Definition of Favourable Conservation Status for barbastelle bat

Defining Favourable Conservation Status Project

Matt Zeale and Natural England

March 2024

Acknowledgements

This definition draws heavily on modelling and an unpublished report prepared by Dr Matt Zeale for Natural England completed in 2022.

We wish to thank the following for their help in the production of this definition:

- Kat Walsh, Natural England
- Colin Bonfield, Natural England
- Carol Williams, Bat Conservation Trust
- Dr Orly Razgour, University of Exeter
- Ian Davidson-Watts
- Members of Natural England's Technical Steering Group in particular Andy Brown and Richard Smith.

Executive summary

This document sets out Natural England's view on favourable conservation status for barbastelle in England.

Favourable conservation status is the minimum threshold at which we can be confident that the species is thriving in England and is expected to continue to thrive sustainably in the future.

This definition has been produced following the Natural England approach to defining favourable conservation status described in the guidance document Defining Favourable Conservation Status in England.

Section 1 of this document describes the species covered by this definition and its ecosystem context.

Section 2 specifies the units used to describe the three favourable conservation status parameters. These are:

- Natural range and distribution (where the species occurs).
- Population (how many there are of the species).
- The extent and quality of habitat supporting the species population.

Section 3 outlines the evidence considered when developing the definition. This definition is based on the best available evidence on the ecology of barbastelle. The evidence covers the current situation, historical changes and possible future changes.

Section 4 sets out the conclusions on the favourable values, that is the value for each of the three parameters when the species has achieved favourable conservation status.

This document does not include any action planning, nor describe actions, to achieve or maintain favourable conservation status. These will be presented separately, for example within strategy documents.

Summary definition of favourable conservation status

Barbastelles are closely associated with broadleaved woodland containing large numbers of veteran and dead trees which provide them with roost sites. Barbastelles predominantly roost under loose bark, switch roosts frequently and require large numbers of roost trees. Roosts can be spread over a large area, typically 100-200 ha.

Barbastelles are specialist hunters of moths and generally forage in woodland and over riparian habitats with a diverse structure supporting large numbers of moths. They can travel up to 20 km from roost sites to preferred foraging areas. They generally avoid built-up areas, appear sensitive to disturbance and are light shy.

Barbastelles are widely distributed through southern and central England, but they are uncommon and occur in low numbers. Their range is highly fragmented, reflecting the distribution of their preferred habitat.

There is considerable uncertainty over the size of the population and how numbers may have changed over time: there are few records prior to 1993 but the number of records has increased considerably in recent years due to the introduction and more widespread use of sensitive acoustic survey equipment capable of detecting their low-amplitude echolocation signals. Habitat suitability modelling suggests the current population may be some 21,000-42,000 bats.

There is some evidence of a contraction in range, with no recent records from Yorkshire, despite an increase in recording effort. Given overall changes in the availability of the preferred habitat, it is possible that supporting habitat has declined and populations of barbastelles have declined in response.

To achieve favourable conservation status, barbastelle populations should increase to 73,000-147,000 individuals, occupying the habitat available across the species' current and historic range. This will necessitate an expansion into six additional counties, new broadleaved woodland and the appropriate management of all potentially suitable habitat for barbastelles across the favourable range.

Table 1 Confidence levels for the favourable values

Favourable conservation status parameter	Favourable value	Confidence in the favourable value
Range and distribution	The current range and distribution plus populations in six additional counties (Cheshire, East Riding of Yorkshire, North Yorkshire, South Yorkshire, Staffordshire and West Yorkshire) where barbastelles are predicted to be present.	**Moderate**
Population	An increase from the current estimated population of 21,000–42,000 individuals in England to 73,000-147,000 individuals.	**Low**
Habitat	The favourable supporting habitat in England is 11,700 km^2 of habitat suitable for barbastelles.	**Low**

As of July 2022, based on a comparison of the favourable values with the current values, barbastelles are not in favourable conservation status. Note, this conclusion is based solely on the information within this document and not on a formal assessment of status nor on focussed and/or comprehensive monitoring of status.

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About the Defining Favourable Conservation Status project

Natural England's Defining Favourable Conservation Status (DFCS) project is defining the minimum threshold at which habitats and species in England can be considered to be thriving. Our Favourable Conservation Status (FCS) definitions are based on ecological evidence and the expertise of specialists.

Through setting our ambition and aspiration for species and habitats, our definitions will inform decision making and actions to achieve and sustain thriving wildlife.

Our FCS definitions will be embedded into delivery of the 25 Year Environment Plan, through the Nature Recovery Network, biodiversity net gain and environmental land management schemes (ELMS).

Conservation bodies will use them to inform their work, including management planning for the land they own. Businesses will have a clear understanding of how their work impacts nature recovery and how they can help contribute to achieving thriving nature.

By considering the evidence for FCS, decisions will be more confident and strategic, with an understanding of their contribution to, or impact on, the national ambition.

1. Species definition and ecosystem context

1.1 Species definition

Barbastelle or western barbastelle *Barbastella barbastellus*, Schreber 1774.

1.2 Species status

Red list status

An assessment of the risk of extinction.

Global: Near Threatened (Piraccini 2016)

European: Vulnerable (Temple & Terry 2007).

GB: Vulnerable (Matthews & Harrower 2020).

England: Vulnerable (Matthews & Harrower 2020).

Conservation status

- Species of Principal Importance under Section 41 of the Natural Environment and Rural Communities (NERC) Act 2006.
- Listed as a Species of Community Interest whose conservation requires the designation of Special Areas of Conservation under the Conservation of Habitats and Species Regulations 2017.
- Listed as a Species of Community Interest in need of strict protection under Annex IV of the Habitats Directive.

1.3 Life cycle

Barbastelles become sexually mature and can breed in their first year of life, although most females probably do not mate for the first time until late summer early in the second year of life (Rydell & Bogdanowicz 1997). Mating occurs predominantly during late summer and early autumn at the entrance to underground sites and in tree cavities, and probably continues to a lesser extent through winter inside hibernacula (Parsons and others 2003; Gottfried 2009). Ovulation and fertilisation are delayed until late winter or early spring, so sperm are stored and possibly nourished in the oviduct or uterus over winter while females are hibernating (Altringham 1996). The gestation period in barbastelles can vary considerably due to environmental factors that affect food supply, but on average is expected to last between 50 and 60 days. If mothers are prevented from feeding and enter torpor – a state of reduced physiological activity – because of poor weather the gestation period can be lengthened significantly (Altringham 1996).

From early May onwards, reproductive females congregate in trees and occasionally in buildings, forming maternity colonies, while males tend to roost separately, either alone or in small groups. Maternity roosts typically comprise 20-40 adults and occasionally more than 50 adults. Very rarely, colonies comprising over 100 individuals have been recorded (for example, Davidson-Watts 2008). Females usually give birth to one pup from late June through to mid or late July, and occasionally into early August; rarely, twins are born (Rydell & Bogdanowicz 1997). Young develop rapidly and begin to fly at around three weeks. Before then, mothers may carry pups between roosts. At around six weeks, the young are weaned and begin to forage for insects. After weaning, the summer colonies break up as adult females begin visiting mating and hibernation sites. Bats reach adult size within about nine weeks, although the rate of development from birth can vary according to the microclimate within roosts and the availability of food (Altringham 1996; Rydell & Bogdanowicz 1997). The average life expectancy of a barbastelle is between five-and-a-half and ten years, although ringed individuals living for nearly 22 years have been recorded (Abel 1970). As with other bats, mortality is thought to be considerably higher in juveniles than in adults (Unikauskajte 1990; Urbańczyk 1992).

Barbastelles hibernate during winter, typically from November to March. Periodic arousal from hibernation has been observed, presumably allowing bats to meet physiological needs (Hanzal & Průcha 1988; Rydell & Bogdanowicz 1997; Thomas & Geiser 1997), but otherwise little is known regarding winter activity or ecology of barbastelles. Winter roosts can be inside underground sites such as caves or mines, between timbers in buildings, or in tree cavities. Usually, bats are found roosting either alone or in small numbers although in central and eastern Europe hundreds, or rarely thousands, of bats can accumulate in underground hibernacula (Urbańczyk 1991; Uhrin 1995).

1.4 Supporting habitat

The habitat required to maintain populations of barbastelles in England is a combination of the habitat required for roosting, including maternity roosts, temporary roosts and hibernation sites, and that required for foraging.

Roost requirements

Barbastelles are foremost a tree-roosting species, although summer roosts in buildings and other sites are used in landscapes where roosting opportunities in trees are more limited. Preferred roosts are in narrow crevices behind loose bark or in tree cavities or splits, and so the species is closely associated with old growth woodland where veteran and dead trees are numerous (Steinhauser and others 2002; Greenaway 2001; Russo and others 2004; Hillen and others 2010; Zeale and others 2012). Roosts under loose bark are favoured by barbastelles across Europe and may be selected in part to avoid competition with birds and other mammals that prefer more stable roost structures (Greenaway 2001; Russo and others 2004). It is probably for this reason also that barbastelles are rarely recorded in larger cavities, such as woodpecker holes, which are favoured by other bat species (Boonman 2000; Ruczyński & Bogdanowicz 2008; Dietz & Pir 2009). Roosts have been identified in butt rot cavities as low as 50 cm above ground level and in crevices and cavities more than 20 m above ground (Carr and others 2018).

Roost sites in more open habitats such as parkland and wood pasture are known although maternity colonies are mostly located in woodland with a closed canopy. Even small populations require large numbers of roost trees as barbastelles switch roosts frequently (Russo and others 2005, 2007; Zeale and others 2012). Roosts have been documented in a wide range of tree species, although oak *Quercus* spp. is used most frequently due to its propensity for developing and retaining preferred roost features (Greenaway 2001; Russo and others 2004; Hillen and others 2010; Zeale 2011; Zeale and others 2012; Carr and others 2018). It is important to note, however, that roosts are selected primarily on the characteristics of the roost feature rather than the tree, and so any tree supporting a suitable roost feature may be used (Zeale 2011; Carr and others 2018). Indeed, roosts have been discovered in a wide range of tree size and age classes.

The roost preferences of female bats can vary during the summer according to their reproductive state and changing environmental conditions. In spring and autumn, females are more likely to roost alone or in small numbers and will select roosts that facilitate torpor during periods of poor weather. During the summer, females roost together in greater numbers and select roosts with microclimates that benefit the development of offspring. For example, in some circumstances breeding females have been found to favour roost features with greater exposure to solar radiation, presumably to capitalise on warmer roost micro-climates that can benefit the development of offspring (Russo and others 2004). These preferences have not been observed in populations universally, however, and so selection of roost features in this way is likely to be site-specific. In central Italy, where summers are relatively hot, crevices behind loose bark are used frequently throughout the year and are selected by lactating females as nursery sites for their young (Russo and others 2004). In the UK, the preference for loose bark tends to decrease in mid-summer and cavities are used more frequently (Greenaway 2001; Carr and others 2018), probably because cavities provide more stable microclimates that buffer against colder night temperatures experienced at more northern latitudes (Russo and others 2005; Zeale 2011). During lactation, the rate of roost switching tends to slow and a colony of bats can remain in a single tree roost for up to two weeks, probably to minimise risks associated with moving dependent young to alternative roosts (Russo and others 2005; Carr and others 2016; Carr and others 2018). At other times of the year, barbastelles typically switch roost every 1-3 days (Russo and others 2005; Hillen and others 2010; Zeale and others 2012; Carr and others 2016; Carr and others 2018).

As many as 50 different roosts can be used by a colony in a single summer and roosts can be spread across a large area, typically in the region of 100-200 ha, although up to 500 ha has been documented. Females display fidelity to roost areas across years, returning to the same woodland each year to give birth and rear young (Hillen and others 2010; Zeale and others 2012). Often the same roosts are used in subsequent years, although many become unsuitable or are lost entirely. Loose bark can become dislodged easily and so a high turnover of new roosts is required to support a colony over multiple years (Russo and others 2004; Zeale 2011). Unmanaged woodland with high structural and floral diversity is considered to be optimal roosting habitat, although ancient woodland sites where a policy of minimum intervention is carried out to restore diversity can be of equal high value, provided that dead trees are retained (Russo and others 2004; Zeale 2011; Carr and others 2018). It is thought that barbastelles are not able to persist in woodland where intensive management and non-selective logging is conducted, although where these habitats exist around optimal roost sites, they can provide additional, albeit limited, roosting opportunities and may be used by bats (Russo and others 2010). Generally, barbastelles are thought to select roost sites away from areas of human disturbance (Russo and others 2004; Zeale 2011).

In landscapes where preferred roost sites are scarce, barbastelles will roost in buildings, including in mortise joints of timber-framed barns, behind wood cladding and wooden window shutters, and rarely in historic churches (Rydell & Bogdanowicz 1997; Schober & Grimmberger 1997). When buildings are occupied by a maternity colony, the colony usually remains in the building throughout the summer, although roost switching between different cavities inside the building usually occurs (Steinhauser and others 2002). In non-forest landscapes, the species has been recorded roosting in rock crevices in cliff walls and occasionally under loose scree (Sierro & Arlettaz 1997; Sierro 1999; Ancillotto and others 2014a, 2014b). Rock crevices can also be used in intensively managed woodland that is largely devoid of preferred roost features (Ancillotto and others 2014a). Barbastelles are rarely recorded in bat boxes, although boxes designed specifically for barbastelles that mimic loose bark have proven successful and boxes can even be adopted in preference to existing natural roosts (Greenaway 2008; Rachwald and others 2018).

Foraging requirements

As specialist hunters of moths, barbastelles forage predominantly in habitats where moth biomass is high and will travel up to 20 km from roost sites to reach productive hunting grounds (Hillen and others 2009; Zeale and others 2012; Ancillotto and others 2014a). Field studies have shown that biomass, rather than diversity, ultimately drives foraging site choice, indicating that barbastelles select areas to maximise ingestion of moths regardless of the variety of species available (Ancillotto and others 2014a). This is supported by molecular diet studies which show that common and abundant moth species are consumed most frequently (Zeale 2011; Carr and others 2021). Barbastelles hunt predominantly where dense vegetation borders open ground, such as woodland edge, treelines, hedgerows, woodland rides, and above woodland canopy, and bats make repeated linear flights back and forth along these edge habitats where moth densities are relatively high (Maudsley 2000; Pywell and others 2004; Merckx and others 2009, 2012).

Barbastelles across Europe commonly exhibit a preference for foraging in woodland and riparian habitats that have high structural diversity (Sierro 1999, 2003; Sierro & Arlettaz 1997; Greenaway 2001; Hillen and others 2009; Zeale and others 2012). These habitats are among the most productive with regard to moths (Kennedy & Southwood 1984; Dodd and others 2008; Salsamendi and others 2012). In agricultural landscapes where preferred habitats are scarce or highly fragmented, open meadows and field boundary features such as treelines and hedgerows contribute significantly to the overall foraging habitat (Greenaway 2008; Hillen 2011; Zeale and others 2012; Davidson-Watts 2014). They have also been recorded foraging along exposed coastal cliffs, although primarily where tall vegetation is present (Harris 2020). Similarly, in non-forested areas of central Italy, where vegetation structure is rare, barbastelles target remaining bankside vegetation along streams that comprises only 1.4% of available habitat (Ancillotto 2014a). Rare cases of barbastelles foraging at streetlights have been documented (Zing 1994), although generally they avoid built-up areas and are considered to be one of the most light-averse bats (Zeale and others 2012). Light pollution is considered a limiting factor for this species (Apoznański and others 2021).

During the spring, when barbastelles roost alone or in small numbers, bats can spend much of the time in torpor. Insect flight activity declines dramatically as ambient temperature falls below 6-10 °C and bats can remain inactive for days at temperatures below 7 °C (Taylor 1963; Jones and others 1995; Zeale 2011). When bats do emerge, they typically forage in woodland close to roosts where the ambient temperature is higher than in the surrounding open countryside and is less likely to fall below the threshold for insect flight (Greenaway 2008; Zeale 2011). During the summer, females can increase their home range area considerably (Zeale and others 2012). Range spans (distance from roost to foraging area) of over 20 km have been recorded in England, although most often bats forage within 7 km of roosts (Greenaway 2001, 2008; Hillen and others 2009; Zeale and others 2012; Ancillotto and others 2014a). Recent research also suggests that the home range areas of breeding females increase in size as they transition from pregnancy through lactation to post-lactation (Greenaway 2008; Hillen and others 2009; Zeale and others 2012). During pregnancy, females have significantly higher wing loading, and so home ranges may be smaller. Lactating females have higher energetic demands than pregnant females, and so larger home range areas during this period have been interpreted as bats exploiting more productive hunting grounds at greater distances from roosts (Greenaway 2008; Hillen and others 2009). However, there is also evidence of barbastelles reducing home range areas in lactation, as research has also suggested for other bat species, possibly because they have to make repeated returns to the roost (Davidson-Watts pers.comm. 2022) In late summer, after young are weaned, females begin visiting mating and hibernation sites that may be many kilometres away from roosts and hunting grounds, and so home ranges can increase considerably (Davidson-Watts & Mckenzie 2006; Zeale and others 2012). It has also been suggested that adult females may increase their home range areas later in the summer to avoid competition with flying young (Steinhauser and others 2002), although it remains unclear whether young bats forage independently from mothers or follow them to hunting grounds. Adult male bats appear to roost close to their foraging areas throughout the summer, and so generally do not travel more than 1-2 km from roosts, except in late summer when visiting mating sites (Hillen and others 2009).

When maternity colonies form, and barbastelles become highly clustered in the landscape, females display high fidelity to largely private foraging areas that overlap only minimally with those of other colony members (Hillen and others 2009; Zeale and others 2012). Fidelity to foraging sites even extends across years so that bats returning to maternity roosts following hibernation continue to use the same hunting grounds (Hillen and others 2010; Zeale and others 2012). This apparent spatial organisation of foraging sites around maternity roosts probably benefits females by minimising costs associated with repeated searching for profitable hunting grounds and the defence of resources against other colony members (Chaverri and others 2007; Hillen and others 2009). In landscapes where profitable hunting grounds are limited, the partitioning of resources in this way probably explains why there is such disparity in the size of home ranges among colony members (Zeale and others 2012). In extreme cases, two bats tracked at the same time from the same colony had home ranges that differed 20-fold in size, from 200 ha to more than 4,000 ha (Zeale 2011). Generally, though, most home range areas are between 400 and 1,500 ha, making barbastelles one of the widest-ranging bat species for its size (Hillen and others 2009; Zeale and others 2012).

1.5 Ecosystem context

Primarily a central and southern European species, the species' range extends into the Caucasus, Anatolia and Morocco, to southern Sweden and south-east Norway, north Wales and eastern England (Lincolnshire). A population on the Canary Islands is at present regarded as the endemic subspecies *B. barbastellus guanchae* (Trujillo and others 2002; Juste and others 2003). Although widely distributed, the species' range is highly fragmented, probably reflecting the scarcity of mature forest habitats with which barbastelles are most strongly associated (Mitchell-Jones and others 1999; Russo and others 2004; Zeale 2011; Rebelo and others 2012). Typically, barbastelles occur in low density and numbers and are generally considered to be rare or uncommon throughout their range (Rydell & Bogdanowicz 1997).

In Britain, the range extends mainly over southern and central England and Wales. The distribution of barbastelles in the UK is limited mainly by low summer temperatures and the availability of suitable woodland habitat (Appendix 1). They have a low probability of occurring in exposed upland habitats and built-up areas with relatively high light pollution (Appendix 1). Genomic analysis has confirmed that artificial lighting also negatively affects connectivity between barbastelle colonies across England, while broadleaf woodlands and riparian habitats facilitate gene flow between colonies (Razgour and others 2023). At the time of writing, at least 118 active maternity colonies are known in the UK; the most northerly is located in Lincolnshire (Davidson-Watts 2014). There is currently no evidence of migration or gene flow between English and European mainland populations (Rebelo and others 2012).

2. Units

2.1 Natural range and distribution

Square kilometres (km^2). This metric has been used in Article 17 reporting and for range estimations.

Counties where barbastelles have been recorded.

2.2 Population

Number of adult individuals.

2.3 Habitat for the species

Square kilometres (km^2). This metric has been used in Article 17 reporting and for range estimations.

3. Evidence

3.1 Current situation

Natural range and distribution

Barbastelles are recorded infrequently but regularly by acoustic detectors and maternity colonies are characterised as comprising a small number of adult females that collectively cover a large home range area, with evidence of territoriality among colony members and between neighbouring colonies (Greenaway 2008; Hillen and others 2009; Zeale and others 2012), indicating a widespread but sparse distribution. Records have increased considerably in recent years, largely due to improvements in, and more widespread use, of sensitive acoustic survey equipment capable of detecting the low-amplitude echolocation calls emitted by the species (Goerlitz and others 2010).

Matthews and others (2018) suggested a range of 67,610 km^2 in England and 74,189 km^2 in the UK. This estimate is the area enclosed by an alpha hull – the minimum size shape to enclose a set of points – encompassing presence data collected between 1995 and 2016. This method assumes all areas within the geographic range are suitable for the species (Figure 1).

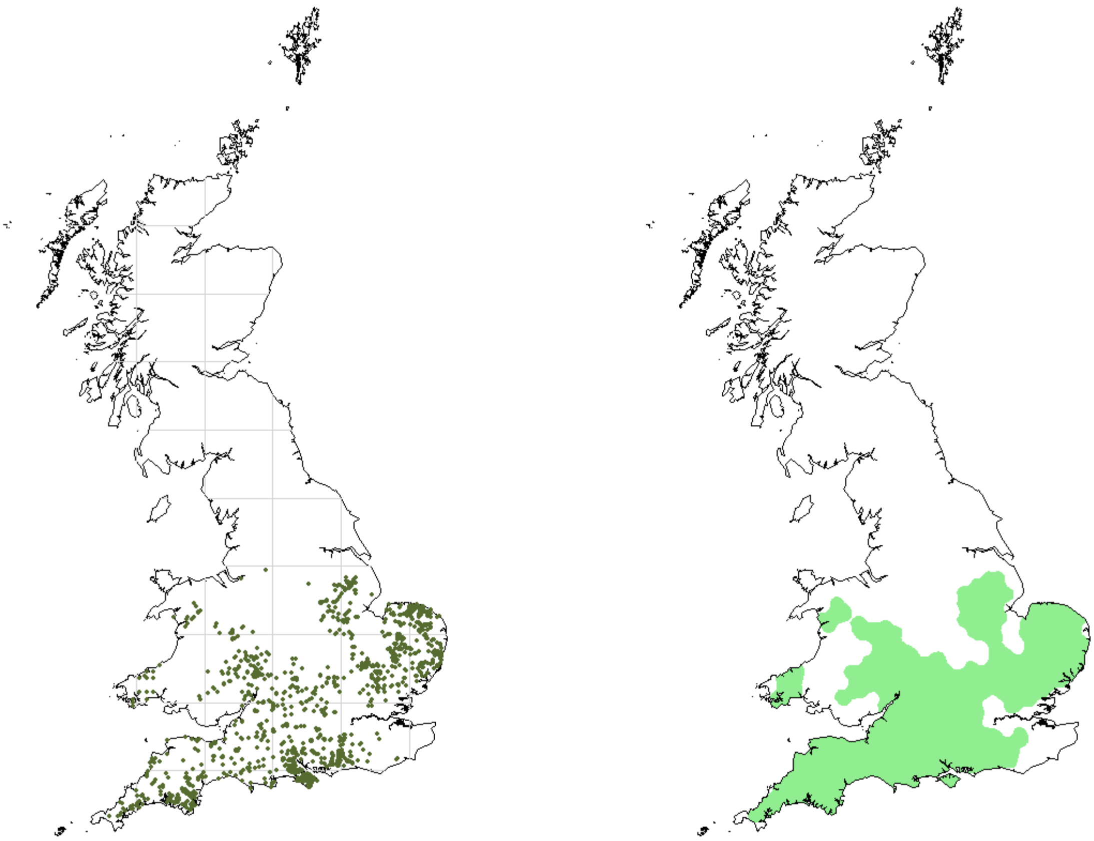

Figure 1 Left: Presence data collected between 1995 and 2016. Right: Smoothed alpha hull of presence records. Areas that contain very isolated records may not have been included

in the area of distribution (from Matthews and others 2018, reproduced under the Open Government Licence).

As described in Appendix 1, Zeale (2022) used a machine-learning method (MaxEnt) to model habitat suitability incorporating presence data collected between 1991 and 2021 and ten environmental variables relevant to barbastelles including summer temperature, landcover, and light pollution. A presence-absence prediction based on a thresholding method was used to estimate a range of 67,909 km^2 in England and 76,196 km^2 in the UK.

While these two estimates are remarkably similar, Zeale's estimate does not assume that all areas within the species' range are suitable and predicts a slightly wider but more fragmented distribution than that suggested by Matthews and others (2018) (Figure 2). Areas predicted to be unsuitable within the species geographic range are primarily areas of very low woodland density, built up areas with relatively high light pollution, and exposed upland habitats. The range is restricted in the north of England primarily by low summer temperatures (Appendix 1).

The species has been recorded in the following counties in England: Bedfordshire; Berkshire; Buckinghamshire; Cambridgeshire; Cornwall; Derbyshire; Devon; Dorset; Essex; Gloucestershire; Hampshire; Herefordshire; Hertfordshire; Isle of Wight; Kent; Leicestershire; Lincolnshire; Norfolk; Northamptonshire; Nottinghamshire; Oxfordshire; Rutland; Shropshire; Somerset; Suffolk; Surrey; Sussex; Warwickshire; Wiltshire; Worcestershire.

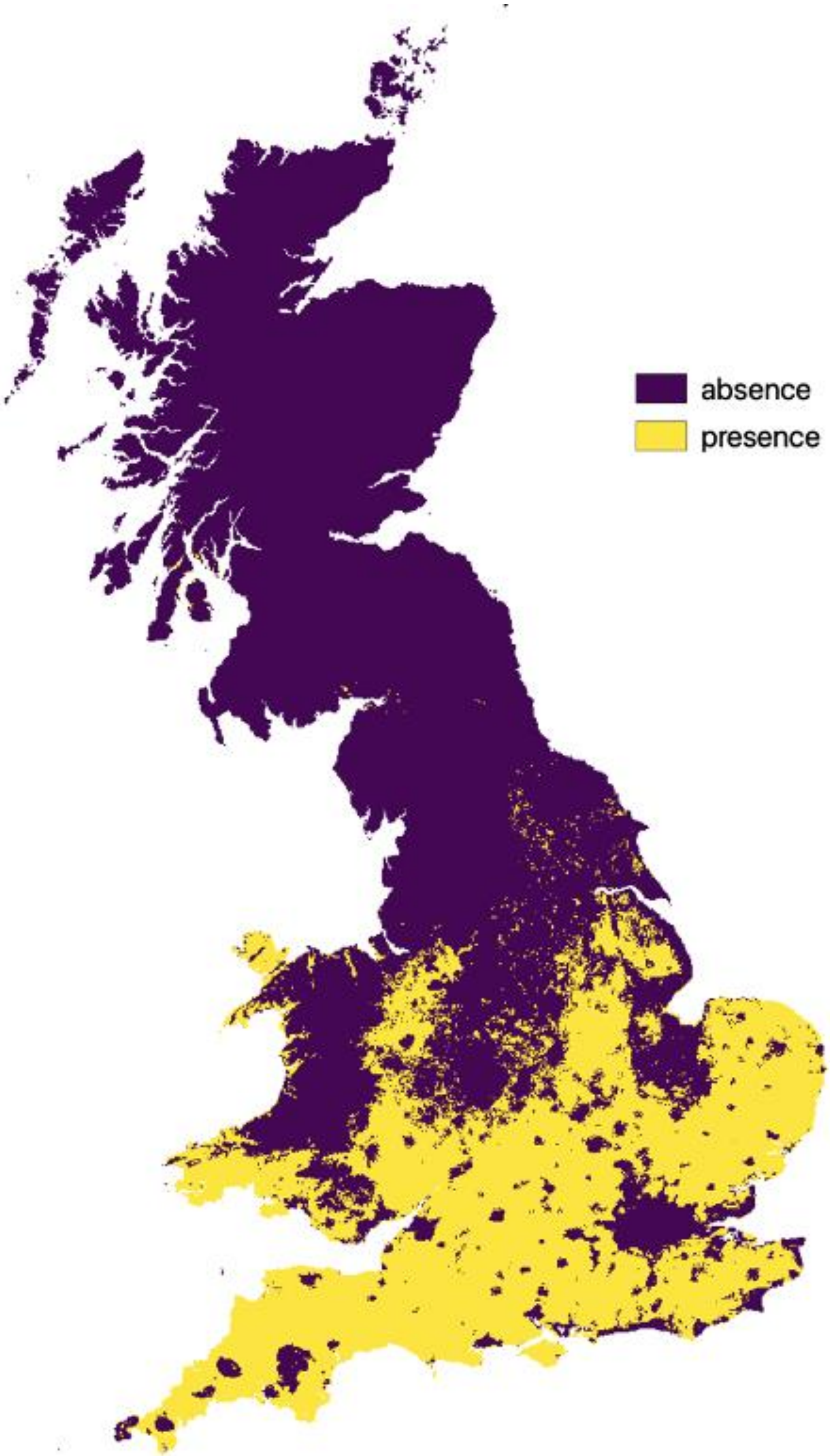

Figure 2 Predicted geographic distribution of barbastelle based on habitat suitability modelling (Appendix 1).

Confidence: Moderate

Population

At the time of writing, 108 maternity colonies are known in England and a further ten maternity colonies are known in Wales. There are undoubtedly many more colonies as yet undiscovered as those that have been identified to date are predominantly clustered in regions where there has been coordinated and targeted survey effort to discover new populations, typically involving radio-tracking methods.

The British population is split between midlands-north and south population clusters. The sampled populations were in Bedfordshire, Warwickshire, Nottinghamshire and Sussex and Devon respectively. The two populations are estimated to have split more than 8,000 years ago, after the post-glacial colonisation of Britain, though there is ongoing gene flow between them (Razgour and others 2023).

As described in Appendix 1, using a machine learning method (MaxEnt) to model (i) the species' geographic distribution in the UK, and (ii) the availability of suitable woodland roosting habitat for maternity colonies (using the 118 known colonies described above to train the model), Zeale (2022) estimated that there may be up to 524 colonies in England and 587 colonies in the UK. Assuming an average of 20-40 adult female bats within a single maternity colony and an adult sex ratio of 1:1, the total adult population of barbastelles was estimated to be in the region of 21,000-42,000 bats in England and 23,500-47,000 bats in the UK. However, it was noted that these figures are highly speculative as they are based on relatively coarse models and broad assumptions regarding occupancy rates, sex ratios and colony size. Indeed, Matthews and others (2018) state that due to a lack of information on the sex ratio of the UK population, the density of maternity roosts and the occupancy of woodlands of different structure or in different regions, as well as the propensity of colonies to fragment frequently such that a single colony may occupy multiple tree roosts at one time, it is particularly challenging to derive a population estimate for this species. They concluded that no estimate of population size could be given. Therefore, as such, these figures provide only an estimate of what the population size may be and they should not be interpreted as the actual size of the population (Appendix 1).

Confidence: Low

Habitat for the species

There are a few estimates of the extent of supporting habitat for barbastelles. However, these are all approximations of the extent of habitat suitable for barbastelles and all the figures should be treated with caution.

The area of supporting habitat for the barbastelle was estimated as 23,800 km^2 for England and 25,590 km^2 for the UK in the 3rd UK Habitats Directive Report (JNCC 2013). However, within the 4th Habitats Directive Report it was determined that there is insufficient information available to make a reliable assessment (JNCC 2019). It is not known whether the amount of habitat in England or the UK is sufficient for the species' long-term survival (JNCC 2019).

Defining habitable area as all broadleaved woodland within the species range, Matthews and others (2018) calculated the total habitable area to be 6,100 km^2. However, the total area of suitable habitat will include other habitats selected by the species when roosting and foraging and so the true habitat area will be larger.

As described in Appendix 1, Zeale (2022) calculated the area of supporting habitat for the species by determining the distribution and extent of habitats known to be preferred by barbastelles for roosting and foraging. Supporting habitat was mapped to a high spatial resolution and included the following habitat types: broadleaved woodland, mixed woodland, woody linear features (hedgerows and treelines), riparian vegetation (bankside vegetation within a 10 m buffer area along rivers, streams and canals), semi-improved grassland (calcareous and neutral grassland) and freshwater wetland habitats (including fen, marsh and swamp). The area of habitat was calculated to be 17,190 km^2 in England and 20,419 km^2 in the UK. Within the species' predicted geographic distribution (determined by species distribution modelling), the area of supporting habitat was estimated to be 10,435 km^2 in England and 12,195 km^2 in the UK. However, it should be noted that this is only an estimate of the habitat available and there may be other environmental or anthropogenic factors that mean the habitat is not suitable for barbastelles.

Confidence: Moderate

3.2 Historical variation in the above parameters

Natural range and distribution

The current estimated range is similar to that indicated by available historical data, with the exception that there are no longer any records from north of the Humber. The considerable increase in records in England and Wales over the last two decades has not increased the range demonstrably beyond that described by Arnold (1993).

The estimated range reported in the most recent Article 17 Report (JNCC 2019) is slightly smaller than that reported in the previous Report (JNCC 2013), however this is due to methodological differences and does not represent a real reduction in range.

Population

There are currently no confident measures of population size, and there are very few records for this species prior to 1993 (Arnold 1993), which has made it difficult to determine whether population size has changed over time.

An earlier estimate of 5,000 individuals across England (4,500) and Wales (500) was suggested by Harris and others (1995), but this was based on subjective estimates of relative abundance as there were few density estimates and a paucity of quantified data on bat numbers in relation to habitat associations and patterns of land use. The estimate was believed on subjective criteria to be within the right order of magnitude, but no greater degree of accuracy was thought to have been achieved (JNCC 2013).

Razgour and others (2023), however, have used a genomic approach to estimate historic population levels and changes in population size. They find that both the northern and southern populations of barbastelle in England have declined by 99% in the past few hundred years. In the north, this loss has occurred in the last 330 years (90% credibility intervals: 72-816 years ago), and in the south in the last 548 years (126-1066 years ago). Despite the severe declines, the populations have low levels of inbreeding and effective population size is likely still high enough to prevent substantial losses of genetic diversity.

Habitat for the species

There is considerable potential for the historical habitable area to have been greater than it is now given habitat changes through loss of woodland, agricultural intensification and built development over the past 500 years. However, detailed information about the habitable area used historically by barbastelles is unavailable, meaning it is not possible to determine whether the habitat area for this species has changed significantly.

Confidence: Low

3.3 The future for the species and its conservation

Barbastelles are not adapting well to anthropogenic changes in the environment. The species continues to exhibit a strong preference for roosting in old-growth broadleaved woodland where veteran and dead trees are numerous, and the availability of preferred roost features is high. Very few maternity roosts in buildings are known. In England, in 2022, only two were known, in Norfolk and Wiltshire. Occasionally, male and individual female bats are reported roosting in buildings (typically uninhabited barns or outbuildings), but this is relatively uncommon. As such, any loss of old-growth woodland is expected to increase pressure on current populations and is a major threat to the species. Given that just 2.5% of the UK is covered by ancient woodland, the availability of suitable woodland roosting habitat is likely to be the primary factor limiting the size and distribution of populations, and so any forestry management practices that continue to remove old, dead or dying trees, or limit the potential for the natural succession of these features, are expected to affect the species status significantly in the future. Although preferred roost features can and do develop on younger trees, such occurrences are relatively infrequent, so new woodlands are unlikely to provide sufficient natural roosting opportunities to support a colony of barbastelles for perhaps 50 years or more. Even in established woodlands where there has been a history of management activities that have resulted in the reduction of roosting opportunities, it may take at least 30 years of favourable management before use of the site by barbastelles increases significantly (Carr and others 2020). There is thus currently no known proven mitigation or compensation for loss of barbastelle woodland roosting habitat over the short to medium term. There are some novel unproven techniques which are discussed further in section 3.4.

Further loss of suitable woodland roosting habitat, which cannot be readily replaced, mitigated or compensated for, will likely result in an increasingly fragmented and sparse distribution and greater risk of genetically isolated populations.In the short to medium term, bat boxes designed specifically for barbastelles will likely be beneficial for supporting existing colonies. Species-specific bat boxes have been used in woodlands where colonies are already established to provide additional roosting opportunities and, in some cases, these may be used in preference to more ephemeral natural roost features, such as defoliating bark (Greenaway 2008; Rachwald and others 2018).

The species appears to be sensitive to disturbance at roosting sites, with some maternity roosts in trees abandoned when approached by people during daylight hours (for example, Russo and others 2004). However, maternity colonies are also known in parklands and woodlands where there is regular human activity, and so sensitivity to disturbance is likely to be site-specific and bats probably habituate, to a certain extent, over time. In any case, increased anthropogenic disturbance at roost sites is likely to have a negative impact on populations, especially during the summer breeding period when females are rearing pups. The increasing human population in England and the continued loss of existing old-growth woodland will likely increase the level of human activity in remaining woodland habitats, placing populations of barbastelles at greater risk of disturbance.

The barbastelle is a light-shy species. Although observations of bats foraging at streetlights have been reported (Rydell and others 1996; Zing 1994), incidences are rare, and this behaviour has not been documented in England despite intensive study of numerous colonies in recent years. In general, the species avoids artificially lit areas and built-up habitats. In addition, genomic studies suggest artificial lighting and associated urban expansion also negatively affect connectivity and movement between colonies (Razgour and others 2023). In England, artificially lit areas are growing each year, both in radiance and extent, and increasingly spreading into the countryside from towns and cities. Today, approximately 80% of England has light-polluted skies at night. The trend towards increasing levels of light pollution in England, especially in rural environments, represents a considerable threat to light-shy bat species, in particular those with highly specialised diets comprised largely of insect taxa that exhibit strong positive phototaxis. As such, light pollution is expected to pose an increasing threat to barbastelle populations in England over the next 50-100 years by fragmenting habitats and reducing the availability of preferred moth prey in dark habitats.

Following emergence, barbastelles typically remain under the woodland canopy until dark. Once dark, however, bats regularly fly across open ground between roosting and foraging sites. Roads, motorways, and other clearings in natural vegetation do not appear to be a major barrier to movement or dispersal in the landscape and so probably do not restrict habitat accessibility to a significant extent (Kerth & Melber 2009). When roads and motorways are lit, however, barrier effects to movement may be substantially stronger.

Being specialist moth-feeders, barbastelles are especially vulnerable to declines in moth populations. Recent substantial declines in moths in England and throughout Europe are therefore cause for considerable concern with respect to future prospects for barbastelle populations (Conrad and others 2006; Fox 2013; Fox and others 2021).

Forest management practices, such as the use of synthetic pesticides to control insect pests, are thought to have contributed to enormous population decreases in barbastelles in eastern Europe in the 1950s to 1970s and ongoing use of pesticides in forestry poses a significant threat to the species. Similarly, agricultural operations that affect the biomass of preferred moth prey, such as the application of insecticides and fertiliser, drainage of wet habitats favoured by moths and other invertebrates, and removal of woodland habitat and field boundary features, such hedgerows and treelines, will have a considerable adverse effect on barbastelle populations in the future.

As is the case for all temperate bat species, climatic conditions are a critical factor in barbastelle survival and productivity and climate change is likely to have a significant impact on populations in the next 50-100 years. Models that take into account future changes in climate predict the climate niche for the barbastelle throughout its current European range will decrease substantially by 2100 (Rebelo and others 2010) with large areas of southern Europe becoming unsuitable. In England, the climate is expected to become more favourable for the species and parts of the north of England that are currently climatically unsuitable are likely to become increasingly more suitable, resulting in a potential range expansion into the north. However, English populations may not be adapted to warm and dry conditions experienced by the species in the Mediterranean and, therefore, there is also the potential for the species to decline within the current range. Under the more extreme scenarios of future climate change bats may struggle to adapt and survive in some parts of the range in the south of England, although this is highly speculative and needs further research. In addition, models predict an increase in bat species richness in the United Kingdom by 2100, as conditions become more favourable to species not currently resident. This could present a potential threat to barbastelle populations in England if it results in an increase in competition for roosting and foraging resources.

Natural range and distribution

The range of the barbastelle in England is limited mainly by low summer temperatures and the availability of suitable woodland roosting habitat (Appendix 1). Climate change could result in an increase in the species range in the north of England, although populations in the south may be negatively affected if they are not able to adapt to predicted warmer and drier conditions.

To increase resilience in the population to changing ecological circumstances, such as climate change, favourable conservation status requires an increase in the current range to include parts of the historic range. Determining the full extent of the species distribution within the current range through coordinated and systematic survey effort, particularly in regions where few or no maternity colonies are known, will also be important to better understand the population structure in Great Britain and to identify isolated populations.

Modelling (see Appendix 1) indicates that barbastelles are predicted to be present in the following counties: Cheshire; South Yorkshire and Staffordshire and, with low probability, in East Riding of Yorkshire, North Yorkshire and West Yorkshire.

For favourable conservation status populations of barbastelle should be present across the species existing range and the six additional counties listed above.

Population

Low population density and slow population growth are likely to have made this species particularly vulnerable to factors such as loss and fragmentation of preferred woodland habitat. Colonies are comprised of few individuals (typically 20-40 adult females) and the relatively few maternity colonies that are known are sparsely distributed across a large geographic area. The lowest population estimate of 21,000 individuals in England and 23,500 individuals in the UK (Appendix 1) indicates that the current population may be larger than the minimum viable population, and genomic analysis indicates that the effective population size is likely high enough to prevent substantial losses of genetic diversity (Razgour and others 2023). However, as there is still considerable uncertainty in the size of the population, it is possible that the actual population could be sufficiently small to be vulnerable to the effects of inbreeding and stochastic events. There are likely many maternity colonies as yet undiscovered, and so locating new colonies should be a priority in order to determine occupancy in different woodland habitats and to enable a more reliable population estimate to be made.

There are large areas within the species' range where it has not been recorded, notably in central Wales and central England, raising concern that some populations may be isolated, although these gaps in the known distribution may be as a result of low survey effort in those areas, rather than an absence of the species.

A genomic study undertaken by Razgour and others (2023) indicated that both the northern and southern populations of barbastelle in England have declined by 99% in the past few hundred years, but despite this the populations have low levels of inbreeding. The causes of this decline are not known. It could have been brought about by natural causes, for example the climate cooling from the late medieval period to the end of the nineteenth century, or as a result of anthropogenic change, for example the move to plantation forestry, or a combination of these factors. Therefore, notwithstanding this information, the favourable population defined here will not directly seek to restore populations to those levels because they may not relate to a favourable population.

Instead, the favourable population is defined in relation to the favourable habitat within the favourable range. Zeale (Appendix 1) found that the potential number of maternity colonies that could be present in England within the species predicted geographic distribution was 1,638 colonies. Assuming an average of 20-40 adult females per colony and a sex ratio of

1:1, the total adult population of barbastelles could be 65,000–131,000 individuals in the current area of supporting habitat. However, favourable conservation status definitions for many habitats that comprise supporting habitat for barbastelles propose significant increases in extent and quality of those habitats. An increase in extent of approximately 12% is proposed for lowland mixed deciduous woodland in favourable conservation status (Natural England 2023), one of the lower increases in extent proposed. Therefore, the proposed favourable population has been increased by approximately 12% to 73,000-147,000 individuals to reflect the lower habitat increase proposed in a favourable situation.

Habitat for the species

The availability of dead and dying trees as roost sites and the lack of preferred foraging habitats, such as wetland, mature woodland and mature hedgerows, are major factors likely to affect the species status. Given the species exacting requirements, the main constraint to increasing current range and population levels is likely to be the availability of new suitable roosting opportunities.

Range expansion to the north for favourable status would have to be facilitated by roost availability and foraging habitat availability and, therefore, the habitat area required for favourable conservation status needs to increase. The proposal here is to increase in line with the increase proposed in the definition of favourable conservation status for lowland mixed deciduous woodland (Natural England 2023). As stated in the previous section, increases in many habitats supporting barbastelles are proposed for favourable conservation status with the increase in extent of lowland mixed deciduous woodland one of the lower figures. Therefore, the figure of approximately 12% represents the minimal area of habitat increase.

Zeale (Appendix 1) calculated the area of supporting habitat within the species predicted geographic distribution as 10,435 km^2 in England. Increasing this figure by 12% (the increase proposed for lowland mixed deciduous woodland) would give a figure of 11,700 km^2 in England (figure rounded). This figure is therefore taken as the minimum area of supporting habitat required for the species for favourable conservation status.

Confidence: Low

3.4 Constraints to expansion or restoration

Genomic research (Razgour and others 2023) has identified limiting factors in the expansion of this species in England as lack of availability of suitable broadleaf woodland and the incursion of artificial lighting that prevents landscape connectivity. Any expansion or restoration of the range in England would need to be facilitated by ensuring availability of suitable woodland roosting habitat and landscape connectivity that is not impacted by artificial lighting.

An increase in the number of maternity roosts would require a reversal in the loss of old-growth woodland and an increase in the availability of veteran and standing dead or decaying trees that develop preferred roost features. In addition, existing and potential roost sites should be protected from disturbance and development.

Restoration and creation of roosting habitat is technically feasible, although it may take decades of favourable management before significant increases in roosting opportunities develop naturally via woodland restoration. However, an increase in broadleaf woodland would greatly aid connectivity and foraging opportunities in the intervening period. The protection and restoration of old-growth woodland will be beneficial to a broad range of species in England.

In the short term novel techniques such as ring barking and ‘veteranisation’ of trees may help to increase roosting opportunities more quickly, however their effectiveness is currently unknown. Additionally in the short to medium term, bat boxes designed specifically for barbastelles will likely be beneficial for supporting existing colonies.

Given the species’ highly specialised diet, an increase in the population will need to be supported by efforts to restore moth populations around existing roost sites and new potential colonisation sites. Focus should be on restoring and increasing wetland and woodland habitats that support high moth biomass. Maintaining and improving hedgerows and treelines will also be beneficial, especially in landscapes where wetland and/or woodland is relatively scarce. These landscape-scale habitat improvements are technically feasible. The maintenance of a mosaic of natural habitats with good connectivity at the landscape scale will also be beneficial to many other species in England.

Within the current range, the distribution of colonies falls into northern and southern population clusters. Ideally priority needs to be given to providing conditions that ensure gene flow is maintained within each of the population clusters to ensure long-term evolutionary potential for the species.

Given the difficulty locating and monitoring colonies of barbastelles there may be many more colonies that are not currently known, or the average size of known colonies may be larger than currently estimated. As such, resources should be focussed towards identifying new colonies and obtaining reliable data on occupancy of different woodland habitats so that the species’ distribution can be more clearly defined, and a reliable estimate of population size made.

Confidence: Moderate

4. Conclusions

4.1 Favourable range and distribution

The favourable range and distribution is the current range and distribution plus populations in six additional counties (Cheshire, East Riding of Yorkshire, North Yorkshire, South Yorkshire, Staffordshire and West Yorkshire) where barbastelle are predicted to be present. Gaps in the species known distribution should be assessed by coordinated and focussed survey effort in suitable woodland roosting habitats to determine presence.

4.2 Favourable population

The current best estimate for the size of the population is between 21,000 and 42,000 individuals in England. As favourable conservation status requires restoration of the historic range, and a thriving situation, the favourable population is defined as 73,000-147,000 individuals within the favourable range and distribution. Further research and survey effort is required to identify new colonies and to improve understanding of the sex ratio and occupancy within different woodland habitats before a more reliable population estimate can be made.

4.3 Favourable supporting habitat

Within the species' favourable range and distribution the area of favourable supporting habitat is estimated to be 11,700 km^2 in England.

References

Abel, G. 1970. Zum Höchstalter der mopsfledermaus (*Barbastella barbastellus*). *Myotis* 8: 38.

Apoznański, G., Kokurewicz, T. S., Petterson, S., Sonia Sánchez-Navarro, S., Górska, M., and Rydell, J. Barbastelles in a production landscape: where do they roost? 2021. *Acta Chiropterologica*, 23(1): 225–232.

Altringham, J. D. 1996. *Bats: Biology and Behaviour*. Oxford: Oxford University Press.

Ancillotto, L., Cistrone, L., Mosconi, F., Jones, G., Boitani, L., and Russo, D. 2014a. The importance of non-forest landscapes for the conservation of forest bats: lessons from barbastelles (*Barbastella barbastellus*). *Biological Conservation* 24: 171-185.

Ancillotto, L., Rydell, J., Nardone, V., and Russo, D. 2014b. Coastal cliffs on islands as foraging habitats for bats. *Acta Chiropteroloigca* 16: 103-108.

Arnold, H. R. 1993. *Atlas of Mammals in Britain,* London, Joint Nature Conservation Committee / Institute of Terrestrial Ecology. HMSO.

Boonman, M. 2000. Roost selection by noctules (*Nyctalus noctula*) and Daubenton's bats (*Myotis daubentonii*). *Journal of Zoology* 251: 385-389.

Carr, A., Zeale, M. R. K., and Jones, G. 2016. The barbastelle in Bovey Valley woods. Report for the Woodland Trust, United Kingdom.

Carr, A., Zeale, M. R. K., Weatherall, A., Froidevaux, J. S. P., and Jones, G. 2018. Ground-based and LiDAR-derived measurements reveal scale-dependent selection of roost characteristics by the rare tree-dwelling bat *Barbastella barbastellus*. *Forest Ecology and Management* 417: 237-246.

Carr, A., Weatherall, A., and Jones, G. 2020. The effects of thinning management on bats and their insect prey in temperate broadleaved woodland. *Forest Ecology and Management* 457: 117682.

Carr, A., Weatherall, A., Fialas, P., Zeale, M. R. K., Clare, E., and Jones, G. 2021. Moths consumed by the barbastelle *Barbastella barbastellus* require larval host plants that occur within the bat's foraging habitats. *Acta Chiropterologica*. 22: 257-269.

Chaverri, G., Gamba-Rios, M., and Kunz, T.H. 2007. Range overlap and association patterns in the tent-making bat *Artibeus watsoni*. *Animal Behaviour* 73: 157-164.

Conrad, K. F., Warren, M., Fox, R., Parsons, M., and Woiwod, I. P. 2006. Rapid declines of common, widespread British moths provide evidence of an insect biodiversity crisis. *Biological Conservation*, 132, 279-291.

Davidson-Watts, I., and McKenzie, A. 2006. Habitat use and ranging of barbastelle bats of the Mottisfont Estate, Hampshire. Report for the National Trust, United Kingdom.

Davidson-Watts, I. 2008. The Isle of Wight woodland bat project. Report for the Peoples Trust for Endangered Species, London, United Kingdom.

Davidson-Watts, I. 2014. Barbastelle bat surveys and tracking at Nocton Wood, Lincolnshire. Report for Beeswax Farms, United Kingdom.

Denzinger, A., and Schnitzler, H-U. 2013. Bat guilds, a concept to classify the highly diverse foraging and echolocation behaviors of microchiropteran bats. *Frontiers in Physiology* 4: 164.

Dietz, C.,and Pir, J. B. 2009. Distribution and habitat selection of *Myotis bechsteinii* in Luxembourg: implications for forest management and conservation. *Folia Zoologica* 58: 327-340.

Dodd, L. E., Lacki, M. J., and Rieske, L. K. 2008. Variation in moth occurrence and implications for foraging habitat of Ozark big-eared bats. *Forest Ecology and Management* 255: 3866-3872.

Fox, R. 2013. The decline of moths in Great Britain: a review of possible causes. *Insect Conservation and Diversity* 6: 5-19.

Fox, R., Dennis, E. B., Harrower, C. A., Blumgart, D., Bell, J. R., Cook, P., Davis, A. M., Evans-Hill, L. J., Haynes, F., Hill, D., Isaac, N. J. B., Parsons, M. S., Pocock, M. J. O., Prescott, T., Randle, Z., Shortall, C. R., Tordoff, G. M., Tuson, D., and Bourn, N. A. D. 2021. *The State of Britain's Larger Moths 2021*. Butterfly Conservation, Rothamsted Research and UK Centre for Ecology & Hydrology, Wareham, Dorset, UK.

Goerlitz, H. R., Ter Hofstede, H. M., Zeale, M. R. K., Jones, G., and Holderied, M. W. 2010. An aerial-hawking bat uses stealth echolocation to counter moth hearing. *Current Biology* 20: 1568–1572.

Gottfried, A. 2009. Use of underground hibernacula by the barbastelle (*Barbastella barbastellus*) outside the hibernation season. *Acta Chiropterologica* 11: 363-373.

Greenaway, F. 2001. The barbastelle in Britain. *British Wildlife* 12: 327-334.

Greenaway, F. 2008. Barbastelle bats In the Sussex West Weald 1997–2008. Report for the Sussex Wildlife Trust/West Weald Landscape Partnership, United Kingdom.

Hanzal, V., and Prucha, M. 1988. Seasonal dynamics of bat communities at winter shelters of Cˇesky kras (Central Bohemia) during 1984–1986. *Lynx (ns)*, 24, 15-35.

Harris, J. 2020. A review of the barbastelle *Babrasbtella barbastellus* in Norfolk based on the work of the Norfolk Barbastelle Study Group. *British Island Bats* 1: 33-49.

Harris, S., Morris, P., Wray, S., and Yalden, D. 1995. *A review of British mammals: population estimates and conservation status of British mammals other than cetaceans.* Peterborough: JNCC.

Hilbers, J. P., Santini, L., Visconti, P., Schipper, A. M., Pinto, C., Rondinini, C., and Huijbregts, M. A. J. 2016. Setting population targets for mammals using body mass as a predictor of population persistence. *Conservation Biology*, 31(2): 385-393.

Hillen, J., Kiefer, A., and Veith, M. 2009. Foraging site fidelity shapes the spatial organisation of a population of female western barbastelle bats. *Biological Conservation* 142: 817-823.

Hillen, J., Kiefer, A., and Veith, M. 2010 Interannual fidelity to roosting habitat and flight paths by female western barbastelle bats. *Acta Chiropterologica* 12: 187-195.

Hillen, J. 2011. *Intra-and interspecific competition in western barbastelle bats (Barbastella barbastellus, Schreber 1774): niche differentiation in a specialised bat species, revealed via radio-tracking* (Doctoral dissertation, Mainz, Univ., Diss., 2011).

Joint Nature Conservation Committee. 2013. *Third Report by the UK under Article 17 on the implementation of the Habitats Directive from January 2007 to December 2012.* Peterborough: JNCC.

Joint Nature Conservation Committee. 2019. *Fourth Report by the UK under Article 17 on the implementation of the Habitats Directive from January 2013 to December 2018.* Peterborough: JNCC.

Jones, G., Duvergé, P. L., and Ransome, R. D. 1995. Conservation biology of an endangered species: field studies of greater horseshoe bats. *Symposia of the Zoological Society of London* 67: 309-324.

Juste, J., Ibáñez, C., Trujillo, D., Muñoz, J., and Ruedi, M. 2003. Phylogeography of barbastelle bats (*Barbastella barbastellus*) in the western Mediterranean and the Canary Islands. *Acta Chiropterologica* 5: 165-175.

Kennedy, C. E. J., and Southwood, T. R. E. 1984. The number of species of insects associated with British trees: a re-analysis. *Journal of Animal Ecology* 53: 455-478.

Kerth, G., and 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.

Mathews, F., and Harrower, C. 2020. *IUCN-compliant Red List assessment for Britain's terrestrial mammals.* Peterborough: Natural England.

Mathews, F., Kubasiewicz, L. M., Gurnell, J., Harrower, C. A., McDonald R. A., and Shore, R. F. 2018. *A Review of the Population and Conservation Status of British Mammals.* A report by the Mammal Society under contract to Natural England, Natural Resources Wales and Scottish Natural Heritage. Peterborough: Natural England.

Maudsley, M. J. 2000. A review of the ecology and conservation of hedgerow invertebrates in Britain. *Journal of Environmental Management* 60: 65-76.

Merckx, T., Feber, R. E., Riordan, P., Townsend, M. C., Bourn, N. A. D., Parsons, M. S., and MacDonald, D. W. 2009. Optimising the biodiversity gain from agri-environment schemes. *Agriculture, Ecosystems and Environment* 130: 177-182.

Merckx, T., Marini, L., Feber, R. E., and MacDonald, D. W. 2012. Hedgerow trees and extended-width field margins enhance macro-moth diversity: implications for management. *Journal of Applied Ecology* 49: 1396-1404.

Mitchell-Jones, A. J., Amori, G., Bogdanowicz, W., Kryštufek, B., Reinjders, P. J. H., Spitzenberger, F., Stubbe, M., Thissen, J. B. M., Vohralík, V., and Zima, J. 1999. *The Atlas of European Mammals*. London: Academic Press.

Natural England. 2023. *Definition of Favourable Conservation Status for lowland mixed deciduous woodland. RP2960*. Natural England.

Parsons, K. N., Jones, G., Davidson-Watts, I., and Greenaway, F. 2003. Swarming of bats at underground sites in Britain — implications for conservation. *Biological Conservation* 111: 63-70.

Piraccini, R. 2016. *Barbastella barbastellus*. The IUCN Red List of Threatened Species 2016: e.T2553A22029285. https://dx.doi.org/10.2305/IUCN.UK.2016-2.RLTS.T2553A22029285.en. (Accessed March 2024)

Pywell, R. F., Warman, E. A., Sparks, T. H., Greatorex-Davies, J. N., Walker, K. J., Meek, W. R., Carvell, C., Petit, S., and Firbank, L. G. 2004. Assessing habitat quality for butterflies on intensively managed arable farmland. *Biological Conservation* 118: 313-325.

Rachwald, A., Gottfried, I., Gottfried, T., and Szurlej, M. 2018. Occupation of crevice-type nest-boxes by the forest dwelling western barbastelle bat *Barbastella barbastellus* (Chiroptera: Vespertilionidae). *Folia Zoologica*, 67(3-4), 231-238.

Razgour, O., Montauban, C., Festa, F., Whitby, D., Juste, J., Ibáñez, C., Rebelo, H., Afonso, S., Bekaert, M., Jones, G., Williams, C., and Boughey, K. 2023. Applying genomic approaches to identify historic population declines in European forest bats. *BioRxiv* https://doi.org/10.1101/2023.05.24.542071 (Accessed March 2024)

Rebelo, H., Tarroso, P., and Jones, G. 2010. Predicted impact of climate change on European bats in relation to their biogeographic patterns. *Global Change Biology* 16: 561-576.

Rebelo, H., Froufe, E., Brito, J. C., Russo, D., Cistrone, L., Ferrand, N., and Jones, G. 2012. Postglacial colonization of Europe by the barbastelle bat: agreement between molecular data and past predictive modelling. *Molecular Ecology* 21: 2761-2774.

Ruczyński, I., and Bogdanowicz, W. 2008. Summer roost selection by tree-dwelling bats *Nyctalus noctula* and *N. leisleri*: a multiscale analysis. *Journal of Mammalogy* 89: 942-951.

Russo, D., Cistrone, L., Jones, G., and Mazzoleni, S. 2004. Roost selection by barbastelle bats (*Barbastella barbastellus*, Chiroptera : Vespertilionidae) in beech woodlands of central Italy: consequences for conservation. *Biological Conservation* 117: 73-81.

Russo, D., Cistrone, L., and Jones, G. 2005. Spatial and temporal patterns of roost use by tree-dwelling barbastelle bats *Barbastella barbastellus*. *Ecography* 28: 769-776.

Russo, D., Cistrone, L., and Jones, G. 2007. Emergence time in forest bats: the influence of canopy closure. *Acta Oecologica* 31: 119-126.

Russo, D., Cistrone, L., Garonna, A. P., and Jones, G. 2010. Reconsidering the importance of harvested forests for the conservation of tree-dwelling bats. *Biodiversity Conservation* 19: 2501-2515.

Rydell, J., Natuschke, G., Theiler, A., and Zingg, P. E. 1996. Food habits of the barbastelle bat *Barbastella barbastellus*. *Ecography* 19: 62-66.

Rydell, J., and Bogdanowicz, W. 1997. *Barbastella barbastellus*. *Mammalian Species* 557: 1-8.

Salsamendi, E., Arostegui, I., Aihartza, J., Almenar, D., Goiti, U., and Garin, I. 2012. Foraging ecology in Mehely's horseshoe bats: influence of habitat structure and water availability. *Acta Chiropterologica* 14: 121-132.

Schober, W., and Grimmberger, E. 1997. *The Bats of Europe and North America*. Neptune City: TFH Publications.

Sierro, A., and Arlettaz, R. 1997. Barbastelle bats (*Barbastella* spp.) specialize in the predation of moths: implications for foraging tactics and conservation. *Acta Oecologica* 18: 91-106.

Sierro, A. 1999. Habitat selection by barbastelle bats (*Barbastella barbastellus*) in the Swiss Alps (Valais). *Journal of Zoology* 248: 429-432.

Sierro, A. 2003. Habitat use, diet and food availability in a population of *Barbastella barbastellus* in a Swiss alpine valley. *Nyctaus* 8: 670-673.

Steinhauser, D., Burger, F., Hoffmeister, U., Matez, G., Teige, T., Steinhauser, P., and Wolz, I. 2002. Untersuchungen zur ökologie der mopsfledermaus, *Barbastella barbastellus* (Schreber, 1774), und der Bechsteinfledermaus, *Myotis bechsteinii* (Kuhl, 1817), im süden des landes Brandenburg. *Schriftenreihe für Landschaftspflege und Naturschutz* 71: 81–98.

Taylor, L. R. 1963. Analysis of the effects of temperature on insects in flight. *Journal of Animal Ecology* 32: 99-117.

Temple, H. J., and Terry, A. (Compilers). 2007. *The Status and Distribution of European Mammals*. Luxembourg: Office for Official Publications of the European Communities.

Thomas, D. W., and Geiser, F. 1997. Periodic arousals in hibernating mammals: is evaporative water loss involved? *Functional Ecology*, 11(5), 585-591.

Trujillo, D., Ibáñez, C., and Juste, J. 2002. A new subspecies of *Barbastella barbastellus* (Mammalia: Chiroptera: Vespertilionidae) from the Canary Islands. *Revue Suisse de Zoologie* 109: 543-550.

Uhrin, M. 1995. The finding of a mass winter colony of *Barbastella barbastellus* and *Pipistrellus pipistrellus* (Chiroptera, Vespertilionidae) in Slovakia. *Myotis*, 32(33), 131-133.

Unikauskajte, A. P. 1990. Vozrastnoj sostav rukokrylykh, zimovavshikh v fortovykh sooruzheniyakh g. Kaunasa v 1978–1985 g.g. Pp. 76–78, in Rukokrylyr. Materialy pyatogo Vsesoyuznogo soveshchaniya po rukokrylym (Chiroptera) (V. Yu. Il’in, P. P. Strelkov, and V. A. Rodionov, eds.). Vsesoyuznoe Teriologicheskoe Obshchestvo (Leningradskoe Otdelenie), Penza, Russia, 174 pp.

Urbańczyk, Z. 1991. Hibernation of *Myotis daubentonii* and *Barbastella barbastellus* in Nietoperek bat reserve. *Myotis*, 29, 115-120.

Urbańczyk, Z. 1992. Biologia I ekologia zimowania mopka *Barbastella barbastellus* (Schreber, 1774) (Mammalia: Chiroptera). PhD thesis, Adam Mickiewicz University, Poznań, Poland.

Zeale, M. R. K. 2011. Conservation biology of the barbastelle (*Barbastella barbastellus*): applications of spatial modelling, ecology and molecular analysis of diet. PhD thesis, University of Bristol, United Kingdom.

Zeale, M. R. K., Butlin, R. K., Barker, G. L. A., Lees, D. C., and Jones, G. 2011. Taxon-specific PCR for DNA barcoding arthropod prey in bat faeces. *Molecular Ecology Resources* 11: 236-244.

Zeale, M. R. K. 2012. Endangered species research: an assessment of barbastelle bats (*Barbastella barbastellus*) in Norway. Report for Fylkesmannen i Vestfold, Norway.

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

Zeale, M. R. K. 2022. Modelling the geographic distribution and favourable supporting habitat for the barbastelle (*Barbastella barbastellus*) in Great Britain. Unpublished report for Natural England, York, UK. Attached at Appendix 1.

Zingg, P. E. 1994. Neue Vorkommen der mopsfledermaus (*Barbastella barbastellus* Schreber, 1774) im Berner Oberland. *Mitt Naturwiss Gesell Thun*. 121-132.

Appendix 1: Modelling the geographic distribution and favourable supporting habitat for the barbastelle (*Barbastella barbastellus*) in Great Britain

Report to Natural England

Author: Dr Matt Zeale

Introduction

The below modelling exercise was undertaken to (i) predict the geographic distribution of the barbastelle, *Barbastella barbastellus*, in Great Britain, (ii) estimate the area of favourable supporting habitat for the species in England and Wales, and (iii) predict the area of suitable woodland roosting habitat for *B. barbastellus* maternity colonies within the species' predicted geographic distribution to inform estimates of population size.

Methods

Modelling procedure

Two ecological niche models were developed to examine (i) the broad scale distribution of *B. barbastellus* in Great Britain (resolution 1 km^2), and (ii) the fine scale availability of suitable woodland roosting habitat for maternity colonies (resolution 50 m^2). Models were built using a presence-only (MaxEnt) approach (Phillips and others 2006), as determining absence of bats is extremely difficult and records of confirmed absences for *B. barbastellus* could not be sourced.

Broad spatial scale model

To model the species distribution in Great Britain, presence records for *B. barbastellus* were obtained from the National Biodiversity Network and the Global Biodiversity Information Facility and combined with records of confirmed maternity colonies obtained from ecologists, researchers and local bat groups. Only records from the past 30 years (1991-2021) were included to reflect current climatic conditions. To avoid pseudoreplication and to address sampling bias in the dataset, duplicate occurrence points were removed and a kernel density analysis performed on the remaining records to develop a bias file to inform sampling of background locations within Maxent. Models were built using ecogeographical variables deemed to be ecologically relevant based on prior knowledge of the biology and ecology of *B. barbastellus*. All variables had a spatial resolution of 1 km^2. The following variables were included: spring, summer and winter temperature; temperature and precipitation seasonality; annual and summer precipitation; elevation (WorldClim); land cover (Land Cover Map 2020, Centre of Ecology and Hydrology, reclassified into ten classes); geology (British Geological Survey, reclassified into 18 classes); human population density (UK gridded population 2011); and night light pollution (National Oceanic and Atmospheric Administration).

Fine spatial scale model

To model the availability of suitable woodland roosting habitat for *B. barbastellus* maternity colonies, records of colonies (n = 118) were obtained from ecologists, researchers and bat groups across England and Wales. In most cases, colonies had been confirmed by radio-tracking of individual bats to tree roosts and subsequent dusk emergence surveys to confirm presence of multiple bats roosting together. In a few cases, evidence from trapping and acoustic surveys strongly indicated the presence of a colony (such as trapping of multiple breeding females and/or juvenile bats soon after sunset), albeit the presence of a colony had not been confirmed by radio-tracking. Models were built using ecogeographical variables that characterised woodland habitats and the availability of surrounding supporting habitat. All variables had a spatial resolution of 50 m in order to maintain reasonable definition of woodland boundaries. A description of the variables used in the model are provided in Table 1.

Table 1 Description of ecogeographical variables used in the fine-scale model (50 m resolution) to examine the availability of suitable woodland roosting habitat for *B. barbastellus* maternity colonies in Great Britain

Variable	Description
Woodland type	National Forestry Inventory dataset (Forestry Commission), reclassified into three classes: broadleaved woodland, mixed mainly broadleaved woodland, and conifer. Woodland classes that are likely to provide little or no roosting opportunities for *B. barbastellus* (such as young trees, coppice, scrub, and felled areas) were removed. The reclassified dataset was combined with the Ancient Woodland Inventory dataset (Natural England) and reclassified into five classes: ancient broadleaved woodland, broadleaved woodland, ancient mixed mainly broadleaved woodland, mixed mainly broadleaved woodland, and conifer. As none of the maternity colonies discovered to date are located within conifer woodland, all conifer types, including conifer plantation on ancient woodland sites (PAWS), were lumped together into a single 'conifer' habitat category to remove unnecessary complexity within the model, which can reduce predictive performance.
Density of roosting habitat	Using the 'woodland type' layer above, conifer woodland was removed from the dataset and the remaining four broadleaved woodland classes reclassified into a single broadleaved woodland class. Based on current evidence, conifer woodland provides negligible roosting opportunities for *B. barbastellus* while each of the broadleaved woodland categories all have potential for supporting barbastelle maternity colonies. The area of broadleaved woodland within 1 km radius of each 50 m grid cell was calculated. As the maximum distance between tree roosts used by a single colony typically does not exceed 1-2 km, an area of 1 km radius was considered appropriate for calculations of woodland density associated with roosting sites.

Variable	Description
Density of foraging habitat	Information from four separate datasets were combined, including Land Cover Map 2020 (Centre for Ecology and Hydrology (CEH)), National Forest Inventory (Forestry Commission), Woody Linear Features (CEH) and OS MasterMap Water Network (Ordnance Survey). The following habitats were extracted from these datasets and combined into a single 'foraging habitat' layer: broadleaved woodland; mixed woodland; woody linear features (hedgerows and treelines); riparian bankside vegetation within a 10 m buffer area along rivers, streams and canals; semi-improved grassland (calcareous and neutral grassland); and freshwater wetland habitats (including fen, marsh and swamp). These habitats are known to be significantly selected by *B. barbastellus* when foraging. These layers were initially mapped at a scale of 5 m resolution in order to preserve definition in linear landscape features (hedgerow, treelines, rivers and canals) and to enable accurate area calculations to be made. The area of foraging habitat within a 6 km radius around each 50 m model grid cell was calculated to provide a measure of density of foraging habitat within core sustenance zones (CSZ), recognised to be 6 km radius around roosts for *B. barbastellus*.
Light pollution	Information on night light pollution was obtained from the National Oceanic and Atmospheric Administration (NOAA) Version 4 DMSP-OLS Nighttime Lights Time Series dataset, rescaled to 50 m resolution.
Human population density	Data on human population density was obtained from the Environmental Data Information Centre UK Gridded Population 2011 dataset (based on Census 2011 records and Land Cover Map 2015), rescaled to 50 m resolution.

Model evaluation

Modelling procedures followed recommendations in Merow and others (2013) and Feng and others (2019), comparing several models with different variables and parameter combinations (regularisation values and number of features included) using the *ENMeval* package in R Studio (ver. 2021.09.0). Selection of the best performing model was based on Akaike information criterion (AIC) scores. For both the broad-scale and fine-scale model, the final full model included all features and a regularisation value of 1, 10 000 background points, and 1,000 iterations. Model performance was tested with ten-fold cross-validation and evaluated based on the Area Under the Curve (AUC) of the Receiver Operating Characteristics (ROC) curve, which measures the model probability of correctly distinguishing presence from random locations. Models with AUC scores higher than 0.8 are considered to have good to high model discrimination ability. Prior to model building, continuous ecogeographical variables were tested for multicollinearity using the *raster* package in R Studio and highly correlated ($R^2 > 0.8$) variables were removed, retaining the more ecologically relevant of the two correlated variables or the variables that contributed most to the model (Merow and others 2013; Razgour and others 2013; Feng and others 2019). For the broad-scale model, the model output was converted into a binary map of predicted presence-absence to illustrate the geographic distribution of *B. barbastellus* using the thresholding method that maximises the sum of sensitivity plus specificity (MSS) (Razgour and others 2013). For the fine fine-scale model, two thresholds were used. Woodland habitat with suitability scores above the MSS threshold were defined as suitable for maternity colonies, while locations with suitability scores between the zero-omission and MMS thresholds were defined as marginally suitable. Woodland with a suitability score below the zero-omission threshold was considered unsuitable for *B. barbastellus* maternity colonies.

Supporting habitat

The area of favourable supporting habitat for *B. barbastellus* in England and Wales was calculated using information from four separate datasets: Land Cover Map 2020 (Centre for Ecology and Hydrology (CEH)); National Forest Inventory (Forestry Commission); Woody Linear Features (CEH); and OS MasterMap Water Network (Ordnance Survey). The following habitats were extracted from these datasets and combined into a single layer: broadleaved woodland; mixed woodland; woody linear features (hedgerows and treelines); riparian vegetation (bankside vegetation within a 10 m buffer area along rivers, streams and canals); semi-improved grassland (calcareous and neutral grassland); and freshwater wetland habitats (including fen, marsh and swamp). These habitats are known to be significantly selected by *B. barbastellus* when roosting and foraging (Sierro 1999, 2003; Sierro and Arlettaz 1997; Greenaway 2001; Hillen and others 2009; Zeale and others 2012) and were mapped at a scale of 5 m resolution in order to define linear landscape features accurately (hedgerow, treelines, rivers and canals) and to enable accurate area calculations of habitat to be made. The total area of supporting habitat was calculated throughout England and Wales, and also within the species' predicted geographic distribution (broad-scale model) within England and Wales.

Population estimates

The potential number of maternity colonies in England and Wales was estimated by determining the number of 5 km grid cells within the species predicted geographic distribution (broad-scale model; MSS threshold) that contain sufficient suitable woodland roosting habitat to support a colony (fine-scale model; MSS threshold), and assuming that only one colony may occupy one 5 km cell (reflecting the species' CSZ and evidence that colony home ranges do not overlap). This represents the potential maximum number of colonies that may be present. A more conservative estimate was made by calculating the ratio of known colonies to potential colonies (suitable 5 km grid cells) in areas where considerable focussed survey work has been undertaken and subsequently adjusting the potential maximum number of colonies in England and Wales by this ratio. The assumption is made that all colonies in these focussed areas have been discovered.

Results

Broad-scale habitat suitability model

The model had a good fit (mean AUCtest = 0.838). The model output and the predicted species geographic distribution are presented in Figure 1. Ten ecogeographical variables were included in the final model, however three variables (summer temperature, landcover, and light pollution) contributed a combined 88% of the model performance. The most informative variable on its own was summer temperature, whereas the variable containing the most unique information was landcover (Figure 2). Based on the model predictions, *B. barbastellus* has a high probability of occurring in woodland areas at lower elevations with relatively higher summer temperatures, lower light pollution, higher winter temperatures, lower summer rainfall, and lower seasonal variation in rainfall. The species has a low probability of occurring in exposed upland habitats and built-up areas. The total area predicted to be suitable for *B. barbastellus* in Great Britain, and where the species is therefore predicted to be present, is 76,196 km^2. The total area predicted to be suitable in England is 67,909 km^2, and in Wales is 8,287 km^2. Individual counties in England and Wales where the species is expected to be present according to the model predictions are shown in Table 2 and Table 3, respectively.

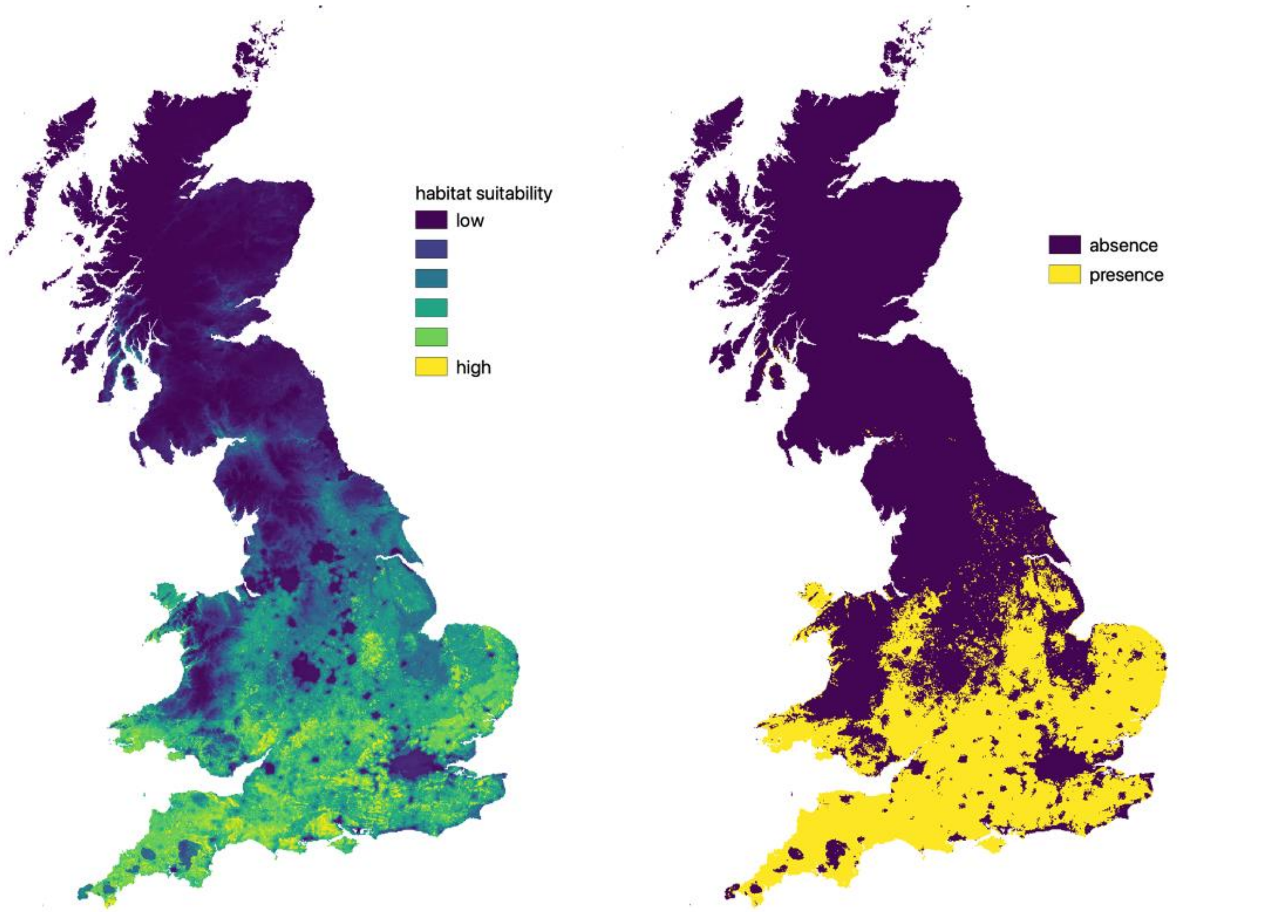

Figure 1 Predictions from the broad-scale model showing the model output of continuous environmental suitability for *B. barbastellus* in Great Britain (left) and the binary species presence-absence prediction (right) based on the thresholding method that maximises the sum of sensitivity plus specificity (MSS)

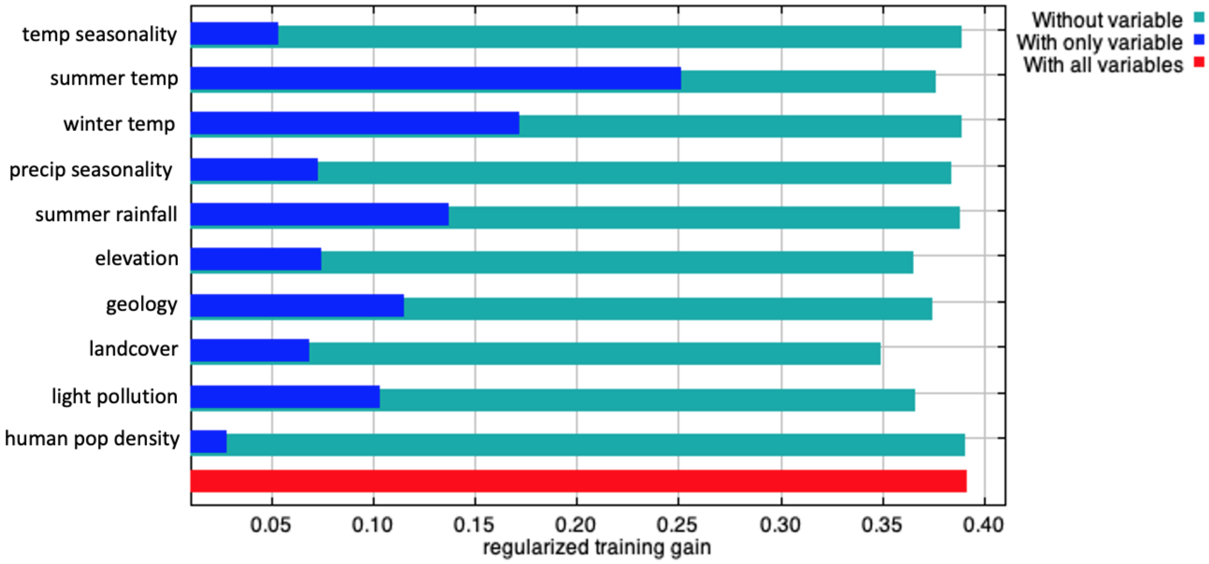

Figure 2 Jackknife of regularised training gain for *B. barbastellus* in Great Britain, listing variables included in the model and their relative contribution to the model in terms of increasing model gain when used in isolation (dark blue bars) and on decreasing model gain when omitted from the model (extent of reduction in light blue bars relative to red bar).

Table 2 Counties in England and where *B. barbastellus* (i) has already been recorded ('Confirmed present'), (ii) is predicted to be present by species distribution models but has not yet been recorded ('Predicted present'), and (iii) is predicted to be present but where models predict very few and/or sparse areas of suitability ('Predicted marginal'). Marginal counties are at the northern edge of the species range

Confirmed present		
Bath and north-east Somerset	Hampshire	Rutland
Bedford	Herefordshire	Shropshire
Bournemouth, Christchurch and Poole	Hertfordshire	Somerset
	Isle of Wight	South Gloucestershire
Bracknell Forest	Kent	Southampton
Bristol, City of	Leicestershire	Suffolk
Buckinghamshire	Lincolnshire	Surrey
Cambridgeshire	Milton Keynes	Swindon
Central Bedfordshire	Norfolk	Torbay
Cornwall	North Somerset	Warwickshire
Derbyshire	Northamptonshire	West Berkshire
Devon	Nottinghamshire	West Sussex
Dorset	Oxfordshire	Wiltshire
East Sussex	Peterborough	Windsor and Maidenhead
Essex	Plymouth	Wokingham
Gloucestershire	Redbridge	Worcestershire
Predicted present		
Barnsley	North East Lincolnshire	Southend-on-Sea
Bromley	North Lincolnshire	Staffordshire
Cheshire East	Rutland	Telford and Wrekin
Cheshire West and Chester	Solihull	Thurrock
Medway		
Predicted marginal		
Doncaster	Leeds	Sheffield
East Riding of Yorkshire	North Yorkshire	Wakefield
Kirklees	Rotherham	Wirral

Table 3 Counties in Wales and where *B. barbastellus* (i) has already been recorded ('Confirmed present'), (ii) is predicted to be present by species distribution models but has not yest been recorded ('Predicted present'), and (iii) is predicted to be present but where models predict very few and/or sparse areas of suitability ('Predicted marginal'). Marginal counties are at the northern edge of the species range

Confirmed present		
Carmarthenshire	Neath Port Talbot	Rhondda Cynon Taf
Ceredigion	Pembrokeshire	Swansea
Gwenydd	Powys	Vale of Glamorgan
Monmouthshire		
Predicted present		
Blaenau Gwent	Cardiff	Torfaen
Bridgend	Merthyr Tydfil	Wrexham
Caerphilly	Newport	
Predicted marginal		
Conwy	Flintshire	Isle of Anglesey
Denbighshire		

Fine-scale habitat suitability model

The model had a good fit (mean AUC_{test} = 0.877). An example of the predictions made by the model are presented in Figure 3. The variable that contributed most to the model was woodland type (40%), followed by density of broadleaved woodland (36%), light pollution (18%), and availability of foraging habitat within 6 km core sustenance zones (6%). The contribution of human population density to the model was negligible (<1%). The most informative variable on its own was woodland type, whereas the variable containing the most unique information was density of broadleaved woodland (Figure 4). Based on the model predictions, *B. barbastellus* maternity colonies have a high probability of occurring in ancient broadleaved woodland within landscapes that are relatively dense with broadleaved woodland, have high availability of foraging habitat, and where light pollution and human population density are low.

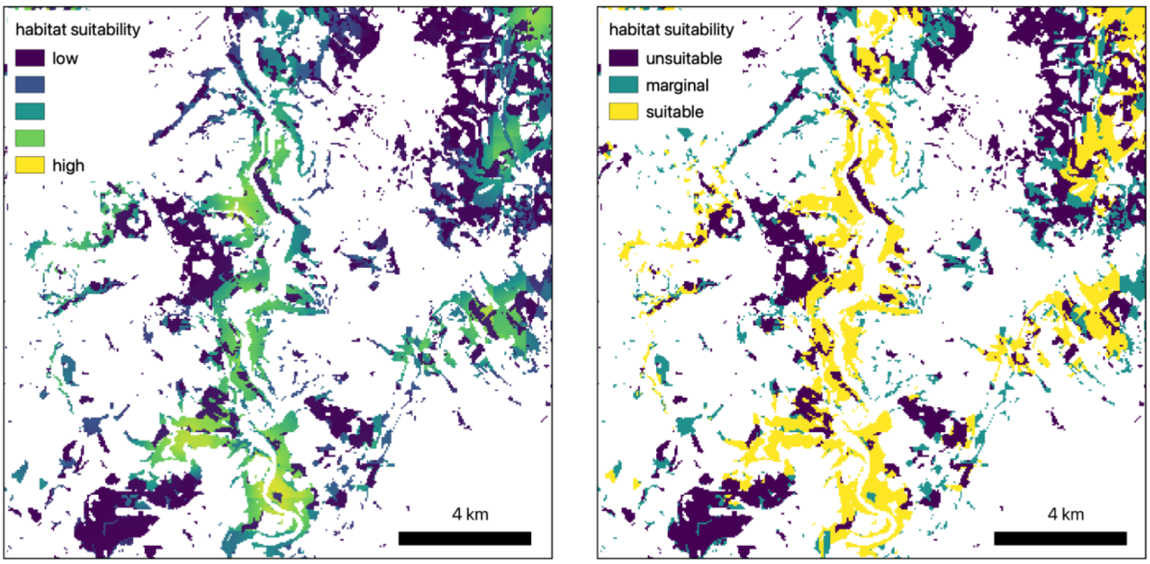

Figure 3 Predictions from the fine-scale model showing the model output of continuous suitability of woodland habitats for *B. barbastellus* maternity colonies (left) and the ternary prediction of suitability (right) showing suitable, marginal, and unsuitable woodland habitat based on zero omission and MSS thresholds

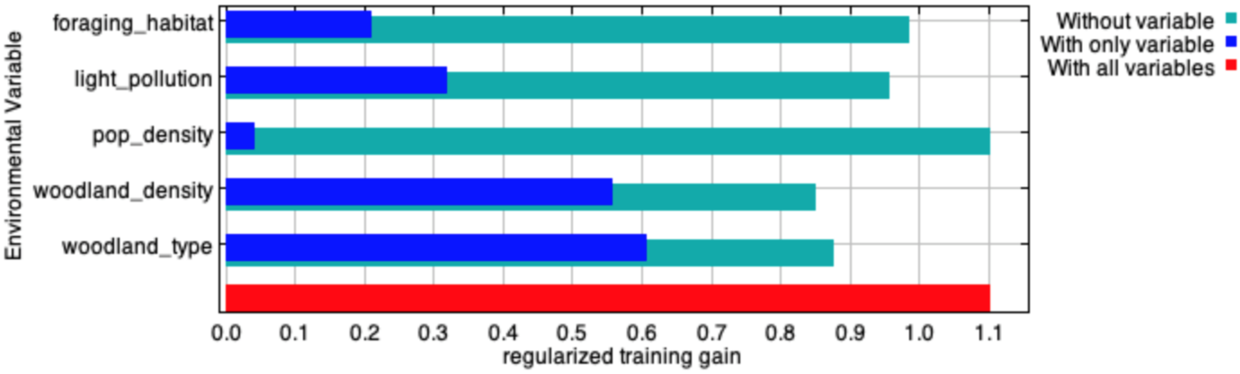

Figure 4 Jackknife of regularised training gain for model predicting suitability of woodland habitats for *B. barbastellus* maternity colonies in Great Britain, listing variables included in the model and their relative contribution to the model in terms of increasing model gain when used in isolation (dark blue bars) and on decreasing model gain when omitted from the model (extent of reduction in light blue bars relative to red bar).

Favourable supporting habitat

The area of favourable supporting habitat for *B. barbastellus* is estimated to be 17,190 km^2 in England and 3,229 km^2 in Wales (combined 20,419 km^2). Within the species' predicted geographic distribution (broad-scale model), the area of favourable supporting habitat is estimated to be 10,435 km^2 in England and 1,760 km^2 in Wales (combined 12,195 km^2).

Woodland roosting habitat

The area of suitable woodland roosting habitat for *B. barbastellus* maternity colonies is estimated to be 3,138 km^2 in England and 450 km^2 in Wales (combined 3,588 km^2). The area of marginal woodland roosting habitat is estimated to be 1,919 km^2 in England and 328 km^2 in Wales (combined 2,247 km^2). Within the species' predicted geographic distribution (broad-scale model), the area of suitable woodland roosting habitat for *B. barbastellus* maternity colonies is estimated to be 2,588 km^2 in England and 292 km^2 Wales (combined 2,880 km^2). The area of marginal woodland roosting habitat is estimated to be 1,455 km^2 in England and 185 km^2 in Wales (combined 1,640 km^2). It is important to note that these values are likely to be overestimates as it was not possible to include additional variables in the model that would reduce the area of predicted suitable woodland further, such as the availability of veteran or dead and decaying trees that are typically favoured by *B. barbastellus*, but which are relatively uncommon. UK-wide data for very fine scale variables such as these currently do not exist.

Planted ancient woodland

None of the maternity colonies discovered to date are located within conifer woodland. As such, within the fine-scale model all conifer types, including conifer plantation on ancient woodland sites (PAWS), were lumped together into a single 'conifer' habitat category to remove unnecessary complexity in the model, which can reduce predictive performance. While conifer woodland is considered to be of negligible value as roosting habitat for *B. barbastellus*, there is potential for planted ancient woodland sites (PAWS) to be reverted to more suitable woodland habitats. The total area of conifer PAWS available in England and Wales is estimated to be 672 km^2 and 199 km^2, respectively. Within the species' predicted geographic distribution (broad-scale model), the area of conifer PAWS is estimated to be 540 km^2 in England and 107 km^2 in Wales.

Population size

The potential number of colonies that may be present within the species predicted geographic distribution (broad-scale model) is estimated to be 1,834, comprising 1,638 colonies in England and 196 colonies in Wales. These are maximum values, based on the assumption that all potential colony sites (modelled 5 km grid cells) are occupied (Figure 5). However, within areas of England and Wales where considerable focussed survey work has been undertaken to locate maternity colonies, approximately one third (32 %) of potential colony sites are occupied by known colonies. As such, the total number of colonies is perhaps more likely to be 524 in England and 63 in Wales (combined 587 colonies). Assuming an average of 20-40 adult females per colony, it is estimated then that there may be between 10,483 and 20,966 breeding females in England and between 1,255 and 2,509 breeding females in Wales (combined 11,738 to 23,475 females). Assuming a sex ratio of 1:1, the total adult population of barbastelles may, therefore, be in the region of 21,000–42,00 individuals in England and 2,500–5,000 individuals in Wales (combined 23,500–47,000 individuals). It must be noted that these figures are highly speculative, based on relatively coarse models and broad assumptions regarding occupancy rates and colony size. As such, these figures provide only an estimate of what the population size of *B. barbastellus* may be. They should not be interpreted as the actual size of the population.

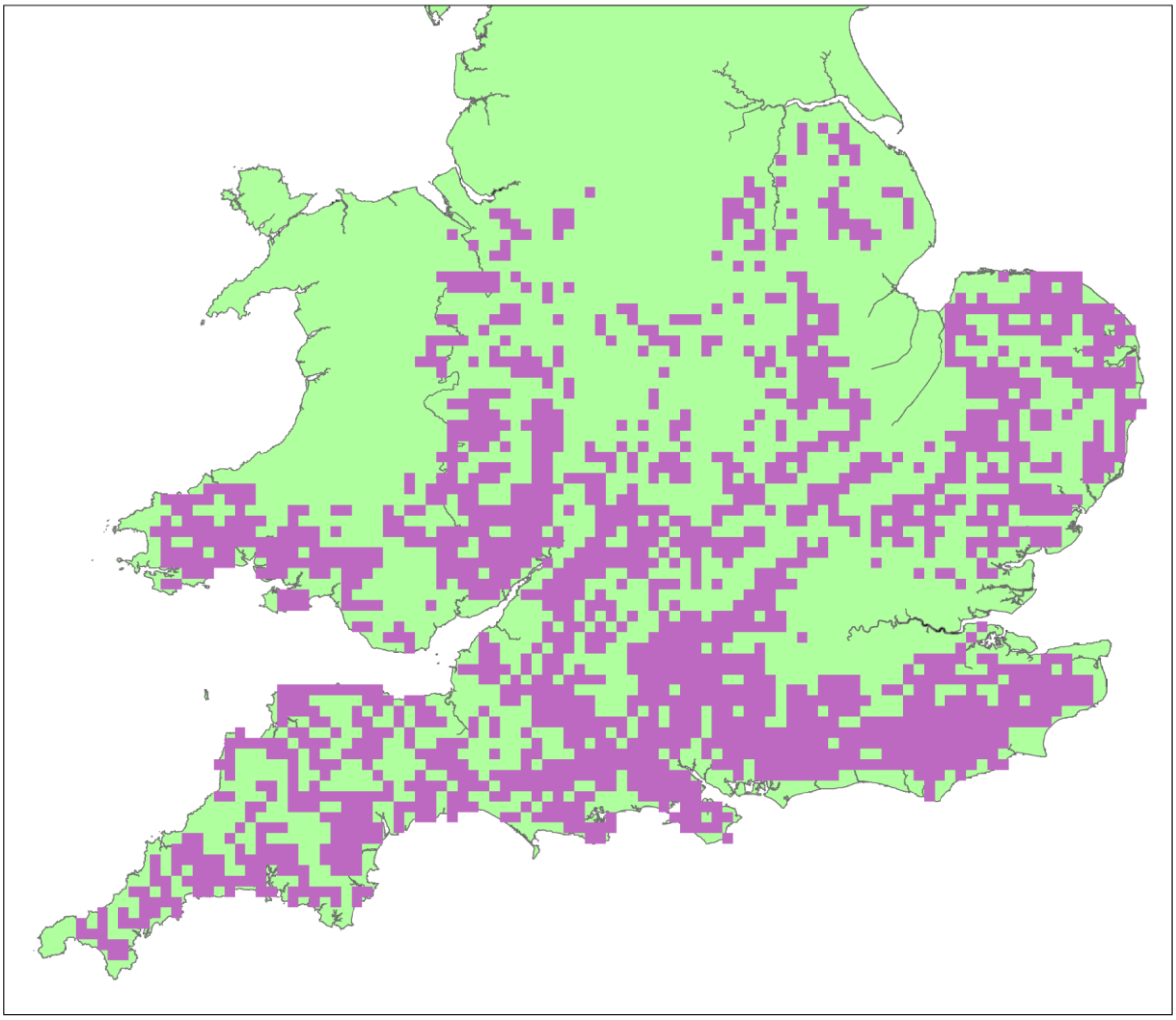

Figure 5 Distribution of 5 km grid squares (*n* = 1,834) predicted to contain sufficient suitable habitat to support a maternity colony of barbastelles (derived from fine-scale model); limited to within the species predicted geographic distribution in the UK (broad-scale model)

Limitations

The accuracy of predictions from ecological niche models are inherently constrained by the environmental datasets on which the models are built. There are now a large number of occurrence records for *B. barbastellus* in Great Britain, obtained predominantly as a result of increasingly widespread use of sensitive automated acoustic detectors, however knowledge of maternity colonies is still very limited (mainly because expensive and licensed advanced survey techniques are required to confirm the presence of colony roosts in woodland). Although the dataset of 118 colonies collected in this study represents a considerable increase in records in recent years, this is still a relatively low number of records on which to build an ecological niche model and there are large regions of England and Wales (within the species predicted geographic distribution) where no colonies have been discovered to date, most likely due to limited or no survey effort with advanced techniques in those regions. In addition, there are few environmental datasets currently available that can be used to define habitat characteristics at fine spatial scales.

For example, in this study it was not possible to include information on a number of factors that strongly influence the suitability of a woodland for *B. barbastellus* maternity colonies, such as tree species composition, availability of veteran or dead and decaying trees, and historical management of the site. Given these limitations, it should be noted that the predictions of the fine-scale model should be treated with caution, and the area of suitable roosting habitat for *B. barbastellus* maternity colonies predicted by this model is most likely an overestimate. In future, as increasingly sophisticated high-resolution environmental datasets become available, and as more colonies are discovered, models can be refined further, and the accuracy and robustness of model predictions can be improved.

References

Feng, X., Park, D. S., Walker, C., Peterson, A. T., Merow, C. and Papes, M. 2019. A checklist for maximising reproducibility of ecological niche models. *Nature Ecology and Evolution*, 3: 1382-1395.

Greenaway, F. 2001. The barbastelle in Britain. *British Wildlife*, 12: 327-334.

Hillen, J., Kiefer, A. and Veith, M. 2009. Foraging site fidelity shapes the spatial organisation of a population of female western barbastelle bats. *Biological Conservation*, 142: 817-823.

Merow, C., Smith, M. J. and Silander, J. A. 2013. A practical guide to MaxEnt for modelling species' distributions: what it does, and why inputs and settings matter. *Ecography*, 36: 1058-1069.

Phillips, S. J., Anderson, R. P. and Schapire, R. E. 2006. Maximum entropy modelling of species geographic distributions. *Ecological Modelling*, 190: 231–259.

Razgour, O., Juste, J., Ibáñez, C., Kiefer, A., Rebelo, H., Puechmaille,.S. J., Arlettaz, R., Burke, T., Dawson, D. A., Beaumont, M. and Jones, G. 2013. The shaping of genetic variation in edge-of-range populations under past and future climate change. *Ecology Letters*, 16: 1258-1266.

Sierro, A. 1999. Habitat selection by barbastelle bats (*Barbastella barbastellus*) in the Swiss Alps (Valais). *Journal of Zoology,* 248: 429-432.

Sierro, A. 2003. Habitat use, diet and food availability in a population of *Barbastella barbastellus* in a Swiss alpine valley. *Nyctaus,* 8: 670-673.

Sierro, A. and Arlettaz, R. 1997. Barbastelle bats (*Barbastella* spp.) specialize in the predation of moths: implications for foraging tactics and conservation. *Acta Oecologica,* 18: 91-106.

Zeale, M. R. K., Davidson-Watts, I. and Jones, G. 2012. Home range use and habitat selection by barbastelle bats (*Barbastella barbastellus*). *Journal of Mammalogy*, 93(4): 1110-1118.

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Citation

Matt Zeale and Natural England. 2024. Definition of Favourable Conservation Status for Barbestelle bat. RP2974. Natural England.

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