Effect of roost management on populations trends of *Rhinolophus hipposideros* and *Rhinolophus ferrumequinum* in Britain and Ireland

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SUMMARY

After a significant population decline during the 20th century, populations of both greater and lesser horseshoe bats have increased over recent decades in Britain and populations of lesser horseshoe bats have increased in Ireland. Vincent Wildlife Trust (VWT) acquired 37 bat reserves since the 1980s with the aim to safeguard the sites and enhance the roosting and hibernation conditions in buildings that were often derelict and sub-optimal for bats**.** These measures have resulted in a strong population size increase of all colonies. However, populations have also been increasing throughout Britain and Ireland as a consequence of legal protection and milder winters resulting in higher survival rates. Therefore, it is not clear whether the measures that have taken place in VWT reserves have led to a greater increase than roosts that have not benefited from the same type of management. We aimed to compare population trends of horseshoe bat roosts under VWT management and non-VWT management from 1999 to 2020 in order to assess its effectiveness. For this, we analysed population trends at sites under different management types (VWT and non-VWT) for lesser horseshoe bats in Britain and Ireland and greater horseshoe bats in Britain. Our results indicated that populations in Britain under VWT management have increased by 366% (CI 225% - 580%) for greater horseshoe bats and 188% (CI 125% - 283%) for lesser horseshoe bats. Roosts that did not benefit from the same levels of management increased respectively by 164% (CI 132% - 199%) and 51% (CI 40% - 60%). In Ireland, populations of lesser horseshoe bats in VWT managed roosts increased by 217% (CI 118% - 364%) while non-VWT managed roosts remained stable (-0.44%; CI -23% - 29%). We conclude that management actions carried out by VWT of greater and lesser horseshoe bat roosts have helped populations recover at a faster rate by securing the integrity of buildings, improving access points and by providing optimal microclimatic conditions within the buildings.

BACKGROUND

The lesser horseshoe bat *Rhinolophus hipposideros* and greater horseshoe bat *Rhinolophus ferrumequinum* are the only horseshoe bat species (Rhinolophidae) present in Britain and Ireland (greater horseshoe bat is not present in Ireland). In Britain, the loss of roosting sites, remedial timber treatment, loss of feeding habitat, and persecution, resulted in a dramatic population decline of both species during the century (Stebbings 1988, Hutson & Mickleburgh 2001, Schofield 2008). Little is known of the history of lesser horseshoe bats in Ireland (McAney et al. 2013). However, there is evidence that cold weather spells in the late 1970s resulted in high mortality levels from which it has taken a long time for the population to recover (McAney 1994).

Both species have been afforded special protection at a national (Wildlife and Countryside Act - 1981; in Ireland, Wildlife Acts 1976 & 2000) and European level under the Habitats Directive (European Commission Directive 92/43/EEC), where they are listed as Annex II species. Alongside legal protection, populations benefited from a series of mild winters and warm springs in the latter 20th and early 21st centuries (Ransome & McOwat 1994). This allowed earlier births, high juvenile survival over winter and enabled adult females to emerge from hibernation in better condition to breed the following year. Consequently, populations have been increasing since the 1980s in Britain and 1990s in Ireland (Barlow et al. 2015, Aughney et al. 2018).

The mammal conservation charity, Vincent Wildlife Trust (VWT), started acquiring bat reserves in the 1980s. VWT has been able to enhance the roosting and hibernation conditions in buildings that were often derelict and sub-optimal for bats. The management of reserves involves ensuring that roosts are free from human or predator disturbance; maintaining/ enhancing the structure of the building to ensure that it is weatherproof and providing optimal microclimatic conditions; retaining adequate roost dimensions and optimising access points. These measures have resulted in a strong population size increase at all of VWT's reserves. For example, Rock Farm (Devon) contained around 200 bats at the point of acquisition in 1980, when the entire British population of greater horseshoe bats had dropped to around 3,000 individuals, and is now home to over 2,000 bats making it one of the the largest maternity colonies of greater horseshoe bats in western Europe. Similarly, VWT's largest lesser horseshoe bat roost in Wales increased from approximately 300 bats in 1999 to over 1,300 twenty years later.

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Although all lesser and greater horseshoe bat roosts are protected in Britain and Ireland, there are no obligations for owners to improve conditions for bats within roost buildings. Therefore, the conditions of bat roosts will vary greatly when they are not under VWT (or other conservation) management, and these may be left to deteriorate over time. There is sufficient evidence that both species are increasing within their respective range in Britain and Ireland (Barlow et al. 2015, Aughney et al. 2018). However, it is not clear whether the actions that have taken place in VWT reserves have led to a more significant increase than colonies that have not benefited from the same levels of intervention. In order to facilitate the continued recovery of both species, it is essential to provide evidence of the impact of such actions on horseshoe bat populations. The aim of our study is to compare population trends of horseshoe bat colonies under VWT management and non-VWT management in order to assess the effectiveness of the range of actions implemented by VWT and understand their impact on the population recovery of both species.

ACTION

Summary of actions

Vincent Wildlife Trust carried out interventions at 18 lesser horseshoe bat reserves in Britain, 12 in Ireland and seven greater horseshoe bat reserves in Britain. The nature of the interventions undertaken involved a suite of enhancements that would fit the specific needs of each site. The purpose of interventions undertaken at VWT reserves were divided into four main categories – (1) insuring the security of each building by improving their structural integrity, resistance to weather and reducing disturbance (Figure 1); (2) improving access points for bats (Figure 2); (3) improving the range and stability of microclimates available (Figure 3); and (4) improving the internal structure and materials of buildings. The interventions associated with these purposes vary widely in the scale and costs required and are described in Table 1 with illustrated examples shown in Figures 1, 2 and 3.

The interventions were not monitored at the time of acquisition and, therefore, it is not possible to assess the impact of each intervention retrospectively. However, roost counts have taken place throughout Britain and Ireland since the 1990s at VWT reserves, but also other roosts throughout both countries. These counts offer a unique opportunity to assess the impact of VWT management on reserves compared to other roosts which have not benefited from the same levels of management.

Figure 1. Examples of horseshoe bat roost buildings (Hendre cottage – a, b; Rose cottage front elevation (c) and rear elevation (d) when first discovered (a, c) and the same buildings following repairs and re-roofing (b, d).

Figure 2. Entrance modifications to improve horseshoe bat roosts. Entrances can be made predator-proof by installing a 'tip tray' (a) and anti-climb surfaces (b). Grills can be installed to deter vandalism (b, d). Baffles can be installed to reduce draughts and light into the building (c, d).

Figure 3. 'Hot boxes' of various design, installed into the apex of the roof interior at horseshoe bat roosts.

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Data collection

We used data from the National Bat Monitoring Programme (NBMP) in Britain and the Irish Bat Monitoring Programme from 1999 to 2020 in Ireland and 1999 to 2019 in Britain (data from 2020 was only available for VWT sites in Britain; Bat Conservation Trust 2021). These programmes consist of annual series of summer roost counts which take place on two dates prior to parturition. The counts are undertaken by volunteers in Britain and by staff from National Parks and Wildife Service and VWT in Ireland for the Irish bat populations. The data collected are then used by Government and conservation organisations to monitor populations, inform policy and improve the conservation of bats.

Data analysis

All analyses were carried out in R version 4.0.4 (R Core Team 2021). We used the package *poptrend* (Knape 2016) to perform generalised additive mixed models (Wood 2017) to estimate population trends at horseshoe bat roosts nationally (full dataset), then under different management types (VWT and non-VWT) in Britain and Ireland. Log-linear models were fitted with a quasipoisson distribution to the counts on each survey. The method developed by Knape (2016) allowed us to decompose population change into a long-term population trend (smooth function of time) and short-term fluctuations as temporal random effects. A site term was included as a random effect included using bs = 're'. We present results using six degrees of freedom as suggested by Fewster et al. (2000), which is 0.3 times the number of years. Index value were derived from the fitted curve using 1999 as a base year set at 1.

CONSEQUENCES

The final analyses included 40 greater horseshoe bat roosts (34 non-VWT and six VWT sites), 305 lesser horseshoe bat roosts in Britain (291 non-VWT and 14 VWT sites) and 199 lesser horseshoe bat roosts in Ireland (187 non-VWT and 12 VWT sites). In Britain, the national and non-VWT population trend models of both horseshoe bat species showed a similar increase, although slightly lower increase rate under non-VWT management (Figure 4 a,b,d & e). The populations of VWT reserves, on the other hand, have undergone a higher population size increase. Greater horseshoe bat populations have increased by 366% (CI 225% - 580%; Figure 4c) from 1999 to 2019 which is equivalent to a 8% (CI 6% - 10%) mean annual increase under VWT management, while lesser horseshoe bats have increased by 188% (CI 125% - 283%; Figure 4f) in 20 years with a mean annual increase of 5.4% (CI 3.8% - 6.9%). In Ireland, the national population of lesser horseshoe bats increased by 25% (CI 22% - 83%) which is equivalent to a mean annual increase of 2.0% (CI 0.9% - 3.2%; Figure 4g). We identified a stable population (-0.4%; CI:-23% - 29%; Figure 4h) under non-VWT management, while the population under VWT management increased strongly by 217% (CI 118% - 364%; Figure 4i) from 1999 to 2020 which is equivalent to a mean annual increase of 5.7% (CI 3.8% - 7.6%).

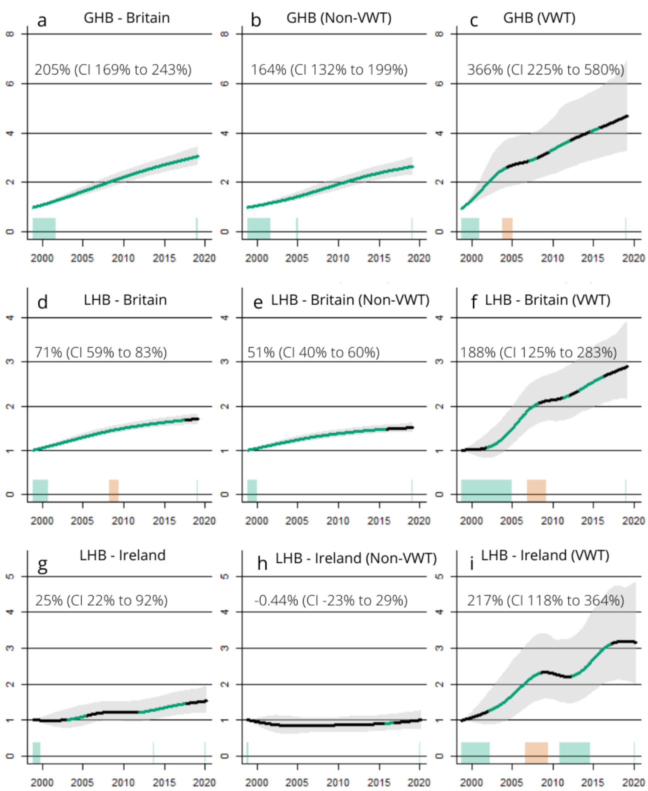

Figure 4. Roost Count index with estimated percentage population change for greater horseshoe bats (GHB) in Britain (a), under non-VWT management (b) and under VWT management (c); lesser horseshoe bats (LHB) in Britain (d) and Ireland (g) and under non-VWT management (e & h) and VWT management (f & i). The solid line in these panels is the estimated long-term component of the trend with 95% confidence intervals (shaded area). The estimates are standardised with respect to the mean of the long-term component of the trends. A green trend line represents a significant increase at the 5% level, while periods where the curvature is significantly positive or negative are marked by green (positive) and orange (negative) rectangles at the bottom of the graphs.

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Table 1. Information on the interventions undertaken at VWT reserves.

Purpose of intervention		**Intervention/Action**	**Scale**
Security of the site	**Improve structural integrity of the building**	Repair foundations	***Major*** – Expenses will be in excess of £10,000 and require 3 months or more to plan and implement. Skilled contractors are required.
		Rebuilding walls	***Major*** – Expenses will be in excess of £10,000 and require 3 months or more to plan and implement. Skilled contractors are required.
		Reroofing (change roof structure/material)	***Major*** – Expenses will be in excess of £10,000 and require 3 months or more to plan and implement. Skilled contractors are required.
	Improve resistance to weather	Repair roof	***Moderate*** – Depends on scale of existing damage. Skilled contractors required.
		Repair walls	***Moderate*** – Depends on scale of existing damage. Skilled copntractors required.
		Repair/block windows and external doors	***Moderate*** – Can typically be achieved with inexpensive materials for less than £3000, but may require scaffolding.
		Install/repair gutters	***Moderate*** – Can typically be achieved with inexpensive materials for less than £3000, but may require scaffolding.
	Reduce disturbance	Install light baffle(s)	***Minor*** – Can be installed with simple tools and materials for less than £500 (Figure 2c & 2d)
		Reduce external lighting	***Minor*** – Lights can be removed or inexpensive cowls installed.
		Predator-proof entrances	***Minor*** – Can be installed with simple tools and materials for less than £500 (Figure 2a & 2b)
Improve access points for bats		Create new entrance	***Moderate*** – Depends on the structure. Windows can be removed cheaply and replaced by grilles for less than £2000
		Enlarge/reduce entrance	***Minor*** – Can be achieved with simple tools and materials for less than £500
		Increase vegetation cover outside entrance	***Minor*** – Suitable shrubs can be planted for less than £100
Improve the range and stability of microclimates available inside the roost		Block gaps	***Minor*** – Can be installed with simple tools and materials for less than £500
		Build hot chamber(s)	***Moderate*** – Requires basic carpentry skills, materials can typically be acquired for less than £1000 (Figure 3)
		Create cool tower	***Moderate*** – Material costs typically less than £1000, requires basic masonry skills.
		Create insulated cool room	***Moderate*** – Insulated timber structures can be constructed for less than £3000 with basic carpentry skills. Often simple structures can be achieved with lower costs by adding insulation to existing areas.
		Create hibernacula	***Major*** – Expenses will be in excess of £10,000 and require 3 months or more to plan and implement. Skilled contractors are required.
		Install water dropping system	***Moderate*** – Typically less than £1000, but can be difficult to perfect and requires regular maintenance.
		Provide access to alcoves/chimney stacks	***Minor*** – Can be achieved with simple tools and materials for less than £500
Internal structure/materials		Replace non-bat friendly roof membrane	***Major*** – Typically requires the roof to be removed and repaired for over £10,000. Requires skilled contractor.
		Repair roof membrane	***Major*** – Typically requires the roof to be removed and repaired for over £10,000. Requires skilled contractor.
		Install perching areas	***Minor*** – Can be installed with simple tools and materials for less than £500

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DISCUSSION

Horseshoe bat populations are increasing throughout Britain and Ireland irrespective of the management type as a result of legal protection and milder winters (Barlow et al. 2015, Aughney et al. 2018). However, our results indicate that interventions, such as those implemented by VWT (see Table 1), towards the protection of maternity roosts helped populations to recover at a faster rate. The range of interventions at each reserve varied between sites but also, more importantly, fitted the needs of each one of these in order to ensure an increase of the population. In Britain, without the acquisition and management of VWT reserves, populations would have likely increased at a slower rate, while the Irish population might have decreased in the early 2000s.

It must also be noted that VWT reserves comprise larger maternity colonies than other sites. This is probably due to the location and population size of reserves at the time of purchase. Such numbers are exceptional throughout western Europe and raise important questions around the vulnerability of the national population to stochastic events at key sites. Horseshoe bats suffer the effects of extreme weather events, with, for example, reduced breeding success following wet springs (Froidevaux et al. 2017). It is likely that the increase of such climatic events over the next decades will have a negative impact on certain roosts, in particular sites that are not managed appropriately, and justifies the need to provide a range of microclimatic conditions within buildings.

Today, both species also face threats beyond the places they roost and some of these, such as artificial lighting, have had a negative effect on colony size of greater horseshoe bats (Froidevaux et al. 2017). Expanding transport infrastructures and increasing light pollution are likely to continue to affect both horseshoe bat species (Stone et al. 2009, Fensome & Mathews 2016) as these species are low flying and photophobic, making them vulnerable to road collision mortality and a reduction in landscape permeability. Changes in agricultural practices may also reduce prey availability. For example, intensification of beef and dairy farming, along with the use of certain anti-parasitic drugs in cattle, has the potential to reduce the availability of insect prey such as dung beetles (Finch et al. 2020).

In conclusion, the management interventions put in place at VWT horseshoe bat reserves have helped populations recover at a faster rate than the national trend. We have listed a suite of interventions to ensure their replicability at other sites (Table 1). Conservation actions for both species must also focus on improving foraging and commuting habitats and, in particular, concentrate on maintaining dark areas.

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REFERENCES

Aughney, T, Roche, N , Langton, S (2018) The Irish Bat Monitoring Programme 2015-2017. *Irish Wildlife Manuals*.

Barlow, K, Briggs, P, Haysom, K, Hutson, A, Lechiara, N, Racey, P, Walsh, A , Langton, S (2015) Citizen science reveals trends in bat populations: the National Bat Monitoring Programme in Great Britain. *Biological Conservation* **182,** 14-26. https://doi.org/10.1016/j.biocon.2014.11.022

Bat Conservation Trust (2021) National Bat Monitoring Programme Annual Report 2020. www.bats.org.uk/our-work/national-bat-monitoringprogramme/reports/nbmp-annual-report.

Fensome, AG , 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. https://doi.org/10.1111/mam.12072

Fewster, RM, Buckland, ST, Siriwardena, GM, Baillie, SR , Wilson, JD (2000) Analysis of population trends for farmland birds using generalized additive models. *Ecology* **81,** 1970-1984. https://doi.org/10.2307/177286

Finch, D, Schofield, H, Floate, KD, Kubasiewicz, LM , Mathews, F (2020) Implications of endectocide residues on the survival of aphodiine dung beetles: A meta-analysis. *Environmental Toxicology and Chemistry* **39,** 863-872. https://doi.org/10.1002/etc.4671

Froidevaux, JS, Boughey, KL, Barlow, KE , Jones, G (2017) Factors driving population recovery of the greater horseshoe bat (*Rhinolophus ferrumequinum*) in the UK: implications for conservation. *Biodiversity and Conservation* **26,** 1601-1621. https://doi.org/10.1007/s10531-017-1320-1

ISSN 1758-2067

Hutson, AM , Mickleburgh, SP (2001) *Microchiropteran bats: global status survey and conservation action plan*, IUCN.

Knape, J (2016) Decomposing trends in Swedish bird populations using generalized additive mixed models. *Journal of Applied Ecology* **53,** 1852-1861. https://doi.org/10.1111/1365-2664.12720

McAney, CM (1994) The lesser horseshoe bat in Ireland – past, present and future. *Folia Zoologica* **43,** 387-392. https://www.jstor.org/stable/25536365

McAney, K, O'Mahony, C, Kelleher, C, Taylor, A , Biggane, S (2013) The Lesser Horseshoe Bat in Ireland: surveys by The Vincent Wildlife Trust. *Irish Naturalists' Journal.* Belfast.

R Core Team (2021) R: A language and environment for statistical computing. *R Foundation for Statistical Computing,.* Vienna, Austria.

Ransome, R , McOwat, T (1994) Birth timing and population changes in greater horseshoe bat colonies (*Rhinolophus ferrumequinum*) are synchronized by climatic temperature. *Zoological journal of the Linnean Society* **112,** 337-351. https://doi.org/10.1111/j.1096-3642.1994.tb00324.x

Schofield, HW (2008) The lesser horseshoe bat: conservation handbook. Vincent Wildlife Trust.

Stebbings, RE (1988) *The conservation of European bats,* London, Christopher Helm Pub Limited.

Stone, EL, Jones, G , Harris, S (2009) Street lighting disturbs commuting bats. *Current Biology* **19,** 1123-1127. https://doi.org/10.1016/j.cub.2009.05.058

Wood, SN (2017) *Generalized additive models: an introduction with R*, CRC press.

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