20 caves in the USA (*10*) found that installing cave gates resulted in population increases or decreased rates of decline for 13 of 20 colonies of Indiana bat *Myotis sodalis*. Thirteen of the populations were declining before cave gates were installed, and either increased (8 populations) or continued to decline at a reduced rate (5 populations) after installation (data reported as statistical model results). Seven of the populations were increasing before cave gates were installed, and either declined (4 populations) or continued to increase at a reduced rate (3 populations) after installation (data reported as statistical model results). Annual population counts were carried out between 1979 and 2009 using a standard protocol before (during 4–15 years) and after (during 4–16 years) installation of cave gates. All caves had average populations of >100 individuals. Change-point detection modelling was used to estimate population trends. The authors state that confounding factors, such as gate design, human activities and regional differences were not accounted for.

A replicated, site comparison study in 1997–2014 of 34 caves in eastern Spain (*11*) found that installing cave gates or fencing did not affect the occupancy or population growth rates of nine bat species. Average occupancy rates were similar in caves with (11 of 20, 57% of caves occupied) and without (8 of 14, 60% of caves occupied) gates or fencing (separate results for cave gates and fencing not reported). Population growth rates also did not differ significantly between caves with or without gates or fencing (data reported as statistical model results). Fourteen caves had fencing installed (2.5 m high gridded metal fences in a 20 m radius around the cave entrance), two caves had rigid panels installed (filling three-quarters of the cave entrance), two caves had iron bars installed (filling the entire cave entrance), and two caves had cave gates installed (with 2 x 1 m^2 openings for bats). Fourteen caves did not have gates or fencing installed. Bats were counted annually using infrared video cameras and bat detectors at cave entrances between May and July in 1997–2014.

(1) Voûte A.M. & Lina P.H.C. (1986) Management effects on bat hibernacula in the Netherlands. *Biological Conservation*, 38, 163–177.

(2) White D.H. & Seginak J.T. (1987) Cave gate designs for use in protecting endangered bats. *Wildlife Society Bulletin,* 15, 445–449.

(3) Richter A.R., Humphrey S.R., Cope J.B. & Brack V. (1993) Modified cave entrances: thermal effect on body mass and resulting decline of endangered Indiana bats (*Myotis sodalis*). *Conservation Biology*, 7, 407–415.

(4) Ludlow M.E. & Gore J.A. (2000) Effects of a cave gate on emergence patterns of colonial bats. *Wildlife Society Bulletin,* 28, 191–196.

(5) Martin K.W., Leslie D.M., Payton M.E., Puckette W.L. & Hensley S.L. (2003) Internal cave gating for protection of colonies of the endangered gray bat (*Myotis grisescens*). *Acta Chiropterologica,* 5, 143–150.

(6) Pugh M. & Altringham J.D. (2005) The effects of gates on cave entry by swarming bats. *Acta Chiropterologica*, 7, 293–300.

(7) Spanjer G.R. & Fenton M.B. (2005) Behavioral responses of bats to gates at caves and mines. *Wildlife Society Bulletin,* 33, 1101–1112.

(8) Alcalde J.T., Artácoz A., & Meijide F. (2012) Recovery of a colony of *Miniopterus schreibersii* from a cave, Cueva de Ágreda, in Soria. Recuperación de la colonia de *Miniopterus schreibersii* de la cueva de Cueva de Ágreda (Soria). *Barbastella*, 5, 32–35.

(9) Paksuz S. & Özkan B. (2012) The protection of the bat community in the Dupnisa Cave System, Turkey, following opening for tourism. *Oryx*, 46, 130–136.

(10) Crimmins S.M., McKann P.C., Szymanski J.A. & Thogmartin W.E. (2014) Effects of cave gating on population trends at individual hibernacula of the Indiana bat (*Myotis sodalis*). *Acta Chiropterologica,* 16, 129–137.

(11) Machado M.C., Monsalve M.A., Castello A., Almenar D., Alcocer A. & Monros J.S. (2017) Population trends of cave-dwelling bats in the Eastern Iberian Peninsula and the effect of protecting their roosts. *Acta Chiropterologica,* 19, 107–118.

7.3. Install fencing around cave entrances to restrict public access

- **Two studies** evaluated the effects of installing fencing around cave entrances on bat populations. One study was in the USA[1] and one in Spain[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Spain[2] found no difference in the population growth rates of bats roosting in caves with and without fencing or gates installed.

BEHAVIOUR (2 STUDIES)

- **Use (1 study):** One replicated, site comparison study in Spain[2] found no difference in the occupancy rates of bats roosting in caves with and without fencing or gates installed.
- **Behaviour change (1 study):** One controlled, before-and-after study in the USA[1] found that more southeastern myotis bats and gray myotis bats emerged from a cave after a steel gate was replaced with a fence.

Background

Fencing may be installed around cave entrances to restrict public access and reduce disturbance to cave-dwelling bats.

A controlled, before-and-after study in 1994–1996 at one cave on a forested limestone ridge in north Florida, USA (*1*) found that replacing a steel bar gate with a fence resulted in more southeastern myotis bats *Myotis austroriparius* and gray myotis bats *Myotis grisescens* emerging from the cave entrance. More bats emerged from the cave entrance when a fence was installed (average 1,517 bats/month, 48% of total bats emerging) instead of a steel bar gate (306 bats/month, 8%). The number of bats emerging from a second ungated open entrance to the cave decreased after the gate was replaced with a fence (from 3,609 to 1,651 bats/month). The cave gate consisted of steel bars 13 mm in diameter spaced 100 mm apart in one direction and 465 mm in the other. Before removal of the gate a 2.2 m high chain-link fence was erected 6–8 m from the cave entrance. Emerging bats were counted monthly at the gated entrance and the open entrance for one year before and one year after the cave gate was removed and replaced with a fence (August 1994 to July 1996).

A replicated, site comparison study in 1997–2014 of 34 caves in eastern Spain (*2*) found that installing fencing or cave gates did not have a significant effect on the occupancy or population growth rates of nine bat species. Average occupancy rates were similar in caves with (11 of 20, 57% of caves occupied) and without (8 of 14, 60% of caves occupied) gates or fencing (separate results for cave gates and fencing not reported). Population growth rates also did not differ significantly between caves with or without fencing or gates (data reported as statistical model results). Fourteen caves had fencing installed (2.5 m high gridded metal fences in a 20 m radius around the cave entrance), two caves had rigid panels installed (filling three-quarters of the cave entrance), two caves had iron bars installed (filling the entire cave entrance), and two caves had cave gates installed (with 2 x 1 m^2 openings for bats). Fourteen caves did not have fencing or gates installed. Bats were counted annually using infrared video cameras and bat detectors at cave entrances between May and July in 1997–2014.

(1) Ludlow M.E. & Gore J.A. (2000) Effects of a cave gate on emergence patterns of colonial bats. *Wildlife Society Bulletin,* 28, 191–196

(2) Machado M.C., Monsalve M.A., Castello A., Almenar D., Alcocer A. & Monros J.S. (2017) Population trends of cave-dwelling bats in the Eastern Iberian Peninsula and the effect of protecting their roosts. *Acta Chiropterologica,* 19, 107–118.

7.4. Impose restrictions on cave visits

- **Four studies** evaluated the effects of imposing restrictions on cave visits on bat populations. One study was in each of the USA[1], Canada[2], Madagascar[3], and Turkey[4].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** Two before-and-after studies in Canada[2] and Turkey[4] found that bat populations within caves increased after restrictions on cave visitors were imposed.

BEHAVIOUR (2 STUDIES)

- **Behaviour change (2 studies):** One study in the USA[1] found that reducing the number of people within cave tour groups did not have a significant effect on the number of take-offs, landings or overall activity (bat movements) of a cave myotis colony roosting within the cave. One study in Madagascar[3] found that increasing visitor approach distances, along with avoiding direct illumination of bats, reduced the alertness and number of take-offs of Madagascan rousettes during experimental cave tours.

Background

Cave visits by recreational users may be restricted to reduce disturbance to bat colonies. Examples of such restrictions are seasonal and daily timing of visits to avoid times when bats are vulnerable, closure to parts of caves close to bat colonies, time limits on visits, supervision of visitors by guides or security guards, and restrictions on the use of lights within caves. Often several restrictions will be used in conjunction and the individual effects of each cannot be distinguished. Relevant individual interventions are also discussed separately in this chapter.

A study in 1997–1998 in one cave in Arizona, USA (*1*) found that reducing the number of people within cave tour groups did not have a significant effect on the number of take-offs, landings or overall activity of a roosting cave myotis *Myotis velifer* colony. A similar number of take-offs and landings were observed, and a similar proportion of the colony was active when tour groups had 1–3 people or 6–8 people (data reported as statistical model results). A colony of 1,000 cave myotis bats roosted in a large cluster within one room of the cave. Experimental tours were carried out through the room with five replicates of each of 24 treatment combinations. Treatments included size of tour group (0, 1–3 or 6–8 people), light intensity and colour (no light, low intensity white light, full red light, full white light), and voice intensity (no people talking, all members of group talking). A total of 120 experimental cave tours were carried out between April and September in 1997 and 1998. Bat behaviour was observed with a night-vision video camera and infrared lights.

A before-and-after study in 1983–2009 at one cave in the Rocky Mountains, Canada (*2*) found that enforcing restrictions on cave visitors resulted in more bats hibernating within the cave. An average of approximately 450 bats/year hibernated in the cave before restrictions were enforced, and 650 bats/year after. The cave (length 2791 m, depth 220 m) was highly popular with recreational visitors. In 1997, seasonal access restrictions were imposed. In 1998, the area was established as a National Park and signs were erected to inform the public about access restrictions. Active enforcement to restrict recreational visitors in winter months began in 2000. An annual census of visual counts of hibernating bats was carried out in 11 chambers within the cave from 1983 to 2000, followed by a census every other year until 2009.

A study in 2004–2005 in one cave in northern Madagascar (*3*) found that increasing visitor approach distances, along with avoiding direct illumination of bats, reduced the alertness and number of take-offs of Madagascan rousettes *Rousettus madagascariensis* during tours. When visitors approached to 12–14 m and did not directly illuminate the bats, the proportion of alert bats (with eyes open; reported as eye-shine ratios) and the average number of take-offs was similar during tours (3 take-offs) compared to before (2 take-offs) and after (4 take-offs). Whereas when visitors approached to 5–6 m and shone headlamps on the bats, there were more alert bats and take-offs during tours (37 take-offs) than before or after (both 1 take-off). Approaching to 12–14 m with direct illumination and approaching to 5–6 m without direct illumination also resulted in more alert bats and/or take-offs during tours than before or after (see original paper for data). A colony of 2,500 Madagascan rousettes roosted in the cave, frequently visited by tourists. Experimental tours were carried out with three replicates of each of four treatment combinations. Groups of three visitors approached bats roosting on the cave wall to 5–6 m or 12–14 m and either directly illuminated bats for one minute (with three LED headlamps, total 4–8 lux) or shone headlamps downwards only. Bat behaviour was recorded with an infrared video camera for 15 minutes before, during and after each of the 12 experimental tours in June–July 2004 and July 2005.

A before-and-after study in 2002–2008 at a cave system in forested mountains of Turkey (*4*) found that restrictions put in place to reduce human disturbance resulted in an increase in the number of 15 bat species using two caves in the system. Maximum counts of bats in the two caves were higher after the cave system was opened to tourism and restrictions were put in place (before:

42,800 hibernating and 7,900 breeding bats; after: 54,600 hibernating and 11,000 breeding bats). A third cave in the system, which remained closed to tourism, had similar numbers of bats throughout the study period. Before opening to tourism, recreational users had made frequent uncontrolled visits to the caves. After opening for tourism in 2003, gates were installed on two entrances, daily and seasonal timing of visits were controlled by security guards, tourists were guided along set routes away from colonies with time limits for visits, information signs were erected, and lights were switched off outside of visiting times. The study does not distinguish between the effects of different restrictions carried out at the same time Bat colonies were counted every 40 days with 15 surveys before (2002–2004) and 38 surveys after opening to tourism (2004–2008). Update 2018: The findings of this study have been challenged, see Furman *et al.* 2012.

Furman A., Çoraman E. & Bilgin R. (2012) Bats and tourism: a response to Paksuz & Özkan. *Oryx,* 46, 330–330.

(1) Mann S.L., Steidl R.J. & Dalton V.M. (2002) Effects of cave tours on breeding *Myotis velifer*. *The Journal of Wildlife Management,* 66, 618–624.
(2) Olson C.R., Hobson D.P., & Pybus M.J. (2011) Changes in population size of bats at a hibernaculum in Alberta, Canada, in relation to cave disturbance and access restrictions. *Northwestern Naturalist*, 92, 224–230.
(3) Cardiff S.G., Ratrimomanarivo F.H. & Goodman S.M. (2012) The effect of tourist visits on the behavior of *Rousettus madagascariensis* (Chiroptera: Pteropodidae) in the caves of Ankarana, northern Madagascar. *Acta Chiropterologica*, 14, 479–490.
(4) Paksuz S. & Özkan B. (2012) The protection of the bat community in the Dupnisa Cave System, Turkey, following opening for tourism. *Oryx*, 46, 130–136.

7.5. Inform the public of ways to reduce disturbance to bats in caves (e.g. use educational signs)

- We found no studies that evaluated the effects of informing the public of ways to reduce disturbance to bats in caves on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Educational or informative signs for the public are often used at bat hibernation sites in conjunction with other interventions to reduce human disturbance. See also '*Impose restrictions on cave visits*'.

7.6. Train tourist guides to minimize disturbance and promote bat conservation

- We found no studies that evaluated the effects of training tourist guides to minimize disturbance and promote bat conservation on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Tourist guides may be trained to minimize disturbance to cave-dwelling bats during cave visits, and to promote bat conservation.

7.7. Minimize alterations to caves for tourism

- We found no studies that evaluated the effects of minimizing alterations to caves for tourism on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Alterations to caves may disturb bats and modify cave microclimates.

7.8. Restrict artificial lighting in caves and around cave entrances

- **One study** evaluated the effects of restricting artificial lighting in caves on bat populations. The study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One controlled study in the USA[1] found that using low intensity white lights or red lights in caves resulted in fewer bat flights than with full white lighting, but the number of bat movements was similar between all three light treatments.

Background

Artificial lighting may disturb bats within caves, causing arousal during hibernation or roost abandonment. Lighting restrictions are often used alongside other interventions to reduce disturbance. See also '*Impose restrictions on cave visits*'.

A controlled study in 1997–1998 in one cave in Arizona, USA (*1*) found that using low intensity white lights or red lights within the cave resulted in fewer flights by roosting cave myotis bats *Myotis velifer* than when full white lighting was used, but the number of bat movements was similar between all three light treatments. When compared with full intensity white lighting, low intensity white lights or red lights resulted in fewer take-offs (full white: 23; low white: 12; red: 14) and landings (full white: 20; low white: 11; red: 12). However, the overall activity of the colony (all bat movements) did not differ between the three light treatments (full white: 64% of the colony active; low white: 62%; red: 63%). All three measures of bat activity were lowest when no lighting was used (take-offs: 9; landings: 9; proportion active: 54%). A colony of 1,000 cave myotis bats roosted in a large cluster within one room of the cave. Experimental tours were carried out through the room with five replicates of each of 24 treatment combinations. Treatments included light intensity and colour (no light, low intensity white light, full red light, full white light), size of tour group (0, 1–3 or 6–8 people), and voice intensity (no people talking, all members of group talking). A total of 120 experimental cave tours were carried out between April and September in 1997 and 1998. Bat behaviour was observed with a night-vision video camera and infrared lights.

(1) Mann S.L., Steidl R.J. & Dalton V.M. (2002) Effects of cave tours on breeding *Myotis velifer*. *The Journal of Wildlife Management,* 66, 618–624.

7.9. Minimize noise levels within caves

- **One study** evaluated the effects of minimizing noise levels within caves on bat populations. The study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One controlled study in the USA[1] found that experimental cave tours with groups that did not talk resulted in fewer bat flights than when groups did talk, but talking did not have an effect on the number of bat movements.

Background

Noise may disturb bats within caves, causing arousal during hibernation or roost abandonment. Noise levels may be minimised by restricting the number or timing of tourist visits or by asking tourists to remain quiet during tours. See also '*Impose restrictions on cave visits*'.

A controlled study in 1997–1998 in one cave in Arizona, USA (*1*) found that experimental cave tours with groups that did not talk resulted in fewer take-offs and landings by a roosting cave myotis *Myotis velifer* colony than when groups did talk, but talking did not have a significant effect on overall colony activity. Bats had fewer take-offs and landings when groups did not talk (take-offs: average 13; landings: average 12) than when all members of the group talked (take-offs: average 16; landings: average 14). Overall activity of the colony (all bat movements) was similar when groups did not talk (average 59% of colony active) or when all members of the group talked (62%). A colony of 1,000 cave myotis bats roosted in a large cluster within one room of the cave. Experimental tours were carried out through the room with five replicates of each of 24 treatment combinations. Treatments included voice intensity (no people talking, all members of group talking), light intensity and colour (no light, low intensity white light, full red light, full white light), and size of tour group (0, 1–3 or 6–8 people). A total of 120 experimental cave tours were carried out between April and September in 1997 and 1998. Bat behaviour was observed with a night-vision video camera and infrared lights.

(1) Mann S.L., Steidl R.J. & Dalton V.M. (2002) Effects of cave tours on breeding *Myotis velifer*. *The Journal of Wildlife Management,* 66, 618–624.

7.10. Introduce guidelines for sustainable cave development and use

- We found no studies that evaluated the effects of introducing guidelines for sustainable cave development and use on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Introducing specific guidelines for sustainable cave development and use in relation to bats may help to reduce disturbance.

7.11. Provide artificial subterranean bat roosts to replace roosts in disturbed caves

- We found no studies that evaluated the effects of providing artificial subterranean bat roosts to replace roosts in disturbed caves on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Artificial subterranean bat roosts could be provided to replace roosts in disturbed caves. Similar interventions are described in '*Threat: Energy production and mining – Mining – Provide artificial subterranean bat roosts to replace roosts in reclaimed mines*' and '*Habitat restoration and protection – Create artificial caves or hibernacula for bats*'.

7.12. Restore and maintain microclimate in modified caves

- We found no studies that evaluated the effects of restoring and maintaining the microclimate in modified caves for roosting bats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Modifying caves may alter the internal microclimate and make conditions unsuitable for roosting bats. It is important that the microclimate is maintained following any modification. Restoring the microclimate of altered caves may also encourage cave-dwelling bats to return to abandoned roosts.

For a similar intervention, see '*Threat: Energy production and mining – Mining – Maintain microclimate in closed/abandoned mines*'. See also '*Install and maintain cave gates to restrict public access*' for one study in which a stone wall and gate influenced the microclimate of a cave with an effect on hibernating bats.

8. Threat: Natural system modifications

This chapter includes threats from actions that convert or degrade habitat as part of the management of natural or semi-natural systems, often to improve human welfare. This includes supressing or increasing the intensity of fires and changing the natural flow of water.

Fire or fire suppression

8.1. Use prescribed burning

- **Fifteen studies** evaluated the effects of prescribed burning on bat populations. Thirteen studies were in the USA[1-7,9–14] and two were in Australia[8,15].

COMMUNITY RESPONSE (2 STUDIES)

- **Community composition (2 studies):** One of two replicated studies (one before-and-after with paired sites, one site comparison) in Australia[8,15] found that the composition of bat species differed between burned and unburned woodland sites[8]. The other study[15] found that the composition of bat species was similar between unlogged forest blocks burned every two or four years and unburned blocks.
- **Richness/diversity (1 study):** One replicated, randomized, site comparison study in Australia[15] found more bat species in unlogged forest blocks burned every four years than in blocks burned every two years or unburned blocks.

POPULATION RESPONSE (9 STUDIES)

- **Abundance (9 studies):** Two replicated, site comparison studies (including one controlled study) in the USA[7,9] found that the activity (relative abundance) of open habitat bat species[7] and evening bats[9] increased with the number of prescribed fires, but there was no effect on other bat species, including cluttered habitat bat species[7]. Four replicated, before-and-after or site comparison studies (including two controlled studies) in the USA[11,12] and Australia[8,15] found that prescribed burning[8,12], prescribed burning along with thinning[11] or prescribed burning every four years[15] resulted in higher overall bat activity[8,11,15] or activity of Florida bonneted bats[12]. One site comparison study in the USA[6] found that two of seven sites that had been burned alongside other restoration practices had higher bat activity than unrestored sites. One replicated, randomized, site comparison study in the USA[10] found that three of four burning and thinning treatments resulted in higher overall bat activity. One replicated, controlled, site comparison study in the USA[2] found similar activity of three bat species in burned and unburned tree stands.

BEHAVIOUR (6 STUDIES)

- **Use (5 studies):** One replicated, controlled before-and-after study in the USA[4] found that more female northern myotis bats roosted in burned than unburned forest. Two replicated, controlled, site comparison studies in the USA[3,5] found that fewer female northern myotis bats[3] and male Indiana bats[5] roosted in burned than unburned forest. One replicated study in the USA[1] found that evening bats roosted in burned but not unburned forest. One replicated, paired sites study in the USA[13] found that burned sites had a higher occupancy of five bat species/species groups than unburned sites, and burn severity had a negative effect on the occupancy of two bat species/species groups.

- **Behaviour change (4 studies):** Two replicated, controlled, site comparison studies in the USA[3,5] found no difference in roost switching frequency or the distance between roost trees for female northern myotis bats[3] and male Indiana bats[5] in burned and unburned forests. One replicated, controlled, before-and-after study in the USA[4] found that female northern myotis home ranges and core areas did not differ in size between burned and unburned forests, but home ranges were closer to burned forest than unburned forest. One replicated, site comparison study in the USA[14] found that home ranges of female Rafinesque's big-eared bats were located similar distances to burned and unburned forest, and male home ranges were closer to unburned forest.

Background

Prescribed burning is a practice used in forest management where controlled burns are conducted to reduce the risk of more damaging uncontrolled natural fires and to stimulate tree germination. Controlled burning alters forest structure, opens up the tree canopy and creates potential roosts in snags.

Although prescribed or controlled burning may benefit bats, there may also be negative effects such as heat injury, smoke and carbon monoxide poisoning, and arousal from torpor. Consideration must be given to fire intensity, ignition procedures and seasonal timing of burns (Dickinson *et al.* 2010).

Dickinson M.B., Norris J.C., Bova A.S., Kremens R.L., Young V. & Lacki M.J. (2010) Effects of wildland fire smoke on a tree-roosting bat: integrating a plume model, field measurements, and mammalian dose-response relationships. *Canadian Journal of Forest Research*, 40, 2187–2203.

A replicated study in 2003–2004 in a deciduous forest in Missouri, USA (*1*) found that evening bats *Nycticeius humeralis* roosted only in areas of the forest where prescribed burning had occurred. Twenty-three bats were tracked to 63 tree roosts in burned areas, and no roosts were found in unburned areas. The burned area of the forest had a more open canopy and more dead trees than the unburned area. Prescribed burning began in 1999 after 50 years of fire suppression and was done every two years in March or April in 55% of the study area. Bats were caught from March 2003 to March 2004 using mist nets across forest roads between the burned and unburned areas of the 1,200-ha forest and in 2–3 ponds or roads in both areas. Twenty-three bats (11 females and 12 males) were fitted with radio-transmitters and tracked to roost trees each day until the transmitter was shed or expired.

A replicated, controlled, site comparison study in 2001–2002 in nine pine forest sites in South Carolina, USA (*2*) found that burned tree stands had similar activity of three bat species to unburned control tree stands, and two bat species had higher activity in thinned stands than burned stands. Activity of big brown bats *Eptesicus fuscus*, eastern red bats *Lasiurus borealis* and eastern pipistrelles *Perimyotis subflavus* did not differ significantly between burned tree stands (big brown bats: average 0.3 bat passes/night; red bats: 0.3 bat passes/night; eastern pipistrelles: 0.1 bat passes/night) and unburned control stands (big brown bats: 0.1 bat passes/night; red bats: 0.5 bat passes/night; eastern pipistrelles: 0.1 bat passes/night). Activity was higher in thinned tree stands than burned stands for big brown bats (1.2 bat passes/night) and eastern red bats (0.7 bat passes/night), but similar for eastern pipistrelles (0.4 bat passes/night). Nine 14 ha stands (loblolly pine *Pinus taeda* and shortleaf pine *Pinus echinata*) were surveyed with three replicates of three treatment types: thinning to an average of 576 live trees/ha (in winter 2000–2001), prescribed burning (burned in April 2001 with strip head fire and flanking fires, average 532 live trees/ha), and a control with no treatment (average 755 live trees/ha). Bat activity was sampled with two bat detectors at random points in each of 12 stands for two full nights/month from May–August 2001 and 2002.

A replicated, controlled, site comparison study in 2007–2008 of four mixed forest sites in West Virginia, USA (*3*) found female northern myotis bats *Myotis septentrionalis* roosting in tree stands treated with prescribed fire and in unburned forest, and roost switching frequency and the distance between roost trees did not differ between burned and unburned forest. Twenty-five roosts were in burned tree stands and 44 in unburned forest, but the difference was not tested for statistical significance. Roost switching frequency and the distance between roost trees did not differ significantly between burned (1–6 days, average 152 m) and unburned forest (1–5 days, 230 m). In April–May 2007 and 2008, three stands (45, 13 and 21 ha) were burned for one day using a strip head fire technique. The remainder of the 1,900-ha forest was left unburned. Bats were captured over streams, pools, trails, and service roads at burned and unburned sites using mist nets in May–August 2007 and 2008. In 2007, three female bats were radio-tracked to eight roosts. In 2008, 33 female bats were radio-tracked to 65 roosts, four of which were used previously in 2007.

A replicated, controlled, before-and-after study in 2006–2007 of three mixed forest sites in Kentucky, USA (*4*) found that burned forest had more female northern myotis *Myotis septentrionalis* roosts than unburned forest, and home ranges were closer to burned than unburned forest. Following prescribed fires, more female northern myotis bat roosts were in burned forest (26 roosts, 74%) than unburned forest (nine roosts, 26%), although no statistical tests were carried out. The average size of home ranges and core areas did not vary significantly between bats radio-tracked before (home range: 60 ha; core area: 11 ha) and after fires (home range: 72 ha; core area 14 ha), but home ranges were closer to burned habitats than unburned habitats following fires. Two sites (435 ha, 185 ha) that were previously unburned were subject to prescribed burning in April 2007, with 54% of the area burned. A third site (2,400 ha) was left unburned. Bats were captured in June–July 2006 and April–September 2007 using mist nets over ponds in burned and unburned sites. Eighteen female bats were radio-tracked nightly for an average of six days.

A replicated, controlled, site comparison study in 2007–2008 in two mixed forests in West Virginia, USA (*5*) found male Indiana bats *Myotis sodalis* roosting in tree stands treated with prescribed fire and in unburned forest, and roost switching frequency and the distance between roost trees did not differ between burned and unburned forest. Sixteen roosts were in burned tree stands and 34 roosts were in unburned forest, but the difference was not tested for statistical significance. Roost switching frequency and the distance between roost trees did not differ significantly between burned (1–4 days, average 220 m) and unburned forest (1–2 days, 477 m). In April–May 2007–2009 three stands (12, 13 and 121 ha) within one of two of the forests (Fernow Experimental Forest, 1900 ha) were subjected to prescribed burning using a strip head fire technique. In the other forest (Petit Farm, 400 ha) in March 2003 an escaped campfire had burned part of the forest stand. Control stands were unburned areas in each of the two forests. Bats were captured over streams, pools, ponds and trails using mist nets in burned and unburned forest in June–July 2004–2006 at Petit Farm and June–July 2008–2009 at Fernow Experimental Forest, and also at a cave swarming site at Fernow Experimental Forest in September–October 2007–2008. A total of fifteen male bats were radio-tracked.

A site comparison study in 2004–2005 in nine forest fragments within the Chicago metropolitan area, USA (*6*) found that two of seven forest fragments that had undergone restortation, including prescribed burning, had higher bat activity than two unrestored forest fragments. Bat activity was higher in two forest fragments that had been restored with multiple prescribed burns, invasive plant species removal and snag recruitment (average 7–19 bat passes/survey) than in two control sites with no restoration (average 1–4 bat passes/survey). Bat activity was similar between control sites and five other forest fragments that had been restored with multiple prescribed burns and various combinations of invasive species removal, snag recruitment and deer population control (1–6 bat passes/survey). Six bat species were recorded in total (see original paper for data for individual species). The study does not distinguish between the effects of prescribed burning and the other interventions carried out. Fire suppression over the last 100 years had altered the structure of the nine forest fragments (10–260 ha in size). Seven of the nine forest fragments were being restored to open up the canopy, reduce tree density and remove invasive plant species. At each of nine sites, four bat detectors recorded bat activity for 4 h from sunset for five nights/year in June–September 2004 and May–August 2005.

A replicated, site comparison study in 2008–2009 of 48 sites in two mixed forests in Florida, USA (*7*) found that the frequency of prescribed burns had no effect on the activity of cluttered habitat bat species, but open habitat bat species were recorded less in forest sites with longer periods between burns. The activity of bat species adapted to cluttered habitats did not differ significantly in forest sites with different burn frequencies (1–2 year burn: average 6 bat passes/site/night; 3–5 year burn: 4 bat passes/site/night; >8 year burn: 6 bat passes/site/night). Bat species adapted to open habitats had lower activity in forest sites with a longer period between burns (>8 years: 0.03 bat passes/site/night) than forest sites with more frequent burns (1–2 year burn: 0.1 bat passes/site/night; 3–5 year burn: 0.05 bat passes/site/night). Twenty-four 40 ha study plots were randomly selected in each of two forests with eight plots for each of three burn frequencies (burns every 1–2 years, 3–5 years or >8 years). Bat detectors recorded nightly bat activity at two randomly chosen sites/burn frequency/night for four evenings/week with sites rotated weekly in May–August 2008 and 2009.

A replicated, controlled, before-and-after, paired sites study in 2008 in six tropical eucalypt woodland sites in northern Queensland, Australia (*8*) found that prescribed burning resulted in higher bat activity and a change in species composition. A greater number of bat calls were recorded at treatment sites after prescribed burning (average 2,423) than before (1,174). There was no significant difference in bat calls at unburned control sites over the same period ('before': 1,008; 'after': 1,568 bat calls). Species composition also differed at the treatment sites before and after burning but did not differ at unburned control sites over the same period (data reported as statistical model results). At least 10 bat species were recorded (see original paper for data for individual species). One site from each of six pairs was burned with a low intensity fire for two days (treatment) with the other remaining unburned (control). Bat activity was recorded using bat detectors at six paired sites for 336 bat detector nights in June and July 2008 before burning, and for 234 bat detector nights during August, September and October 2008 after burning.

A replicated, controlled, site comparison study in 2010–2012 in 26 savanna and woodland sites in Missouri, USA (*9*) found that prescribed burning increased occupancy rates of burned sites for one of five bat species. Occupancy rates of the evening bat *Nycticeius humeralis* increased at burned sites with a greater number of prescribed fires in the past 10 years (data reported as statistical model results). The number of fires did not have a significant effect on the occupancy rates of burned sites for four other bat species (northern long-eared bat *Myotis septentrionalis*, big brown bat *Eptesicus fuscus*, eastern red bat *Lasiurus borealis*, tri-coloured bat *Perimyotis subflavus*). At each of 26 sites, surveys were carried out at 4–28 sampling points in managed forest and unmanaged mature forest. Managed forests had been burned (with 1–8 fires over 10 years) and thinned to restore savanna or woodland. Bat detectors recorded bat activity at each sampling point for two full consecutive nights during 1–2 years in 2010–2012.

A replicated, randomized, site comparison study in 2013–2014 of 10 hardwood tree stands in Tennessee, USA (*10*) found that burned and thinned tree stands had higher overall bat activity for three of four treatment types than untreated tree stands. Overall bat activity was higher in tree stands burned in the autumn and thinned to 7m^2/ha (average 280 bat passes) or 14m^2/ha (292 bat passes) than untreated control tree stands (95 bat passes). Tree stands burned in the spring had higher bat activity than controls stands when thinned to 14m^2/ha (656 bat passes) but not 7m^2/ha (123 bat passes). Six groups of bat species were recorded (see original paper for data for individual species groups). The study does not distinguish between the effects of burning and thinning. Each of four treatments (burning in the autumn or spring with thinning to 7 or 14 m^2/ha) was randomly applied to two tree stands (20 ha, 80–100 years old). Two tree stands were untreated controls (average 20 m^2/ha). Overstorey thinning was carried out in June 2008 and prescribed fires in October 2010 and 2012 (autumn) and March 2011 and 2013 (spring). Each of 10 stands was surveyed with a bat detector for seven full nights on three occasions in May–July 2013 and 2014.

A replicated, site comparison study in 2006–2010 of twelve tree stands in two upland hardwood forests in Ohio, USA (*11*) found that burned and thinned tree stands had higher overall bat activity than untreated tree stands. Overall bat activity was higher in tree stands burned and thinned with 50% of the overstorey retained (average 16–30 bat passes/night) and tree stands burned and thinned with 70% of the overstorey retained (14–24 bat passes/night) than in untreated control stands (3–4 bat passes/night). Four bat species or species groups were recorded (see original paper for data for individual species). The study does not distinguish between the effects of burning and thinning. In each of two forests, four tree stands (10 ha) were treated with thinning (commercially thinned between June 2005 and March 2006 with 50% or 70% overstorey retained) and prescribed fire (backing and strip fires in autumn 2009 or spring 2010) and two tree stands were untreated controls. In each of 12 tree stands, eight points were sampled with bat detectors for 3 h/night over a total of six nights in May–August 2006 and June–September 2009 and 2010.

A replicated, before-and-after, controlled study in 2015–2016 of two upland pine *Pinus elliottii* forests in south Florida, USA (*12*) found that prescribed burning increased the activity of Florida bonneted bats *Eumops floridanus*. Activity of Florida bonneted bats was higher at treatment sites after prescribed burning than before but did not change at unburned control sites (data reported as statistical model results). Similarly, the activity of Florida bonneted bats did not differ between treatment and control sites before burning but was higher at burned than unburned control sites after prescribed burning. Two prescribed burns (one in the dry season, one in the wet season) were carried out in each of two upland pine forest conservation areas. Burned areas were 46–549 ha. Bat activity was recorded at three sites within each of four treatment areas and at three adjacent unburned control sites for 12 nights before burning and 24 nights after burning in February and March 2016 (wet season) and June 2015 and July 2016 (dry season).

A replicated, paired sites study in 2014–2015 in 11 paired areas of mixed forest in Tennessee and Kentucky, USA (*13*) found that burned sites had a higher occupancy of five bat species or species groups than unburned sites, and burn severity had a negative effect on *Myotis* spp. and tri-colored bats *Perimyotis subflavus*. Overall, burned sites had a higher occupancy of five bat species/species groups (big brown bats *Eptesicus fuscus*/silver-haired bats *Lasionycteris noctivagans*, eastern red bats *Lasiurus borealis*/evening bats *Nycticeius humeralis*, *Myotis* spp., tri-colored bats, hoary bats *Lasiurus cinereus)* than unburned sites (data reported as statistical model results). Occupancy of *Myotis* spp. and tricolored bats was higher in sites burned with a low severity than a moderate severity. A total of 164 paired forest sites were surveyed within 11 burned and 11 unburned areas (each 10–1,150 ha). Burned areas had been treated with low or moderate intensity prescribed fire (or wildfire at one site) at least once in the past 10 years. Bat presence and activity were recorded simultaneously with bat detectors at paired sites for at least two full nights in May–August 2014 and 2015.

A replicated, site comparison study in 2009–2011 in managed upland forest in Kentucky, USA (*14*) found that home ranges of female Rafinesque's big-eared bats *Corynorhinus rafinesquii* were similar distances from burned and unburned forest, whereas the home ranges of male bats were closer to unburned forest. Home ranges of female bats (including non-reproductive, pregnant, lactating, and post-lactating females) were not located significantly closer to burned forest than unburned forest (data reported as statistical model results). Home ranges of male bats were further from burned forest than unburned forest. Prescribed burns of low-moderate intensity were carried out each spring within an area of deciduous, coniferous, and mixed forest. Burned areas were an average of 252 ha. Forty-one adult Rafinesque's big-eared bats (33 females, eight males) from four colonies were captured in mist nets and radio-tagged. Each bat was tracked to an average of 38 locations over 2–5 nights in May–September 2009–2011.

A replicated, randomized, site comparison study in 1990–2004 of 18 forest sites in New South Wales, Australia (*15*) found that unlogged forest blocks burned every four years had higher overall bat activity and more bat species than blocks burned every two years or unburned blocks, but species composition did not differ and burning had no effect in logged forest. Higher bat activity (2–3 times) and more bat species were recorded in unlogged forest blocks burned every four years than in blocks burned every two years or unburned blocks (data reported as statistical model results). Species composition did not differ significantly between treatments. Burning every two or four years in logged forest blocks did not have a significant effect on bat activity, species richness or composition compared to unburned logged forest. Fifteen bat species or species groups were recorded (see original paper for data for individual species). Three blocks (8–56 ha) in logged and unlogged forest were randomly allocated to one of three treatments: burning every four years, burning every two years, no burning. Prescribed burns began in 1990. Logging was carried out in 1987–1988 with mature trees retained (33% of the original basal area). Each of 18 blocks was surveyed with two bat detectors for two consecutive nights in December 1999, 2001 and 2004.

(1) Boyles J.G. & Aubrey D.P. (2006) Managing forests with prescribed fire: implications for a cavity-dwelling bat species. *Forest Ecology and Management,* 222, 108–115.

(2) Loeb S.C. & Waldrop T.A. (2008) Bat activity in relation to fire and fire surrogate treatments in southern pine stands. *Forest Ecology and Management,* 255, 3185–3192.

(3) Johnson J.B., Edwards J.W., Ford W.M. & Gates J.E. (2009) Roost tree selection by northern myotis (*Myotis septentrionalis*) maternity colonies following prescribed fire in a Central Appalachian Mountains hardwood forest. *Forest Ecology and Management,* 258, 233–242.

(4) Lacki M.J., Cox D.R., Dodd L.E. & Dickinson M.B. (2009) Response of northern bats (*Myotis septentrionalis*) to prescribed fires in eastern Kentucky forests. *Journal of Mammalogy,* 90, 1165–1175.
(5) Johnson J.B., Ford W.M., Rodrigue J.L., Edwards J.W. & Johnson C.M. (2010) Roost selection by male Indiana myotis following forest fires in Central Appalachian hardwood forests. *Journal of Fish and Wildlife Management*, 1, 111–121.
(6) Smith D.A. & Gehrt S.D. (2010) Bat response to woodland restoration within urban forest fragments. *Restoration Ecology* 18, 914–923.
(7) Armitage D.W. & Ober H.K. (2012) The effects of prescribed fire on bat communities in the longleaf pine sandhills ecosystem. *Journal of Mammalogy,* 93, 102–114.
(8) Inkster-Draper T.E., Sheaves M., Johnson C.N. & Robson S.K.A. (2013) Prescribed fire in eucalypt woodlands: immediate effects on a microbat community of northern Australia. *Wildlife Research,* 40, 70–76.
(9) Starbuck C.A., Amelon S.K. & Thompson F.R. III (2015) Relationships between bat occupancy and habitat and landscape structure along a savanna, woodland, forest gradient in the Missouri Ozarks. *Wildlife Society Bulletin,* 39, 20–30.
(10) Cox M.R., Willcox E.V., Keyser P.D. & Vander Yacht A.L. (2016) Bat response to prescribed fire and overstory thinning in hardwood forest on the Cumberland Plateau, Tennessee. *Forest Ecology and Management*, 359, 221–231.
(11) Silvis A., Gehrt S.D. & Williams R.A. (2016) Effects of shelterwood harvest and prescribed fire in upland Appalachian hardwood forests on bat activity. *Forest Ecology and Management*, 360, 205–212.
(12) Braun de Torrez E.C., Ober H.K. & McCleery R.A. (2018) Activity of an endangered bat increases immediately following prescribed fire. *The Journal of Wildlife Management*, 82, 1115–1123.
(13) Burns L.K.L., Loeb S.C. & Bridges W.C., Jr. (2019) Effects of fire and its severity on occupancy of bats in mixed pine-oak forests. *Forest Ecology and Management*, 446, 151–163.
(14) Johnson J.S., Lacki M.J. & Fulton S.A. (2019) Foraging patterns of Rafinesque's big-eared bat in upland forests managed with prescribed fire. *Journal of Mammalogy*, 100, 500–509.
(15) Law B., Kathuria A., Chidel M. & Brassil T. (2019) Long-term effects of repeated fuel-reduction burning and logging on bats in south-eastern Australia. *Austral Ecology*, 44, 1013–1024.

Dams and water management/use

8.2. Create or maintain small dams to provide foraging and drinking habitat for bats

- **One study** evaluated the effects of maintaining small dams as foraging and drinking habitat for bats on bat populations. The study was in Portugal[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in Portugal[1] found that reservoirs created using small dams had greater activity (relative abundance) of four bat species than the streams feeding into them.

BEHAVIOUR (0 STUDIES)

Background

Large dams are likely to have a negative impact on bats due to habitat loss and fragmentation (e.g. Rebelo & Rainho 2009). However, small dams along rivers can create pools and reservoirs within natural habitats, which may provide foraging and drinking resources for bats. For interventions that involve creating other types of water sources, see '*Habitat restoration and creation – Create artificial water sources*'.

Rebelo H. & Rainho A. (2009) Bat conservation and large dams: spatial changes in habitat use caused by Europe's largest reservoir. *Endangered Species Research,* 8, 61–68.

A replicated, site comparison study in 2011 at five dams in northeast Portugal (*1*) found that dam reservoirs had greater foraging and drinking activity of four bat species than the streams feeding into them. The bat species were common pipistrelle *Pipistrellus pipistrellus*, Kuhl's pipistrelle *Pipistrellus kuhlii*, Daubenton's bat *Myotis daubentonii* and European free-tailed bat *Tadarida teniotis* (data reported as statistical model results). Mixed results were reported for six other bat species, but numbers were too low for statistical analysis. Dam reservoirs varied in size from 50,000 to 280,000 m^2. All streams had annual average flow rates of 100–300 mm and similar riparian vegetation. At each of five dams, bat activity was recorded using bat detectors at four sampling points (the upstream and downstream sides of both the dam and stream). Each point was randomly sampled on three nights (for 3 h from sunset) between July and October 2011 with one stream and one dam point sampled simultaneously.

(1) Hintze F., Duro V., Carvalho J.C., Eira C., Rodrigues P.C. & Vingada J. (2016) Influence of reservoirs created by small dams on the activity of bats. *Acta Chiropterologica,* 18, 395–408.

8.3. Relocate bat colonies roosting inside dams

- **One study** evaluated the effects of relocating bat colonies inside dams on bat populations. The study was in Argentina[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One study in Argentina[1] found that almost two-thirds of a large colony of Brazilian free-tailed bats relocated to a different dam compartment five months after being displaced from six compartments where the colony originally roosted.

BEHAVIOUR (0 STUDIES)

Background

Bats have been reported roosting within the internal compartments of large dams, which may become flooded during water release. Roosts should be identified and relocated prior to flooding.

A study in 2002–2003 at one dam reservoir in Tucumán Province, Argentina (*1*) found that almost two-thirds of a large colony of Brazilian free-tailed bats *Tadarida brasiliensis* relocated to a different internal dam compartment after being displaced from the six compartments where the colony originally roosted. Approximately 1,400,000 Brazilian free-tailed bats were estimated to be roosting in one dam compartment five months after the displacement of a colony of approximately 2,000,000 bats from six of the seven dam compartments where it previously roosted. The study was conducted inside a dam wall (100 m long, 90 m high). The wall housed seven compartments used by Brazilian free-tailed bats. In October 2012, bats were deterred from six of the seven compartments using high intensity lights and naphthalene vapour. Once empty of bats, the dam compartments were sealed with metal doors. Bat numbers were estimated by three observers based on the area occupied by each single bat. Bats were counted three times between October 2002 and March 2003.

(1) Regidor, H., Mosa, S., & Núñez, A. (2003) Confinement of a colony of *Tadarida brasiliensis*, a management alternative compatible with conservation. Confinamento de una colonia de *Tadarida brasiliensis*, una alternativa de manejo compatible con la conservación. *Chiroptera Neotropical*, 9, 157–162.

9. Threat: Invasive or problematic species and disease

Invasive and other problematic species of animals, plants and diseases have caused significant declines in many bat species worldwide. Invasive species may prey on bats, provide competition for resources, alter habitats, or infect bats with new diseases. This chapter describes the evidence from interventions designed to reduce the threat from invasive or problematic species and disease.

For evidence relating to the translocation of bats, e.g. to predator or disease-free areas, see '*Species management – Translocation – Translocate bats*'.

Invasive species

9.1. Control invasive plant species

- **One study** evaluated the effects of controlling invasive plant species on bat populations. The study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One site comparison study in the USA[1] found that two of seven forest fragments where invasive plant species had been removed alongside other restoration practices had higher bat activity (relative abundance) than two unrestored forest fragments.

BEHAVIOUR (0 STUDIES)

Background

Invasive plant species can threaten native biodiversity and alter bat foraging habitats such as forest and woodland. For example, invasive tree and vine species have caused the deterioration of foraging habitat of the Seychelles sheath-tailed bat *Coleura seychellensis* and have been found to obstruct roost entrances (Gerlach 2009).

Gerlach, J. (2009) Conservation of the Seychelles sheath-tailed bat *Coleura seychellensis* on Silhouette Island, Seychelles. *Endangered Species Research,* 8, 5–13.

A site comparison study in 2004–2005 in nine forest fragments within the Chicago metropolitan area, USA (*1*) found that two of seven forest fragments that had undergone restoration, including invasive plant species removal, had higher bat activity than two unrestored forest fragments. Bat activity was higher in two forest fragments that had been restored with invasive plant species removal, multiple prescribed burns, and snag recruitment (average 7–19 bat passes/survey) than in two control sites with no restoration (average 1–4 bat passes/survey). Bat activity was similar between control sites and five other forest fragments that had been restored with various combinations of invasive plant species removal, multiple prescribed burns, snag recruitment and deer population control (1–6 bat passes/survey). Six bat species were recorded in total (see original paper for data for individual species). The study does not distinguish between the effects of invasive plant species removal and the other interventions carried out. Fire suppression over the last 100 years had altered the structure of the nine forest fragments (10–260 ha in size). Seven of the nine forest fragments were being restored to open the canopy, reduce tree density and remove invasive plant species. At each of nine sites, four bat detectors recorded bat activity for 4 h from sunset for five nights/year in June–September 2004 and May–August 2005.

(1) Smith D.A. & Gehrt S.D. (2010) Bat response to woodland restoration within urban forest fragments. *Restoration Ecology* 18, 914–923.

9.2. Control invasive predators

- **One study** evaluated the effects of controlling invasive predators on bat populations. The study was in New Zealand[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, before-and-after study in New Zealand[1] found that controlling ship rats resulted in increased survival probabilities for female long-tailed bats.

BEHAVIOUR (0 STUDIES)

Background

Introduced predators such as rats, feral cats and snakes can threaten bat populations. For example, the brown tree snake *Boiga irregularis* which invaded Guam in the 1950s, was responsible for the extermination of two bat species.

A replicated, before-and-after study in 1993–2015 in a rainforest in Eglinton Valley, New Zealand (*1*) found that ship rat *Rattus rattus* control resulted in increased survival probabilities of female bats within three long-tailed bat *Chalinolobus tuberculatus* colonies. Average annual survival probabilities for both adult and juvenile female bats were higher in years with rat control (adult female: 0.82; juvenile female: 0.76) than without (adult female: 0.55; juvenile female: 0.55). Population trends were positive for all three bat colonies when rats were controlled, and negative for when rats were not controlled (data reported as statistical model results). Rats within the roosting ranges of all three bat colonies were poisoned using bait stations in 2006–2009 following high beech *Nothofagaceae* spp. seedfall and an increase in numbers. Bats were captured annually during the breeding season over 22 summers in 1993–2015 (average 6–8 captures/colony/year). Mark-recapture data were used to calculate survival probabilities.

(1) O'Donnell C.F.J., Pryde M.A., van Dam-Bates P. & Elliott G.P. (2017) Controlling invasive predators enhances the long-term survival of endangered New Zealand long-tailed bats (*Chalinolobus tuberculatus*): implications for conservation of bats on oceanic islands. *Biological Conservation,* 214, 156–167.

9.3. Control invasive non-predatory competitors

- We found no studies that evaluated the effects of controlling invasive non-predatory competitors of bats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Non-predatory invasive species may compete with bats for resources. For example, the invasive rose-ringed parakeet *Psittacula krameria* has been reported to compete with and attack Leisler's bats *Nyctalus Leisleri* roosting in tree cavities (Hernández-Brito *et al*. 2018).

Hernández-Brito D., Carrete M., Ibáñez C., Juste J. & Tella J.L. (2018) Nest-site competition and killing by invasive parakeets cause the decline of a threatened bat population. *Royal Society Open Science,* 5, 172477.

9.4. Control harmful invasive bat prey species

- We found no studies that evaluated the effects of controlling harmful invasive bat prey species on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Bats may feed on harmful invasive prey species. For example, ghost bats *Macroderma gigas* have been reported to eat poisonous invasive cane toads *Rhinella marina* in Australia, which may have contributed to ghost bat population declines (White *et al*. 2016).

White A.W., Morris I., Madani G. & Archer M. (2016) Are cane toads *Rhinella marina* impacting ghost bats *Macroderma gigas* in Northern Australia? *Australian Zoologist,* 38, 183–191.

9.5. Exclude domestic and feral cats from bat roosts and roost entrances

- We found no studies that evaluated the effects of excluding domestic and feral cats from bat roosts and roost entrances on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Cats can injure or kill bats and have been reported to wait at roost entrances for bats to emerge (e.g. Scrimgeour *et al*. 2012, Ancillotto *et al*. 2013). Excluding both domestic and feral cats from bat roosts and roost entrances may reduce bat mortality. For other interventions relating to cat predation, see '*Keep domestic cats indoors at night*' and '*Use collar-mounted devices on cats to reduce predation of bats*'.

Ancillotto L., Serangeli M.T. & Russo D. (2013) Curiosity killed the bat: domestic cats as bat predators. *Mammalian Biology - Zeitschrift für Säugetierkunde,* 78, 369–373.

Scrimgeour J., Beath A. & Swanney M. (2012) Cat predation of short-tailed bats (*Mystacina tuberculata rhyocobia*) in Rangataua Forest, Mount Ruapehu, Central North Island, New Zealand. *New Zealand Journal of Zoology,* 39, 257–260.

9.6. Keep domestic cats indoors at night

- We found no studies that evaluated the effects of keeping domestic cats indoors at night on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Keeping domestic cats indoors at night may reduce the number of bats killed or injured by hunting cats. For other interventions relating to cat predation, see '*Exclude domestic and feral cats from bat roosts and roost entrances*' and '*Use collar-mounted devices on cats to reduce predation of bats*'.

9.7. Use collar-mounted devices on cats to reduce predation of bats

- We found no studies that evaluated the effects of using collar-mounted devices on cats to reduce predation of bats on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Collar-mounted devices, such as bells, alarms, and lights may reduce predation by making cats more conspicuous. Cats equipped with collar-mounted bells, sonic devices and a 'pounce protector bib' have been found to capture fewer mammals than without the devices (Nelson *et al*. 2005, Calver *et al.* 2007). Bats were among the mammals caught, but numbers captured with and without the devices were not reported.

For other interventions relating to cat predation, see '*Exclude domestic and feral cats from bat roosts and roost entrances*' and '*Keep domestic cats indoors at night*'.

Calver M., Thomas S., Bradley S. & McCutcheon H. (2007) Reducing the rate of predation on wildlife by pet cats: the efficacy and practicability of collar-mounted pounce protectors. *Biological Conservation,* 137, 341–348.

Nelson S.H., Evans A.D. & Bradbury R.B. (2005) The efficacy of collar-mounted devices in reducing the rate of predation of wildlife by domestic cats. *Applied Animal Behaviour Science,* 94, 273–285.

Problematic native species

9.8. Protect bats within roosts from disturbance or predation by native species

- We found no studies that evaluated the effects of protecting bat roosts from disturbance or predation by native species on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Roosting bats can be vulnerable to disturbance or predation by native species. Modifying roost entrances to exclude problematic species may protect bats within roosts. For example, metal sheeting may be placed below a roost entrance to prevent mammalian predators from climbing up to the roost (e.g. see Schofield 2008).

See also '*Control invasive predators*' and '*Control invasive non-predatory competitors*'.

Schofield H.W. (2008) *The Lesser Horseshoe Bat Conservation Handbook*. Vincent Wildlife Trust, Ledbury.

9.9. Modify bat roosts to reduce negative impacts of one bat species on another

- We found no studies that evaluated the effects of modifying bat roosts to reduce negative impacts of one bat species on another on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Different bat species occupying the same roosts may have negative impacts on one another. Bat roosts could be modified to reduce interactions between such species.

Disease

9.10. Carry out surveillance of bats to prevent the spread of disease/viruses to humans to reduce human-wildlife conflict

- We found no studies that evaluated the effects of carrying out surveillance of bats to prevent the spread of disease/viruses to humans to reduce human-wildlife conflict.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Bats can carry diseases and viruses that may spillover to human populations with serious risks to public health (e.g. see Schneeberger & Voigt 2016). Carrying out surveillance of bats for diseases and viruses, particularly in areas where bats and humans are in close contact, could provide an early warning system for potential spillover events and may allow preventative measures to be taken. This may reduce the persecution and culling of bats. Surveillance programmes and sampling protocols should aim to minimize disturbance to bats.

Schneeberger K. & Voigt C.C. (2016) Zoonotic viruses and conservation of bats. Pages 263–292 in: Voigt C.C. & Kingston T. (eds.) *Bats in the Anthropocene: Conservation of Bats in a Changing World.* Springer International Publishing, Cham.

White-nose syndrome

White-nose syndrome is a condition in which a fungus *Pseudogymnoascus destructans* (previously called *Geomyces destructans*) invades the skin around the muzzle and wings of hibernating bats (e.g. see Frick *et al*. 2016). Infection causes bats to rouse from torpor more frequently and for longer periods, using up vital fat reserves and resulting in death. The disease has spread rapidly across North America and is responsible for the deaths of millions of bats (USFWS 2012).

Frick W.F., Puechmaille S.J. & Willis C.K.R (2016) White-Nose Syndrome in Bats. Pages 245–262 in: Voigt C.C. & Kingston T. (eds.) *Bats in the Anthropocene: Conservation of Bats in a Changing World.* Springer International Publishing, Cham.

USFWS (2012) *North American bat death toll exceeds 5.5 million from white-nose syndrome.* US Fish & Wildlife Service, Virginia, USA.

9.11. Restrict human access to bat caves to reduce the spread of the white-nose syndrome pathogen

- We found no studies that evaluated the effects of restricting human access to bat caves to reduce the spread of the white-nose syndrome pathogen on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Restricting human access to bat caves may help to reduce the spread by humans of the fungus *Pseudogymnoascus destructans* that causes white-nose syndrome.

9.12. Decontaminate clothing and equipment after entering caves to reduce the spread of the white-nose syndrome pathogen

- We found no studies that evaluated the effects of decontaminating clothing and equipment after entering caves to reduce the spread of the white-nose syndrome pathogen on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Decontaminating clothing and equipment after entering caves may reduce the spread of the white-nose syndrome fungus *Pseudogymnoascus destructans* by humans.

We found no studies evaluating the effects of decontaminating equipment when moving between caves on the spread of the white-nose syndrome fungus between bat populations. One study examined the effectiveness of different treatments to kill the white-nose syndrome fungus *Pseudogymnoascus destructans* on clothing and materials used by cavers. Cleaning mud and sediment from clothing followed by treatment with commercially available disinfectants (e.g. household bleach) successfully killed the fungus, as did soaking clothing in water above 50˚C for at least 20 minutes (Shelley *et al*. 2013).

Shelley V., Kaiser S., Shelley E., Williams T., Kramer M., Haman K., Keel K. & Barton H.A. (2013) Evaluation of strategies for the decontamination of equipment for *Geomyces destructans*, the causative agent of white-nose syndrome (WNS). *Journal of Cave and Karst Studies,* 75, 1–10.

9.13. Modify bat hibernacula environments to increase survival of bats infected with white-nose syndrome

- **One study** evaluated the effects of modifying hibernacula environments to increase the survival of bats infected with white-nose syndrome. The study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, randomized, controlled study in the USA[1] found that a greater number of little brown bats infected with the white-nose syndrome fungus survived in hibernation chambers at 4°C than at 10°C.

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One replicated, randomized, controlled study in the USA[1] found that little brown bats infected with the white-nose syndrome fungus stayed in hibernation for longer in hibernation chambers at 4°C than at 10°C.

Background

In laboratory conditions, the optimal temperature for the growth and performance of the white-nose syndrome fungus *Pseudogymnoascus destructans* has been found to be 12.5–15.8°C (Verant *et al.* 2012). Wild bats infected with white-nose syndrome were found to have higher fungal loads and greater population declines in hibernacula with warmer temperatures (Langwig *et al*. 2012, 2016). Warming or cooling hibernacula above or below these temperatures, e.g. by modifying airflow, may slow fungus growth and improve survival rates of infected bats.

Langwig K.E., Frick W.F., Bried J.T., Hicks A.C., Kunz T.H. & Marm Kilpatrick A. (2012) Sociality, density-dependence and microclimates determine the persistence of populations suffering from a novel fungal disease, white-nose syndrome. *Ecology Letters,* 15, 1050–1057.

Langwig K.E., Frick W.F., Hoyt J.R., Parise K.L., Drees K.P., Kunz T.H., Foster J.T. & Kilpatrick A.M. (2016) Drivers of variation in species impacts for a multi-host fungal disease of bats. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 371.

Verant M.L., Boyles J.G., Waldrep Jr. W., Wibbelt G. & Blehert D.S. (2012) Temperature-dependent growth of *Geomyces destructans*, the fungus that causes bat white-nose syndrome. *PLoS ONE,* 7, e46280.

A replicated, randomized, controlled study in 2013–2014 in a laboratory in Pennsylvania, USA (*1*) found that bats infected with the white-nose syndrome fungus *Pseudogymnoascus destructans* were more likely to survive and stayed in hibernation for longer when placed in hibernation chambers at 4°C than at 10°C. A greater proportion of bats infected with the white-nose syndrome survived during hibernation at 4°C (43–67% of 14–15 bats) than at 10°C (7–53% of 14–15 bats). Infected bats also stayed in torpor for longer at 4°C (average 9–12 days) than at 10°C (6–7 days). For uninfected control bats, no significant differences were found between the two temperatures for survival (4°C: 80% of 14–15 bats survived; 10°C: 57% of 14–15 bats survived) or hibernation duration (4°C: average 13 days; 10°C: 11 days). In November 2013, 147 hibernating little brown bats *Myotis lucifugus* were collected from two mines. Bats were randomly placed into five groups for each of the two temperature treatments (4°C and 10°C; total 14–15 bats/group). Four groups were inoculated with different amounts of the white-nose syndrome fungus (500, 5,000, 50,000, or 500,000 spores). One control group was inoculated with a harmless saline solution. All bats were fitted with temperature dataloggers and placed within flight cages with internal chambers set to 4°C or 10°C (and ≤90% relative humidity) for 148 days.

(1) Johnson J.S., Reeder D.M., McMichael J.W. III, Meierhofer M.B., Stern D.W.F., Lumadue S.S., Sigler L.E., Winters H.D., Vodzak M.E., Kurta A., Kath J.A. & Field K.A. (2014) Host, pathogen, and environmental characteristics predict white-nose syndrome mortality in captive little brown myotis (*Myotis lucifugus*). *PLOS ONE,* 9, e112502.

9.14. Treat bat hibernacula environments to reduce the white-nose syndrome pathogen reservoir

- We found no studies that evaluated the effects of treating hibernacula environments to reduce the white-nose syndrome pathogen reservoir on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

The white-nose syndrome fungus *Pseudogymnoascus destructans* can grow on a variety of substrates and can persist in hibernacula environments (such as caves and mines) for long periods without bats being present (e.g. Lorch *et al.* 2013). Bat hibernacula could be treated with environmental cleaning agents or bacterium treatments that inhibit fungal growth, to reduce the pathogen reservoir. However, these approaches have the potential to damage cave environments and other cave-dwelling species at some sites.

Lorch J.M., Muller L.K., Russell R.E., O'Connor M., Lindner D.L. & Blehert D.S. (2013) Distribution and environmental persistence of the causative agent of white-nose syndrome, *Geomyces destructans*, in bat hibernacula of the Eastern United States. *Applied and Environmental Microbiology,* 79, 1293–1301.

9.15. Vaccinate bats against the white-nose syndrome pathogen

- We found no studies that evaluated the effects of vaccinating bats against the white-nose syndrome pathogen on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Vaccinating bats against the white-nose syndrome pathogen *Pseudogymnoascus destructans* could reduce bat mortality. However, an effective vaccine has yet to be developed and practical methods for large-scale implementation would need to be investigated. Research is on-going.

9.16. Treat bats for infection with white-nose syndrome

- **Two studies** evaluated the effects of treating bats with a probiotic bacterium to reduce white-nose syndrome infection. One study was in Canada[1] and one in the USA[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Survival (2 studies):** One randomized, controlled study in Canada[1] found that treating little brown bats with a probiotic bacterium at the time of infection with white-nose syndrome (but not 21 days prior) increased survival within cages in a laboratory. One randomized, controlled study in the USA[2] found that treating little brown bats with a probiotic bacterium within a mine increased survival for free-flying bats, but not caged bats.
- **Condition (2 studies):** One randomized, controlled study in Canada[1] found that little brown bats caged in a laboratory and treated with a probiotic bacterium at the time of infection with white-nose syndrome had reduced symptoms of the disease, but bats treated 21 days prior to infection had worse symptoms. One randomized, controlled study in the USA[2] found that little brown bats kept within cages in a mine and treated with a probiotic bacterium had a similar severity of white-nose syndrome to untreated bats.

BEHAVIOUR (0 STUDIES)

Background

Various treatments for bats infected with white-nose syndrome have been suggested including antifungal agents, antimicrobial and enzyme inhibitors, and ultraviolet light. Some treatments have been tested on the white-nose syndrome fungus *Pseudogymnoascus destructans* in laboratories (e.g. Cornelison *et al*. 2014, Palmer *et al.* 2018), but we found only two studies that tested treatments on infected bats.

Cornelison C.T., Keel M.K., Gabriel K.T., Barlament C.K., Tucker T.A., Pierce G.E. & Crow S.A. (2014) A preliminary report on the contact-independent antagonism of *Pseudogymnoascus destructans* by *Rhodococcus rhodochrous* strain DAP96253. *BMC Microbiology,* 14, 246.

Palmer J.M., Drees K.P., Foster J.T. & Lindner D.L. (2018) Extreme sensitivity to ultraviolet light in the fungal pathogen causing white-nose syndrome of bats. *Nature Communications,* 9, 35.

A randomized, controlled study in 2013–2015 in a laboratory in Manitoba, Canada (*1*) found that treating bats with a probiotic bacterium *Pseudomonas fluorescens* at the time of, but not 21 days prior, to infection with white-nose syndrome reduced symptoms and increased survival. For bats that received the probiotic treatment at the time of white-nose syndrome infection, four of five disease symptoms were lower than for untreated, infected control bats (data reported as statistical model results). For bats that received the treatment 21 days prior to infection, all five symptoms were greater than for untreated, infected control bats. Bats that received the probiotic treatment at the time of infection also had higher survival rates (71% of bats survived after 185 days) than untreated, infected control bats (18% of bats survived). Survival rates between all other treatment groups did not differ significantly. Eighty-five little brown bats *Myotis lucifugus* were collected from a hibernaculum and equally divided into five treatment groups (probiotic treatment 21 days prior to white-nose syndrome infection, probiotic treatment at time of infection, probiotic treatment only, infection with white-nose syndrome only, no treatment). Bats were kept in nylon mesh cages and monitored for up to 185 days during hibernation.

A randomized, controlled study in 2015–2016 at a mine in Wisconsin, USA (*2*) found that treating little brown bats *Myotis lucifugus* with a probiotic bacterium *Pseudomonas fluorescens* increased survival for free-flying bats but not caged bats. A greater proportion of free-flying bats treated with the probiotic bacterium survived over winter (six of 13 bats, 46%) than untreated bats (one of 12 bats, 8%). Survival was unknown for five other free-flying bats that lost their tags. Survival and severity of white-nose syndrome did not differ for treated and untreated bats kept in cages within the mine (both: four of 15 bats survived, 26%). In November 2015, sixty bats infected with white-nose syndrome were captured within the mine and randomly assigned to a treatment group (probiotic bacterium sprayed on the wings and tail; 29 bats) or untreated control group (31 bats). Fifteen treated and 15 untreated bats were placed in two separate metal cages (46 x 30 x 51 cm) mounted to the mine ceiling. The other 30 bats (16 treated, 14 untreated) were fitted with tags and released. Free-flying bats detected by a tag receiver at the mine entrance after 8 March 2016 were assumed to have survived over winter. Bats were removed from the cages in March 2016 and had one wing photographed under ultraviolet light to measure disease severity.

(1) Cheng T.L., Mayberry H., McGuire L.P., Hoyt J.R., Langwig K.E., Nguyen H., Parise K.L., Foster J.T., Willis C.K.R., Kilpatrick A.M. & Frick W.F. (2017) Efficacy of a probiotic bacterium to treat bats affected by the disease white-nose syndrome. *Journal of Applied Ecology*, 54, 701–708.
(2) Hoyt J.R., Langwig K.E., White J.P., Kaarakka H.M., Redell J.A., Parise K.L., Frick W.F., Foster J.T. & Kilpatrick A.M. (2019) Field trial of a probiotic bacteria to protect bats from white-nose syndrome. *Scientific Reports*, 9, 9158.

9.17. Breed bats in captivity to supplement wild populations affected by white-nose syndrome

- We found no studies that evaluated the effects of breeding bats in captivity to supplement wild populations affected by white-nose syndrome.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Captive breeding may be used as a strategy to supplement or re-establish wild populations. However, simulation modelling suggests that this is unlikely to be an effective strategy for bats affected by white-nose syndrome due to a lack of specialist infrastructure and expertise, and the need for disease-free target populations (Davy & Whitear 2016).

For a general intervention relating to captive breeding, see '*Species management – Ex-situ conservation – Breed bats in captivity*'.

Davy C.M. & Whitear A.K. (2016) Feasibility and pitfalls of ex situ management to mitigate the effects of an environmentally persistent pathogen. *Animal Conservation,* 19, 539–547.

9.18. Cull bats infected with white-nose syndrome

- We found no studies that evaluated the effects of culling bats infected with white-nose syndrome on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Culling of bats infected with white-nose syndrome has been considered as a possible means of reducing transmission and slowing the spread of the disease. However, this has not been tested and simulation modelling indicates that culling is unlikely to be an effective method to control the spread of white-nose syndrome (Hallam & McCracken 2011).

Hallam T.G. & McCracken G.F. (2011) Management of the panzootic white-nose syndrome through culling of bats. *Conservation Biology*, 25, 189–194.

10. Threat: Pollution

Bats may be affected both directly and indirectly by many different types of pollution. Light pollution is a threat to nocturnal bats. Noise pollution can cause disturbance and interfere with echolocation. Water-borne pollutants and pesticides can degrade foraging habitats and reduce prey availability. Pesticides may also be consumed directly by bats that feed on fruit, flowers and arthropods, and bats may become contaminated with other pollutants, such as toxic heavy metals. Exposure to contaminants, particularly pesticides, has been implicated as a major factor contributing to declines in bat populations. However, little is known about the long-term impacts of pollutants that persist and accumulate in the environment.

Domestic and urban waste water

10.1. Change effluent treatments of domestic and urban waste water

- **One study** evaluated the effects of different sewage treatments on the activity of foraging bats. The study was in the UK[1]. We found no studies that evaluated the effects of changing effluent treatments of domestic and urban waste water discharged into rivers on bat populations.

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, site comparison study in the UK[1] found higher activity (relative abundance) of foraging bats over filter bed sewage treatment works than over active sludge systems.

BEHAVIOUR (0 STUDIES)

Background

Organic pollution occurs when treated sewage effluents containing organic compounds are discharged into rivers affecting plant growth and the number and diversity of insects. Riparian habitats are important for foraging bats and changes in water quality may have positive effects on foraging activity for some species, and negative effects for others (Vaughan *et al.* 1996, Kalcounis-Rüppell *et al.* 2007, Abbott *et al.* 2009).

We found evidence that filter sewage bed treatment works can provide foraging habitat for bats. However, the results should be treated with caution as a subsequent study found that insects above these filter beds were contaminated with endocrine disrupting chemicals that may have adverse effects on bats feeding on them (Park *et al.* 2009).

Abbott I.M., Sleeman D.P. & Harrison S. (2009) Bat activity affected by sewage effluent in Irish rivers. *Biological Conservation*, 142, 2904–2914.
Kalcounis-Rüppell M.C., Payne V., Huff S.R. & Boyko A. (2007) Effects of wastewater treatment plant effluent on bat foraging ecology in an urban stream system. *Biological Conservation*, 138, 120–130.
Park K.J., Müller C.T., Markman S., Swinscow-Hall O., Pascoe D. & Buchanan K.L. (2009) Detection of endocrine disrupting chemicals in aerial invertebrates at sewage treatment works. *Chemosphere,* 77, 1459–1464.
Vaughan N., Jones G. & Harris S. (1996) Effects of sewage effluent on the activity of bats (Chiroptera: Vespertilionidae) foraging along rivers. *Biological Conservation,* 78, 337–343.

A replicated, site comparison study in 2003 at 30 sewage treatment works and in central and southern Scotland, UK (*1*) found that percolating filter beds had higher activity of *Pipistrellus* spp. over them than activated sludge systems, and activity over filter beds was similar to that along nearby river banks. The number of *Pipistrellus* spp. bat passes recorded over percolating filter beds (54) was higher than over activated sludge systems (9). Activity of *Pipistrellus* spp. over filter beds (average 15 bat passes/site) was also similar to that along nearby river banks (23 bat passes/site), whereas activity over activated sludge sites (3 bat passes/site) was lower than along nearby river banks (18 bat passes/site). At filter beds, waste water is sprayed over inert filter material creating a microbial film which supports high insect numbers. In activated sludge systems, sewage and bacterial sludge are mixed creating an unfavourable habitat for insects. At each of 30 sites (18 filter bed, 12 activated sludge), bat activity was recorded with bat detectors at three points/site for 15 minutes each after dusk in June–August 2003. At each of 23 sites (15 filter bed, 8 activated sludge), recordings were also made at two points on the river bank 50 and 75 m upstream from the sewage treatment works.

(1) Park K.J. & Cristinacce A. (2006) Use of sewage treatment works as foraging sites by insectivorous bats. *Animal Conservation*, 9, 259–268.

10.2. Prevent pollution from sewage treatment facilities from entering watercourses

- We found no studies that evaluated the effects of preventing pollution from sewage treatment facilities from entering watercourses on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Pollution from sewage treatment facilities can degrade riparian habitats and severely reduce insect populations.

10.3. Reduce or prevent the use of septic systems near caves

- We found no studies that evaluated the effects of reducing or preventing the use of septic systems near caves on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Leaking septic systems are a major cause of groundwater pollution. Septic systems installed in karst areas are particularly likely to fail due to thin soils, sloping topography and unstable foundations. Pollution from septic systems can degrade underground habitats (e.g. Graening & Brown 2003), with potential impacts on roosting bats.

Graening G.O. & Brown A.V. (2003) Ecosystem dynamics and pollution effects in an Ozark cave stream. *Journal of the American Water Resources Association,* 39, 1497–1507.

Industrial effluents

10.4. Introduce or enforce legislation to prevent ponds and streams from being contaminated by toxins

- We found no studies that evaluated the effects of introducing or enforcing legislation to prevent ponds and streams from being contaminated by toxins on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Contamination of ponds and streams by toxins can reduce the availability of prey and cause the build-up of toxins in the food chain. Toxic heavy metals have been found in high concentrations in bats (Zukal *et al.* 2015), although little is known about the long-term impacts.

Zukal J., Pikula J. & Bandouchova H. (2015) Bats as bioindicators of heavy metal pollution: history and prospect. *Mammalian Biology - Zeitschrift für Säugetierkunde,* 80, 220–227.

Agricultural and forestry effluents

10.5. Introduce legislation to control the use of hazardous substances

- We found no studies that evaluated the effects of introducing legislation to control the use of hazardous substances on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Introducing legislation to control the use of hazardous substances such as fertilizers, pesticides, fungicides and herbicides could reduce the negative impacts on wildlife, including bats. Such laws exist in some countries.

10.6. Reduce pesticide, herbicide, or fertiliser use

- **Four studies** evaluated the effects of reducing pesticide, herbicide and fertiliser use on bat populations. One study was in each of Mexico[1], Portugal[2], Germany[3] and Columbia[4].

COMMUNITY RESPONSE (3 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in Portugal[2] found that farms using few or no chemicals had different compositions of bat species to farms using high chemical inputs.
- **Richness/diversity (2 studies):** One site comparison study in Mexico[1] found that coffee agroforestry plantations using few or no chemicals had a higher diversity of insect-eating bat species than plantations with high chemical inputs, but the diversity of fruit and nectar-eating bat species did not differ. One paired sites study in Germany[3] recorded more bat species over grassland with moderate or no fertiliser applications than grassland with high fertiliser applications.

POPULATION RESPONSE (3 STUDIES)

- **Abundance (2 studies):** Two site comparison or paired sites studies (one replicated) in Portugal[2] and Germany[3] found that farms[2] or grasslands[3] with few or no chemical inputs had higher overall bat activity (relative abundance) than those using high chemical inputs.
- **Condition (1 study):** One replicated, site comparison study in Columbia[4] found that great fruit-eating bats captured in 'silvopastoral' areas that used no chemicals, along with agroforestry, had higher body weights and body condition scores than those in conventional farming areas that used chemicals.

BEHAVIOUR (0 STUDIES)

Background

Pesticides, herbicides, and fertilisers may degrade bat foraging habitats and reduce the availability of prey. Bats may also become directly contaminated, as these substances can persist and accumulate in ecosystems. Exposure to contaminants may not only kill bats but can have serious sub-lethal effects. For example, pesticide exposure can cause altered behaviour, reproductive failure, and disruption of hormones and the immune system (Bayat *et al*. 2014).

For studies that involve excluding the use of pesticide, herbicide, or fertiliser alongside other interventions, see '*Threat: Agriculture – All farming systems – Use organic farming instead of conventional farming*'.

Bayat S., Geiser F., Kristiansen P. & Wilson S.C. (2014) Organic contaminants in bats: trends and new issues. *Environment International,* 63, 40–52.

A site comparison study in 2004–2005 in five agroforestry plantations and one montane rainforest in southeastern Chiapas, Mexico (*1*) found that coffee agroforestry plantations using few or no chemicals had a higher diversity of insect-eating bat species than coffee agroforestry plantations with high chemical inputs, but the diversity of fruit and nectar-eating bat species did not differ. A higher diversity of insect-eating bat species was captured in plantations with low chemical use than in plantations with high chemical inputs (data reported as diversity index). The number of fruit and nectar-eating bat species was similar in plantations with low and high chemical use. More bat species were recorded in native rainforest (37 species) than in any of the five coffee agroforestry plantations (23–26 species). One site of native rainforest was sampled, and five sites on coffee agroforestry plantations with different amounts of chemical use (either none, organic compost, or different combinations of Thiodan, herbicide and fertilizer). Plantations with the highest chemical input used all three chemical types. At each of six sites, bats were captured with six mist nets placed along a 150 m transect for 6 h from sunset on two nights. Surveys were repeated every 50 days from March 2004 to June 2005.

A replicated, site comparison study in 2010 of 36 Mediterranean olive farms in southwestern Portugal (*2*) found that traditional farms using few or no chemicals had greater bat activity and different compositions of bat species than intensive farms using high chemical inputs, but they did not differ significantly from semi-intensive farms. Bat activity overall was higher in traditional farms (average 6 bat passes/night) than intensive farms (1 bat pass/night). Species composition also differed (data reported as Sørenson's index). No significant differences in bat activity or species composition were found between traditional and semi-intensive farms (average 3 bat passes/night). At least eight bat species were recorded (see original paper for data for individual species). Thirty-six olive farms (13 traditional, 12 semi-intensive and 11 intensive) were surveyed. Traditional farms used few or no chemicals, semi-intensive farms used a moderate chemical input and intensive farms used high and frequent chemical inputs (dimethoate and deltamethrin). Tree density and the use of mechanical methods varied between farms. Three olive farms (one per management type) were simultaneously surveyed every night for one week between July and September 2010 with a bat detector deployed in the centre of each farm.

A site comparison study in 2012–2013 of three grassland sites in Brandenburg, Germany (*3*) found that grasslands with moderate or no fertiliser applications had higher overall bat activity and more bat species than a grassland with high amounts of fertiliser applied. Overall bat activity (of 11 bat species) and the number of bat species recorded were higher over grasslands with moderate (average 11 bat passes/hour, 7 bat species/night) or no fertiliser applications (17 bat passes/hour, 7 bat species/night) than high fertiliser applications (5 bat passes/hour, 5 bat species/night). One site (1 ha) was sampled in each of three grasslands treated with different amounts of nitrogen (N) fertiliser (high applications: 225 kg/ha; moderate: 100 kg/ha; none applied). The site with high fertiliser applications was harvested three times/year, and the site with moderate fertiliser application was grazed (1 cow/ha). Sites were located a similar distance to settlements, water bodies and other land use types. At each of three sites, two bat detectors recorded bat activity simultaneously over a total of 46 nights in May–October 2012 and April–October 2013.

A replicated, site comparison study in 2011–2012 of four tropical forest fragments in livestock farming areas in Córdoba, Columbia (*4*) found that great fruit-eating bats *Artibeus lituratus* captured in 'silvopastoral' areas that used no chemicals, along with agroforestry, had higher body weights and body condition scores than those within conventional farming areas that used chemicals. Great fruit-eating bats captured in 'silvopastoral' areas had a higher average body weight (64 g) and body condition score (0.93) than those captured in conventional farming areas (59.5 g; 0.86). In August 2011–July 2012, great fruit-eating bats were captured at forest fragments within each of two 'silvopastoral' areas (total 260 bats) and two conventional farming areas (total 69 bats). 'Silvopastoral' areas grazed livestock amongst trees, shrubs, and crops, without chemicals. Conventional areas grazed livestock in monocultures with little tree or shrub cover, and used agrochemicals, pesticides, and herbicides. Each of four sites was sampled 15 times for three consecutive nights with mist nets (6 x 3 m) deployed within the forest fragment (nine nets) and surrounding area (five nets). Nets were deployed for 12 h/night (18:00–06:00 h) and checked every 45 minutes. Each captured bat was weighed, forearm length was measured, and body condition calculated (body weight/forearm length). Bats were marked before release.

(1) Estrada C.G., Damon A., Hernández C.S., Pinto S.L. & Núñez G.I. (2006) Bat diversity in montane rainforest and shaded coffee under different management regimes in southeastern Chiapas, Mexico. *Biological Conservation,* 132, 351–361.

(2) Herrera J.M., Costa P., Medinas D., Marques J.T. & Mira A. (2015) Community composition and activity of insectivorous bats in Mediterranean olive farms. *Animal Conservation,* 18, 557–566.

(3) Starik N., Göttert T., Heitlinger E. & Zeller U. (2018) Bat community responses to structural habitat complexity resulting from management practices within different land use types - a case study from north-eastern Germany. *Acta Chiropterologica*, 20, 387–405.

(4) Chacón-Pacheco J.J. & Ballesteros-Correa J. (2019) Better body condition of *Artibeus lituratus* in fragments of tropical dry forest associated with silvopastoral systems than in conventional livestock systems in Córdoba, Colombia. Mejor condición corporal de *Artibeus*

lituratus en fragmentos de bosque seco asociados a sistemas silvopastoriles que en sistemas convencionales de ganadería en Córdoba, Colombia. *Oecologia Australis,* 23, 589–605.

10.7. Use organic pest control instead of synthetic pesticides

- We found no studies that evaluated the effects of using organic pest control instead of synthetic pesticides on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Many organic pesticides made from natural substances are less harmful than synthetic pesticides. For studies that involve using organic pest control alongside other interventions, see '*Threat: Agriculture – All farming systems – Use organic farming instead of conventional farming*'.

10.8. Change effluent treatments used in agriculture and forestry

- We found no studies that evaluated the effects of changing the effluent treatments used in agriculture and forestry on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Changing effluent treatments could reduce the effects of pollution from agriculture and forestry.

10.9. Prevent pollution from agricultural land or forestry from entering watercourses

- We found no studies that evaluated the effects of preventing pollution from agriculture or forestry from entering watercourses on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Measures may be taken to prevent pollution from agricultural land or forestry from entering watercourses. This could include leaving a buffer around watercourses, restricting the use of plant and machinery in proximity to watercourses and installing appropriate drainage systems to divert contaminated water away from watercourses. See also '*Plant riparian buffer strips*'.

10.10. Plant riparian buffer strips

- We found no studies that evaluated the effects of planting riparian buffer strips on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Vegetation may be planted at the edge of waterways to reduce the amount of pollution entering the water within agricultural and forestry areas, and help protect riparian foraging habitats for bats.

For a similar intervention, see '*Prevent pollution from agricultural land or forestry from entering watercourses*'. See also '*Threat: Biological resource use – Logging & wood harvesting – Retain riparian buffers in logged areas*' and '*Threat: Agriculture – All farming systems – Retain riparian buffers on agricultural land*' for studies that retain riparian buffers as habitat for bats.

Light pollution

Light pollution may disturb bats and degrade important habitats. Some bat species avoid lit areas, whereas others are attracted to street lights to forage putting them at risk of predation or collisions with traffic. For recent reviews on the effects of artificial lighting on bats, see Stone *et al.* (2015) and Rowse *et al*. (2016).

Rowse E.G., Lewanzik D., Stone E.L., Harris S. & Jones G. (2016) Dark matters: the effects of artificial lighting on bats. Pages 187–213 in*:* Voigt C.C. & Kingston T. (eds.) *Bats in the Anthropocene: Conservation of Bats in a Changing World.* Springer International Publishing, Cham.

Stone E.L., Harris S. & Jones G. (2015) Impacts of artificial lighting on bats: a review of challenges and solutions. *Mammalian Biology,* 80, 213–219.

10.11. Leave bat roosts and roost entrances unlit

- **Five studies** evaluated the effects of leaving bat roosts and roost entrances unlit on bat populations. Two studies were in the UK[2,4], and one study was in each of Canada[1], Hungary[3] and Sweden[5].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Abundance (1 study):** One replicated, controlled study in Canada[1] found that numbers of big brown bats and little brown bats roosting in buildings increased when roosts were left unlit and decreased when roosts were illuminated with artificial lights.
- **Condition (1 study):** One replicated, controlled study in Hungary[3] found that juvenile bats had a higher body mass and greater forearm length at unlit roosts than at roosts with artificial lighting.

BEHAVIOUR (4 STUDIES)

- **Use (1 study):** One replicated, before-and-after study in Sweden[5] found that all of 13 unlit churches continued to be used by brown long-eared bat colonies over 25 years, but bat colonies abandoned their roosts at 14 of 23 churches that were either partly or fully lit with floodlights.
- **Behaviour change (3 studies):** Three controlled studies (including two replicated studies) in the UK[2,4] and Hungary[3] found that more bats emerged[2,4], and bats emerged earlier and foraged for shorter periods[3], when roosts were left unlit than when they had artificial lighting.

Background

Lighting in the vicinity of a bat roost may cause disturbance, altered behaviour and roost abandonment.

A replicated, controlled study in 1970 of 11 bat colonies within buildings in Ontario, Canada (*1*) found that when bat roosts were left unlit, numbers of big brown bats *Eptesicus fuscus* and little brown bats *Myotis lucifugus* increased, whereas numbers decreased when roosts were illuminated with artificial lights. The number of big brown bats at a roost that was left unlit increased by 97%, whereas numbers decreased by 41–96% at illuminated roosts. The same was true for little brown bats (unlit roost: 57% increase; illuminated roosts: 53–89% decrease). Two bat roosts (one big brown bat, one little brown bat) were left unlit, and nine roosts (six big brown bat, three little brown bat) were illuminated with artificial lights. All 11 bat roosts were in attics and contained nursery colonies. Three types of light were used: safety lamps (60 or 100-W incandescent bulbs), cool fluorescent lamps (40-W tubes) or spotlights (150 W). Emerging bats were counted at each of the 11 roosts during 46 nights in May–August 1970.

A replicated, controlled study in 2000 at two bat roosts within buildings in Aberdeenshire, UK (*2*) found that when roosts were left unlit more soprano pipistrelles *Pipistrellus pygmaeus* emerged than when roosts were illuminated with white or blue lights at both roosts, or red lights at one of two roosts. More soprano pipistrelles emerged when both roosts were left unlit (average 40 and 90 bats) than when roosts were illuminated with white light (2 and 24 bats) or blue light (6 and 62 bats). Red light only had an effect at one of two roosts. More bats emerged at one roost when it was unlit (40 bats) than when it was illuminated with red light (13 bats), but at the second roost similar numbers emerged with (72 bats) and without red light (90 bats). A hand-held halogen light with coloured filters was placed within 3–5 m of each of the two roosts. Over 20 nights in July–

August 2000, nights with roosts unlit and nights with lighting were alternated. On nights with lighting, white, blue, and red lights were rotated in a random order and changed every 30 seconds. On each of 20 nights, the number of bats emerging per 30 second interval was counted at dusk.

A replicated, controlled study in 2003–2006 at nine buildings in north and south-east Hungary (*3*) found that three bat species departed from roosts earlier and over a shorter period and juveniles were larger at roosts without artificial lighting. Lesser mouse-eared bats *Myotis oxygnathus* emerged between 21:10 and 22:15 at an unlit roost, compared to between 21:15 and 23:00 at an illuminated roost at which lights were turned off at 22:00 (over half the bats emerged after that time). Greater horseshoe bats *Rhinolophus ferrumequinum* showed a similar pattern. Geoffroy's bats *Myotis emarginatus* emerged between 21:00 and 22:00 at an unlit roost, but only after lights were switched off at 23:30 at an illuminated roost. The forearm length of juvenile bats was greater at unlit roosts (Geoffroy's bat: 36 mm; mouse-eared bat: 46–57 mm) than illuminated roosts (Geoffroy's bat: 31 mm; mouse-eared bat: 37–57 mm). Body mass of juveniles was also greater at unlit roosts (Geoffroy's bat: 6 g; mouse-eared bat: 15–23 g) than illuminated roosts (Geoffroy's bat: 5 g; mouse-eared bat: 11–20 g). The timing of emergence was measured (1–3 times) at two buildings when illuminated and when unlit, and at one unlit building. Body mass and forearm length of juvenile bats were measured at five illuminated buildings (133 bats) and three unlit buildings with similar conditions (same type of roof, 108 bats). Experiments were carried out in June–August 2003, 2005 and 2006.

A controlled study in 2012 at a church in Norfolk, UK (*4*) found that when bat roost entrances were left unlit more Natterer's bats *Myotis nattereri* emerged than when entrances were illuminated with artificial light. Eleven bats emerged from the roost when the entrances were left unlit, whereas no bats emerged on the first night entrances were illuminated, and two bats emerged on the second night. On the third night, after the light was switched off, all 11 bats emerged. However, emergence times were reported to be earlier than those recorded prior to lighting (data not provided). A 400-W halogen lamp was placed 7.5 m below the roost and directed upwards to illuminate the roost entrances. In July–August 2012, the movements of 11 radio-tagged adult female Natterer's bats were monitored during four nights with the roost left unlit, four nights with the light switched on and four nights after the light was switched off.

A replicated, before-and-after study in 1980–2016 of 36 rural churches in southwestern Sweden (*5*) found that all of 13 unlit churches continued to be used by brown long-eared bat *Plecotus auritus* colonies over 25 years, but bat colonies abandoned their roosts at 14 of 23 churches that were either partly or fully lit with floodlights. Unlit churches continued to be used by more bat colonies (13 of 13, 100%) than partly lit churches (7 of 13 bat colonies, 54%) or fully lit churches (2 of 10 bat colonies, 20%). Fewer bat colonies abandoned their roosts at partly lit churches (6 of 13, 46%) than at fully lit churches (8 of 10, 80%). All 36 churches were surveyed during one daytime visit in summer between 1980 and 1990 before lights were installed. Floodlights (1–4 lights) were installed on 23 churches (date of installation not reported). Lights were directed upwards illuminating the walls and tower of each church either on one side (partly lit, 13 churches) or from all directions (fully lit, 10 churches). Thirteen churches were left unlit. Surveys were repeated at each of 36 churches in May–October 2016 after lighting had been installed. Other confounding effects, such as changes in habitat and food availability in the wider landscape, were not accounted for.

(1) 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.

(2) 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.

(3) Boldogh S., Dobrosi D. & Samu P. (2007) The effects of the illumination of buildings on house-dwelling bats and its conservation consequences. *Acta Chiropterologica*, 9, 527–534.

(4) Zeale M.R.K., Bennitt E., Newson S.E., Packman C., Browne W.J., Harris S., Jones G. & Stone E. (2016) Mitigating the impact of bats in historic churches: the response of Natterer's bats *Myotis nattereri* to artificial roosts and deterrence. *PLOS ONE,* 11, e0146782.

(5) Rydell J., Eklöf J. & Sánchez-Navarro S. (2017) Age of enlightenment: long-term effects of outdoor aesthetic lights on bats in churches. *Royal Society Open Science,* 4, 161077.

10.12. Avoid illumination of bat commuting routes

- **Three studies** evaluated the effects of avoiding the illumination of bat commuting routes on bat populations. Two studies were in the UK[2,3] and one was in the Netherlands[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (3 STUDIES)

- **Abundance (3 studies):** One replicated, before-and-after study in the Netherlands[1] found similar numbers of pond bats flying along unlit canals and canals illuminated with lamps. Two replicated, controlled studies in the UK[2,3] found greater activity (relative abundance) of lesser horseshoe bats[2,3] and myotis bats[3] along unlit hedges than along hedges illuminated with street lights, but activity was similar for common and soprano pipistrelles and *Nyctalus/Eptesicus* species along unlit and illuminated hedges[3].

BEHAVIOUR (2 STUDIES)

- **Behaviour change (2 studies):** One replicated, before-and-after study in the Netherlands[1] found that 28–96% of pond bats changed their flight paths along canals to avoid light spill from lamps. One replicated, controlled study in the UK[2] found that lesser horseshoe bats were active earlier along unlit hedges than along those illuminated with street lights.

Background

Bat commuting routes provide essential connectivity between roosts and foraging habitats. Bats prefer to commute under the cover of darkness to avoid predation and may abandon commuting routes if they are illuminated with artificial lighting.

A replicated, before-and-after study in 2005 at four canals in the Netherlands (*1*) found that unlit canals and canals illuminated with lamps had similar numbers of pond bats *Myotis dasycneme* flying along them at all of four sites, but bats were observed avoiding the lights. At all of four sites the number of bats flying along canals did not differ when they were unlit (122–493 bats) or illuminated with lamps (114–413 bats). However, at all of three sites where observations were made, bats changed their flight paths to fly around the light, with more bats doing so when lamps were facing along canals (96% of bats) than across them (28–42% of bats). At each of four sites, the canal was lit with a 1,000 W halogen lamp (1–30 lux with a 10 m range) either along the canal (three sites) or across the canal (one site). In July–August 2005, bats were surveyed during 2–4 unlit nights immediately before and after 1–4 nights with the lamps switched on. Two surveyors/site counted passing bats (at all of four sites) and made observations of behaviour (at three of four sites).

A replicated, controlled study in 2008 along eight hedgerows in the south of the UK (*2*) found that unlit hedges had higher activity of lesser horseshoe bats *Rhinolophus hipposideros,* and bats were active earlier in the evening, than along hedges illuminated with street lights. Unlit hedges had higher lesser horseshoe bat activity (average 79 bat passes) than hedges illuminated with street lights (average 7–10 bat passes). Lesser horseshoe bats were also active earlier on nights when hedges were unlit (average 30 minutes after sunset) than on nights when they were illuminated with street lights (79 minutes after sunset). Each of eight hedges was illuminated with two portable high-pressure sodium street lights (average 53 lux). In April–July 2008, observations and bat detector recordings were made for seven nights at each of eight sites with a silent unlit control treatment for one night, a noise treatment on the second night (with the generator powering the lights), four nights with the lit treatment and a final night with a repeat of the noise treatment.

A replicated, randomized, controlled study in 2009 of 10 hedges in southwest England and Wales, UK (*3*) found that unlit hedges had higher activity for two of five bat species or species groups than hedges illuminated with street lights. Higher activity was recorded along unlit hedges than illuminated hedges for lesser horseshoe bats *Rhinolophus hipposideros* (unlit: average 100 bat passes/night; illuminated: average 5–37 bat passes/night) and *Myotis* spp. (unlit: average 35 bat passes/night; illuminated: average 5 bat passes/night). Activity did not differ significantly along unlit and illuminated hedges for common pipistrelle *Pipistrellus pipistrellus*, soprano pipistrelle *Pipistrellus pygmaeus* or *Nyctalus*/*Eptesicus* spp. (see original paper for detailed results). Hedges were illuminated with LED street lights (24 x 2.4 watt high power LED's). At each of 10 sites, two bat detectors recorded activity in May–August 2009 for six nights with each of five treatments: a silent unlit control treatment, a noise treatment repeated twice (with the generator powering the lights) and three lit treatments in a randomized order of low (3.6 lux), medium (6.6 lux) and high intensity (49.8 lux).

(1) Kuijper D.P.J., Schut J., van Dullemen D., Limpens H., Toorman H., Goossens N. & Ouwehand J. (2008) Experimental evidence of light disturbance along commuting routes of pond bats *Myotis dasycneme*. *Lutra,* 51, 37–49.

(2) Stone E.L., Jones G. & Harris S. (2009) Street lighting disturbs commuting bats. *Current Biology,* 19, 1123–1127.
(3) Stone E.L., Jones G. & Harris S. (2012) Conserving energy at a cost to biodiversity? Impacts of LED lighting on bats. *Global Change Biology,* 18, 2458–2465.

10.13. Avoid illumination of bat foraging, drinking and swarming sites

- **Two studies** evaluated the effects of avoiding the illumination of bat drinking sites on bat populations. Both studies were in Italy[1,2] and one was also in Israel[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** Two replicated before-and-after studies (one randomized) in Italy[1,2] found that unlit water troughs had greater activity (relative abundance) of five of six bat species/species groups and six of eight bat species/species groups than troughs illuminated with artificial light. One of the studies[2] also found that unlit desert ponds in Israel had greater activity (relative abundance) of three bat species than illuminated ponds.

BEHAVIOUR (0 STUDIES)

Background

Key bat habitats such as foraging, drinking, and swarming sites should be left unlit to avoid disturbance to bats. Dark buffer zones may also be retained around them.

A replicated, randomized, before-and-after study in 2015 of four cattle troughs within forest in central Italy (*1*; same study area as *2*) found that unlit troughs had higher drinking activity for five of six bat species/species groups than troughs illuminated with artificial light. More drinking buzzes were recorded for five bat species/species groups when troughs were unlit than when they were illuminated with artificial light: barbastelle bat *Barbastella barbastellus* (unlit: 584; lit: 306), brown long-eared bat *Plecotus auritus* (unlit: 78; lit: 0), *Myotis* spp. (unlit: 599; lit: 134), Kuhl's pipistrelle *Pipistrellus kuhlii* (unlit: 116; lit: 64) and Savi's pipistrelle *Hypsugo savii* (unlit: 39; lit: 10). For the common pipistrelle *Pipistrellus pipistrellus*, the difference was not significant when troughs were unlit (240 drinking buzzes) or illuminated (165 drinking buzzes). Each of four cattle troughs consisted of two troughs (6 x 1.5 m) joined together. Troughs were illuminated with a portable LED (light-emitting diode) white light (average 49 lux). Each of four sites was surveyed using bat detectors on two nights with five randomized lit and unlit 10-minute periods/night in July–August 2015.

A replicated, before-and-after study in 2015–2016 at six cattle troughs within forest in Italy and three natural desert ponds in Israel (*2*) found that unlit troughs within forests had higher drinking activity for six of eight bat species/species groups than troughs illuminated with artificial light, and unlit desert ponds had higher drinking activity for all of three bat species than illuminated ponds. At forest sites, more drinking buzzes (average/30 min interval) were recorded when troughs were unlit than when they were illuminated for barbastelle bat *Barbastella barbastellus* (unlit: 250; illuminated: 140), *Myotis* spp. (unlit: 160; illuminated: 40), Natterer's bat *Myotis nattereri* (unlit: 35; illuminated: 8), brown long-eared bat *Plecotus auritus* (unlit: 50; illuminated: 4), common pipistrelle *Pipistrellus pipistrellus* (unlit: 88; illuminated: 76) and Leisler's bat *Nyctalus leisleri* (unlit: 11; illuminated: 4). The difference was not significant for Kuhl's pipistrelle *Pipistrellus kuhlii* (unlit: 28; illuminated: 46) or Savi's pipistrelle *Hypsugo savii* (unlit: 18; illuminated: 7). At desert sites, more drinking buzzes were recorded when ponds were unlit than when they were illuminated for desert pipistrelle *Hypsugo bodenheimeri* (unlit: 1,040; illuminated: 260), trident bat *Asellia tridens* (unlit: 240; illuminated: 70) and Kuhl's pipistrelle (unlit: 45–1,270; illuminated: 10–350). Troughs (same study area as *1*) and ponds were illuminated with a portable LED (light-emitting diode) white light. At each of nine sites, one bat detector recorded bat activity for four hours on two consecutive nights (one unlit, one lit) in July–August 2015 (forest) and July 2016 (desert).

(1) Russo D., Cistrone L., Libralato N., Korine C., Jones G. & Ancillotto L. (2017) Adverse effects of artificial illumination on bat drinking activity. *Animal Conservation,* 20, 492–501.
(2) Russo D., Ancillotto L., Cistrone L., Libralato N., Domer A., Cohen S. & Korine C. (2019) Effects of artificial illumination on drinking bats: a field test in forest and desert habitats. *Animal Conservation*, 22, 124–133.

10.14. Direct lighting away from bat access points or habitats

- We found no studies that evaluated the effects of directing lighting away from bat access points or habitats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Directional lighting or hoods may be used to direct lighting away from bat access points or habitats to reduce disturbance to bats. See also '*Leave bat roosts and roost entrances unlit*'.

10.15. Restrict timing of lighting

- **One study** evaluated the effects of restricting the timing of lighting on bat populations. The study was in France[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, paired sites study in France[1] found that turning off street lights for part of the night resulted in mixed results for activity (relative abundance), depending on bat species, when compared with leaving street lights switched on all night.

BEHAVIOUR (0 STUDIES)

Background

Dimming or switching off artificial lighting when not in use or at certain times of night (e.g. when bats are most active) may reduce the impact on bats. A study in the UK found that streetlights would need to be switched off until midnight to coincide with peak activity of the greater horseshoe bat *Rhinolophus ferrumequinum* (Day *et al*. 2015).

Day J., Baker J., Schofield H., Mathews F. & Gaston K.J. (2015) Part-night lighting: implications for bat conservation. *Animal Conservation,* 18, 512–516.

A replicated, paired sites study prior to 2015 at 36 paired rural sites in France (*1*) found that turning off street lights for part of the night resulted in higher activity for two bat species, lower activity for one bat species and similar activity for five bat species when compared with leaving street lights switched on all night. The average number of bat passes/night was higher with part-night lighting than full-night lighting for *Plecotus* spp. (part-night lighting: 2.3; full-night lighting: 0.6) and common noctules *Nyctalus noctula* (data not reported), but lower with part than full-night lighting for common pipistrelles *Pipistrellus pipistrellus* (part-night lighting: 515; full-night lighting: 1,130). Activity was similar under both light treatments for Kuhl's pipistrelles *Pipistrellus kuhlii*, Nathusius' pipistrelles *Pipistrellus nathusii*, Leisler's bats *Nyctalus leisleri*, serotine bats *Eptesicus serotinus* and *Myotis* spp. (see original paper for detailed results). Each of 36 pairs of sites had one site with street lighting (high-pressure sodium lights, 10–99 lux) and one unlit control site within similar habitats. Street lights were either turned off for part of the night (between midnight and 05:00 h, 24 sites) or were left on for the full night (12 sites). Each of 36 pairs was sampled simultaneously using bat detectors for one full night between May and August (year not reported).

(1) Azam C., Kerbiriou C., Vernet A., Julien J.-F., Bas Y., Plichard L., Maratrat J. & Le Viol I. (2015) Is part-night lighting an effective measure to limit the impacts of artificial lighting on bats? *Global Change Biology,* 21, 4333–4341.

10.16. Use low intensity lighting

- **Three studies** evaluated the effects of using low intensity lighting on bat populations. The three studies were in the UK[1–3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** One replicated, randomized, controlled study in the UK[2] found that activity (relative abundance) of lesser horseshoe bats, but not myotis bats, was higher along hedges with medium or low intensity lighting than hedges with high intensity lighting. One replicated, randomized, controlled study in the UK[3] found that activity of myotis bats, but not common pipistrelles, was higher along treelined roads with street lights dimmed to an intensity of 25% than roads with streetlights dimmed to 50% or left undimmed.

BEHAVIOUR (1 STUDY)

- **Behaviour change (1 study):** One replicated, controlled study in the UK[1] found that more soprano pipistrelles emerged from two roosts when the intensity of red lights was reduced by placing filters over them.

Background

Light pollution may be minimized by reducing light levels, e.g. by dimming lights or using low wattage or low intensity lights.

A replicated, controlled study in 2000 at two bat roosts within buildings in Aberdeenshire, UK (*1*) found that reducing the intensity of red light by adding 2–3 filters resulted in more soprano pipistrelles *Pipistrellus pygmaeus* emerging from the roosts than when only one filter was used. More soprano pipistrelles emerged from both roosts when red lights had two (73 and 72 bats) or three filters (76 and 127 bats) placed over them than when only one filter was used (35 and 26 bats). Over four nights in July–August 2000, each of two roosts were surveyed for one night with no lighting and for one night with red light of different intensities. A hand-held halogen light with 1–3 red filters was placed within 3–5 m of each of the two roosts. The number of filters (1–3) used on the red lights were rotated in a random order and changed every 30 seconds. On each of four nights, the number of bats emerging per 30 second interval was counted at dusk.

A replicated, randomized, controlled study in 2009 of 10 hedges in southwest England and Wales, UK (*2*) found that reducing the intensity of street lights along hedges resulted in higher activity of lesser horseshoe bats *Rhinolophus hipposideros* but had no effect on the activity of *Myotis* species. For lesser horseshoe bats, activity was higher when hedges were lit with low intensity lights (average 37 bat passes/night) and medium intensity lights (22 bat passes/night) than with high intensity lights (5 bat passes/night). For *Myotis* spp. there was no significant difference in activity between low, medium, and high intensity lights (average 5 bat passes/night for each). Hedges were illuminated with LED street lights (24 x 2.4 watt high power LED's). At each of 10 sites, two bat detectors recorded activity in May–August 2009 for six nights with each of five treatments: a silent unlit control treatment, a noise treatment repeated twice (with the generator powering the lights) and three lit treatments in a randomized order of low (3.6 lux), medium (6.6 lux) and high intensity (49.8 lux).

A replicated, randomized, controlled study in 2015 at 21 road sites in Hertfordshire, UK (*3*) found that street lights dimmed to an intensity of 25% had higher activity of *Myotis* spp. but lower activity of common pipistrelles *Pipistrellus pipistrellus* than street lights dimmed to 50% or left undimmed. A greater number of *Myotis* spp. passes were recorded at street lights dimmed to 25% than at street lights dimmed to 50% or left undimmed (data reported as statistical model results). Fewer common pipistrelle passes were recorded at street lights dimmed to 25% than at street lights dimmed to 50% or left undimmed. The activity of *Myotis* spp. and common pipistrelles did not differ between street lights dimmed to 25% and unlit controls. Each of 21 sites had three lighting columns (10 m high lamp posts with neutral light-emitting diode (LED) lights) along a stretch of treelined road. Each of four lighting treatments (controlled using pulse modulation) was applied for two consecutive nights/site in May–August 2015: 0% (unlit), 25% (average 11 lux), 50% (average 20 lux), undimmed (average 36 lux). Bat activity was recorded with a bat detector attached to the middle lighting column.

(1) 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.

(2) Stone E.L., Jones G. & Harris S. (2012) Conserving energy at a cost to biodiversity? Impacts of LED lighting on bats. *Global Change Biology,* 18, 2458–2465.

(3) Rowse E.G., Harris S. & Jones G. (2018) Effects of dimming light-emitting diode street lights on light-opportunistic and light-averse bats in suburban habitats. *Royal Society Open Science*, 5, 180205.

10.17. Use 'warm white' rather than 'cool' LED lights

- We found no studies that evaluated the effects of using 'warm white' LED lights rather than 'cool' LED lights on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

LEDs (light-emitting diodes) are increasingly being used in the lighting industry. It has been suggested that 'warm white' LED lights emitting little or no ultraviolet component may have less of an impact on bats than 'cool' lights emitting blue and ultraviolet wavelengths (e.g. Stone *et al.* 2015). Bat vision is more sensitive to light with shorter wavelengths (e.g. Müller *et al*. 2009), and ultraviolet lights can attract insects and foraging bats. For similar interventions, see '*Use ultraviolet filters on lights*' and '*Use red lighting rather than other lighting colours*'.

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.

Stone E.L., Harris S. & Jones G. (2015) Impacts of artificial lighting on bats: a review of challenges and solutions. *Mammalian Biology,* 80, 213–219.

10.18. Use ultraviolet filters on lights

- **One study** evaluated the effects of using ultraviolet filters on lights on bat populations. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, randomized, controlled study in the UK[1] found that hedges lit with ultraviolet filtered lights had higher soprano pipistrelle, but not common pipistrelle activity (relative abundance) than hedges lit with unfiltered light.

BEHAVIOUR (0 STUDIES)

Background

Ultraviolet filters may be fitted to existing lights to filter out the ultraviolet component and reduce the attraction of insects and foraging bats. For similar interventions, see '*Use 'warm white' rather than 'cool' LED lights*' and '*Use red lighting rather than other lighting colours*'.

A replicated, randomized, controlled study in 2014 at five hedges in Devon, UK (*1*) found that hedges lit with ultraviolet (UV) filtered lights had higher activity for one of two bat species than at hedges lit with unfiltered lights or unlit hedges. Soprano pipistrelle *Pipistrellus pygmaeus* activity was higher at hedges lit with UV filtered lights (average 5 bat passes/night) than at hedges lit with unfiltered lights (3 bat passes/night) or at unlit hedges (4 bat passes/night). Common pipistrelle *Pipistrellus pipistrellus* activity did not differ significantly between any of the light treatments (data not reported). At each of five hedges, two lights (8W LED flood lamps with additional UV bulbs) were set up 15 m apart and 5 m high. Filtered lights were covered with UV film filters to reduce UV emissions by 40%. Three treatments (UV filtered lights, unfiltered lights, unlit/control) were carried out at each pair of lights in a random order for three nights each between July and October 2014. Two additional unlit locations were also surveyed at each site. During each night, bat activity was recorded using bat detectors placed at the treatment site and at the unlit locations for 3 h from sunset.

(1) Mathews F., Gaston K., Bennie J., Day J., Schofield H. & Baker J. (2015) *WC1011: The biodiversity impacts of street lighting. Appendix G: An experimental test of a mitigation strategy to reduce the impacts of lighting on bats*. Department for Environment, Food and Rural Affairs (Defra), UK.

10.19. Use red lighting rather than other lighting colours

- **Three studies** evaluated the effects of red lighting on bat populations. Two studies were in the Netherlands[2,3] and one was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** One replicated, controlled, site comparison study in the Netherlands[2] found that red lighting resulted in higher activity (relative abundance) for one of three bat species groups than white or green lighting. One site comparison study in the Netherlands[3] found that culverts illuminated with red light had similar activity of commuting Daubenton's bats as culverts illuminated with white or green light.

BEHAVIOUR (1 STUDY)

- **Behaviour (1 study):** One replicated, controlled study in the UK[1] found that more soprano pipistrelles emerged from a roost when lit with red light than when lit with white light, but no difference was found between red and blue lights.

Background

Red lighting may have a reduced effect on bats compared to lighting of other colours, as bat vision is more sensitive to shorter wavelengths (blue and ultraviolet light) than longer wavelengths (red light) (Müller *et al*. 2009). However, a study in Latvia found that migratory bats may be attracted to red lighting, which could have negative consequences (Voigt *et al*. 2019).

For similar interventions, see '*Use 'warm white' rather than 'cool' LED lights*' and '*Use ultraviolet filters on lights*'.

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.

Voigt C.C., Rehnig K., Lindecke O. & Pētersons G. (2018) Migratory bats are attracted by red light but not by warm-white light: implications for the protection of nocturnal migrants. *Ecology and Evolution,* 8, 9353–9361.

A replicated, controlled study in 2000 at two bat roosts within buildings in Aberdeenshire, UK (*1*) found that when roosts were illuminated with red light more soprano pipistrelles *Pipistrellus pygmaeus* emerged than when roosts were illuminated with white light, but no difference was found between red and blue lights. At both roosts, more bats emerged when the roost entrance was illuminated with red light (13 and 72 bats) than when it was illuminated with white light (2 and 24 bats). No difference was found between red and blue light (6 and 62 bats emerging) at either roost. A hand-held halogen light with coloured filters was placed within 3–5 m of each of the two roosts. Over 20 nights in July–August 2000, nights with roosts unlit and nights with lighting were alternated. On nights with lighting, white, blue, and red lights were rotated in a random order and changed every 30 seconds. On each of 20 nights, the number of bats emerging per 30 second interval was counted at dusk.

A replicated, controlled, site comparison study in 2012–2016 at eight forest sites in the Netherlands (*2*) found that red lighting had higher activity for one of three bat species groups than white or green lighting, and similar activity was recorded for all three species groups in red lighting and darkness. For *Myotis* and *Plecotus* spp. more bat passes were recorded in red light (66) and darkness (67) than in white (31) and green light (22). For *Pipistrellus* spp. fewer bat passes were recorded in red light (5,940) and darkness (3,655) than in white (17,157) and green light (9,695). None of the light treatments had a significant effect on the number of bat passes recorded for *Nyctalus* or *Eptesicus* spp. (red light: 495; white light: 719; green light: 950; dark: 521). At each of eight sites, one 100 m transect was set up for each of four treatments (red light, white light, green light or left dark). Five 4 m high light posts were installed along each transect. Lights (8 lux) were turned on from sunset to sunrise. Bat detectors recorded bat activity for 5–15 nights/transect in June–July and August–September in each year between 2012 and 2016.

A site comparison study in 2015 of two road culverts near Elburg, Netherlands (*3*) found that culverts illuminated with red light had similar activity of commuting Daubenton's bats *Myotis daubentonii* as culverts illuminated with green or white light. The average number of Daubenton's bat passes did not differ significantly between culverts illuminated with red (43 bat passes/night), green (37 bat passes/night) or white light (39 bat passes/night). Activity was similar when culverts were left unlit (34 bat passes/night). Two light-emitting diode (LED) lamps of three colours (red, green, white) were installed on the ceiling of each of two identical, parallel road culverts (31 m long, 1.6 m diameter) carrying a stream. Different light treatments (unlit; red, green, or white light at 5 lux intensity) were applied simultaneously in each of the two culverts with treatments changed each night over a total of 47 nights in July–August 2015. Two bat detectors fitted alongside the lamps in each of the two culverts recorded bat activity.

(1) 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.

(2) Spoelstra K., van Grunsven R.H.A., Ramakers J.J.C., Ferguson K.B., Raap T., Donners M., Veenendaal E.M. & Visser M.E. (2017) Response of bats to light with different spectra: light-shy and agile bat presence is affected by white and green, but not red light. *Proceedings of the Royal Society B: Biological Sciences,* 284.

(3) Spoelstra K., Ramakers J.J.C., van Dis N.E. & Visser M.E. (2018) No effect of artificial light of different colors on commuting Daubenton's bats (*Myotis daubentonii*) in a choice experiment. *Journal of Experimental Zoology Part A: Ecological and Integrative Physiology*, 329, 506–510.

10.20. Use glazing treatments to reduce light spill from inside lit buildings

- We found no studies that evaluated the effects of using glazing treatments to prevent light spill from inside lit buildings on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Glazing treatments, including one-way glass, tinted or obscured glass or retrofitted films may be fitted to reduce light spill from inside lit buildings.

Noise pollution

Anthropogenic noise has been found to deter bats and reduce foraging success (e.g. Schaub *et al*. 2008, Siemers & Schaub 2011, Luo *et al*. 2015; Bunkley & Barber 2015). Excessive noise may also disturb roosting and hibernating bats.

Bunkley J.P. & Barber J.R. (2015) Noise reduces foraging efficiency in pallid bats (*Antrozous pallidus*). *Ethology,* 121, 1116–1121.

Luo J., Siemers B.M. & Koselj K. (2015) How anthropogenic noise affects foraging. *Global Change Biology,* 21, 3278–3289.

Schaub A., Ostwald J. & Siemers B.M. (2008) Foraging bats avoid noise. *Journal of Experimental Biology,* 211, 3174–3180.

Siemers B.M. & Schaub A. (2011) Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. *Proceedings of the Royal Society of London B Biological Sciences,* 278, 1646–1652.

10.21. Impose noise limits in proximity to bat roosts and habitats

- We found no studies that evaluated the effects of imposing noise limits in proximity to bat roosts and habitats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Noise limits may be imposed in proximity to bat roosts and important bat habitats to reduce disturbance.

10.22. Install sound barriers in proximity to bat roosts and habitats

- We found no studies that evaluated the effects of installing sound barriers in proximity to bat roosts and habitats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Sound barriers such as fences, walls or embankments may be installed in proximity to bat roosts and habitats to reduce noise levels. Specially designed barriers that reflect or absorb sound are available. A buffer of trees and vegetation may also be used.

For an intervention that aims to reduce noise disturbance within buildings see '*Threat: Residential and commercial development – Install sound-proofing insulation between bat roosts and areas occupied by humans within developments*'.

Timber treatments

Background

Chemicals such as insecticides and fungicides are often applied to roof timbers in buildings where bats roost, to protect against wood-boring beetles and wood-rotting fungus. Chemicals, such as lindane (or gamma HCH) and pentachlorophenol (PCP) were found to be lethal to bats (e.g. Racey & Swift 1986, Boyd *et al.* 1988, Shore et *al*. 1991) and were linked with declines in bat populations in the 1980s (Stebbings & Griffith 1986). Two early studies tested the effects of alternative chemicals on bats in laboratories and found some to be more harmful than others (Racey & Swift 1986, Shore et *al*. 1991). 'Mammal-safe' timber treatments have since been developed in some countries.

Boyd I.L., Myhill D.G. & Mitchell-Jones A.J. (1988) Uptake of gamma-HCH (lindane) by pipistrelle bats and its effect on survival. *Environmental pollution*, 51, 95–111.

Racey P.A. & Swift S.M. (1986) Residual effects of remedial timber treatments on bats. *Biological Conservation*, 35, 205–214.

Shore R.F., Myhill D.G., French M.C., Leach D.V. & Stebbings R.E. (1991) Toxicity and tissue distribution of pentachlorophenol and permethrin in pipistrelle bats experimentally exposed to treated timber. *Environmental Pollution*, 73, 101–118.

Stebbings R.E. & Griffith F. (1986) *Distribution and status of bats in Europe*. Institute of Terrestrial Ecology, Huntingdon, UK.

10.23. Use mammal-safe timber treatments in roof spaces

- We found no studies that evaluated the effects of using mammal-safe timber treatments in roof spaces on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

'Mammal-safe' timber treatments have been developed in some countries. In the UK, for example, such treatments are now widely available and are regulated by The Health and Safety Executive with strict directions for use.

10.24. Restrict timing of timber treatment application

- **One study** evaluated the effects of restricting the timing of timber treatment application on bat populations. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, controlled laboratory study in the UK[1] found that treating timber with lindane and pentachlorophenol 14 months prior to exposure by bats increased survival but did not prevent death.

BEHAVIOUR (0 STUDIES)

Background

Restricting the timing of timber treatment application, e.g. to periods when bats are not present within a roost, may reduce the impact on bats.

A replicated, controlled study in 1982–1984 in a laboratory in northeast Scotland, UK (*1*) found that treating cages with a commercial remedial timber treatment 14 months prior to exposure by common pipistrelle bats *Pipistrellus pipistrellus* resulted in bats surviving for longer than when cages were treated six weeks before exposure, but all bats still died. Bats survived longer in cages that had been treated 14 months previously (average 15 days) than cages treated six weeks previously (average four days), but all bats still died within 23 days of exposure. Female common pipistrelle bats were caught at nursery roosts and 10–14 bats were used in each of two trials. Experimental and control cages (40 x 20 x 20 cm) were made from steel or zinc and lined with plywood. Experimental cages were treated with timber treatment (1% w/v lindane and 5% w/v pentachlorophenol in an organic solvent) either 14 months or six weeks before the experiments. Control cages were left untreated. All cages were kept in unheated rooms with constant conditions, and bats were inspected daily for 113–120 days during summer in 1982–1984.

(1) Racey P.A. & Swift S.M. (1986) Residual effects of remedial timber treatments on bats. *Biological Conservation*, 35, 205–214.

11. Climate change and severe weather

Climate change is a very broad-scale threat, and most conservation efforts will be required on a landscape scale. As temperatures rise, bats may be required to expand their ranges to higher latitudes and altitudes. Ensuring the availability of well-connected habitats and roosting sites in these areas is an important factor, although there are likely to be many complex and species-specific issues involved (Sherwin *et al*. 2013).

Changes in the patterns of rainfall, and in the frequency and intensity of extreme weather events are also a threat to bats. Tropical storms can have a major impact on bats, causing direct habitat damage and destruction. Extreme heatwaves can cause mass mortality.

Most of the interventions for this threat relate to maintaining existing habitats as conditions change, as well as ensuring the availability of new habitats and suitable dispersal corridors for bats as range shifts occur. However, it may be difficult to directly evaluate the effects of these interventions before significant climate change events have occurred.

For more general conservation interventions relating to conserving and creating habitats, see '*Habitat protection*' and '*Habitat restoration and creation*'.

Sherwin H.A., Montgomery W.I. & Lundy M.G. (2013) The impact and implications of climate change for bats. *Mammal Review,* 43, 171–182.

11.1. Adapt bat roost structures to buffer against temperature extremes

- We found no studies that evaluated the effects of adapting bat roost structures to buffer against temperature extremes on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

The frequency, intensity and duration of heat waves is expected to increase with climate change. Adapting bat roost structures to buffer against extreme temperatures could help to protect bats during extreme weather events.

For an intervention that aims to maintain the microclimate of artificial roosts, see '*Species management – Manage microclimate of artificial bat roosts*'.

11.2. Enhance natural habitat features to improve landscape connectivity to allow for range shifts of bats

- We found no studies that evaluated the effects of enhancing natural habitat features to improve landscape connectivity to allow for range shifts of bats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Landscape connectivity is important to allow for the range shift of bats in response to climate change (e.g. Aguiar *et al*. 2016). Natural habitat features such as forest corridors may be enhanced and/or extended to reduce habitat fragmentation.

This intervention will also depend on the availability of suitable habitats in new areas. See '*Provide suitable bat foraging and roosting habitat at expanding range fronts*'.

Aguiar L.M.S., Bernard E., Ribeiro V., Machado R.B. & Jones G. (2016) Should I stay or should I go? Climate change effects on the future of Neotropical savannah bats. *Global Ecology and Conservation,* 5, 22–33.

11.3. Provide suitable bat foraging and roosting habitat at expanding range fronts

- We found no studies that evaluated the effects of providing suitable bat foraging and roosting habitat at expanding range fronts on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

The ability of bats to shift their ranges in response to climate change will depend on the availability of suitable foraging and roosting habitat. Protecting, creating or restoring suitable habitat at expanding range fronts may help bats to move to new areas. However, this intervention will also depend on the availability of dispersal routes between habitats. See '*Enhance natural habitat features to improve landscape connectivity to allow for range shifts of bats*'.

11.4. Manage natural water bodies in arid areas to prevent desiccation

- We found no studies that evaluated the effects of managing natural water bodies in arid areas to prevent desiccation on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

The availability of water in arid areas is predicted to decrease under future climate change scenarios (Intergovernmental Panel on Climate Change 2014). Desert bats depend on these water resources for both drinking and foraging (Razgour *et al.* 2010) and reduced water availability can affect their survival and reproductive success (Adams & Hayes 2008). Studies that experimentally reduced desert pond sizes to simulate predicted water loss due to climate change found reduced bat activity and species richness, particularly for larger, less manoeuverable bat species (Razgour *et al*. 2010, Hall *et al*. 2016, Razgour *et al.* 2018).

For evidence relating to artificial water sources, see '*Habitat restoration and creation – Create artificial water sources*'.

Adams R.A. & Hayes M.A. (2008) Water availability and successful lactation by bats as related to climate change in arid regions of western North America. *Journal of Animal Ecology,* 77, 1115–1121.

Hall L.K., Lambert C.T., Larsen R.T., Knight R.N. & McMillan B.R. (2016) Will climate change leave some desert bat species thirstier than others? *Biological Conservation,* 201, 284–292.

Intergovernmental Panel on Climate Change (2014) *Climate Change 2014 – Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects: Working Group II Contribution to the IPCC Fifth Assessment Report: Volume 1: Global and Sectoral Aspects.* Cambridge, Cambridge University Press.

Razgour O., Korine C. & Saltz D. (2010) Pond characteristics as determinants of species diversity and community composition in desert bats. *Animal Conservation,* 13, 505–513.

Razgour O., Persey M., Shamir U. & Korine C. (2018) The role of climate, water and biotic interactions in shaping biodiversity patterns in arid environments across spatial scales. *Diversity and Distributions,* 24, 1440–1452.

12. Habitat protection

Habitat destruction is the largest single threat to biodiversity and habitat fragmentation and degradation often reduce the quality of remaining habitat. Habitat protection is therefore one of the most frequently used conservation interventions, particularly in the tropics and in other areas with large patches of surviving natural vegetation.

Habitat protection can be through the designation of legally protected areas, using national or local legislation. It can also be through the designation of community conservation areas or similar schemes, which do not provide formal protection but may increase the profile of a site and make its destruction less likely. Alternatively, protection can be of entire habitat types, for example through the European Union's Habitats Directive. On a smaller scale, habitat protection may involve ensuring areas of important habitat are retained during detrimental activities.

12.1. Legally protect bat habitats

- **Five studies** evaluated the effects of legally protecting bat habitats on bat populations. Four studies were in Europe[1–4] and one was in India[5].

COMMUNITY RESPONSE (2 STUDIES)

- **Community composition (1 study):** One replicated, site comparison study in India[5] found that the composition of bat species was similar in protected forest and unprotected forest fragments.
- **Richness/diversity (2 studies):** Two replicated, site comparison or paired sites studies in Europe[3] and India[5] found that the number of bat species did not differ between protected and unprotected forests[3] or forest fragments[5]. One replicated, site comparison study in France[4] found that protected sites had a greater number of bat species than unprotected sites.

POPULATION RESPONSE (4 STUDIES)

- **Abundance (4 studies):** One replicated, site comparison study in the UK[1] found that the activity (relative abundance) of Daubenton's bats was higher over rivers on farms in protected areas than in unprotected areas. One replicated, paired sites study in Europe[4] found that the activity of common noctule bats was higher in protected forests than unprotected forests, but bat activity overall did not differ. Two replicated, site comparison studies in France[4] and India[5] found higher overall bat activity[4], higher activity of three of six bat species/species groups[4] and a greater number of bats[5] in protected sites[4] and forests[5] than unprotected sites[4] and forests[5].

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One study in Spain[2] found that the distributions of 10 of 11 bat species overlapped with areas designated to protect them significantly more than by chance.

Background

National legislation for bats varies around the world. In some countries, bat roosts and important bat habitats are legally protected, but in others there is no protection at all.

Assessing the effectiveness of protected areas is particularly difficult. For example, protected and unprotected areas might start off with different quality habitats (protection being granted to the best quality habitat). Protected areas are also more likely to be in remote areas, so less accessible to threats such as harvesting (Joppa & Pfaff 2009). Finally, effectiveness is best monitored over long timescales, but this increases the chance that other factors influence the ecosystem. The most reliable studies would compare protected and unprotected areas over time, and possibly correct for some of the biases.

For other interventions relating to the legal protection of bats, see '*Threat: Residential and commercial development – Legally protect bats during development*' and '*Species management – Legally protect bat species*'.

Joppa L.N. & Pfaff A. (2009) High and far: biases in the location of protected areas. *PLoS ONE*, 4, e8273.

A replicated, site comparison study in 2009–2012 of 80 rivers on farms in Wales, UK (*1*) found that rivers in protected areas had higher activity of Daubenton's bats *Myotis daubentonii* than rivers in unprotected areas, but the activity of soprano pipistrelles *Pipistrellus pygmaeus* did not differ between protected and unprotected areas. The average number of bat passes/year for Daubenton's bats was higher over rivers in protected areas on both agri-environment farms (2.3 bat passes) and conventional farms (3.3 bat passes) than rivers in unprotected areas on agri-environment scheme farms (1.6 bat passes) and conventional farms (2.3 bat passes). A similar number of bat passes/year were recorded over rivers in protected and unprotected areas for soprano pipistrelles (data not reported). Surveys were carried out at 46 protected rivers (26 on agri-environment scheme farms, 20 on conventional farms) and 34 unprotected rivers (14 on agri-environment scheme farms, 20 20 on conventional farms). Protected areas were designated as Sites of Special Scientific Interest. No details were reported about the origin of the rivers; water may have originated from outside the protected area. One transect was carried out along each river in August and September in 2009, 2010 and 2011.

A study in 2015 of protected areas in Spain (*2*) found that the distributions of 10 of 11 target bat species and 13 of 18 non-target bat species overlapped with protected 'Special Conservation Areas' (SACs) significantly more than expected by chance. The distributions of nine of 11 target bat species and 13 of 18 non-target bat species also overlapped with 'Special Protection Areas' (SPAs) designated to protect birds. The amount of overlap between bat species distributions and either of the protected area types did not differ significantly between target and non-target species. Both SPAs and SACs were part of the legally protected European

Natura 2000 network. Target species were of highest conservation concern and listed in Annex II of the European Habitats Directive. All other (non-target) bat species were listed in Annex IV. The mean percentage overlap between species distributions (grid cells in which the species occurred) and the protected areas were calculated using an existing bat dataset for mainland Spain and the Balearic Islands.

A replicated, paired sites study in 2011–2012 in 11 managed beech *Fagus sylvatica* forests in Germany, Austria, France and the UK (*3*) found that legally protected forests had higher activity for one of 20 bat species than unprotected forests, but overall bat activity and the number of bat species was similar between protected and unprotected forests. The number of common noctule *Nyctalus noctula* calls was higher in protected (141 calls) than unprotected forests (18 calls). However, the difference was not significant for 19 other bat species (see original paper for detailed results) or the number of bat calls recorded overall (protected forests: 1,223 calls; unprotected forests: 1,995 calls). The same was true for species richness (17 bat species recorded in both protected and unprotected forests). Surveys were conducted in 11 pairs of forest (one protected, one unprotected) managed for timber production. Protected forests were part of the Natura 2000 network. All stands were >10 ha with trees 80–120 years old and had a similar number of roost trees and volume of snags. Bat activity was recorded with bat detectors at eight locations per stand during one full night in May or July in 2011 or 2012.

A replicated, site comparison study in 2006–2013 along 1,608 road transects in France (*4*) found that legally protected sites had higher overall bat activity, more bat species, and higher activity of three of six bat species/species groups than unprotected sites. Overall bat activity was 24% higher within protected sites than outside them, and the number of bat species recorded was 14% higher (data reported as statistical model results). The activity of three bat species/species groups was also higher within protected sites than unprotected sites: common pipistrelle *Pipistrellus pipistrellus* (14% higher in protected sites), serotine bat *Eptesicus serotinus* (105% higher) and *Myotis* spp. (368% higher). For three other bat species (Kuhl's pipistrelle *Pipistrellus kuhlii*, common noctule bat *Nyctalus noctula*, Leisler's bat *Nyctalus leisleri*) activity did not differ between protected and unprotected sites. Legally protected sites were part of the Natura 2000 network. Data were collected as part of a citizen science programme. Volunteers recorded bat activity while driving along 1,608 x 2 km road transects (each repeated an average of 2.4 times) through different habitats in protected and unprotected areas (number of sites for each not reported) between June and July in 2006–2013.

A replicated, site comparison study in 2010–2013 of 10 rainforest sites in the Western Ghats, India (*5*) found that protected forest had a greater number of bats than unprotected forest fragments, but the number of bat species and species compositions were similar. The total number of bats captured and recorded was higher in protected forest (average 35 bats/site) than unprotected forest fragments (17 bats/site). However, the average number of bat species recorded did not differ significantly (protected forest: 8 bat species/site; unprotected forest fragments: 6 bat species/site), and nor did the composition of bat species (data reported as statistical model results). Seventeen bat species were recorded in total (see original paper for data for individual species). Five protected rainforest sites and five unprotected rainforest fragments (2–103 ha) were surveyed. At each of 10 sites, bats were captured with five mist nets and recorded with bat detectors at five sampling points during two nights between January and May in 2010–2013 and November–December 2014.

(1) MacDonald M.A., Morris A.J., Dodd S., Johnstone I., Beresford A., Angell R., Haysom K., Langton S., Tordoff G., Brereton T., Hobson R., Shellswell C., Hutchinson N., Dines T., Wilberforce E.M., Parry R. & Matthews V. (2012) *Welsh Assembly Government Contract 183/2007/08 to Undertake Agri-environment Monitoring and Services. Lot 2 – Species Monitoring. Final report: October 2012.*

(2) Lisón F., Sánchez-Fernández D. & Calvo J.F. (2015) Are species listed in the Annex II of the Habitats Directive better represented in Natura 2000 network than the remaining species? A test using Spanish bats. *Biodiversity and Conservation*, 24, 2459–2473.

(3) Zehetmair T., Müller J., Runkel V., Stahlschmidt P., Winter S., Zharov A. & Gruppe A. (2015) Poor effectiveness of Natura 2000 beech forests in protecting forest-dwelling bats. *Journal for Nature Conservation,* 23, 53–60.

(4) Kerbiriou C., Azam C., Touroult J., Marmet J., Julien J.-F. & Pellissier V. (2018) Common bats are more abundant within Natura 2000 areas. *Biological Conservation,* 217, 66–74.

(5) Wordley C.F.R., Sankaran M., Mudappa D. & Altringham J.D. (2018) Heard but not seen: comparing bat assemblages and study methods in a mosaic landscape in the Western Ghats of India. *Ecology and Evolution*, 8, 3883–3894.

12.2. Retain buffer zones around core habitat

- We found no studies that evaluated the effects of retaining buffer zones around core habitat on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Retaining areas of natural or semi-natural vegetation around core habitat can help to protect the habitat and wildlife that it supports from the detrimental effects of habitat loss or disturbance. Core bat habitats include foraging, drinking and swarming sites, as well as roosts and hibernacula. Buffers may also be retained along important bat commuting routes.

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared core bat habitats where a buffer has been kept intact with similar/nearby areas where buffers have not been kept. There must have been an active decision (i.e. intervention) to retain the buffer and the study must state when the intervention was carried out.

For interventions relating to retaining buffers around bat habitats in logged forests, see '*Threat: Biological resource use – Logging and wood harvesting – Retain buffers around roost trees in logged areas*' and '*Threat: Biological resource use – Logging and wood harvesting – Retain riparian buffers in logged areas*'. For planting of buffer zones to reduce pollution see '*Threat: Pollution – Agricultural and forestry effluents – Plant riparian buffer strips*'.

12.3. Conserve roosting sites for bats in old structures or buildings

- **Three studies** evaluated the effects of conserving roosting sites for bats in old structures or buildings on bat populations. Two studies were in the UK[1,3] and one was in Germany[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One before-and-after study in the UK[1] found that a greater number of bats hibernated in a railway tunnel after walls with access grilles were installed at the tunnel entrances and wood was attached to the tunnel walls.

BEHAVIOUR (2 STUDIES)

- **Uptake (1 study):** One before-and-after study in Germany[2] found that numbers of bats hibernating in a disused cellar after it was emptied of rubbish increased over 11 years.
- **Use (2 studies):** One before-and-after study in Germany[2] found that a disused cellar that was emptied of rubbish was used by hibernating bats of four species. One before-and-after study in the UK[3] found that Natterer's bats used a roost that was 'boxed-in' within a church, but the number of bats using the roost was reduced by half.

Background

Old structures or buildings and the roosting spaces within them may be conserved as roosting sites for bats. Conflict may arise when old buildings are also used by humans, and solutions may be sought to both conserve bat roosts and reduce any negative impacts on human inhabitants or visitors.

A before-and-after study in 1993–1997 of a disused railway tunnel in Wiltshire, UK (*1*) found that conserving a roosting site by constructing walls with access grilles at the ends of the tunnel, along with attaching wood to the tunnel walls, resulted in an increase in the number of hibernating bats. More bats were counted hibernating in the tunnel after the end walls were constructed and wood attached (before: 117 bats; two years after: 190 bats). During fourteen subsequent surveys (dates not reported), the number of hibernating bats increased to 678, with 30% of bats roosting behind the wood on the tunnel walls. The majority (94%) were Natterer's bats *Myotis nattereri.* Brown long-eared bats *Plecotus auritus*, Daubenton's bats *Myotis daubentonii*, whiskered/Brandt's bats *Myotis mystacinus/brandtii* and barbastelle bats *Barbastella barbastellus* were also recorded. The end walls with access grilles were constructed in 1994, and wood was attached to the tunnel walls in 1994 and 1995. The temperature was reported to be more stable after the end walls were constructed (before: not reported; after: 8˚C) and humidity inside the tunnel increased (before: 80%; after: 95%). Hibernating bats were counted in the winters of 1993 and 1996/1997.

A before-and-after study in 2000–2011 in a cellar in Brandenburg, Germany (*2*) found that after the cellar was emptied of rubbish, an increasing number of bats used it as a winter roost over an 11-year period. Results were not statistically tested. Eleven years after an ice cellar was emptied of rubbish, 127 bats of four species were recorded hibernating, compared to eight bats of three species in the year the cellar was emptied. Natterer's *Myotis nattereri*, Daubenton's *Myotis daubentonii*, brown long-eared *Plecotus auritus* and barbastelle *Barbastella barbastellus* bats hibernated in the cellar in increasing numbers (winter 2000/01: Natterer's = 4; Daubenton's = 1, brown long-eared = 3, barbastelle = 0 individuals; winter 2010/11: Natterer's = 59; Daubenton's = 30, brown long-eared = 30, barbastelle = 8 individuals). Greater mouse-eared bats *Myotis myotis* were also recorded in low numbers throughout the study (0–4 individuals/year; see original paper for details). In 2000 and 2001, a disused stone cellar (4.5 m wide x 6 m long x 9 m high; previously used for ice storage) located in a biosphere reserve (1,291 km^2) was emptied of rubble and rubbish to create space for roosting bats. Human access was prohibited. Bats were monitored once/year between December and mid-February in 2000/01–2010/11. In winters of 2000/01 and 2001/2, the authors report that the census may have been limited by the height of their ladder.

A before-and-after study in 2012–2013 at one church in Norfolk, UK (*3*) found that two sections of an existing roost within the church that were 'boxed-in' continued to be used by Natterer's bats *Myotis nattereri*, but the number of bats using the roost after it had been 'boxed-in' was reduced by half. The 'boxed-in' areas continued to be used by up to 52% of bats (46 of 88) that originally roosted in the church. Up to 28 of the bats that originally roosted in the church used an external roost location in the church porch as a new roost site. The 'boxed-in' areas (5 m long) were accessible to bats via existing entry points and were sealed off from the internal spaces of the church. They included roof timbers and mortise joints that had previously been used by the bats. The roosts were 'boxed-in' after the build-up of droppings and urine within the church interior caused problems for human visitors. Emergence surveys and radio-tracking were carried out at each site between July and September in 2012 or 2013.

(1) Mitchell-Jones A.J., Bihari Z., Masing M. & Rodrigues L. (2007) *Protecting and managing underground sites for bats. EUROBATS Publication Series No. 2 (English version)*. UNEP/EUROBATS Secretariat, Bonn, Germany.

(2) Haensel J., Itterman L. & Tismer R. (2011) Renovated ice cellar in Glambeck (Schorfheide-Chorin biosphere reserve) - an ideal winter roost for bats. Hergerichteter Eiskeller in Glambeck (Biosphärenreservat Schorfheide-Chorin) - ein ideales Winterquartier für Fledermäuse. *Nyctalus*, 16, 51–57.

(3) Zeale M.R.K., Bennitt E., Newson S.E., Packman C., Browne W.J., Harris S., Jones G. & Stone E. (2016) Mitigating the impact of bats in historic churches: the response of Natterer's bats *Myotis nattereri* to artificial roosts and deterrence. *PLOS ONE,* 11, e0146782.

12.4. Retain veteran and standing dead trees as roosting sites for bats

- We found no studies that evaluated the effects of retaining veteran and standing dead trees on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Veteran or damaged trees (of any age and size) and standing dead trees ('snags') can provide important roosting sites for bats within crevices, cavities and behind loose bark.

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared areas where veteran and standing dead trees have been kept as roosting sites for bats with similar/nearby areas where they have been removed. There must have been an active decision (i.e. intervention) to retain the trees and the study must state when the intervention was carried out.

For an intervention that involves creating roost features in trees, see '*Habitat restoration and creation – Create artificial hollows and cracks in trees for roosting bats*'. See also '*Threat: Residential and commercial development – Create or restore bat foraging habitat in urban areas*' for one study that uses snag recruitment alongside other practices for forest restoration.

12.5. Retain existing bat commuting routes

- We found no studies that evaluated the effects of retaining existing bat commuting routes on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Some bats are highly faithful to their commuting routes. Retaining existing commuting routes (e.g. along hedgerows and treelines) allows bats to access important habitats and resources across the landscape. For an intervention that involves creating new commuting routes, see '*Habitat restoration and creation – Create new unlit commuting routes using planting*'.

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared areas where existing bat commuting routes have been kept intact with similar/nearby areas where commuting routes have been removed or otherwise degraded. There must have been an active decision (i.e. intervention) to retain the habitat features used by commuting bats and the study must state when the intervention was carried out.

12.6. Retain remnant habitat patches

- We found no studies that evaluated the effects of retaining remnant habitat patches on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Remnant patches of natural or semi-natural vegetation, such as forest and woodland, may provide important habitat for bats, particularly in disturbed or highly modified landscapes (e.g. Law *et al*. 1999, Saldana-Vazquez *et al*. 2013, De Torrez *et al.* 2018).

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared remnant habitats that has been kept intact with similar/nearby areas where remnant habitats have been removed or otherwise degraded. There must have been an active decision (i.e. intervention) to retain the remnant habitats and the study must state when the intervention was carried out.

For studies that provide evidence for retaining remnant forest on agricultural land, see '*Threat: Agriculture – All farming systems – Retain remnant forest or woodland on agricultural land*'.

De Torrez E.C.B., Ober H.K. & McCleery R.A. (2018) Critically imperiled forest fragment supports bat diversity and activity within a subtropical grassland. *Journal of Mammalogy*, 99, 273–282.

Law B.S., Anderson J. & Chidel M. (1999) Bat communities in a fragmented forest landscape on the south-west slopes of New South Wales, Australia. *Biological Conservation*, 88, 333–345.

Saldana-Vazquez R.A., Castro-Luna A.A., Sandoval-Ruiz C.A., Hernandez-Montero J.R. & Stoner K.E. (2013) Population composition and ectoparasite prevalence on bats (*Sturnira ludovici*; Phyllostomidae) in forest fragments and coffee plantations of central Veracruz, Mexico. *Biotropica*, 45, 351–356.

12.7. Retain connectivity between habitat patches

- We found no studies that evaluated the effects of retaining connectivity between habitat patches on bat populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Habitat destruction and fragmentation are important factors in the decline of bat populations. Retaining linear habitat features and corridors of native vegetation between suitable habitat patches may help to maintain bat populations (e.g. Frey-Ehrenbold *et al*. 2013, Heim *et al*. 2015).

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared areas where connectivity between habitat patches has been kept intact with similar/nearby areas where connectivity has been removed or otherwise degraded. There must have been an active decision (i.e. intervention) to retain the connecting features and the study must state when the intervention was carried out.

For similar interventions, see '*Retain existing bat commuting routes*' and '*Habitat restoration and creation – Restore or create linear habitat features/green corridors*'.

Frey-Ehrenbold A., Bontadina F., Arlettaz R. & Obrist M.K. (2013) Landscape connectivity, habitat structure and activity of bat guilds in farmland-dominated matrices. *Journal of Applied Ecology,* 50, 252–261.

Heim O., Treitler J.T., Tschapka M., Knörnschild M. & Jung K. (2015) The importance of landscape elements for bat activity and species richness in agricultural areas. *PLOS ONE,* 10, e0134443.

12.8. Retain wetlands

- We found no studies that evaluated the effects of retaining wetlands on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Wetland habitats are important for bats, providing a foraging and drinking resource (e.g. see Korine *et al*. 2016). Retaining wetlands may help to maintain bat populations.

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared wetlands that have been kept intact with similar/nearby areas where wetlands have been removed or otherwise degraded. There must have been an active decision (i.e. intervention) to retain the wetlands and the study must state when the intervention was carried out.

Korine C., Adams R., Russo D., Fisher-Phelps M. & Jacobs D. (2016) Bats and water: Anthropogenic alterations threaten global bat populations. Pages 215–241 in*:* Voigt C.C. & Kingston T. (eds.) *Bats in the Anthropocene: Conservation of Bats in a Changing World.* Springer International Publishing, Cham.

12.9. Retain native forest and woodland

- We found no studies that evaluated the effects of retaining native forest and woodland on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Native forests and woodland are important for bats providing both roosting and foraging habitat. Retaining native forests and woodland may help to maintain bat populations.

To be included as evidence for this intervention, studies must have monitored a comparison, i.e. compared native forest or woodland that has been kept intact with similar/nearby areas where native forest or woodland has been cut down or otherwise degraded. There must have been an active decision (i.e. intervention) to retain the native forest or woodland and the study must state when the intervention was carried out.

For studies that provide evidence for retaining remnant forest on agricultural land, see '*Threat: Agriculture – All farming systems – Retain remnant forest or woodland on agricultural land*'.

13. Habitat restoration and creation

Habitat destruction is one of the largest threats to bats and habitat protection remains one of the most important and frequently used conservation interventions. However, in many parts of the world, restoring damaged habitats or creating new habitat patches may also be possible. Habitat restoration or creation is often required by law as a response to activities or developments that destroy large areas of natural habitats.

Studies describing the effects of interventions that involve restoration processes that use fire are discussed in the section '*Threat: Natural system modifications – Fire and fire suppression – Use prescribed burning*'.

13.1. Create artificial hollows and cracks in trees for roosting bats

- **One study** evaluated the effects of creating artificial hollows and cracks in trees for roosting bats. The study was in Australia[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated study in Australia[1] found that eight of 16 artificial hollows cut into trees for bats, birds, and marsupials with two different entrance designs were used by roosting long-eared bats.

Background

Some bat species roost within naturally forming crevices and cavities within trees. Similar features could be created artificially in existing trees to provide roosting opportunities for bats.

A study that uses snag recruitment alongside other practices for forest restoration is described in '*Threat: Residential and commercial development – Create or restore bat foraging habitat in urban areas*'.

A replicated study in 2015–2016 of 16 trees within a timber production forest in New South Wales, Australia (*1*) found that half of the artificial hollows created in trees were used by long-eared bats *Nyctophilus* spp., and the design of the entrance did not have a significant effect on use. Eight of 16 artificial hollows were used by long-eared bats, including one of six hollows designed for bats and seven of 10 hollows designed for marsupials and birds, although use of the two designs did not differ significantly. Artificial hollows were created in 16 trees (33–54 mm diameter at breast height) within a forested area of 4 ha. In September 2015, one hollow (35 cm high x 9–20 cm wide and 4 m above the ground) was created in each of 16 trees using a chainsaw. A section of tree (4 cm deep) was reattached to the front of each hollow with an entrance hole either at the base (designed for bats, 38 mm diameter) or the top (designed for marsupials and birds, 38 or 76 mm diameter). Each of 16 hollows was monitored over 12–15 months in 2015–2016 with heat/motion activated cameras.

(1) Rueegger N. (2017) Artificial tree hollow creation for cavity-using wildlife – Trialling an alternative method to that of nest boxes. *Forest Ecology and Management,* 405, 404–412.

13.2. Reinstate bat roosts in felled tree trunks

- **One study** evaluated the effects of reinstating a bat roost within a felled tree trunk on bat populations. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One before-and-after study in the UK[1] found that a roost reinstated by attaching the felled tree trunk to a nearby tree continued to be used by common noctule bats as a maternity roost.

Background

If bat roosts are discovered in trees after felling, it may be possible to reinstate the felled tree trunk. However, this should be considered as a last resort, and original roost trees should be protected. See '*Habitat protection – Retain veteran and standing dead trees as roosting sites for bats*' and '*Threat: Biological resource use – Logging and wood harvesting – Protect roost trees during forest operations*'.

A before-and-after study in 2009–2013 in a broadleaf woodland in Milton Keynes, UK (*1*) found that a roost reinstated by attaching the felled tree trunk to a nearby tree continued to be used by common noctule bats *Nyctalus noctula* as a maternity roost. A similar number of bats used the roost before (47–75 bats) and after (37–46 bats) felling and reinstatement of the roost, although no statistical tests were carried out. The roost was in an ash *Fraxinus excelsior* tree within a 23-ha ancient semi-natural woodland. The tree was accidentally felled in December 2011. The tree trunk was reinstated within five days of felling by attaching it to a nearby tree using 19 mm steel banding and rubber straps. The access points were orientated to recreate their original positions prior to felling. A replacement top was constructed from ash wood to shelter the roost. The reinstated section and top were 3.4 m high x 0.5 m wide. Emergence counts were carried out at the roost twice in 2010 before felling and once/year in 2012 and 2013 after reinstatement.

(1) Damant C.J. & Dickins E.L. (2013) Rapid response mitigation to noctule *Nyctalus noctula* roost damage, Buckinghamshire, UK. *Conservation Evidence*, 10, 93–94.

13.3. Create artificial caves or hibernacula for bats

- **Four studies** evaluated the effects of creating artificial caves or hibernacula for bats on bat populations. Two studies were in the UK[1,4] and two were in Germany[2,3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (4 STUDIES)

- **Uptake (1 study):** One study in the UK[4] found that the number of bats using an artificial hibernaculum increased in each of nine years after it was built.
- **Use (4 studies):** One study in the UK[1] found that an artificial cave was used by a small number of brown long-eared bats. Three studies in Germany[2,3] and the UK[4] found that artificial hibernacula were used by up to four bat species.

Background

Artificial caves or hibernacula could be created for bats where natural sites are limited or where these habitats have been lost. Hibernacula would need to be carefully designed to ensure a stable microclimate.

For similar interventions, see '*Threat: Human intrusions and disturbance – Caving and tourism – Provide artificial subterranean bat roosts to replace roosts in disturbed caves*' and '*Threat: Energy production and mining – Provide artificial subterranean bat roosts to replace roosts in reclaimed mines*'. Some bat species may also hibernate in bat boxes, which are discussed in '*Species management – Provide bat boxes for roosting bats*'.

A study in 2004–2006 at a wetland nature reserve in Cambridgeshire, UK (*1*) found that an artificial cave was used by 1–2 hibernating brown long-eared bats *Plecotus auritus* in each of two years after construction. Bats were found hibernating attached to the cave roof or in between the concrete cave roof sections. The cave (2 m wide x 2 m high x 30 m long) consisted of a trench dug into the underlying limestone with a pre-cast concrete roof containing elongated bat bricks with six gaps in each. A door made of steel and oak boards was constructed to restrict access by predators and humans. Two slots in the top of the door allowed bats to pass through and a fine wire mesh on the bottom of the door allowed air flow. The cave was installed in 2004 and inspected for bats in 2005 and 2006.

A before-and-after study in 1974–2007 in a disused former brickwork factory in Brandenburg, Germany (*2*) found that artificial hibernacula were used by four bat species during at least three winters. In the three years after artificial hibernacula were installed, 35–55 bats/year of four bat species hibernated in the disused factory, compared to 5–24 bats/year of up to six bat species in the 20 years prior to hibernacula installation. The bat species recorded hibernating after artificial hibernacula were installed included greater mouse-eared *Myotis myotis*, Daubenton's *Myotis daubentonii*, Natterer's *Myotis nattereri* and brown long-eared bats *Plecotus auritus*. Barbastelle *Barbastella barbastellus,* Bechstein's *Myotis bechsteinii* and grey long-eared bats *Plecotus austriacus* were also recorded before the hibernacula were installed. In September–October 2005, a number of hibernacula (made from a composite material of concrete and sawdust) and large hollow concrete blocks and bricks (numbers of each not reported) were hung from walls and ceilings in a tunnel (2 m high x 140 m long). Hibernating bats were monitored in the tunnel during most winters in 1974/1975–1990/1991, 1993/1994, 1994/1995, 1996/1997 and 2002/2003–2006/2007 (20 years before and three years after the hibernacula were installed).

A replicated study in 2007–2009 of eight bat roosts in eastern Germany (*3*) found that most artificial hibernacula made of styrofoam and corrugated plastic were used by up to four bat species. Nine of 10 artificial hibernacula installed in eight different winter roosts were used by up to 15 bats at a time. Bat species recorded using the hibernacula included Natterer's bat *Mytois nattereri*, Daubenton's bat *Myotis daubentonii*, brown long-eared bat *Plecotus auritus* and barbastelle bat *Barbastella barbastellus*. Hibernacula were made from styrofoam insulation panels (40 mm deep x 500 mm wide x 400 mm long) with see-through corrugated PVC sheets attached to the front (see original paper for details). Ten hibernacula were installed in eight winter roosts in autumn 2007. Monitoring methods were not reported.

A study in 2004–2013 in a forest in Thetford, UK (*4*) found that an artificial hibernaculum was used by hibernating bats of four species with numbers increasing in each of nine years after it was built. The artificial hibernaculum was first used by one brown long-eared bat *Plecotus auritus* in 2007, the second winter after it was built. In 2008, two brown long-eared bats were counted in the hibernaculum. From 2009 to 2013, three bat species were counted in the hibernaculum (brown long-eared bats, Daubenton's bats *Myotis daubentonii* and Natterer's bats *Myotis nattereri*) with the total number increasing each year (2009: 13–16 bats; 2010: 18–31 bats; 2011: 31 bats; 2012: 25–50 bats; 2013: 54–62 bats). The hibernaculum (built in 2004) consisted of a 95 m long 'Y' shaped concrete block tunnel with an access grille, ventilation pipes and bat bricks built into the ceiling. Hanging planks and logs with slots cut into them were placed inside the tunnel. Bats were counted inside the tunnel during 1–4 months in winter in 2006–2013.

(1) Gulickx M.M.C., Beecroft R.C. & Green A.C. (2007) Creating a bat hibernaculum at Kingfishers Bridge, Cambridgeshire, England. *Conservation Evidence*, 4, 41–42.

(2) Herter R. (2007) Unconventional wall and ceiling elements made from wood-concrete residues as ideal winter accommodation for bats. Unkonventionell aus Holzbetonresten hergestellte Wand- und Deckenelemente als ideale Winterquartierausstattung für Fledermäuse. *Nyctalus*, 12, 325–330.

(3) Blohm, T. (2009) Experience with styrofoam hibernacula in winter bat roosts. Erfahrungen mit Verstecken aus Styropor in Fledermauswinterquartieren. *Nyctalus*, 14, 47–48.

(4) Gibbons N. (2013) Two Mile Bottom bat hibernaculum from folly to fantasy. *Suffolk Natural History*, 49.

13.4. Create new unlit bat commuting routes using planting

- We found no studies that evaluated the effects of creating new unlit bat commuting routes using planting on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Linear features such as hedgerows and treelines provide important commuting routes for bats (Limpens & Kapteyn 1991, Verboom & Huitema 1997, Downs & Racey 2006). Where original commuting routes cannot be retained, new unlit commuting routes could be planted. However, it will take a considerable amount of time for hedgerows or trees to become established and sufficiently mature. Existing commuting routes should be retained where possible. See '*Habitat protection – Retain existing bat commuting routes*'.

For an intervention that involves diverting bat commuting routes, see '*Threat: Transportation - Roads – Divert bats to safe crossing points over or under roads/railways with plantings or fencing*'.

Downs N.C. & Racey P.A. (2006) The use by bats of habitat features in mixed farmland in Scotland. *Acta Chiropterologica,* 8, 169–185.

Limpens H.J. & Kapteyn K. (1991) Bats, their behaviour and linear landscape elements. *Myotis*, 29, 39–48.

Verboom B. & Huitema H. (1997) The importance of linear landscape elements for the pipistrelle *Pipistrellus pipistrellus* and the serotine bat *Eptesicus serotinus*. *Landscape Ecology*, 12, 117–125.

13.5. Restore or create forest or woodland

- **Two studies** evaluated the effects of restoring forests on bat populations. One study was in Brazil[1] and one in Australia[2].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One site comparison study in Brazil[1] found that a reforested area had lower bat diversity than a native forest fragment.

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, controlled, site comparison study in Australia[2] found that forests restored after mining had higher or similar bat activity (relative abundance) as unmined forests for five of seven bat species.

BEHAVIOUR (0 STUDIES)

Background

Restoring or creating forest and woodland may provide bats with important habitat in disturbed or fragmented landscapes.

A study that examined the effects of forest restoration in an urban area is described in '*Threat: Residential and commercial development – Create or restore bat foraging habitats in urban areas*'.

A site comparison study in 2007–2008 in two native forest fragments in southern Brazil (*1*) found that a reforested area had lower bat diversity than a protected native forest fragment. In the reforested area, 105 bats of six species were captured, and in the protected forest fragment, 397 bats of 14 species were captured (diversity data reported as diversity indices). No comparisons were made before and after restoration, or with unrestored areas. Both forests consisted of native tree species. The protected forest fragment (108 ha) had been selectively logged 20 years previously. The reforested area (12 ha) had previously been cleared for agriculture and cattle grazing, and had been planted with native tree species in 2002. At each of two sites, bats were captured in eight mist nets at ground level for 6 h from sunset on two consecutive nights. Each site was surveyed four times in spring, summer, autumn, and winter in 2007 or 2008.

A replicated, controlled, site comparison study in 2010–2012 of 64 restored forest sites in southwestern Australia (*2*) found that restored forests had higher or similar bat activity as natural forests for five of seven bat species, and activity varied with the age of restored forest. Four bat species had similar or higher activity in young restored forest (<5 years old; average 0.3–8.3 bat passes/night) and natural unmined forest (average 0.3–15.5 bat passes/night), but lower activity in older restored forest (>10 years old; average 0.1–6.3 bat passes/night). One bat species had similar activity in older restored forest (>15 years old; average 0.6–1.1 bat passes/night) and unmined forest (average 0.9–2.5 bat passes/night), but lower activity in young restored forest (<5 years old; average 0.2–0.3 bat passes/night). Two bat species had consistently lower bat activity in all ages of restored forest (0.2–51 bat passes/night) than in unmined forest (3–68 bat passes/night). See original paper for more detailed results. All 64 sites were northern jarrah *Eucalyptus marginata* forest fragments. Restored sites had previously been cleared and mined. Surveys were carried out at 8–16 sites in restored forest of four different ages (0–4, 5–9, 9–14 and >15 years since restoration) and in eight natural unmined forest sites. All restored sites were >4 ha in size with at least one edge bordered by unmined forest. A bat detector was deployed for four full nights at each of 64 sites between October and March in 2010/2011 and 2011/2012.

(1) Gallo P.H., dos Reis N.R., Andrade F.R. & de Almeida I.G. (2010) Bats (Mammalia: Chiroptera) in native and reforested areas in Rancho Alegre, Parana, Brazil. *Revista de Biologia Tropical*, 58, 1311–1322.

(2) Burgar J.M., Stokes V.L. & Craig M.D. (2017) Habitat features act as unidirectional and dynamic filters to bat use of production landscapes. *Biological Conservation,* 209, 280–288.

13.6. Restore or create grassland

- **One study** evaluated the effects of creating grassland on bat populations. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, paired sites study in the UK[1] found that pipistrelle activity (relative abundance) did not differ between species-rich grassland created on agri-environment scheme farms and improved pasture or crop fields on conventional farms.

BEHAVIOUR (0 STUDIES)

Background

Grassland provides an important foraging habitat for many bat species, particularly unimproved or semi-unimproved species-rich grassland that has not been intensively grazed, drained or treated with artificial fertilisers or herbicides. Management of grassland may involve a combination of interventions that involve specific mowing or grazing regimes and reduced inputs.

A study that involves the restoration of grassland alongside other habitats at ex-quarry sites is described in '*Threat: Energy production and mining – Mining – Restore bat foraging habitat at ex-quarry sites*'.

A replicated, paired sites study in 2008 on 16 pairs of farms in Scotland, UK (*1*) found that grassland created on agri-environment scheme farms had similar activity of *Pipistrellus* species as improved pasture or crop fields on conventional farms. The activity of common pipistrelles *Pipistrellus pipistrellus* and soprano pipistrelles *Pipistrellus pygmaeus* was similar over species-rich grassland on agri-environment farms and improved pasture or crop fields on conventional farms (data reported as statistical model results). On agri-environment scheme farms, pasture or crop fields had been converted to grassland by sowing with a low productivity grass and herb mix and restricting fertiliser, pesticides, mowing and grazing. Each of 16 species-rich grasslands on agri-environment scheme farms were paired with 16 pastures or crop fields on conventional farms with similar farming activities and surrounding habitats. Each of 16 pairs of farms was sampled once on the same night in June–September 2008. At each of 32 sites, bat activity was recorded continuously from 45 minutes after sunset using bat detectors along transects 2.5–3.7 km in length.

(1) Fuentes-Montemayor E., Goulson D. & Park K.J. (2011) Pipistrelle bats and their prey do not benefit from four widely applied agri-environment management prescriptions. *Biological Conservation*, 144, 2233–2246.

13.7. Restore or create linear habitat features/green corridors

- We found no studies that evaluated the effects of restoring or creating linear habitat features/green corridors on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Linear habitat features, such as riparian corridors, woodland edge, tree lines and hedgerows, are important to maintain connectivity across the landscape for bats. These features may be restored or created to connect patches of isolated natural or semi-natural habitat.

13.8. Restore or create wetlands

- **One study** evaluated the effects of restoring wetlands on bat populations. The study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, controlled, before-and-after study in the USA[1] found that restoring wetlands increased overall bat activity (relative abundance), and restored wetlands had similar bat activity to undisturbed wetlands.

BEHAVIOUR (0 STUDIES)

Background

Wetlands can support high numbers of aquatic insects and provide important foraging and drinking habitats for bats. Wetlands may be created in proximity to existing habitats or habitat corridors. Restoration of wetlands may involve a combination of interventions, such as removing invasive and emergent plants and maintaining bankside vegetation and trees.

A study that involves the restoration of wetlands alongside other habitats at ex-quarry sites is described in '*Threat: Energy production and mining – Mining – Restore bat foraging habitat at ex-quarry sites*'.

For evidence relating to managing water bodies in arid areas, see '*Threat: Climate change and severe weather – Manage natural water bodies in arid areas to prevent desiccation*'.

A replicated, controlled, before-and-after study in 2000–2001 of six restored and six undisturbed wetlands in South Carolina, USA (*1*) found that restoring wetlands increased overall bat activity, and restored wetlands had similar bat activity to undisturbed wetlands. Overall bat activity was higher over wetlands after restoration (average 7 bat passes/30 minutes) than before (2 bat passes/30 minutes). Before restoration, overall bat activity was lower at drained wetlands (average 2 bat passes/30 minutes) than undisturbed wetlands (17 bat passes/30 minutes). However, after restoration there was no significant difference (restored: 15 bat passes/30 minutes; undisturbed: 9 bat passes/30 minutes). Seven bat species were recorded in total (see original paper for data for individual species). Wetlands were Carolina bays (0.5–1.5 ha) that were either undisturbed (three sites) or had been drained >50 years previously and restored in 2000 (drainage and forest removed; three sites). At each of 12 sites, bat activity was recorded during a random 30-minute time interval between dusk and midnight with 1–2 bat detectors before restoration (in 2000) and after (in 2001).

(1) Menzel J.M., Menzel M.A., Kilgo J.C., Ford W.M. & Edwards J.W. (2005) Bat response to Carolina bays and wetland restoration in the southeastern U.S. Coastal Plain. *Wetlands*, 25, 542–550.

13.9. Create artificial water sources

- **Five studies** evaluated the effects of creating artificial water sources for bats on bat populations. One study was in each of the USA[1], Germany[2], South Africa[3], Israel[4] and Mexico[5].

COMMUNITY RESPONSE (1 STUDY)

- **Richness/diversity (1 study):** One replicated, paired sites study in South Africa[3] found a similar number of bat species over farm ponds and in grassland/crops, trees, vineyards, or orchards.

POPULATION RESPONSE (5 STUDIES)

- **Abundance (5 studies):** Five replicated studies (including four site comparisons and one paired sites study) in the USA[1], Germany[2], South Africa[3], Israel[4] and Mexico[5] found that bat activity (relative abundance) was similar[2,4] or higher[1–5] over reservoirs, helipонds and drainage ditches[1], retention ponds[2], farm/cattle ponds[3,5], and waste water treatment pools[4] compared to over natural wetlands[1,4], nearby vineyards[2,3], surrounding forest[5] or grassland/crops, trees, and orchards[3].

Background

Artificial water sources may be created to provide foraging and drinking resources for bats in arid areas, or in areas where natural wetlands have been lost.

For an intervention that relates to managing livestock water troughs for bats, see '*Threat: Agriculture – Livestock farming – Manage livestock water troughs as a drinking resource for bats*'. For an intervention that involves using small dams to create water sources, see '*Threat: Natural system modifications – Dams and water management/use – Create or maintain small dams to provide foraging and drinking habitat for bats*'.

A replicated, controlled, site comparison study in 2006–2007 of 15 artificial water sources within a plantation and three natural wetland sites in North Carolina, USA (*1*) found that artificial water sources of two types had higher bat activity than natural wetland sites. Bat activity was higher at heliponds (201 bat passes/site/night) and drainage ditches (ditch interior: 61 bat passes/site/night; ditch edge: 60 bat passes/site/night) than at natural wetland sites (21 bat passes/site/night). Seven bat species were recorded (see original paper for data for individual species). Heliponds were small ponds (12 m x 24 m x 2.5 m deep) used by helicopters for the suppression of forest fires. Drainage ditches (1–2.5 m wide and 0.6–1.2 m deep) were positioned every 80–100 m within and along the edge of tree stands. The natural wetland (350 ha) was adjacent to the plantation. On each of 116 nights in June–July 2006 and 2007, bat activity was sampled simultaneously with bat detectors at two of four sites rotated in a random order (five heliponds, five ditch interiors, five ditch edges, three natural wetlands).

A replicated, site comparison study in 2009 at seven ponds within vineyards in Landau, Germany (*2*) found that artificial retention ponds had similar or higher bat activity for three species groups than adjacent vineyards. Activity of *Pipistrellus* spp. and *Myotis* spp. was higher over retention ponds (*Pipistrellus* spp.: 1,421 bat passes/night; *Myotis* spp.: 65 bat passes/night) than in nearby vineyards (*Pipistrellus* spp.: 8 bat passes/night; *Myotis* spp.: 3 bat passes/night), but the activity of *Eptesicus* and *Nyctalus* spp. did not differ significantly (ponds: 55 bat passes/night; vineyards: 14 bat passes/night). All seven retention ponds (0.1–1.3 ha) had bankside vegetation. At each of seven sites, bat activity was recorded using bat detectors and thermal infrared imaging cameras simultaneously at the pond and at a vineyard site 80 m away for 8–9 full nights in June–August 2009.

A replicated, paired sites study in 2010–2011 of 30 pairs of farmland sites in the Western Cape, South Africa (*3*) found that farm dams and ponds had higher overall bat activity but a similar number of bat species when compared with open grassland/crops, trees, vineyards or orchards. Overall bat activity and the activity of all six bat species analysed was higher over farm dams and ponds than in open grassland/crops, trees, vineyards, or orchards (data reported as statistical model results). The activity of three bat species also increased with dam/pond size. The number of bat species recorded did not differ significantly between dams/ponds and other habitat types or with dam/pond size (data reported as statistical model results). Three sampling points were surveyed at each site including a farm dam or stock pond (0.1–172 ha in size) and two other habitats (open grassland/crops, trees, vineyards, or orchards). A bat detector was deployed for 4.5 h from sunset for two or more nights at each sampling point between November 2010 and April 2011.

A replicated, site comparison study in 2005 of 33 natural and artificial water sources in the Negev Desert, Israel (*4*) found that artificial water sources had similar or higher activity for eight of 12 bat species than natural water sources. Six bat species had higher activity at artificial water sources (average 6–71 bat passes/night) than natural water sources (average 1–20 bat passes/night). The activity of two bat species was similar at artificial (average 39–208 bat passes/night) and natural water sources (average 38–189 bat passes/night). Three bat species had lower activity at artificial water sources (average 0.5–2 bat passes/night) than natural water sources (average 11–19 bat passes/night). One bat species was recorded only at natural water sources (0.4 bat passes/night). See original paper for data for individual species. Surveys were carried out at 17 artificial water sources (water reservoirs or waste water treatment pools) and 16 natural water sources (natural springs and pools). At each of 33 sites, one bat detector recorded bat activity at the waters edge for one full night in May–June 2005.

A replicated, site comparison study in 2005–2006 of six cattle ponds in a pine-oak forest reserve in Mexico (*5*) found that three of six ponds had higher bat activity than surrounding habitats during the dry season, but activity was similar over ponds and surrounding forest and meadows in the rainy season. At three sites, bat activity was higher over ponds than along transects up to 500 m away during the dry season (data reported as statistical model results). However, during the rainy season, bat activity was similar over ponds and along transects. One other site had similar bat activity at ponds and transects in both dry and rainy seasons. Two other sites had variable or little bat activity with no obvious pattern. Nine bat species were recorded (see original paper for data for individual species). The ponds were constructed to provide water for cattle. They were naturally recharged during the rainy season and varied in size (dry season: 0–12,450 m^2; rainy season: 600–19,790 m^2). Bat detectors recorded bat activity for 3 h from sunset during two consecutive nights at each pond and along transects up to 500 m perpendicular to the ponds. Surveys were repeated in the dry spring and rainy summer seasons in 2005 and 2006.

(1) Vindigni M.A., Morris A.D., Miller D.A. & Kalcounis-Rueppell M.C. (2009) Use of modified water sources by bats in a managed pine landscape. *Forest Ecology and Management,* 258, 2056–2061.

(2) Stahlschmidt P., Pätzold A., Ressl L., Schulz R. & Brühl C.A. (2012) Constructed wetlands support bats in agricultural landscapes. *Basic and Applied Ecology,* 13, 196–203.

(3) Sirami C., Jacobs D.S. & Cumming G.S. (2013) Artificial wetlands and surrounding habitats provide important foraging habitat for bats in agricultural landscapes in the Western Cape, South Africa. *Biological Conservation,* 164, 30–38.

(4) Korine C., Adams A.M., Shamir U. & Gross A. (2015) Effect of water quality on species richness and activity of desert-dwelling bats. *Mammalian Biology*, 80, 185–190.

(5) López-González C., Lozano A., Gómez-Ruiz E.P. & López-Wilchis R. (2016) Activity of insectivorous bats is related to water availability in a highly modified Mexican temperate forest. *Acta Chiropterologica*, 18, 409–421.

14. Species management

Most of the chapters in this book are aimed at minimizing threats, but there are also some interventions which aim specifically to increase population numbers, by increasing reproductive rates or introducing individuals, for example. Such interventions may be used in response to a wide range of threats.

Species management

14.1. Legally protect bat species

- We found no studies that evaluated the effects of legally protecting bat species on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Perhaps the most common intervention in response to declining species is to provide legal protection. Bats are protected by national and/or international law in many countries. This typically includes protection against killing, injuring, capturing, disturbing or trading bats, or damaging, destroying, or obstructing access to their roosts. Activities that are likely to affect bats in these ways may be against the law and require licences from a government licensing authority.

Assessing the effectiveness of legal protection can be difficult. Effectiveness is best monitored over long timescales, but this increases the chance that other factors may influence population recovery. The legal protection of threatened species can also lead to a range of other conservation actions being implemented at the same time, along with increased research and monitoring efforts.

Increasing population trends for some bat species in the UK may have occurred as a result of legal protection introduced in the 1980s, among other factors such as an increased awareness of bat conservation and changes in agricultural practices (Barlow *et al*. 2015). Similarly, the recovery and de-listing of the lesser long-nosed bat *Leptonycteris yerbabuenae* in the USA and Mexcio may have occurred as a result of legal protection, along with bat-friendly farming iniatives and education programmes (US Fish & Wildlife Service 2016).

Evidence that relates specifically to the legal protection of bats during development is discussed in '*Threat: Residential and commercial development – Legally protect bats during development*', and for the legal protection of habitats, see '*Habitat protection – Legally protect bat habitats*'.

Barlow K.E., Briggs P.A., Haysom K.A., Hutson A.M., Lechiara N.L., Racey P.A., Walsh A.L. & Langton S.D. (2015) Citizen science reveals trends in bat populations: the National Bat Monitoring Programme in Great Britain. *Biological Conservation,* 182, 14–26.
US Fish & Wildlife Service (2016) *Species status assessment for the lesser long-nosed bat*. December 2016. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, NM. 96 pp.

14.2. Provide bat boxes for roosting bats

- **Forty-four studies** evaluated the effects of providing bat boxes for roosting bats on bat populations. Twenty-seven studies were in Europe[1,3,6,8,11,13,14,15,17,19,21–24,26,27,29–33,35–37,39,40,43], nine studies were in North America[2,4,5,9,12,16,18,25,42], five studies were in Australia[7,10,38,41,44], two studies were in South America[20,28] and one study was a worldwide review[34].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (44 STUDIES)

- **Uptake (9 studies):** Nine replicated studies in Europe[1,14,17,21,23,30,31,40] and the USA[25] found that the number of bats using bat boxes increased by 2–10 times up to 10 years after installation.
- **Use (43 studies):** Forty-one of 43 studies (including 34 replicated studies and two reviews) in Europe, the USA, South America, and Australia found that bats used bat boxes installed in forest or woodland[1,3,6–10,13,17,18,20–22,24–28,30,31,38–42,44], forestry plantations[10], farmland[12,16,36], pasture[20,28], wetlands[14,32], urban areas and buildings[5,11,15,18,19,26,29,33,37,43], bridges[4], underpasses[15] or unknown habitats[23]. The other two studies in the USA[2] and UK[35] found that bats displaced from buildings did not use any of 43 bat houses of four different designs[2] or 12 heated bat boxes of one design[35]. One review[34] of 109 studies across Europe, North America and Asia found that 72 bat species used bat boxes, although only 18 species commonly used them, and 31 species used them as maternity roosts. Twenty-two studies (including 17 replicated studies, one before-and-after study and two reviews)[2,6,10,12,13,17,19,21,23–26,29,31–33,35,37,39,40,43,44] found bats occupying less than half of bat boxes provided (0–49%). Nine replicated studies[4,5,8,9,11,14,16,20,28] found bats occupying more than half of bat boxes provided (54–100%).

OTHER (23 STUDIES)

- **Bat box design (16 studies):** Three studies in Germany[8], Portugal[11] and Australia[44] found that bats used black bat boxes more than grey[11], white[8,11] or wooden[44] boxes. One of two studies in Spain[6] and the USA[16] found higher occupancy rates in larger bat boxes. One study in the USA[9] found that bats used both resin and wood cylindrical bat boxes, but another study in the USA[25] found that resin bat boxes became occupied more quickly than wood boxes. One study in the UK[17] found higher occupancy rates in concrete than wooden bat boxes. One study in the USA[42] found that Indiana bats used rocket boxes more than wooden bat boxes or bark-mimic roosts. One study in Spain[14] found that more bats occupied bat boxes that had two compartments than one compartment in the breeding season. One study in Lithuania[22] found that bat breeding colonies occupied standard and four/five chamber bat boxes and individuals occupied flat bat boxes. Four studies in the USA[18], UK[27], Spain[32] and Australia[44] found bats selecting four of nine, three of five, three of four and one of five bat box designs. One study in the UK[31] found that different bat box designs were used by different species. One study in Costa Rica[20] found that bat boxes simulating tree trunks were used by 100% of bats and in group sizes similar to natural roosts.

- **Bat box position (11 studies):** Three studies in Germany[8], Spain[14] and the USA[16] found that bat box orientation and/or the amount of exposure to sunlight affected bat occupancy, and one study in Spain[6] found that orientation did not have a significant effect on occupancy. Two studies in the UK[17] and Italy[23] found that bat box height affected occupancy, and two studies in Spain[7] and the USA[16] found no effect of height. Two studies in the USA[12] and Spain[14] found higher occupancy of bat boxes on buildings than on trees. One study in Australia[10] found that bat boxes were occupied more often in farm forestry sites than in native forest, one study in Poland[13] found higher occupancy in pine relative to mixed deciduous stands, and one study in Costa Rica[28] found higher occupancy in forest fragments than in pasture. One study in the USA[12] found higher occupancy rates in areas where bats were known to roost prior to installing bat boxes. One review in the UK[43] found that bat boxes were more likely to be occupied when a greater number of bat boxes were installed across a site.

Background

Bats roost in caves, built structures, natural crevices (e.g. in rocks) and in trees. The provision of bat boxes is a widely used intervention, as a conservation measure and for research, and there is a lot of literature on the use of these structures by bats. However, the many different designs of bat box available makes it difficult to draw consistent conclusions as evidence in support of each individual design is lacking. Studies are also needed that evaluate the long-term effects of providing artificial roosts on bat populations, by observing changes in bat numbers over time, ideally in areas with and without bat boxes.

For evidence relating to other types of artificial roosts used during building developments, see '*Threat: Residential and commercial development – Create alternative bat roosts within developments*'.

A replicated study in 1975–1987 in a mature coniferous forest in Suffolk, UK (*1*) found that the total population of brown long-eared bats *Plecotus auritus* (males, females and juveniles) occupying bat boxes doubled over the study period. The number of bats occupying the boxes increased from 73 to 140 bats. A total of 480 bat boxes were installed, but the proportion of boxes occupied is not reported. Bats roosted in the boxes both individually and in clusters of up to 20 bats. Bat boxes (10 x 15 x 15 cm internal dimensions) were constructed from untreated wood and installed in 1975. Two groups of four boxes (each facing north, south, east, and west) were installed on each of 60 trees at a height of 3 or 5 m. In 1984 and 1985, the boxes were redistributed across 10 new sites within the forest. Boxes were checked and bats removed for identification and ringing 2–4 times/year in 1976–1987.

A replicated study in 1988–1990 at an urban institute in New York, USA (*2*) found that displaced little brown bats *Myotis lucifugus* did not use any of 43 bat houses of four different designs and sizes. The four designs tested were 20 very small bat houses (longest dimension <0.4 m, volume 0.002 m^2, installed 3–4 m high on trees), eight small bat houses (20 x 15 x 15 cm with partitioned spaces, installed 2–7 m high on building walls), 11 Bat Conservation International (BCI) style bat houses (50 x 20 x 15 cm, installed 2–7 m high on building walls) and four large "Missouri" style bat houses (2.3 x 1 x 1 m with partitioned spaces below and an attic-like space above, installed on building roofs). Bats were excluded from five buildings in 1988–1990 due to renovations. Bats were captured and confined to bat houses overnight on 1–4 occasions/year between May and August in 1988–1990 with the aim of increasing uptake. Thirty-nine of 43 bat houses were regularly checked for bats between May and August 1988–1990.

A replicated study in 1976–1993 in a 360 km^2 area of mixed woodland near Wareham, UK (*3*) found a total of 1,662 bats of three species occupying up to 500 bat boxes at 20 sites. The bat species occupying bat boxes included: brown long-eared bats *Plecotus auritus* (976 bats), common pipistrelles *Pipistrellus pipistrellus* (355 bats), and Natterer's bats *Myotis nattereri* (286 bats). Since 1976, approximately 500 timber bat boxes (10 x 15 x 15 cm internal dimensions) were installed across the study area. At each of 20 sites, three boxes were installed (facing north, southeast, and southwest) on each of six trees 2.5–3 m above the ground. Boxes were checked and bats ringed approximately four times/year in March–October from 1977 to 1993.

A replicated study in 1996–1998 of 15 river bridges in coniferous forest in Oregon, USA (*4*) found that bats used 13 of 15 (87%) bat boxes installed under 15 flat bottom bridges along five large streams. Within a year of installation, 10 boxes were used by bats. Bats were observed day roosting in five different boxes on 14 occasions (all solitary bats except for one group of eight individuals). Guano was collected from traps beneath 12 different boxes on 1–16 occasions. Wooden boxes (60 cm long x 60 cm wide x 30 cm deep) with eight boards placed inside (12 or 19 mm apart) to form crevices were fixed to the underside of the bridges between September 1996 and May 1997. Bridges varied in size (230–475 m width, 11–27 m length, and 3–6 m above the water). Day roosting bats were counted with a spotlight and guano traps were checked during 15 weekly surveys in June–September 1997 and 1998.

A replicated study in 1991–1993 in an urban area of Pennsylvania, USA (*5*) found that maternity colonies of big brown bats *Eptesicus fuscus* and little brown bats *Myotis lucifugus* used pairs of bat boxes at five of nine sites after they had been excluded from buildings. At four of five sites where boxes were not used, bats either re-entered the building, found new roosts nearby or were not seen again. All occupied bat boxes faced a southeastern or southwestern aspect and received at least seven hours of direct sunlight. Unoccupied bat boxes received less than five hours of direct sunlight. Each of nine sites had a maternity colony of >30 bats that were excluded from buildings in 1991–1992. Homeowners installed pairs of wooden bat boxes (76 x 30 x 18 cm), one horizontally (30 cm tall) and one vertically (76 cm tall) side by side on the building close to the original roost.

Emerging bats were counted on two nights in May–June and June–August in 1992 or 1993.

A replicated study in 1996–1998 in a pine grove *Pinus sylvestris in* Guadalajara, Central Spain (*6*) found bats occupying 8% of boxes and bat droppings in 2% of boxes checked. Bat species occupying the boxes were brown long-eared bats *Plecotus auritus* (176 bats) and common pipistrelles *Pipistrellus pipistrellus* (2 bats). Larger bat boxes were occupied more (9%) than smaller boxes (7%). The height and orientation of boxes did not have a significant effect on bat occupation. The larger boxes were based on the "Richter II" model (external dimensions: 40 cm height x 25 cm length x 22 cm width, internal capacity: 3,600 cm^3). The smaller boxes were based on the "Stratmann FS 1" model (external dimensions: 40 cm height x 30 cm length x 11 cm width, internal capacity: 2,000 cm^3). During April 1996, 203 bat boxes were installed on trees (108 large, 95 small) at heights of 2.9–5.5 m in rows spaced 50 m apart with an average density of 4 boxes/ha. Sixteen surveys with 2,134 total box visits were carried out in August–October 1996 and March–October 1997 and 1998.

A study in 1994–1997 in one forest site in Victoria, Australia (*7*) found that lesser long-eared bats *Nyctophilus geoffroyi*, large forest bats *Vespadelus darlingtoni*, southern forest bats *Vespadelus regulus* and eastern false pipistrelles *Falsistrellus tasmaniensis* used nest boxes. A total of 73 bats of the four species were captured in nest boxes installed for feathertail gliders *Acrobates pygmaeus*. In July 1994, forty nest boxes were installed in a 7 ha area of forest dominated by *Eucalyptus* spp. Boxes were 50 m apart, had a 15 mm-wide entrance hole and were attached to tree trunks at 4.5 m above the ground. Nest boxes were checked approximately every two months between July 1995 and May 1997.

A replicated study in 1987–1996 in a deciduous forest in Bavaria, Germany (*8*) found that female Bechstein's bats *Myotis bechsteinii* roosted in 43 of 75 (57%) bat boxes, and black boxes in sunny locations were preferred by female bats during and after lactation. Female bats roosted more often during and after lactation in black bat boxes (186 bats during, 90 bats after) than white boxes (134 bats during, 22 bats after), and more in sun exposed boxes (276 bats during, 112 bats after) than shaded boxes (44 bats during, no bats after). Before giving birth, females roosted more in shaded locations (111 bats) than sunny locations (43 bats) but did not show a significant preference for black (76 bats) or white boxes (78 bats). Boxes of both colours were warmer in sunny locations (black: average 22°C; white: 20°C) than in the shade (black: 18°C; white: 17°C), and black bat boxes were warmer than white boxes. Seventy-five bat boxes (Schwegler design 2FN) were installed in 1987–1993. In 1996, 52 of the 75 boxes were rehung in pairs (one painted white, the other black) on 26 trees (half at shaded sites, half on trees exposed to the sun). Bat boxes were checked daily and box temperatures recorded in April–November 1996.

A replicated, controlled study in 1999–2000 in Fort Valley Experimental Forest, Arizona, USA (*9*) found that bats used 17 of 20 artificial roosts (eight resin and nine wood) placed on snags in thinned (10 roosts) and unthinned (eight roosts) pine stands. Bats did not roost more often in natural control snags (five roosts). There was no difference in the use of two artificial bat roost designs (resin and wood, both 60 x 60 cm cylindrical designs). Resin roosts were made from polyester moulds shaped and painted to resemble exfoliating bark. Wood roosts were made from treated hardboard. Five resin and five wood artificial roosts were placed 2–4 m above the ground on snags in three unharvested stands and three thinned stands with a natural control roost on a snag at least 75 m away from each artificial roost. Nets below roosts were checked for guano 3–4 times in July–August in 1999 and 2000.

A replicated study in 1996–2000 in three farm forest plantations and one native forest in Queensland, Australia (*10*) found that 19 of 96 bat boxes (20%) were used by Gould's long-eared bats *Nyctophilus gouldi* as maternity and other roosts. More bat boxes were occupied at two farm forestry sites in fragmented landscapes than in native forest (no boxes used) and one of the farm forestry sites bordering it (one box used). Approximately 20 other bat species were known to occur in the study area but did not use the bat boxes. Bat boxes were made from laminated plywood built to the British Tanglewood Wedge design (40 cm long x 20 cm wide x maximum of 18.5 cm deep). Twenty-four boxes were attached to trees at each of three sites 3 m or 6 m above the ground, evenly spaced and in different aspects. Boxes were checked 5–9 times between April 1996 and November 2000.

A replicated study in 2001 of three urban sites in Alentejo and Algarve, Portugal (*11*) found that soprano pipistrelles *Pipistrellus pygmaeus* used six of nine bat boxes. More bats were seen emerging from black bat boxes (maximum of 38) than grey boxes (maximum of six), although this difference was not statistically tested. No bats were seen to emerge from white bat boxes. The internal temperatures of different coloured bat boxes varied significantly (average maximum temperatures: black 37°C, grey 34°C and white 28°C). Maximum daily temperatures inside black bat boxes did not differ to those in roosts in the attics of nearby buildings. Three bat boxes (painted black, grey or white, all Bat Conservation International models) were placed facing south side by side at each of three sites 20 m from maternity roosts. Bat box temperatures were monitored using sensors and data loggers. Bat boxes were checked, and emerging bats counted, weekly in May–June 2001.

A replicated study in 1997 of 95 bat boxes in farmland, campgrounds and preserved areas in Colorado, USA (*12*) found bats occupying 11 of 95 bat boxes (12% occupancy rate) at multiple sites, and occupancy was higher in areas where bats roosted prior to installing bat boxes. Big brown bats *Eptesicus fuscus* occupied 6 boxes, *Myotis* spp. two boxes and little brown bats *Myotis lucifugus* one box. Droppings of unknown bat species were found below two boxes. All bat boxes were occupied by one or two individuals, except one colony of 20 big brown bats. In areas where bats roosted prior to bat box installation, the occupancy rate increased to 64%. Bat box occupancy also increased when bat boxes had large landing areas, were mounted on buildings, and in areas of low canopy cover and human disturbance. No bat boxes mounted on trees were occupied. Ninety-five bat boxes were installed in preserved areas (47), remote campgrounds (8), rural farmland (39) and irrigated farmland (1), and placed on trees (40), buildings (42) and poles (13). Details of the locations of occupied bat boxes were not reported. Bat boxes were checked for occupancy and guano on the ground below at 15 or 30-day intervals in May–September 1997.

A replicated study in 1998–2001 of three forest stands in a mixed forest in Poland (*13*) found that an average of four of 102 bat boxes (4%) were occupied by bats, and boxes became occupied more quickly in pine tree stands than deciduous stands. Bat species roosting in bat boxes were Nathusius' pipistrelles *Pipistrellus nathusii*, or brown long-eared bats *Plecotus auritus* roosting individually or in groups. Bat boxes were occupied within two months in the pine stand, but within 13 months or more in beech and oak-beech stands. In 1998, 34 wooden bat boxes (Stratmann design, 40 x 13 x 4 cm) were installed in each of three stands (pine *Pinus sylvestris*, beech *Fagus sylvatica* and oak-beech *Fagus sylvatica-Quercus robur*). At all three stands, bat boxes were checked every 10 days in July–September 1998–1999, every two weeks in April–June 1999 and for two days in August 2001. The pine forest stand was also checked twice in July–August 2000.

A replicated study in 1999–2004 of a wetland on an island in Catalonia, Spain (*14*) found that soprano pipistrelles *Pipistrellus pygmaeus* used 69 bat boxes of two different designs with an average occupancy rate of 71%, and occupancy increased with time since installation. Occupation rates by females with pups increased from 15% in 2000 to 53% in 2003. Bat box preferences were detected in the breeding season only, with more bats in east-facing bat boxes (average 22 bats/box vs 12 bats/box west-facing), boxes with double compartments (average 25 bats/box vs 12 bats/box single compartment) and boxes placed on posts (average 18 bats/box) and houses (average 12 bats/box). Few bats used bat boxes on trees (average 2 bats/box). A total of 69 wooden bat boxes (10 cm deep x 19 cm wide x 20 cm high) of two types (44 single and 25 double compartment) were placed on three supports (10 trees, 29 buildings and 30 electricity posts) facing east and west. From July 2000 to February 2004, bat boxes were checked on 16 occasions. Bats were counted in boxes or upon emergence when numbers were too high to count within the box.

A replicated, before-and-after study in 2002–2005 in a railway underpass and two barn cellars in Brandenburg, Germany (*15*) found that styrofoam bat boxes and strips were used by at least one bat species after being installed. A styrofoam bat box installed in a railway underpass was used by five brown long-eared bats *Plecotus auritus* within two weeks of installation. A week after the box was removed, the author reports that no bats were observed in the underpass. A second styrofoam bat box and strip installed in a cellar previously uninhabited by bats was used by two brown long-eared bats the following winter. Styrofoam strips and two hollow concrete blocks installed in a second cellar already inhabited by bats were used by brown long-eared, Daubenton's *Myotis* *daubentonii* and Natterer's *Myotis nattereri* bats (see original paper for details). In October 2002, a styrofoam bat box (40 x 40 cm with 2–5 cm wide interior columns) was installed in a railway drainage underpass (23 m long, 1.9 m wide and 1.8 m high). In autumn/winter 2003–2004, a styrofoam bat box and strip (1 m long, with gaps and cavities cut into it) were attached to the ceiling of a barn cellar. In September 2003, styrofoam strips (0.2 x 1 m) and two hollow concrete blocks were added to the walls of a second barn cellar. Bats were monitored after bat boxes and strips were installed (details were not provided).

A replicated study in 1997–2004 in 66 agricultural areas in California, USA (*16*) found that bats of five species used 141 of 186 bat boxes (76% occupancy rate), and the size, height and colour of bat boxes did not affect occupancy. Bat boxes were used by groups (48%) and individual bats (28%). Five bat species were recorded within bat boxes, with the Brazilian free-tailed bat *Tadarida brasiliensis* and *Myotis* spp. accounting for the majority of bat box occupancy (67% and 26% respectively). Size, colour, and height of the bat boxes did not affect bat occupancy. Bat colonies (average of 64 bats) were more likely to use bat boxes that were shaded or exposed to the morning sun, mounted on buildings and close to a water source. Individual bats were more likely to use bat boxes that were mounted on poles and exposed to the full or afternoon sun. All bat boxes were plywood with one or more chambers and were small (<90 cm roosting space) or large (>90 cm roosting space). Bat boxes were mounted 2–9.5 m high singly, side by side or back to back on barns, sheds, poles, bridges, or silos. Boxes were placed in different orientations and painted light, medium and dark colours. Bat boxes were checked annually in 1997–2004.

A replicated, site comparison study in 1985–2005 at 52 woodland sites in the UK (*17*) found an overall bat box occupation rate of 9%, although occupancy varied with box design and height, and increased with time since installation. A total of 5,986 boxes were occupied of 68,715 box inspections. Concrete bat boxes had higher occupancy rates than wooden boxes, with Schwegler design 1FF and 2FN boxes occupied the most (90% of records). Occupancy rates, bat counts and species counts were higher in bat boxes established for more than four years (18% occupancy, 60 bats and 15 species/100 box inspections) than boxes established for less than one year (8% occupancy, 22 bats and six species/100 box inspections). Occupancy rates were higher for Natterer's bats *Myotis nattereri* in lower bat boxes (3% at ≤4 m, 2% at ≥7 m), and higher for common noctule bats *Nyctalus noctula* in higher bat boxes (5% at ≤4 m, 7% at ≥7 m). Bat boxes were installed on 1,410 trees across 52 sites (10–208 trees/site). Ten different bat box designs were included in the study (Schwegler designs 1FF, 1FS, 1FW, 2F, 2FN, SW, Wedge, Martin, CJM and Messenger). Boxes were inspected at monthly intervals in 1985–2005, but not all boxes were inspected monthly or yearly.

A replicated study in 1992–1999 in several small woodlots in a suburban area in Indiana, USA (*18*) found that four of nine artificial roost designs were used by a total of 709 bats over seven years. The designs used were single box (428 bats), triple box (210 bats), shake garland (96 bats) and Missouri-style bat boxes (65 bats). Five bat species used the artificial roosts both individually and in groups, with northern myotis bats *Myotis septentrionalis* using them most frequently (690 of the total 709 bats). From 1992 to 1994, 3,204 artificial roosts of nine designs were installed. Single boxes (715) were "bird house" style attached to deciduous trees. Triple boxes (259) were three single boxes surrounding deciduous trees. Single shakes (697) consisted of a pair of overlapping cedar shingles nailed to a tree. Shake garlands (842) had 10–20 shakes encircling deciduous tree trunks. Missouri style boxes (56) were 0.9 x 1.8 m. Tarpaper boxes (30) were wooden (0.9 x 0.9 m) and lined with tarpaper. Plastic/tarpaper skirts (176) had a length of tarpaper/plastic folded over and wrapped around a tree. Exfoliations (338) were loosened bark with the lower end wedged. Moved trees (91) were trees greater than 25 cm (diameter) at breast height which were topped and moved to loosen bark. Missouri style and tarpaper boxes were placed on posts 2.4 m high. The remaining structures were placed 3–11 m high on trees (same study areas as *42*). All structures were checked at least once/year in 1992–1999.

A study in 2004–2008 of five road developments and three residential and commercial developments in Ireland (*19*) found bats of four species occupying 33 of 150 bat boxes (22%) and bat droppings in 77 of 150 bat boxes (77%) across all eight sites. Overall, 91 individual bats were recorded occupying bat boxes, including soprano pipistrelles *Pipistrellus pygmaeus* (68), common pipistrelles *Pipistrellus pipistrellus* (17), Leisler's bats *Nyctalus leisleri* (5) and Daubenton's bat *Myotis daubentonii* (1). Bat droppings of *Pipistrellus* spp. were recorded in 62 bat boxes, Leisler's bat droppings were recorded in 12 bat boxes and *Myotis* spp. droppings were recorded in three bat boxes. Bat boxes were either woodcrete (137 bat boxes: either Schwegler designs 1FD, 1FF, 1FN, 1FS, 2F, 2FN or 2F-DPF), wedge-shaped wooden bat boxes (5 boxes) or standard wooden bat boxes (8 boxes). At each of eight sites, 3–33 bat boxes were installed in 2002–2008 as mitigation for habitat loss. Each of the 150 bat boxes was checked once in June, October, or November 2008.

A replicated, controlled study in 2000–2006 in tropical forest and pasture in the Caribbean lowlands, Costa Rica (*20*) found that bats colonized all 45 artificial roosts in simulated tree trunks installed in forest and forest remnants within an average of three weeks. Five nectar or fruit-eating bat species colonized the artificial roosts permanently in group sizes (2–5 bats) similar to those in natural roosts (3–16 bats): Pallas' long-tongued bat *Glossophaga soricina,* Commissaris's long-tongued bat *Glossophaga commissarisi,* Seba's short-tailed bat *Carollia perspicillata,* Sowell's short-tailed bat *Carollia sowelli* and chestnut short-tailed bat *Carollia castanea*. Artificial roosts were simulated hollow tree trunks made from sawdust concrete slabs forming a square box (54 x 54 x 194 cm or 74 x 74 x 154 cm) and installed in the shade within forest (22 roosts) and forest remnants within pasture (23 roosts). Natural roosts were found and checked along a systematic line transect search. Artificial roosts were checked every 42 days on average with a total of 1,009 checks in 2000–2006.

A replicated study in 2003–2008 in a mixed forest in Poland (*21*) found that the occupancy of 70 bat boxes by four bat species increased by more than three times over two years. Bat box occupancy increased from 13% (9 of 70 boxes) in 2005 to 49% (34 of 70 boxes) in 2006 and 2007. Four bat species occupied bat boxes: greater mouse-eared bat *Myotis myotis,* common noctule *Nyctalus noctula,* Nathusius' pipistrelle *Pipistrellus nathusii* and brown long-eared bat *Plecotus auritus*. In 2007, bat boxes were colonized first by brown long-eared bats in March and last occupied in October by common noctules. Nathusius' pipistrelles were the most abundant species that used bat boxes (74% of records from May to September) and were found in the largest clusters in July (14 individuals). In 2003, 70 wooden bat boxes (Stratmann, internal dimensions 25 x 25 x 7 cm) were installed on trees 2.5–3 m above the ground with a southeastern orientation. In 2005 and 2006, bat boxes were checked once in August and from March 2007 to February 2008 boxes were checked monthly.

A replicated study in 2009 in 13 mixed or pine forests in East Lithuania (*22*) found that six bat species used bat boxes of four designs, but occupancy rates were not reported. Two bat species occupied the majority of bat boxes: Nathusius' pipistrelles *Pipistrellus nathusii* (79% of all bats recorded and occupied boxes at all 13 sites) and soprano pipistrelles *Pipistrellus pygmaeus* (18% of all bats and occupied boxes at seven of 13 sites). The remaining bat species (pond bat *Myotis dasycneme*, brown long-eared bat *Plecotus auritus*, common noctule *Nyctalus noctula* and northern bat *Eptesicus nilssonii*) accounted for 2% of bats using bat boxes. Breeding colonies of Nathusius' pipistrelles and soprano pipistrelles were found in standard and four and five chamber bat boxes. Flat bat boxes were not used by breeding colonies but were the only type of box in which all six bat species were found. In total, 504 bat boxes were installed (30–60 in each of 13 sites): 250 standard boxes (25 x 15 x 10 cm), 168 flat boxes (35 x 4 x 15 cm), 27 four chamber (30 x 15 x 15 cm) and 59 five chamber boxes (55 x 35 x 19.5 cm). Standard and flat wooden bat boxes were installed in 2004–2008, and four and five chamber bat boxes were installed in 2007–2008. All boxes were attached to trees facing southeast or southwest, 4–6 m above the ground and 20–200 m apart. Bat box checks and emergence surveys were carried out six times in May–October 2009.

A replicated study in 2007–2009 across Italy (*23*) found that up to a fifth of bat boxes were used by bats during the first year after installation, and use increased with box height and time since installation. The proportion of bat boxes used by bats increased in each of three years after installation (year one: range 12–21%; year two: 26–35%; year 3: 40%). Bat box use was also found to increase with the height of the boxes above the ground (data reported as correlation coefficients). Bat boxes were wooden with a single internal chamber and one entrance at the base. Boxes were installed by volunteers (total number of boxes not reported) following a public information project and advertising campaign. Monthly checks for signs of use (presence of bats or bat droppings) were carried out for approximately 300 bat boxes. Bats were not identified to species and details of bat box locations or habitat types were not reported.

A replicated study in 2005–2009 in seven sites of mixed woodland in northeast England, UK (*24*) found that the overall bat occupancy of 90 bat boxes varied from 9% in 2006 to 18% in 2007. Occupancy rates in subsequent years were similar (12% in 2008 and 17% in 2009). The highest occupancy rate at one site was 27% (seven of 26 boxes). Four bat species occupied bat boxes: *Pipistrellus* spp., brown long-eared bat *Plecotus auritus*, Natterer's bat *Myotis nattereri* and whiskered/Brandt's bat *Myotis mystacinus*/*Myotis brandtii*. In 2006, birds (*Parus* spp.) occupied 37% of bat boxes. The installation of bird boxes (2–15 boxes/site) in February 2008 reduced bird occupancy of bat boxes to 17%. Woodland sites were small (<3 ha) linear blocks with trees <40 years old. In 2005–2006, bat boxes (Schwegler design 2FN, 16 cm diameter x 36 cm high) were installed in sets of three on trees, covering different aspects at least 4 m above the ground. Boxes were checked for bats in November 2006 and 2007, September 2008 and October 2009.

A replicated, randomized study in 2009–2010 in 26 managed pine forest sites in northern Arizona, USA (*25*) found that almost half the 104 artificial roosts installed across 26 sites were occupied by bats by the second year after installation. Bat occupancy was higher in the second year (49 of 104 roosts at 22 of 26 sites) than the first year (19 of 104 roosts at 13 of 26 sites). Resin roosts were occupied more quickly than wood roosts (resin: within 406 days; wood: 439 days). A total of 47 bats of five species were captured emerging from all artificial roosts. Four artificial roosts were installed/site 5 m above the ground on live ponderosa pine *Pinus ponderosa* trees. Half were constructed from wood (40 cm wide x 45 cm tall) and half from resin (60 x 60 cm). Roosts were checked every two weeks during May and September in 2009 and 2010. Mist nets or funnel bags were used to capture bats on emergence at dusk.

A replicated study in 2012 in urban parks and forested areas of 11 regions in Navarra, Spain (*26*) found that 60% of installed bat boxes had signs of occupation by 10 bat species. Out of 405 bat boxes installed, 241 had signs of bat occupation (60%) and bats were found roosting in 107 (26%). In total, 345 individuals of 10 species were recorded: 247 soprano pipistrelles *Pipistrellus pygmaeus*, 28 common pipistrelles *Pipistrellus pipistrellus,* 36 Leisler's bats *Nyctalus leisleri,* 16 common noctules *Nyctalus noctula,* seven brown long-eared bats *Plecotus auritus*, six greater noctules *Nyctalus lasiopterus*, two Kuhl's pipistrelles *Pipistrellus kuhlii*, one Daubenton's bat *Myotis daubentonii*, one whiskered bat *Myotis mystacinus* and one barbastelle bat *Barbastella barbastellus*. Approximately 500 bat boxes of seven different models were placed 4–7 m high in forest areas, urban parks and close to rivers. Between September and November 2012, 405 bat boxes were inspected. Bat use of unoccupied boxes was assessed by the presence of guano.

A replicated, controlled study in 2011–2012 in ancient, mixed deciduous woodland in Buckinghamshire, UK (*27*) found that brown long-eared bats *Plecotus auritus* and Natterer's bats *Myotis nattereri* preferred three of five bat box designs. Three Schwegler designs were occupied most by brown long-eared and Natterer's bats: 1FS (33% of total occupations), 2FN (29%), and 2F (27%). Schwegler 1FF boxes were rarely used (11%), and wooden Apex boxes were not used at all. Groups of five Schwegler woodcrete boxes (2F: 33 x 16 cm; 2FN: 36 x 16 cm; 1FS: 44 x 28 cm; 1FF: 43 x 27 cm) and one wooden Apex box (40 x 12 cm) were erected around 13 trees in March 2011. Groups of bat boxes were evenly spaced along a transect line of 300 m through the woodland. Bat boxes were checked monthly in May–October 2011 and 2012.

A replicated, site comparison study in 2009–2010 in five pasture and tropical forest fragments in Costa Rica (*28*) found that 26 of 48 bat boxes were used by at least five bat species, although only three boxes were colonised as permanent day roosts. Overall, 54% of bat boxes were occupied by bats. More bat boxes were occupied in forest fragments (17 of 18, 94%) than in pasture (12 of 30, 40%). At each of five sites, six bat boxes were installed in pasture on wooden or steel posts or on 4 m long tree limbs (replanted and allowed to grow for three months), and three to six bat boxes were installed on trees in adjacent forest fragments. Bat boxes were constructed from wood and concrete (interior dimensions: 40 x 40 x 60 cm) and mounted 2–3 m above the ground. Visual checks were carried out twice/month in 2009 and 2010, and motion-activated infrared video cameras were installed.

A review of 389 bat mitigation licences issued from 2003 to 2005 in England, UK (*29*) found that only three of 24 (13%) bat boxes were used by bats after development. The roost status, bat species and number of bats using the roosts before and after development were not reported. Most licensees (67%) failed to submit post-development reports, and post-development monitoring was conducted at only 24 of 1,690 (1%) bat boxes. The licences analysed were submitted to Natural England between 2003 and 2005, and were issued for three types of development (renovation, conversion and demolition).

A replicated study in 2005–2014 in a fiord landscape in Norway (*30*) found that the number of soprano pipistrelle bats *Pipistrellus pygmaeus* using bat boxes increased more than tenfold over three years, with three larger bat boxes being used as maternity roosts. Soprano pipistrelles were first recorded using the boxes in 2010, five years after installation, with less than 100 individual bats counted. This number increased to an estimated 1,000–1,600 individuals in 2012 and 2013. Fewer bats were reported roosting in hollow trees after bat boxes were installed (data not reported and no statistical tests were carried out). All bat boxes had a black coating and were either Schwegler designs (2F, 2FN, 1FS, 1FW or 1FQ), a Bat Conservation International design, or from Hasselfeldt Naturschutz (Fledermausgroßraumhöhle FGRH with partitions). Bat boxes were installed in 2005–2014 in groups at three sites (total number of boxes not reported). Bat boxes and hollow trees previously used as roosts were inspected eight times between June and August 2012, and seven times between May and August 2013. Counts of emerging bats were also carried out in June 2014.

A replicated study in 1999–2015 of three broadleaved/mixed woodlands in County Galway, Ireland (*31*) found that bat boxes were used by seven bat species/species groups with an overall occupancy rate of 20% over 17 years. *Pipistrellus* spp. had the highest occupancy rate of boxes (14%) followed by Leisler's bats *Nyctalus leisleri* (3%), brown long-eared bats *Plecotus auritus* (2%) and Daubenton's bats *Myotis daubentonii* (0.4%). *Pipistrellus* spp. were found more often in Schwegler design 1FF boxes, and brown long-eared bats in Schwegler design 2FN boxes (data reported as statistical model results). Occupancy rates were also found to increase over time for *Pipistrellus* spp., brown long-eared bats, and Leisler's bats (data reported as statistical model results). In 1999, 162 Schwegler woodcrete bat boxes (designs 2FN, 1FF, 1FW or 2FN) were installed across three sites. They were hung on trees 4 m above the ground in pairs. The number of boxes varied at each site (10, 50, 62) and some boxes were relocated during the project. A total of 7,370 bat box inspections were carried out. Boxes were checked monthly between April and September in 1999–2015, although checks were not carried out in June or July from 2002 onwards.

A study in 2010–2015 in one wetland reserve in Basque Country, Spain (*32*) found that four bat species used bat boxes of three of four designs. Thirty-five of 93 bat boxes (38%) were occupied by bats seven years after installation. Overall, 240 individual bats were counted in bat boxes, including soprano pipistrelles *Pipistrellus pygmaeus* (207), Leisler's bats *Nyctalus leisleri* (19), Kuhl's pipistrelles *Pipistrellus kuhlii* (13) and a Daubenton's bat *Myotis daubentonii* (1). Three of four box designs were occupied by 0.5–1.6 bats/visit. No bats were detected in boxes of one design (Schwegler 1FW). In late 2008, 95 bat boxes were installed in one 206 ha wetland reserve. Boxes of four different designs (Schwegler 1FF, 1FW, 2F double wall, 2FN) were attached to trees and buildings at a height of 3–6 m. Bat boxes were checked nine times between 2010 and 2015.

A replicated, before-and-after study in 2011–2015 of 17 building developments with replacement bat maternity roosts across Scotland, UK (*33*) found that three bat boxes provided at one site were used by a maternity colony, but bat boxes at 16 other sites were not used by maternity colonies. At one site, a group of three unheated bat boxes (Schwegler design 1FFH) was used by a maternity colony of soprano pipistrelles *Pipistrellus pygmaeus* after development, but fewer bats used them than the original roost (average count in original roost: 62 bats; average count in bat boxes after development: 20 bats). Alternative roosts at 16 other sites with heated (seven sites) or unheated bat boxes (9 sites) were not used by maternity colonies, but bat boxes at two sites (one heated, one unheated) were used by 2–5 individual bats. Bat boxes were mounted internally or externally on developed buildings, or on nearby trees, either singly or in groups (2–15 bat boxes). Bat box design varied at each site. The numbers of bats counted before development at each roost were extracted from reports submitted with licence applications. Bats were counted at each roost after development during at least one dusk emergence or dawn re-entry survey between May and September 2015.

A review in 2016 of 109 studies of bat box use from 17 countries across Europe, North America, Australia and Asia (*34*) found that 71 bat species were reported to use bat boxes, although only 18 species commonly used boxes and 31 species used boxes as maternity roosts. Bat box design and dimensions varied between studies. Most bat boxes were made of timber, although woodcement was also frequently used in Europe. Sixty-seven of the reviewed studies used bat boxes for research purposes, 42 for bat conservation and one for community education. Twenty-two studies in this review (*1–5,7–14,16,18,20–22,24,25,27,28*) have been summarized individually.

A replicated study in 2012–2013 at six churches in Norfolk, UK (*35*) found that Natterer's bats *Myotis nattereri* did not use any of the 12 heated bat boxes provided after being displaced from roosts inside the churches. Two bat boxes (Bat Conservation International design) containing heat mats and thermostats were installed at each of six churches, one inside the church and one outside at roof height. Acoustic deterrents and artificial lighting were used to deter bats from their existing roost locations inside the churches where droppings and urine were causing problems. Emergence surveys and radio-tracking were carried out at each site between July and September in 2012 or 2013.

A before-and-after study in 2014–2016 in one agricultural site in Navarra, Spain (*36*) found that common pipistrelles *Pipistrellus pipistrellus* colonized one bat box installed on a building constructed as an artificial roost. Six common pipistrelles roosted in the bat box in 2014 in the same summer that it was installed. Numbers increased to 15 in 2015 and to 36 in 2016. In July 2014, one bat box was attached to the outside wall of a building (2.6 x 2.6 x 3.2 m) constructed as an artificial roost. The artificial roost was built to replace a bat roost destroyed in a nearby building in 2013. Bats were counted weekly from mid-April to mid-July in 2015 and 2016 using an infrared light.

A before-and-after study in 2010–2017 of a residential building development in the Cotswold Hills, UK (*37*) found that five wall-integrated bat boxes were not used by a common pipistrelle *Pipistrellus pipistrellus* maternity colony six years after the original roost in a stone cottage wall was demolished. In 2010 (the year before demolition), the original roost was used by >76 bats. During the six years after construction, the bat boxes were used by low numbers of individual bats (0–3 bats/year) and were not used as a maternity roost. The five bat boxes (Schwegler design 1FR) were integrated within a purpose-built bat wall constructed on the east-facing gable end of an existing hay barn 30 m from the original roost. The bat wall also had multiple stone crevices leading to internal cavities. The original roost was demolished in late winter 2010 and the bat wall was completed in early spring 2011. Surveys were carried out every year in 2010–2017 including daytime inspections and evening emergence counts on 1–3 separate occasions/year.

A replicated study in 1994–2016 at four sites of regenerating forest in Melbourne, Australia (*38*) found that bat boxes were used more than expected by one bat species, whereas 12 bat species made little or no use of them. Gould's wattled bat *Chalinolobus gouldii* used bat boxes 72% more than expected based on its documented occurrence in the area. The species formed maternity groups in bat boxes at all four sites. Seven bat species used bat boxes infrequently and less than expected. Five bat species did not use bat boxes at all. A total of 126 bat boxes of nine designs were installed on trees 4–6 m above the ground at four sites (20–40 boxes/site). Bat box checks were carried out monthly or bi-monthly over 5–22 years/site. A total of 444 surveys were carried out across all four sites.

A replicated, randomized, site comparison study in 2004–2012 in five pine forests in Spain (*39*) found that bat boxes were used by three bat species with an overall occupancy rate of 15% over nine years. During 1,659 bat box inspections, 255 bat boxes were found to be occupied. Leisler's bat *Nyctalus leisleri* was found in 29 of 200 bat boxes (15%) in groups of 1–11 individuals. *Pipistrellus* spp. (soprano pipistrelle *Pipistrellus pygmaeus* and Kuhl's pipistrelle *Pipistrellus kuhlii*) were found in 39 of 200 bat boxes (20%), either breeding or alone (1–5 bats). Bat box occupancy rates increased with forest cover and distance from human settlements (data reported as statistical model results). Two hundred open-sided wooden bat boxes (10 cm deep x 19 cm wide x 200 cm high) were randomly installed on trees between 2003 and 2005 in clusters of 3–5 boxes in five pine forests. Boxes were placed 4 m above the ground with randomly chosen orientations. Annual box checks were carried out in each of nine years between 2004 and 2012 in summer and/or autumn.

A replicated study prior to 2016 in 146 forests and parks in Bavaria, Germany and Austria (*40*) found that 25 of 146 (17%) groups of bat boxes were used as maternity roosts, 61 of 146 (42%) were used regularly by individual bats, and 60 of 146 (41%) were used only occasionally by individual bats or were not used at all. Thirteen bat species were recorded using the bat boxes. Bat box use increased with time since installation (<5 years: 26–54% of box groups regularly used; >10 years: 83–98%) and the size of bat box groups (<10 boxes/group: 58% of box groups regularly used; >30 boxes/group: 100%). However, these results were not tested for statistical significance. A total of 6,500 bat boxes were installed in groups on trees in 146 forests and parks. Boxes were installed in three group sizes (with approximately a third of the 146 boxes in each): small (3–10 boxes), medium (11–30 boxes) or large (>30 boxes). Boxes were also installed at three different time periods (with approximately a third of the 146 boxes in each): <5 years, 5–10 years and >10 years before the survey. Details and dates of installation and bat box surveys were not reported.

A replicated, before-and-after study in 1988–2018 in restored woodland near Melbourne, Australia (*41*) found that Gould's wattled bats *Chalinolobus gouldii* used bat boxes more frequently than seven other bat species and were captured in higher numbers in the study area after bat boxes were installed. Ninety percent of bats (21,424 of 23,778) recorded using 37 bat boxes in 1994–2018 were Gould's wattled bats. Gould's wattled bats were recorded using bat boxes in each of 25 years of the study and used them as maternity roosts. Seven other bat species did not use bat boxes as maternity roosts and were recorded in them only occasionally and/or in low numbers (<1–6% of bats recorded; see original paper for data for individual species). More Gould's wattled bats were captured in the study area after bat boxes were installed (average 49 bats/survey) than before (2 bats/survey) but the difference was not tested for statistical significance. Thirty-seven bat boxes of four designs (details not reported) were attached to *Eucalyptus* spp. trees (4–6 m above the ground). Boxes were checked monthly in 1994–2007 and every two months in 2008–2018. Bats were captured using four harp traps for two consecutive nights in autumn in each of two years before bat boxes were installed (1988, 1992) and in each of 18 years after (1996–2004, 2006–2013, 2018).

A replicated study in 2015–2016 of suburban woodlots in Indiana, USA (*42*) found that rocket boxes were used by more Indiana bats *Myotis sodalis* than bat boxes or bark-mimic roosts, and four of five rocket boxes installed were used as maternity roosts. Artificial roost type had a significant effect on maximum weekly counts of bats emerging (data reported as statistical model results). Maximum nightly counts and the total number of bat days (days in which at least one bat was observed using the roost) were higher in rocket boxes (205–210 bats/night; 4,340–7,770 bat days) than in bat boxes (7–22 bats/night; 24–172 bat days) or bark-mimic roosts (1–2 bats/night; 7–15 bat days), although no statistical tests were carried out. Six clusters of three bat boxes were installed (three in 2015, three in 2016) with each cluster containing one of each roost type: rocket box (2-chambered wooden box, 26 cm wide x 107 cm high), bat box (3-chambered traditional wooden birdhouse style box, 18 cm wide x 40 cm high), bark-mimic roost (modified BrandenBark polyurethane roost, 16 cm wide x 130 cm wide). Roosts were installed on posts (6 m high) along the southern edge of wooded areas (same study area as *18*). Bats were excluded from one of the six clusters to allow roost temperatures to be monitored. Daytime checks and emergence counts were carried out at least twice/week in March–October 2015 and 2016.

A review in 2018 of 119 studies of building developments in the UK (*43*) found that a third of bat boxes installed to replace destroyed roosts were used by bats, mainly *Pipistrellus* spp., and bats were more likely to use bat boxes when a greater number were installed across a site. Bats were present in 31% of bat boxes after development with the majority used by *Pipistrellus* spp. (27%). A small number of bat boxes were used by brown long-eared bats (2%) and *Myotis* spp. (2%). The roost status and number of bats using the roosts before and after development were not reported. The probability of at least one bat box being occupied by bats increased when a greater number of bat boxes were installed across a site (data reported as statistical model results). The 119 studies (dates not reported) were collected from multiple sources, including practitioner reports and licence applications from across the UK, and reviewed in 2018.

A replicated study in 2010–2016 in woodland adjacent to a coal mine site in New South Wales, Australia (*44*) found that 5–7% of bat boxes were occupied by three bat species, and a black box design was occupied more than four plywood designs by long-eared bats *Nyctophilus* spp. Bat boxes were occupied during 69 of 1,308 checks in the first year of the study, and 39 of 536 checks in the second year. Three of 13 tree cavity-roosting bat species known to be present used bat boxes

(Gould's wattled bat *Chalinolobus gouldii*, Gould's long-eared bat *Nyctophilus gouldi*, lesser long-eared bat *Nyctophilus geoffroyi*). Most occupied bat boxes (72–85%) were used by solitary bats. Two boxes had maternity roosts. In the second year, long-eared bats had greater occupancy in a new design of black box (74%) than in four plywood designs (7%). In 2010–2014, a total of 109 plywood bat boxes were installed on trees (2.5–7 m high) in 24 clusters in a biodiversity-offset area. Four designs were used (one, two or four-chambered bat boxes and a wedge-shaped box; see original paper for details). In 2015–2016, bat boxes within eight of the 24 clusters were replaced with two boxes of a new design (four-chambered black box with air vents; 61 cm high x 45 cm wide). Boxes were checked monthly during the first year of the study (2014–2015) and once every 1–2 months in the second year (2015–2016).

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14.3. Regularly clean bat boxes to increase occupancy

- We found no studies that evaluated the effects of regularly cleaning artificial bat roosts to increase occupancy on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Some bat boxes can accumulate large amounts of droppings or debris and regular cleaning may increase bat occupancy. However, disturbance to resident bats during cleaning must be considered.

14.4. Manage microclimate of artificial bat roosts

- **Three studies** evaluated the effects of managing the microclimate of artificial bat roosts on bat populations. Two studies were in the UK[1,2] and one was in Spain[3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One before-and-after study in Spain[3] found more bats in two artificial roosts within buildings after they had been modified to reduce internal roost temperatures.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One replicated, before-and-after study in the UK[1] found that heated bat boxes were used by common pipistrelle bats at one of seven sites, but none were used by maternity colones. One replicated study in the UK[2] found that none of the 12 heated bat boxes installed within churches were used by displaced Natterer's bats.

Background

The microclimate of artificial roosts may be managed to ensure that conditions remain suitable for roosting bats.

A replicated, before-and-after study in 2011–2015 of seven building developments with replacement bat maternity roosts across Scotland, UK (*1*) found that two heated bat boxes were used by individual bats at one of seven sites but in numbers lower than the original roost, and none were used by maternity colonies. At one site, two heated bat boxes installed inside the roof of a building were used by individual common pipistrelle bats *Pipistrellus pipistrellus* but in lower numbers than the original roost (bat box: 5 bats; original roost: average 14 bats). At six sites, heated bat boxes installed on the exterior of buildings were not used by bats. The original roosts were used by maternity colonies of common pipistrelles (average 5–13 bats) and soprano pipistrelles *Pipistrellus pygmaeus* (average 36–167 bats). The numbers of bats counted before development were extracted from reports submitted with licence applications. Bats were counted at each roost after development during at least one dusk emergence or dawn re-entry survey in May–September 2015.

A replicated study in 2012–2013 at six churches in Norfolk, UK (*2*) found that Natterer's bats *Myotis nattereri* did not use any of the 12 internal and external heated bat boxes provided after being displaced from roosts inside the churches. Two bat boxes (Bat Conservation International design) containing heat mats and thermostats were installed at each of six churches, one inside the church and one outside at roof height. Acoustic deterrents and artificial lighting were used to deter bats from their existing roost locations inside the churches where droppings and urine were causing problems. Emergence surveys and radio-tracking were carried out at each site between July and September in 2012 or 2013.

A before-and-after study in 2014–2016 in one agricultural site in Navarra, Spain (*3*) found more bats in artificial roosts after they were modified to reduce overheating. During the second summer of the study, five bat pups were found dead after a heatwave. The roosts were modified to reduce overheating, and in the following summer more bats were counted within them than in the previous summer (417 vs 91 Geoffroy's bats *Myotis emarginatus*, 93 vs 48 greater horseshoe bats *Rhinolophus ferrumequinum*, 44 vs 33 lesser horseshoe bats *Rhinolophus hipposideros* and 36 vs 15 common pipistrelles *Pipistrellus pipistrellus*). In July 2014, two buildings (2.6 x 2.6 x 3.2–4 m), 100 m apart, were constructed as artificial roosts to replace roosts that were destroyed in a building in 2013. With the aim of reducing overheating before summer 2016, the buildings were painted white and the ceiling was elevated. Bats were counted weekly from mid-April to mid-July in 2015 and 2016 using an infrared light.

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(2) Zeale M.R.K., Bennitt E., Newson S.E., Packman C., Browne W.J., Harris S., Jones G. & Stone E. (2016) Mitigating the impact of bats in historic churches: the response of Natterer's bats *Myotis nattereri* to artificial roosts and deterrence. *PLOS ONE,* 11, e0146782.
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Ex-situ conservation

14.5. Breed bats in captivity

- **Eight studies** evaluated the effects of breeding bats in captivity on bat populations. Three studies were in the USA[1,4,6], two in the UK[2,3], and one in each of Italy[5], Brazil[7] and New Zealand[8].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (8 STUDIES)

- **Reproductive success (6 studies):** Six studies in the USA[1,4], UK[2,3], Italy[5] and Brazil[7] found that 6–100% of female bats captured in the wild successfully conceived, gave birth and reared young in captivity. Two studies in the UK[2] and Brazil[7] found that two of five[2] and two of three[7] bats born in captivity successfully gave birth to live young.
- **Survival (8 studies):** Seven studies in the USA[1,4,6], UK[2,3], Italy[5] and Brazil[7] found that 20–100% of bat pups born in captivity survived from between 10 days to adulthood. One study in New Zealand[8] found that two of five New Zealand lesser short-tailed bat pups born in captivity survived, both of which were hand-reared.

BEHAVIOUR (0 STUDIES)

Background

Captive breeding involves taking wild animals into captivity and establishing and maintaining breeding populations. It tends to be undertaken when wild populations become small or fragmented or when they are declining rapidly. The aim is usually to release captive-bred animals back to natural habitats. See 'Release captive-bred bats'. Some captive populations may also be used for research to benefit wild populations. Although there are many captive-breeding programmes for bats in zoos around the world, we found only five studies that evaluated the reproductive success and survival of bats in captivity.

For a similar intervention relating to the management of white-nose syndrome in bats, see '*Threat: Invasive species and disease – Disease – White-nose syndrome – Breed bats in captivity to supplement wild populations affected by white-nose syndrome*'.

A study in 1958–1959 in a laboratory in Connecticut, USA (*1*) found that three of five Jamaican fruit-eating bats *Artibeus jamaicensis* born in captivity survived for 10–50 days and appeared to be in good health. Three bat pups were born 11, 12 and 13 months after their mothers were captured in the wild and had survived for 10–50 days at the time of the study. One other pregnancy was aborted (seven months after the mother was captured) and one bat pup died within 24 h of birth (eight months after the mother was captured). Twelve adult bats were captured in Mexico in July and August 1958 and brought to the laboratory in September 1958 to establish a breeding colony. They were kept in a darkened flight room at 80°F and fed banana and melon. Vitamins were added to drinking water. The captive bats were regularly observed for 13 months from September 1958 (dates not reported).

A study in 1966–1968 in a laboratory in the UK (*2*; same experimental set up as *3*) found that seven of 24 female common noctule bats *Nyctalus noctula* captured in the wild successfully conceived, gave birth and reared young in captivity, and two of five female bats born in captivity also gave birth. Thirteen of 24 female bats captured in the wild conceived in captivity. Nine female bats gave birth to live young, seven of which were weaned successfully. Two of five one-year old female bats born in captivity in 1967 successfully gave birth to live young. Wild male and female bats were captured from hibernacula or summer roosts (number of bats and dates not reported). Bats were housed in groups within metal cages lined with grooved plywood and fed with mealworms and vitamin powder. Observations were made during 1967 and 1968 (dates not reported).

A study in 1969 in a laboratory in the UK (*3*; same experimental set up as *2*) found that six of 33 female common noctule bats *Nyctalus noctula* captured in the wild successfully conceived, gave birth and reared young in captivity. Fifteen of 33 female bats captured in the wild conceived in captivity. Eleven female bats gave birth to live young, six of which were weaned successfully. Five pups were rejected by their mothers. Wild male and female bats were captured from hibernacula or summer roosts (number of bats and dates not reported). Bats were housed in groups within metal cages lined with grooved plywood and fed with mealworms and vitamin powder. Observations were made in 1969 (dates not reported).

A study in 1968–1970 in a flight room at Cornell University, USA (*4*) found that five of 18 pregnant Pallas's long-tongued bats *Glossophaga soricina* gave birth to live young, and one of five bat pups born was successfully reared to adulthood. Four of five bat pups were rejected by their mothers. Bats were collected from the wild in Trinidad in February 1968 (93 males, 23 females) and July 1968 (173 females) and transported to the university 2–7 days after capture. All bats were kept in a darkened flight room at 24–26°C with wood and wire cages for roosting. They were fed on peach nectar with added minerals. One to three males were added to cages with 15–20 females to encourage breeding. Observations were made for up to 584 days after bats were captured in 1968–1970.

A study in 1993–1994 in a flight room in Tuscany, Italy (*5*) found that a Savi's pipistrelle bat *Pipistrellus savii* captured in the wild successfully conceived, gave birth, and reared two pups in captivity. The young Savi's pipistrelle bat was captured in July 1993 and was observed mating in captivity in September 1993. Following hibernation, she gave birth to two pups on 27 July 1994. The pups (one male, one female) increased in body weight (by approximately 3 g), reached adult size within four weeks and were capable of flight by 35–40 days after birth. The Savi's pipistrelle was housed in a flight room (3 x 3 x 3 m with roosting sites on the walls) with a mixed colony of Savi's pipistrelles and Kuhl's pipistrelles *Pipistrellus kuhlii*. She was fed mealworm *Tenebrio molitor* and provided with water and multivitamins, plus a milk supplement while nursing. The pups were measured and weighed every four days. The authors report that two female bats in the colony also gave birth to three pups in 1995, which all survived and reached adult size (no further details were provided).

A study in 1991–2005 at a zoo in Florida, USA (*6*) found that over 13 years 63 little golden-mantled flying foxes *Pteropus pumilus* were born in captivity, 45 of which survived their first year after birth. In 1991, seven male and six female bats were either imported or donated to establish a breeding colony. Breeding was initiated every year in 1992–2005. In 2005, breeding was temporarily stopped, and individual bats were loaned to other institutions to reduce the population.

A study in 2001–2005 at a zoo in Brazil (*7*) found that three female pale-faced bats *Phylloderma stenops* captured in the wild conceived and gave birth to seven pups in captivity, and two of three female bats born in captivity gave birth to one pup each. Three female pale-faced bats captured in the wild successfully conceived and gave birth to seven pups (three males, four females) within 23–34 months after capture. Six pups survived and one died within 24 h of birth after being rejected by its mother. Two of three surviving female bats gave birth to one pup each at 13–15 months old. Five bats (one male, three females) were captured in 2001 and 2002 from two different regions and grouped together in a wire cage (90 x 60 x 80 cm) within a flight enclosure with 16 other bat species. Bats were fed with a semi-liquid diet of chopped fruit, egg, cow meat, dog food, honey, dehydrated shrimp, salt and a vitamin and mineral complex. Each bat was identified with a microchip and coloured plastic necklace. Observations were made twice/day for 10 minutes in 2001–2005.

A study in 2007–2014 at a zoo in Auckland, New Zealand (*8*) found that two of five New Zealand lesser short-tailed bats *Mystacina tuberculata* born in captivity survived and were successfully hand-reared. In 2012, two live pups (one male, one female) were born and removed from the colony for hand-rearing after showing signs of dehydration. Both pups reached adult body weight (approximately 14 g) at seven weeks of age, were observed flying at 10 weeks and successfully rejoined the colony at 12 weeks. One other pup was stillborn in 2010. Two other pups born in 2012 died at 16 and 22 days old. The colony of 13 adult bats was transferred to the zoo in 2007 following a failed translocation attempt. The two hand-reared pups were removed from the main enclosure at 2 and 18 days old and placed in an incubator. The pups were fed milk formula and weaned onto mealworms *Tenebrio molitor* and moths. Electrolytes were given to treat dehydration. At 50 days of age, the pups were placed in a small cage within the main enclosure and gradually re-introduced to the adult group.

(1) Novick A. (1960) Successful breeding in captive *Artibeus*. *Journal of Mammalogy*, 41, 508–509.

(2) Racey P.A. & Kleiman D.G. (1970) Maintenance and breeding in captivity of some vespertilionid bats, with special reference to the noctule. *International Zoo Yearbook*, 10, 65–70.

(3) Racey P.A. (1970) The breeding, care and management of vespertilionid bats in the laboratory. *Laboratory Animals,* 4, 171–183.

(4) Rasweiler IV J.J. (1973) Care and management of the long-tongued bat, *Glossophaga soricina* (Chiroptera: Phyllostomatidae), in the laboratory, with observations on estivation induced by food deprivation. *Journal of Mammalogy*, 54, 391–404.

(5) Dondini G. & Vergari S. (1995) Rearing and first reproduction of the Savi's pipistrelle *Pipistrellus savii* at Group of Study and Conservation Chiroptera, Florence. *International Zoo Yearbook*, 34, 143–146.

(6) Pope B. (2010) Hand rearing infant bats: little golden mantled flying fox (*Pteropus pumilus*) at Lubee Bat Conservancy and associated vitamin C deficiency. Pages 397–406 in*:* Barnard S. (ed.) *Bats in Captivity Volume 2: Aspects of Rehabilitation.* Logos Press, Washington D.C.

(7) Esbérard C.E.L. (2012) Reproduction of *Phylloderma stenops* in captivity (Chiroptera, Phyllostomidae). *Brazilian Journal of Biology*, 72, 171–174.

(8) Searchfield D. (2016) First breeding and hand rearing of the New Zealand lesser short-tailed bat *Mystacina tuberculata* at Auckland Zoo. *International Zoo Yearbook*, 50, 165–173.

14.6. Release captive-bred bats

- We found no studies that evaluated the effects of releasing captive-bred bats on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

The aim of captive breeding is usually to release captive-bred animals back to natural habitats, either to original sites once conditions are suitable, to reintroduce species to sites that were occupied in the past or to introduce species to new sites. For studies that released hand-reared bats into the wild, see '*Rehabilitate injured/orphaned bats to maintain wild bat populations*'.

14.7. Rehabilitate injured/orphaned bats to maintain wild bat populations

- **Four studies** evaluated the effects of rehabilitating injured/orphaned bats on bat populations. Two studies were in the UK[1,2], one was in Italy[3] and one in Brazil[4].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (4 STUDIES)

- **Survival (4 studies):** One study in Brazil[4] found that two hand-reared orphaned greater spear-nosed bats survived for over three months in captivity. Two studies in the UK[2] and Italy[3] found that 70–90% of hand-reared pipistrelle bats survived for at least 4–14 days after release into the wild, and six of 21 bats joined wild bat colonies[3]. One study in the UK[1] found that pipistrelle bats that flew in a large flight cage for long periods before release survived for longer and were more active than bats that flew for short periods or in a small enclosure. One study in the UK[2] found that 13% of ringed hand-reared pipstrelle bats were found alive in bat boxes 38 days to almost four years after release into the wild.
- **Condition (1 study):** One study in Brazil[4] found that two orphaned greater spear-nosed bats increased in body weight and size after being hand-reared and reached a normal size for the species after 60 days.

BEHAVIOUR (0 STUDIES)

Background

Injured or orphaned bats may be rehabilitated with the aim of releasing them back into the wild to maintain wild bat populations. This often involves the use of volunteers, which may help to raise awareness for bat conservation. Although bat rehabilitation activities are carried out in many countries, we only found two studies that provide evidence for the effects of this intervention on the survival of rehabilitated bats. We found no studies evaluating the effects of this intervention on maintaining wild bat populations.

A study in 2002–2006 at a wildlife rehabilitaton centre in the UK (*1*) found that five hand-reared *Pipistrellus* spp. bats released into the wild after prolonged flight training in a large flight cage survived for at least 5–10 nights and were active each night, but seven bats released after a limited amount of flight training or training in a limited space did not survive or were less active after release. Five bats that flew for 21 days in a large flight cage (7 x 4 x 2.3 m) before release were radio-tracked for 5–10 days after their release and were recorded actively flying each night. Two bats that flew in a smaller flight enclosure (3 x 2 x 1.8 m) before release flew well on the first night after release but did not fly on the second and third nights. Five bats that flew for 20 minutes/day in an enclosed room before release were found on the ground within 48 h of release (four bats) or contact was lost with the radio tag (one bat). All of 12 injured or orphaned bats were hand-reared by domestic carers (seven bats) or a wildlife rehabilitation centre (five bats). Bat pups were kept in an incubator and fed a milk substitute. At 3–4 weeks old, they were moved to unheated bat boxes and weaned onto mealworms. Bats were radio-tracked for 1–10 nights following release from their bat boxes at sites close to known bat roosts in 2002, 2005 or 2006.

A study in 2006–2007 at a wildlife rehabilitation centre in the UK (*2*) found that seven of 10 hand-reared pipistrelle bats survived for at least 4–10 days after release into the wild, and 13% of released ringed bats returned to bat boxes 38 days to 3.8 years after release. Seven bats (two common pipistrelles *Pipistrellus*

pipistrellus, five soprano pipistrelles *Pipistrellus pygmaeus*) were radio-tracked for 4–10 days after release before the signal with their radio tags was lost. Three common pipistrelles were taken back into captivity after 1–4 nights after becoming trapped in buildings or unable to fly. Five of 39 (13%) ringed bats were found alive in bat boxes used for release 38 days to 3.8 years after release. All bats were admitted to the centre as juveniles and hand-reared using the same methods as (*2*). Before release, all bats flew freely in an outdoor flight cage. Thirty-nine bats were fitted with rings and released from bat boxes in 2006–2007. Bat boxes were checked daily for ringed bats in 2006–2007. Ten bats were fitted with radio tags and released from bat boxes in August and September 2007. Radio-tracking was carried out for 1–10 nights following release.

A study in 2008–2009 in a rural area of central Italy (*3*) found that 19 of 21 hand-reared Kuhl's pipistrelle bats *Pipistrellus kuhlii* survived for at least 4–14 days after release into the wild, and six joined wild Kuhl's pipistrelle colonies. Six of the 19 bats joined two wild Kuhl's pipistrelle colonies roosting in nearby buildings. Another six roosted in buildings previously unoccupied by bats, and seven continued to roost in two bat boxes used for release. Two bats could not be tracked as contact was lost with their radio tags within two days of release. Thirty-seven orphaned newborn bats (18 in 2008, 19 in 2009) were reared in heated boxes and fed powdered milk. At 3–4 weeks old, bats were weaned with mealworms and moved to a flight room (8 x 5 x 3 m) with four bat boxes. After 12 days in the flight room, bats able to fly continuously for ≥10 minutes on one night were selected for release. Twenty-one bats (11 in 2008, 10 in 2009) were fitted with radio tags and released 1 h before sunset in the same region they came from. Two bat boxes from the flight room were hung on trees at the release site. Radio-tracking was carried out over 14 nights after bats were released in 2008 and 2009.

A study in 2001–2002 in a research centre in Rio de Janeiro, Brazil (*4*) found that two hand-reared greater spear-nosed bats *Phyllostomus hastatus* survived over three months and reached normal body size for the species. Over approximately two months, the body weight of two hand-reared greater spear-nosed bats increased from 21–40 g to 86–97 g. After 60 days, both individuals had reached a body size normal for the species (forearm of 88 mm). Two abandoned greater spear-nosed bats with an estimated age of 15–20 days were taken into captivity in November 2001. Bats were initially fed 1–2 ml of commercial baby formula with a syringe every 2 h. The amount of food was increased by 1–2 ml/week. After the second month, the bats were fed an equal amount of baby formula and avocado for three days and thereafter a mix of fruit (75%), bird food (15%), dog food (5%), egg (2.5%), cow meat (5%) and honey (0.5%).

(1) Kelly A., Goodwin S., Grogan A. & Mathews F. (2008) Post-release survival of hand-reared pipistrelle bats (*Pipistrellus* spp). *Animal Welfare,* 17, 375–382.

(2) Kelly A., Goodwin S., Grogan A. & Mathews F. (2012) Further evidence for the post-release survival of hand-reared, orphaned bats based on radio-tracking and ring-return data. *Animal Welfare,* 21, 27–31.

(3) Serangeli M.T., Cistrone L., Ancillotto L., Tomassini A. & Russo D. (2012) The post-release fate of hand-reared orphaned bats: survival and habitat selection. *Animal Welfare,* 21, 9–18.

(4) Esbérard C.E.L., Motta A.G., & Gonçalves A.C. (2002) Artificial rearing of greater spear-nosed bats (*Phyllostomus hastatus*). Recria artificial de falso-vampiro (*Phyllostomus hastatus*). *Chiroptera Neotropical*, 8, 152–155.

Translocation

14.8. Translocate bats

- **Two studies** evaluated the effects of translocating bats on bat populations. One study was in New Zealand[1] and one in Switzerland[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Reproductive success (1 study):** One study in Switzerland[2] found that a female greater horseshoe bat that settled at a release site after translocation had a failed pregnancy.
- **Survival (1 study):** One study in Switzerland[2] found that four of 18 bats died after translocation.
- **Condition (1 study):** One study in New Zealand[1] found that lesser short-tailed bats captured at release sites eight months after translocation were balding and had damaged, infected ears.

BEHAVIOUR (2 STUDIES)

- **Uptake (2 studies):** Two studies in New Zealand[1] and Switzerland[2] found that low numbers of bats remained at release sites after translocation.
- **Behaviour change (1 study):** One study in Switzerland[2] found that bats homed after release at translocation sites less than 20 km from their original roosts.

Background

Translocation involves the transport and release of animals from one area to another. This may be done to protect against threats from introduced predators, competitors or disease, or to supplement existing populations. Previous studies on the homing behaviour of bats have shown that bats will often attempt to fly long distances to return home when released in new areas (e.g. Holland *et al*. 2006).

Holland R.A., Thorup K., Vonhof M.J., Cochran W.W. & Wikelski M. (2006) Bat orientation using Earth's magnetic field. *Nature,* 444, 702.

A study in 2005 on Kapiti Island, New Zealand (*1*) found that nine of 20 translocated lesser short-tailed bats *Mystacina tuberculata* were recorded at the release site 232 days after release, and all were in poor condition. After eight months, captured bats were balding and had damaged infected ears and were subsequently returned to captivity. Four male and 16 female captive bred juveniles were released on the Island in April 2005 and provided with roosts and supplementary food (consistently for 55 days after release and irregularly for 156 days after release). Kapiti Island is a 1,965-ha nature reserve of forest and scrub located 40 km south west of the source bat population on mainland New Zealand. Bats were monitored using infrared video cameras and caught in harp traps during three study periods after release in 2005 (eight weeks in April–June, five weeks in August–September, one week in November–December).

A study in 2006–2008 of four sites in alpine villages in Switzerland (*2*) found that two of 11 greater horseshoe bats *Rhinolophus ferrumequinum* and none of seven lesser horseshoe bats *Rhinolophus hipposideros* remained at release sites in the long term after translocation, 10 bats homed after release and four died with three days of release. Two greater horseshoe bats (one male, one female) translocated 149 km settled in the release area and the female was regularly observed in a new roost in 2007 and 2008, but had an unsuccessful pregnancy in 2007. Two female lesser horseshoe bats remained at release sites 54–57 km away during 10 days of radio-tracking, but were not recorded beyond this period. Eight greater horseshoe bats and two lesser horseshoe bats homed after release at sites <20 km from their original roosts. One greater horseshoe bat and three lesser horseshoe bats died of shock or predation within three days of release. Male and female greater horseshoe bats (11) and lesser horseshoe bats (7) of three age classes (adult, 1–2 years and yearlings) were captured from large colonies and translocated to small relict colonies in similar habitats 11–149 km away in May–August 2006. Released bats were monitored with infrared video and radio-tracked for up to 10 days after release. Roosts at release sites were regularly checked in 2007 and 2008.

(1) Ruffell J. & Parsons S. (2009) Assessment of the short-term success of a translocation of lesser short-tailed bats *Mystacina tuberculata*. *Endangered Species Research*, 8, 33–39.
(2) Weinberger I.C., Bontadina F. & Arlettaz R. (2009) Translocation as a conservation tool to supplement relict bat colonies: a pioneer study with endangered horseshoe bats. *Endangered Species Research*, 8, 41–48.

15. Education and awareness raising

It has been suggested that there is a universal requirement for education and awareness raising about the diversity of bats, their role in the environment and their conservation (Hutson *et al*. 2001). Education should not only be aimed at professionals but also at members of the public. This is likely to be especially important following events such as the recent pandemic of the coronavirus disease (COVID-19), in which bats were implicated as potential hosts of the SARS-CoV-2 virus. There have been considerable efforts by scientists and conservation organisations to convey positive messages about bats and prevent unnecessary (and ineffective) culling and persecution of endangered bat populations.

This intervention involves general information and awareness raising campaigns in response to a range of threats. Studies are included that measure the effect of an action that may be done to change human behaviour for the benefit of bat populations.

It should be noted that there are many complex factors that influence human behaviour and providing education does not guarantee that behaviour will change. It may be necessary to collaborate with social scientists to design appropriate education programmes that consider the attitudes, values, and social norms of the target audience (e.g. see Kingston 2016).

Studies describing educational campaigns in response to specific threats are described in the chapter on that threat category (e.g. '*Threat: Residential and commercial development – Educate homeowners about building and planning laws relating to bats to reduce disturbance to bat roosts*').

Hutson A.M., Mickleburgh S.P. & Racey P.A. (2001) *Microchiropteran bats: global status, survey and conservation action plan*. IUCN/SSC Chiroptera Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.

Kingston T. (2016) Cute, creepy, or crispy – how values, attitudes, and norms shape human behavior toward bats. Pages 571–595 in*:* Voigt C.C. & Kingston T. (eds.) *Bats in the Anthropocene: Conservation of Bats in a Changing World.* Springer International Publishing, Cham.

15.1. Educate the public to improve perception of bats to improve behaviour towards bats

- We found no studies that evaluated the effects of educating the public to improve the perception of bats to improve behaviour towards bats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Bats have long been the victims of negative public opinion due to mythology involving vampires and witchcraft, and associations with disease, such as rabies, the Ebola virus, and more recently the coronavirus disease (COVID-19). Education programmes, campaigns and events to dispel myths and to educate the public about the importance of bats and bat conservation have been put in place in some countries and may benefit bat populations by improving human behaviour towards bats. Three studies in the USA (Rule & Zhbanova 2012, Hoffmaster *et al*. 2016, Lu *et al*. 2017) and two in the UK (Kaninsky *et al.* 2018) found that providing education to the public resulted in more positive perceptions and beliefs about bats.

Hoffmaster E., Vonk J. & Mies R. (2016) Education to action: improving public perception of bats. *Animals,* 6, 6.

Kaninsky M., Gallacher S. & Rogers Y. (2018) *Confronting people's fears about bats: combining multi-modal and environmentally sensed data to promote curiosity and discovery*. Proceedings - Designing Interactive Systems Conference, Hong Kong, China, 9–13 June 2018, 931–943.

Lu H., McComas K.A., Buttke D.E., Roh S., Wild M.A. & Decker D.J. (2017) One Health messaging about bats and rabies: how framing of risks, benefits and attributions can support public health and wildlife conservation goals. *Wildlife Research,* 44, 200–206.

Rule A. & Zhbanova K. (2012) Changing perceptions of unpopular animals through facts, poetry, crafts, and puppet plays. *Early Childhood Education Journal,* 40, 223–230.

15.2. Engage policymakers to make policy changes beneficial to bats

- We found no studies that evaluated the effects of engaging policymakers to make policy changes beneficial to bats or human behaviours directly beneficial to bats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Raising awareness amongst policymakers of the need for bat conservation may result in improved legal protection of bats and bat habitats.

15.3. Promote careful bat-related eco-tourism to improve behaviour towards bats

- We found no studies that evaluated the effects of promoting careful bat-related eco-tourism to improve behaviour towards bats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Eco-tourism may help to promote bat conservation and raise funds for conservation and research. However, it requires careful implementation as large-scale or unregulated eco-tourism can cause considerable disturbance to bats (e.g. Biswas *et al*. 2011).

Biswas J., Shrotriya S., Rajput J. & Sasmal S. (2011) Impacts of ecotourism on bat habitats in caves of Kanger Valley National Park, India. *Research Journal of Environmental Sciences,* 5, 752–762.

15.4. Educate farmers, land managers and local communities about the benefits of bats to improve management of bat habitats

- We found no studies that evaluated the effects of educating farmers, land managers and local communities about the benefits of bats to improve management of bat habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Educating farmers, land managers and local communities about the benefit of bats and appropriate habitat management for bats may help to raise awareness and promote 'bat-friendly' activities and behaviours. For a similar intervention, see '*Threat: Agriculture – All farming systems – Engage farmers and landowners to manage land for bats*'.

15.5. Provide training to conservationists, land managers, and the building and development sector on bat ecology and conservation to reduce bat roost disturbance

- We found no studies that evaluated the effects of providing training to conservationists, land managers, and the building and development sector on bat ecology and conservation to reduce bat roost disturbance.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

This intervention involves providing training of best practice methods to professionals who come into contact with bats and their roosts, such as ecologists, conservationists, tradesmen, architects, and land managers. Training should be given to specific guidelines as applicable for the laws of the country and the protection status of bats.

15.6. Provide training to wildlife control operators on least harmful ways of removing bats from their roosts

- We found no studies that evaluated the effects of providing training to wildlife control operators on the least harmful ways of removing bats from their roosts.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

In some situations, it may be necessary to remove bats from roosts in buildings where there is conflict with humans, e.g. for public health reasons. Providing training to wildlife operators on appropriate exclusion techniques may reduce harm to evicted bats. Training should be given to specific guidelines as applicable for the laws of the country and the protection status of bats.

15.7. Educate pest controllers and homeowners/tenants to reduce the illegal use of pesticides in bat roosts

- We found no studies that evaluated the effects of educating pest controllers and homeowners/tenants to reduce the illegal use of pesticides in bat roosts on bat populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

In some countries, e.g. in Africa, pest controllers, homeowners and tenants have been reported to illegally kill bat colonies in buildings using pesticides. Although the pesticides themselves are not illegal, they have not been registered for use on bats and many people are unaware of this.

15.8. Educate farmers, local communities, and pest controllers to reduce indiscriminate culling of vampire bats

- We found no studies that evaluated the effects of educating farmers, local communities and pest controllers to reduce indiscriminate culling of vampire bats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Bats may be indiscriminately killed by farmers and local communities in attempts to reduce the spread of rabies. Providing education about vampire bats and non-lethal measures to prevent the spread of rabies may reduce unnecessary killing of bats. A study in Costa Rica found that men who knew more about bat ecology (from previous education programmes and/or watching television) were less likely to have intentions to indiscriminately kill bats (Reid *et al*. 2016).

Interventions relating to non-lethal measures of rabies control are described in '*Threat: Agriculture – Livestock farming – Replace culling of bats with non-lethal methods of preventing vampire bats from spreading rabies to livestock*' and '*Threat: Biological resource use – Hunting – Replace culling of bats with non-lethal methods of preventing vampire bats from spreading rabies to humans*'.

Reid J.L. (2016) Knowledge and experience predict indiscriminate bat-killing intentions among Costa Rican men. *Biotropica,* 48, 394–404.

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Appendix 1: English journals (and years) searched

Journals (and years) searched and for which relevant papers have been added to the Conservation Evidence discipline-wide literature database. An asterisk indicates the journals most relevant to this synopsis.

Journal	**Years searched**	**Topic**
Acrocephalus	2009–2018	All biodiversity
Acta Chiropterologica*	1999–2019	All biodiversity
Acta Herpetologica	2006–2018	All biodiversity
Acta Oecologica	1990–2018	All biodiversity
Acta Theriologica	1977–2014	All biodiversity
African Bird Club Bulletin	1994–2017	All biodiversity
African Journal of Ecology	1963–2016	All biodiversity
African Journal of Herpetology	1990–2018	All biodiversity
African Journal of Marine Science	1983–2018	All biodiversity
African Primates	1995–2012	All biodiversity
African Sea Turtle Newsletter	2014–2018	All biodiversity
African Zoology	1979–2013	All biodiversity
Agriculture, Ecosystems and Environment*	1983–2019	All biodiversity
Ambio	1972–2011	All biodiversity
American Journal of Primatology	1981–2019	All biodiversity
American Naturalist*	1867–2019	All biodiversity
Amphibia-Reptilia	1980–2018	All biodiversity
Amphibian & Reptile Conservation	1996–2018	All biodiversity
Animal Biology	2003–2013	All biodiversity
Animal Conservation*	1998–2019	All biodiversity
Animal Nutrition	2015–2019	All biodiversity
Animal Welfare	1992–2019	All biodiversity
Animals	2011–2019	All biodiversity
Annales Zoologici Fennici	1964–2013	All biodiversity
Annales Zoologici Societatis Zoologicae Botanicae Fennicae Vanamo	1932–1963	All biodiversity
Annual Review Ecology and Systematics*	1970–2019	All biodiversity
Antarctic Science	1980–2018	All biodiversity
Anthrozoos	1987–2019	All biodiversity
Apidologie	1958–2009	All biodiversity
Applied Animal Behaviour Science	1984–2019	All biodiversity
Applied Herpetology	2003–2009	All biodiversity
Applied Vegetation Science	1998–2017	All biodiversity

Aquarium Sciences and Conservation	1997–2001	All biodiversity
Aquatic Biology	2007–2018	All biodiversity
Aquatic Botany	1975–2017	All biodiversity
Aquatic Conservation: Marine and Freshwater Ecosystems	1991–2018	All biodiversity
Aquatic Ecology	1968–2018	All biodiversity
Aquatic Ecosystem Health & Management	1998–2018	All biodiversity
Aquatic Invasions	2006–2016	All biodiversity
Aquatic Living Resources	1988–2018	All biodiversity
Aquatic Mammals	1972–2018	All biodiversity
Arid Land Research and Management	1987–2013	All biodiversity
Asian Herpetological Research	2010–2018	All biodiversity
Asian Primates	2008–2012	All biodiversity
Asiatic Herpetological Research	1993–2008	All biodiversity
Auk	1980–2016	All biodiversity
Austral Ecology*	1977–2019	All biodiversity
Australasian Journal of Herpetology	2009–2012	All biodiversity
Australian Mammalogy*	2000–2018	All biodiversity
Avian Conservation and Ecology	2005–2016	All biodiversity
Basic & Applied Herpetology	2011–2018	All biodiversity
Basic and Applied Ecology*	2000–2019	All biodiversity
Behavior	1948–2013	All biodiversity
Behavior Ecology	1990–2013	All biodiversity
Biawak	2001–2017	All biodiversity
Bibliotheca Herpetologica	1999–2017	All biodiversity
Biocontrol	1956–2016	All biodiversity
Biocontrol Science and Technology	1991–1996	All biodiversity
Biodiversity	2000–2018	All biodiversity
Biodiversity and Conservation*	1994–2019	All biodiversity
Biological Conservation*	1981–2019	All biodiversity
Biological Control	1991–2017	All biodiversity
Biological Invasions	1999–2017	All biodiversity
Biology and Environment: Proceedings of the Royal Irish Academy	1993–2017	All biodiversity
Biology Letters	2005–2018	All biodiversity
Biotropica*	1990–2019	All biodiversity
Bird Conservation International	1991–2016	All biodiversity
Bird Study	1980–2016	All biodiversity
Boreal Environment Research	1996–2014	All biodiversity
Bulletin of the Chicago Herpetological Society	1990–2018	All biodiversity
Bulletin of the Herpetological Society of Japan	1999–2008	All biodiversity

Bulletin of the Maryland Herpetological Society	1980–2015	All biodiversity
Canadian Field Naturalist*	1987–2019	All biodiversity
Canadian Journal of Fisheries and Aquatic Sciences	1901–2018	All biodiversity
Canadian Journal of Forest Research	1971–2018	All biodiversity
Caribbean Herpetology	2010–2018	All biodiversity
Caribbean Journal of Science	1961–2013	All biodiversity
CCAMLR Science	1985–2016	All biodiversity
Chelonian Conservation and Biology	1993–2018	All biodiversity
Chelonian Research Monographs	1996–2017	All biodiversity
Coastal Engineering	2000–2018	All biodiversity
Collinsorum	2012–2016	All biodiversity
Community Ecology	2000–2012	All biodiversity
Conservation Biology*	1987–2019	All biodiversity
Conservation Evidence*	2004–2019	All biodiversity
Conservation Genetics	2000–2013	All biodiversity
Conservation Letters*	2008–2019	All biodiversity
Contemporary Herpetology	1998–2009	All biodiversity
Contributions to Primatology	1974–1991	All biodiversity
Copeia	1910–2018	All biodiversity
Copeia	2004–2016	Reptile Conservation
Cunninghamia	1981–2016	All biodiversity
Current Herpetology	1964–2018	All biodiversity
Dodo	1977–2001	All biodiversity
Ecological and Environmental Anthropology	2005–2008	All biodiversity
Ecological Applications*	1991–2019	All biodiversity
Ecological Entomology	1985–2018	All biodiversity
Ecological Indicators	2001–2007	All biodiversity
Ecological Management & Restoration*	2000–2019	All biodiversity
Ecological Restoration*	1981–2019	All biodiversity
Ecology*	1936–2019	All biodiversity
Ecology Letters	1998–2019	All biodiversity
Écoscience	1994–2019	All biodiversity
Ecosystems	1998–2013	All biodiversity
Emu	1980–2016	All biodiversity
Endangered Species Bulletin	1966–2003	All biodiversity
Endangered Species Research	2004–2019	All biodiversity
Entomologia Experimentalis et Applicata	2015–2018	All biodiversity
Environmental Conservation*	1974–2019	All biodiversity
Environmental Entomology	1990–2018	All biodiversity
Environmental Evidence*	2012–2019	All biodiversity

Environmental Management*	1977–2019	All biodiversity
Environmentalist	1981–1988	All biodiversity
Estuaries and Coasts	2013–2017	All biodiversity
Ethology Ecology & Evolution	1989–2014	All biodiversity
European Journal of Soil Science	1950–2012	Soil Fertility
European Journal of Wildlife Research*	2004–2019	All biodiversity
Evolutionary Anthropology	1992–2014	All biodiversity
Evolutionary Ecology	1987–2014	All biodiversity
Evolutionary Ecology Research	1999–2014	All biodiversity
Fire Ecology	2005–2016	All biodiversity
Fish and Fisheries	2000–2018	All biodiversity
Fisheries	2017–2018	All biodiversity
Fisheries Management and Ecology	1990–2018	All biodiversity
Fisheries Oceanography	1992–2018	All biodiversity
Fisheries Research	1990–2018	All biodiversity
Flora	1991–2017	All biodiversity
Folia Primatologica	1963–2014	All biodiversity
Folia Zoologica	1959–2013	All biodiversity
Forest Ecology and Management*	1976–2019	All biodiversity
Freshwater Biology	1975–2016	All biodiversity
Freshwater Science	1982–2018	All biodiversity
Frontiers in Marine Science	2017–2018	All biodiversity
Frontiers in Psychology	2019	All biodiversity
Functional Ecology	1987–2013	All biodiversity
Genetics and Molecular Research	2002–2013	All biodiversity
Geoderma	1967–2012	Soil Fertility
Gibbon Journal	2005–2011	All biodiversity
Global Change Biology	1995–2017	All biodiversity
Global Ecology and Biogeography	1991–2014	All biodiversity
Global Ecology and Conservation	2014–2018	All biodiversity
Grass and Forage Science	1980–2017	All biodiversity
Herpetofauna	2003–2007	All biodiversity
Herpetologica	1936–2018	All biodiversity
Herpetologica	2013–2016	Reptile Conservation
Herpetological Bulletin	1980–2003	Amphibian Conservation
Herpetological Bulletin	2003–2013	Reptile Conservation
Herpetological Bulletin	2014–2016	All biodiversity
Herpetological Conservation and Biology	2006–2012	Amphibian Conservation
Herpetological Conservation and Biology	2006–2012	Reptile Conservation
Herpetological Conservation and Biology	2006–2018	All biodiversity
Herpetological Journal	1985–2014	All biodiversity

Herpetological Monographs	1982–2018	All biodiversity
Herpetological Review	1967–2018	All biodiversity
Herpetology Notes	2008–2018	All biodiversity
Herpetozoa	1988–2018	All biodiversity
Human Wildlife Interactions*	2007–2019	All biodiversity
Hydrobiologia	2000–2018	All biodiversity
Hystrix, the Italian Journal of Mammalogy*	1986–2019	All biodiversity
Ibis	1980–2016	All biodiversity
ICES Journal of Marine Science	1990–2018	All biodiversity
iForest	2008–2016	All biodiversity
Insect Conservation and Diversity	2008–2018	All biodiversity
Integrative Zoology	2006–2013	All biodiversity
International Journal of Pest Management (formerly PANS Pest Articles & News Summaries 1969 - 1975, PANS 1976-1979 & Tropical Pest Management 1980-1992)	1969–1979	All biodiversity
International Journal of Primatology	1980–2019	All biodiversity
International Journal of the Commons	2007–2016	All biodiversity
International Journal of Wildland Fire	1991–2016	All biodiversity
International Wader Studies	1970–1972	All biodiversity
International Zoo Yearbook	1960–2019	All biodiversity
Invasive Plant Science and Management	2008–2016	All biodiversity
Israel Journal of Ecology & Evolution	1963–2013	All biodiversity
Italian Journal of Zoology	1978–2013	All biodiversity
Journal for Nature Conservation*	2002–2019	All biodiversity
Journal of Animal Ecology*	1932–2019	All biodiversity
Journal of Apicultural Research	1962–2009	All biodiversity
Journal of Applied Animal Nutrition	2012–2019	All biodiversity
Journal of Applied Animal Welfare Science	1998–2019	All biodiversity
Journal of Applied Ecology*	1964–2019	All biodiversity
Journal of Aquatic Plant Management	1962–2016	All biodiversity
Journal of Arid Environments	1993–2017	All biodiversity
Journal of Avian Biology	1980–2016	All biodiversity
Journal of Bat Research & Conservation (formerly Barbastella)*	2000–2019	All biodiversity
Journal of Cetacean Research and Management	1999–2018	All biodiversity
Journal of Coastal Research	2015–2018	All biodiversity
Journal of Ecology*	1933–2019	All biodiversity
Journal of Ecology & Natural Resources	2017–2019	All biodiversity
Journal of Environmental Management*	1973–2019	All biodiversity

Journal of Experimental Marine Biology and Ecology	2000–2018	All biodiversity
Journal of Field Ornithology	1980–2016	All biodiversity
Journal of Forest Research*	1996–2019	All biodiversity
Journal of Great Lakes Research	1975–2017	All biodiversity
Journal of Herpetological Medicine and Surgery	2009–2018	All biodiversity
Journal of Herpetology	1968–2016	All biodiversity
Journal of Insect Conservation	1997–2018	All biodiversity
Journal of Insect Science	2003–2018	All biodiversity
Journal of Kansas Herpetology	2002–2011	All biodiversity
Journal of Mammalian Evolution	1993–2014	All biodiversity
Journal of Mammalogy*	1919–2019	All biodiversity
Journal of Mountain Science	2004–2016	All biodiversity
Journal of Negative Results: Ecology & Evolutionary Biology	2004–2016	All biodiversity
Journal of North American Herpetology	2014–2017	All biodiversity
Journal of Ornithology	2004–2018	All biodiversity
Journal of Primatology	2012–2013	All biodiversity
Journal of Raptor Research	1966–2016	All biodiversity
Journal of Sea Research	1961–2018	All biodiversity
Journal of the Japanese Institute of Landscape Architecture	1934–2017	All biodiversity
Journal of the Marine Biological Association of the United Kingdom	1887–2018	All biodiversity
Journal of Tropical Ecology*	1986–2019	All biodiversity
Journal of Vegetation Science	1990–2017	All biodiversity
Journal of Wetlands Ecology	2008–2012	All biodiversity
Journal of Wetlands Environmental Management	2012–2016	All biodiversity
Journal of Wildlife Diseases	1965–2012	All biodiversity
Journal of Wildlife Management*	1945–2019	All biodiversity
Journal of Zoo and Aquarium Research	2013–2019	All biodiversity
Journal of Zoo and Wildlife Medicine	1970–2019	All biodiversity
Journal of Zoology*	1966–2019	All biodiversity
Jurnal Primatologi Indonesia	2009	All biodiversity
Kansas Herpetological Society Newsletter	1974–2001	All biodiversity
Knowledge and Management of Aquatic Ecosystems (formerly Bulletin Français de la Pêche et de la Pisciculture)	1986–2018	All biodiversity
Lake and Reservoir Management	1984 –2016	All biodiversity
Land Degradation and Development	1989–2016	All biodiversity
Land Use Policy	1984–2012	Soil Fertility

Latin American Journal of Aquatic Mammals	2002–2018	All biodiversity
Lemur News	1993–2012	All biodiversity
Limnologica - Ecology and Management of Inland Waters	1999–2018	All biodiversity
Mammal Research*	2001–2019	All biodiversity
Mammal Review*	1970–2019	All biodiversity
Mammal Study*	2005–2019	All biodiversity
Mammalia*	1937–2019	All biodiversity
Mammalian Biology*	2002–2019	All biodiversity
Mammalian Genome	1991–2013	All biodiversity
Management of Biological Invasions	2010–2016	All biodiversity
Mangroves and Salt Marshes	1996–1999	All biodiversity
Marine and Freshwater Research	1980–2018	All biodiversity
Marine Ecology	1980–2018	All biodiversity
Marine Ecology Progress Series	2000–2018	All biodiversity
Marine Environmental Research	1978–2018	All biodiversity
Marine Mammal Science	1985–2018	All biodiversity
Marine Pollution Bulletin	2010–2018	All biodiversity
Marine Turtle Newsletter	1976–2018	All biodiversity
Mesoamerican Herpetology	2014–2017	All biodiversity
Mires and Peat	2006–2016	All biodiversity
Natural Areas Journal	1992–2017	All biodiversity
Nature Conservation	2012–2019	All biodiversity
Neobiota	2011–2017	All biodiversity
Neotropical Entomology	2004–2018	All biodiversity
Neotropical Primates	1993–2012	All biodiversity
New Journal of Botany	2011–2013	All biodiversity
New Zealand Journal of Marine and Freshwater Research	1967–2018	All biodiversity
New Zealand Journal of Zoology*	1974–2019	All biodiversity
New Zealand Plant Protection	2000–2016	All biodiversity
Northwest Science	2007–2016	All biodiversity
Oecologia*	1969–2019	All biodiversity
Oikos*	1949–2019	All biodiversity
Ornitologia Neotropical	1990–2018	All biodiversity
Oryx*	1950–2019	All biodiversity
Ostrich	1980–2016	All biodiversity
Pacific Conservation Biology*	1993–2019	All biodiversity
Pakistan Journal of Zoology	2004–2013	All biodiversity
Phyllomedusa	2002–2018	All biodiversity
Plant Ecology	1948–2007	All biodiversity

Plant Protection Quarterly	2008–2016	All biodiversity
PLOS*	1980–2019	Key word: 'bat*'
Polish Journal of Ecology	2002–2013	All biodiversity
Population Ecology	1952–2013	All biodiversity
Preslia	1973–2017	All biodiversity
Primate Conservation	1981–2014	All biodiversity
Primates	1957–2013	All biodiversity
Rangeland Ecology & Management (previously Journal of Range Management 1948-2004)	1948–2016	All biodiversity
Raptors Conservation	2005–2016	All biodiversity
Regional Studies in Marine Science	2015–2018	All biodiversity
Reptile Rap - Newsletter of the South Asian Reptile Network (SARN)	1999–2016	All biodiversity
Restoration Ecology*	1993–2019	All biodiversity
Riparian Ecology and Conservation	2013–2017	All biodiversity
River Research and Applications	1987–2016	All biodiversity
Russian Journal of Herpetology	1994–2018	All biodiversity
Slovak Raptor Journal	2007–2016	All biodiversity
Small Ruminant Research	1988–2017	All biodiversity
Soil Biology & Biochemistry	1969–2012	Soil Fertility
South African Journal of Botany	1982–2016	All biodiversity
South African Journal of Wildlife Research	1971–2014	All biodiversity
South American Journal of Herpetology	2006–2018	All biodiversity
Southern Forests: a journal of Forest Science	2008–2013	All biodiversity
Systematic Reviews Centre for Evidence-Based Conservation*	2004–2016	All biodiversity
Testudo	1978–2017	All biodiversity
The Condor	1980–2009	All biodiversity
The Open Ornithology Journal	2008–2016	All biodiversity
The Rangeland Journal	1976–2016	All biodiversity
The Southwestern Naturalist	1956–2018	All biodiversity
Trends in Ecology and Evolution*	1986–2019	All biodiversity
Tropical Conservation Science	2008–2018	All biodiversity
Tropical Ecology	1960–2018	All biodiversity
Tropical Grasslands	1967–2010	All biodiversity
Tropical Zoology	1988–2018	All biodiversity
Turkish Journal of Zoology	1996–2014	All biodiversity
Ursus	1968–2019	All biodiversity
Vietnamese Journal of Primatology	2007–2009	All biodiversity
Wader Study Group Bulletin	1970–1977	All biodiversity
Waterbirds	1983–2016	All biodiversity

Weed Biology and Management	2001–2016	All biodiversity
Weed Research	1961–2017	All biodiversity
West African Journal of Applied Ecology	2000–2016	All biodiversity
Western North American Naturalist	2000–2017	All biodiversity
Wetlands	1981–2016	All biodiversity
Wetlands Ecology and Management	1989–2016	All biodiversity
Wildfowl	1948–2018	All biodiversity
Wildlife Biology	1995–2013	All biodiversity
Wildlife Monographs	1958–2013	All biodiversity
Wildlife Research*	1956–2012 1974–2019	Bat Conservation All biodiversity
Wildlife Society Bulletin*	1973–2019	All biodiversity
Wilson Journal of Ornithology	1980–2016	All biodiversity
Zeitschrift für Jagdwissenschaft	1955–2003	All biodiversity
Zhurnal Obshchei Biologii	1972–2013	All biodiversity
Zoo Biology	1982–2019	All biodiversity
ZooKeys	2008–2013	All biodiversity
Zoologica Scripta	1971–2014	All biodiversity
Zoological Journal of the Linnean Society	1856–2013	All biodiversity
Zootaxa	2004–2014	All biodiversity

Appendix 2: Non-English journals (and years) searched

Non-English journals (and years) searched and for which relevant papers have been added to the Conservation Evidence discipline-wide literature database. An asterisk indicates the journals most relevant to this synopsis.

Journal	Years searched	Topic	Language
Mertensiella	1988–2017	All biodiversity	German
Salamandra	1965–2018	All biodiversity	German
Der Zoologische Garten: Zeitschrift für die gesamte Tiergärtnerei (Neue Folge) The Zoological Garden	2007–2017	All biodiversity	German
Insecta	1992–2014	All biodiversity	German
Tuexenia	1981–2016	All biodiversity	German
Libellula	1982–2016	All biodiversity	German
Forstarchiv Forestry Archive	2007–2017	All biodiversity	German
Zeitschrift für Feldherpetologie Journal for Field Herpetology	1994–2017	All biodiversity	German
Arachnologische Mitteilungen Arachnological Letters	1991–2017	All biodiversity	German
Fachzeitschrift für Waldökologie, Landschaftsforschung und Naturschutz Journal for Forest Ecology, Landscape Research and Nature Conservation	2004–2016	All biodiversity	German
Silva Fera: Wissenschaftliche Nachrichten aus dem Wildnisgebiet Dürrenstein Silva Fera: Scientific News from the Dürrenstein Wilderness Area	2012–2017	All biodiversity	German
Inatura Forschung Online Inatura Research Online	1996–2007	All biodiversity	German
ABU-Info (Arbeitsgemeinschaft Biologischer Umweltschutz im Kreis Soest e.V.) ABU-Info (Working Group for Biological Environmental Protection in Soest District	2006–2017	All biodiversity	German
ANLiegen Natur: 'Zeitschrift für Naturschutz, Pflege der Kulturlandschaft und Nachhaltige Entwicklung Concerning Nature: Journal for Nature Conservation and Applied Landscape Ecology	2006–2017	All biodiversity	German

Natur und Landschaft Nature and Landscape	1990–2017	All biodiversity	German
Pulsatilla	2000–2007	All biodiversity	German
Ornithologische Beobachter Ornithological Observer	1950–2017	All biodiversity	German
Die Orchidee The Orchid	1949–2016	All biodiversity	German
Naturschutz und Landschaftsplanung Conservation and Landscape Planning	2003–2017	All biodiversity	German
Hercynia	1963–2017	All biodiversity	German
Allgemeine Forst und Jagdzeitung German Journal of Forest Research	2000–2016	All biodiversity	German
Nyctalus* International Bat Journal	2005–2017	All biodiversity	German
Ornithologischer Anzeiger Ornithological Journal	1951–2017	All biodiversity	German
Archiv für Forstwesen und Landschaftsökologie Archive for Forestry and Landscape Ecology	2013	All biodiversity	German
Botanik und Naturschutz in Hessen Botany and Nature Conservation in Hessen	1987–2018	All biodiversity	German
The Bird Fauna Die Vogelwelt	2005–2017	All biodiversity	German
Biodiversität und Naturschutz in Ostösterreich Biodiversity and Conservation in Eastern Austria	2015–2018	All biodiversity	German
Journal für Ornithologie Journal of Ornithology	1959–2003	All biodiversity	German
Mitteilungen des Badischen Landesvereins für Naturkunde und Naturschutz Communications of the Baden Association for Natural History and Nature Conservation	1953–2015	All biodiversity	German
Freiberg Online Geoscience - FOG	1998–2017	All biodiversity	German
Gesunde Pflanzen: Pflanzenschutz, Verbraucherschutz, Umweltschutz Healthy Plants: Crop Protection, Consumer Protection, Environment Protection	2002–2017	All biodiversity	German
Vogelwarte The Bird Observatory	2005–2017	All biodiversity	German
Die Bodenkultur: Journal of Land Management, Food and Environment	2016–2017	All biodiversity	German

The Soil Culture: Journal for Land Management, Food and Environment			
RANA - Mitteilungen für Feldherpetologie und Ichthyofaunistik RANA - Communications for Field Herpetology and Ichthyofauna	1983–2016	All biodiversity	German
Die Erde The Earth	1952–2004	All biodiversity	German
Auenmagazin Floodplains Journal	2010–2017	All biodiversity	German
Bulletin de la Société des Naturalistes Luxembourgeois Bulletin of the Luxemburgian Naturalist Society	1950–2017	All biodiversity	German and French
Mammalian Science* 哺乳類科学	1961–2016	All biodiversity	Japanese
The Journal of the Japanese Landscape Architectural Society 造園学雑誌	1925–1927	All biodiversity	Japanese
Landscape Ecology and Management 景観生態学	2005–2016	All biodiversity	Japanese
Japanese Journal of Ecology 日本生態学会誌	1954–2017	All biodiversity	Japanese
Doubutsugaku zasshi 動物学雑誌	1888–1983	All biodiversity	Japanese
Bulletin of the Herpetological Society of Japan 爬虫両棲類学会報	1999–2008	All biodiversity	Japanese
Journal of the Japanese Forest Society 日本森林学会誌	2005–2017	All biodiversity	Japanese
Wildlife and Human Society 野生生物と社会	2013–2017	All biodiversity	Japanese
Ecology and Civil Engineering 応用生態工学	1998–2017	All biodiversity	Japanese
Japanese Journal of Conservation Ecology 保全生態学研究	1996–2016	All biodiversity	Japanese
Journal of Mammalogical Society of Japan* 哺乳動物学雑誌	1959–1986	All biodiversity	Japanese
Landscape Research Japan Online ランドスケープ研究(オンライン論文集)	2008–2017	All biodiversity	Japanese

Bulletin of the International Association for Landscape Ecology-Japan 国際景観生態学会日本支部会報	2002–2003	All biodiversity	Japanese
Strix ストリクス	1982–2017	All biodiversity	Japanese
Journal of the Japanese Forestry Society 日本林学会誌	1985–2004	All biodiversity	Japanese
Japanese Journal of Ornithology 日本鳥学会誌	1917–2015	All biodiversity	Japanese
Wildlife Conservation Japan 野生生物保護	1995–2013	All biodiversity	Japanese
Journal of Natural Environment نشریه محیط زیست طبیعی	2010–2017	All biodiversity	Persian
Experimental Animal Biology زیست شناسی جانوری تجربی	2012–2017	All biodiversity	Persian
Journal of Environmental Sciences علوم محیعلوم محیطیطی	2004–2017	All biodiversity	Persian
Journal of Animal Environment فصلنامه محیط زیست جانوری	2014–2017	All biodiversity	Persian
Journal of Environmental Studies محیط شناسی	1975–2017	All biodiversity	Persian
Environmental Researches پژوهش های محیط زیست	2010–2017	All biodiversity	Persian
Iranian Journal of Applied Ecology بوم شناسی کاربردی	2012–2017	All biodiversity	Persian
Iranian Journal of Natural Resources مجله منابع طبیعی ایران	2002–2009	All biodiversity	Persian
Journal of Animal Researches پژوهش های جانوری	2013–2017	All biodiversity	Persian
Iheringia Série Zoologia	2000–2018	All biodiversity	Portuguese
Revista Bioikos	1987–2016	All biodiversity	Portuguese
Brazilian Journal of Ecology Revista Brasileira de Ecologia	1997–2009	All biodiversity	Portuguese
Biota Neotropica	2001–2011	All biodiversity	Portuguese
Floresta	1969–2017	All biodiversity	Portuguese
Boletim da Sociedade Brasileira de Mastozoologi*	1985–2017	All biodiversity	Portuguese
Biodiversidade Brasileira	2011–2016	All biodiversity	Portuguese
Revista Brasileira de Gestão Ambiental e Sustentabilidade	2014–2017	All biodiversity	Portuguese
MG Biota	2008–2016	All biodiversity	Portuguese

Chiroptera Neotropical*	1995–2015	All biodiversity	Portuguese
Evolução e Conservação da Biodiversidade	2010–2011	All biodiversity	Portuguese
Megadiversidade	2005–2009	All biodiversity	Portuguese
Revista CEPSUL - Biodiversidade e Conservação Marinha	2010–2017	All biodiversity	Portuguese
Brazilian Journal for Nature Conservation Natureza & Conservação	2003–2009	All biodiversity	Portuguese
Neotropical Biology and Conservation	2006–2017	All biodiversity	Portuguese
Russian Journal of Ornithology Русский орнитологический журнал	1993–2017	All biodiversity	Russian
Herald of Game Management Вестник охотоведения	2007–2016	All biodiversity	Russian
Bulletin of Moscow Society of Naturalists. Biological series Бюллетень МОИП, серия биологическая	1935–2016	All biodiversity	Russian
Russian Journal of Ecology Экология	1993–2017	All biodiversity	Russian
Povolzhsky Journal of Ecology Поволжский экологический журнал	2002–2016	All biodiversity	Russian
Current Studies in Herpetology Современная герпетология	2000–2016	All biodiversity	Russian
Biology Bulletin Известия РАН, серия биологическая	1957–2017	All biodiversity	Russian
Russian Journal of Zoology Зоологический журнал	1939–2017	All biodiversity	Russian
Steppe Bulletin Степной бюллетень	1998–2016	All biodiversity	Russian
Journal of Ichthyology Вопросы ихтиологии	1961–2017	All biodiversity	Russian
Contemporary Problems of Ecology Сибирский экологический журнал	1994–2017	All biodiversity	Russian
Mammalogy Notes*	2014–2017	All biodiversity	Spanish
Mastozoología Neotropical* Neotropical Mastozoology	1994–2017	All biodiversity	Spanish
Edentata	1994–2018	All biodiversity	Spanish
Ecología Austral Austral Ecology	2001–2018	All biodiversity	Spanish
Revista Catalana de Ornitologia Catalan Journal of Ornithology	2002–2018	All biodiversity	Spanish
Ardeola	1954– 2019	All biodiversity	Spanish

Hidrobiológica Hydrobiology	1991–2018	All biodiversity	Spanish
Gestión Ambiental	1999–2017	All biodiversity	Spanish
Ocelotlán	2003–2012	All biodiversity	Spanish
A Carriza: Sociedad Gallega de Ornitologia	2001–2009	All biodiversity	Spanish
Revista Chilena de Ornitología Chilean Journal of Ornithology	2016–2018	All biodiversity	Spanish
Novitates Caribaea	1999–2019	All biodiversity	Spanish
Madera y Bosques Wood and Forests	1995–2018	All biodiversity	Spanish
Revista Nicaragüense de Biodiversidad Nicaraguan Journal of Biodiversity	2015–2019	All biodiversity	Spanish
Revista Mexicana de Biodiversidad Mexican Journal of Biodiversity	2005–2018	All biodiversity	Spanish
Mediterránea Mediterranean	1982–2015	All biodiversity	Spanish
Semiárida	2013–2018	All biodiversity	Spanish
Boletín de la Real Sociedad Española de Historia Natural Bulletin of the Royal Spanish Society of Natural History	2003–2017	All biodiversity	Spanish
Bosques Latitud Cero Forests Latitude Zero	2014–2018	All biodiversity	Spanish
Anales de Biología	1984–2019	All biodiversity	Spanish
Revista Peruana de Biología Peruvian Journal of Biology	1974–2019	All biodiversity	Spanish
Boletín Científico Centro de Museos Bulletin of the Museum Scientific Center	1996–2019	All biodiversity	Spanish
Revista de Biología Tropical Journal of Tropical Biology	1976–2018	All biodiversity	Spanish
Revista Chilena de Historia Natural Chilean Journal of Natural History	1897–2018	All biodiversity	Spanish
Therya*	2010–2018	All biodiversity	Spanish
Cuadernos de Herpetología Herpetology notes	2010–2018	All biodiversity	Spanish
Boletín de la Sociedad Argentina de Botánica Bulletin of the Argentinean Society of Botany	2013–2018	All biodiversity	Spanish
Butlletí del Grup Català d'Anellament Bulletin of the Catalan Ring Group	1981–2001	All biodiversity	Spanish
Orinoquia	2003–2018	All biodiversity	Spanish

Acta Zoológica Mexicana Mexican Zoological Journal	1984–2019	All biodiversity	Spanish
Biodiversity and Natural History	2015–2017	All biodiversity	Spanish
Galemys*	1997–2017	All biodiversity	Spanish
Boletín Chileno de Ornitología Chilean Ornithology Bulletin	1994–2015	All biodiversity	Spanish
Zoologica Baetica	1990–2015	All biodiversity	Spanish
Centros: Revista Cientifica Universitaria Centros: Scientific Journal of the University	2012–2018	All biodiversity	Spanish
Huitzil: Revista Mexicana de Ornitología Journal of Mexican Ornithology	2000–2018	All biodiversity	Spanish
Bioma (El Salvador)	2012–2016	All biodiversity	Spanish
Quebracho	2008–2018	All biodiversity	Spanish
Etología Ethology	1989–2003	All biodiversity	Spanish
Historia Natural Natural History	2011–2018	All biodiversity	Spanish
Arxius of Miscel·lània Zoològica	2003–2019	All biodiversity	Spanish
Agrociencia Uruguay Agroscience Uruguay	1997–2017	All biodiversity	Spanish
Ecología Aplicada Applied Ecology	2002–2018	All biodiversity	Spanish
Boletín de la Asociación Herpetológica Española Bulletin of the Spanish Herpetological Association	2004–2018	All biodiversity	Spanish
El Hornero: Revista de Ornitología Neotropical	2003–2017	All biodiversity	Spanish
Revista Española de Herpetologia Spanish Journal of Herpethology	2003–2007	All biodiversity	Spanish
Revista Internacional de Contaminación Ambiental International Journal of Pollution	1985–2018	All biodiversity	Spanish
Colombia Forestal	2000–2018	All biodiversity	Spanish
Revista Mexicana de Mastozoología*	1995–2017	All biodiversity	Spanish
Revista Mexicana de Ciencias Forestales Mexican Journal of Forestry Sciences	2010–2018	All biodiversity	Spanish
Boletín de Biodiversidad de Chile Bulletin of Biodiversity of Chile	2009–2014	All biodiversity	Spanish
Studia Oecológica	1981–1995	All biodiversity	Spanish
Grupo Jaragua	1997–2011	All biodiversity	Spanish

Ecosistemas y Recursos Agropecuarios Ecosystems and Agropecuary Resources	1994–2018	All biodiversity	Spanish
BioScriba	2008–2017	All biodiversity	Spanish
Ecosistemas Ecosystems Journal	2001–2018	All biodiversity	Spanish
Cedamaz	2014–2018	All biodiversity	Spanish
Animal Biodiversity and Conservation	2001–2019	All biodiversity	Spanish
Folia Amazónica	1988–2018	All biodiversity	Spanish
Notulas Faunisticas	2008–2018	All biodiversity	Spanish
Caldasia	1940–2019	All biodiversity	Spanish

Appendix 3: Conservation reports (and years) searched

Conservation reports (and years) searched and for which relevant studies have been added to the Conservation Evidence discipline-wide literature database. An asterisk indicates the reports most relevant to this synopsis.

Organisation	Years searched	Details
Amphibian Survival Alliance	1994–2012	Vol 9 – Vol 104
British Trust for Ornithology	1981–2016	Report 1–687
IUCN-SSC Cetacean Specialist Group	1989–2018	Dated reports at https://iucn-csg.org/downloads/
IUCN-SSC Crocodile Specialist Group	2006–2018	CSG Articles
IUCN-SSC Crocodile Specialist Group	2005–2017	CSG Reports
IUCN-SSC Invasive Species Specialist Group	1995–2013	Aliens: The Invasive Species Bulletin (IUCN) Vol 1–33
IUCN-SSC Marine Mammal Protected Area Specialist Group	2017–2018	Dated documents at https://www.marinemammalhabitat.org/downloads/
Joint Nature Conservation Committee*	1991–2018	Reports 1–627
Natural England*	1991–2018	
North Atlantic Marine Mammal Commission	1998–2018	NAMMCO outputs (Scientific publication series Vol1(1998)–10(2018) at https://nammco.no/library/
Scottish Natural Heritage*	2016–2018	Reports 1–945
Sea Mammal Research Unit	2012–2018	Marine Mammal Scientific Support to Scottish Government reports at http://www.smru.st-andrews.ac.uk/research-policy/reports-to-scottish-government/
Sea Mammal Research Unit	1990–2018	SMRU reports for funders at http://www.smru.st-andrews.ac.uk/reports/
Whale and Dolphin Conservation	2001–2018	

Appendix 4: Literature reviewed for the Bat Synopsis

The diagram below shows the total numbers of journals and report series searched for this synopsis, the total number of publications searched (title and abstract) within those, and the number of publications that were summarized from each source of literature.