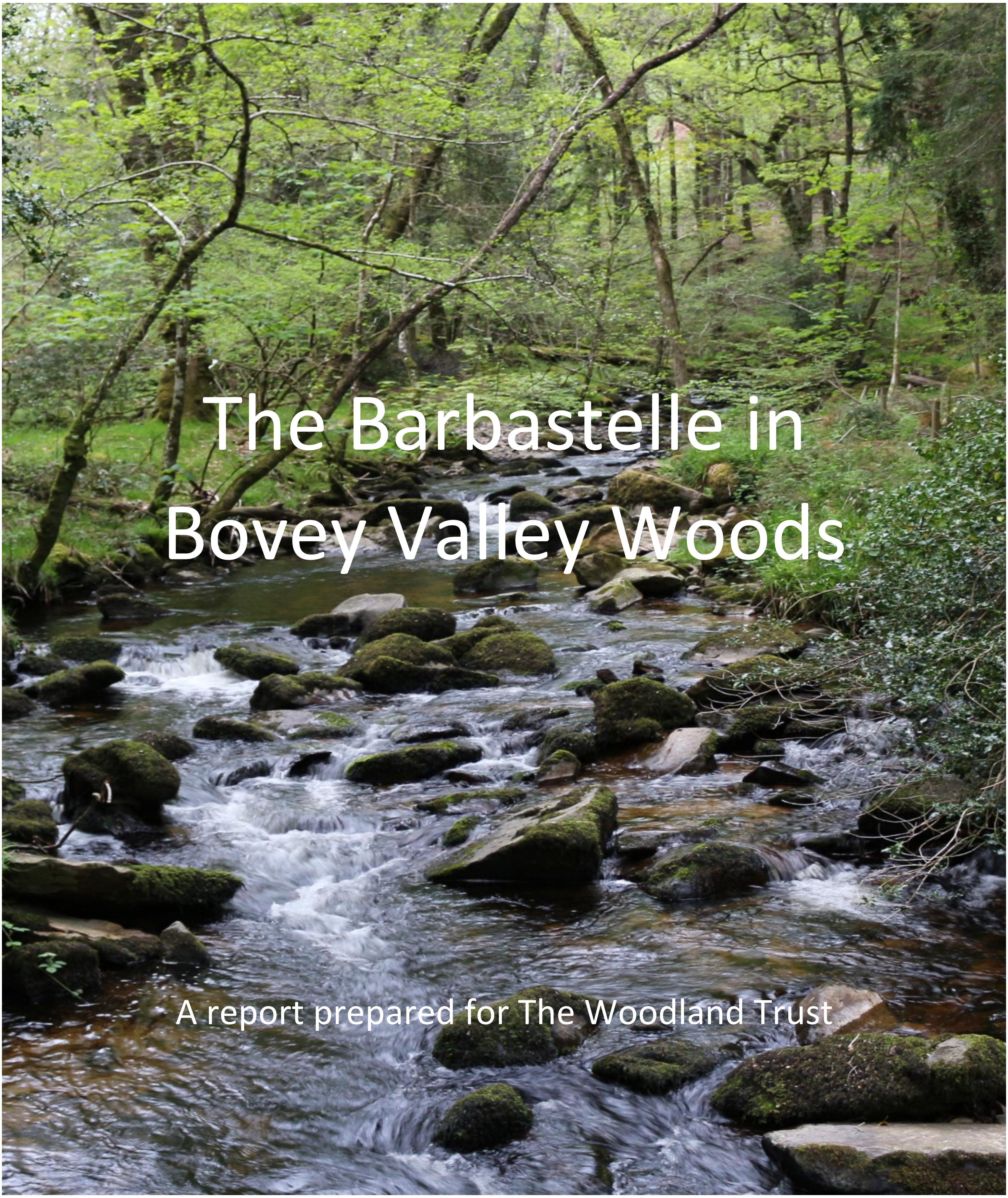
The Barbastelle in Bovey Valley Woods



A report prepared for The Woodland Trust

Moor than meets the eye
Landscape Partnership

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The Barbastelle in Bovey Valley Woods

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1 Introduction

1.1 Background

Barbastella barbastellus (Schreber, 1774) is classified as 'Near Threatened' according to the International Union for the Conservation of Nature (Piraccini, 2016). Despite predicted population declines of up to 30 % over the coming decade, large scale European surveying has indicated a steady increase in population size (Haysom *et al*. 2013), and several new breeding colonies have been identified within England and Wales in recent years (Zeale, 2011). It is widely agreed that historic population declines, current low numbers and fragmented colonies are associated with loss of old growth broadleaved woodland habitat (Russo *et al*. 2004; Zeale, 2011; Piraccini, 2016). Pressures on populations have been especially severe in areas of agricultural intensification with associated pesticide use reducing the availability of favoured moth prey (Zeale *et al*. 2012) and although pesticide use may be less of an issue any factors reducing moth biomass will degrade foraging opportunity for *B. barbastellus* (Ancillotto *et al*. 2015). The species is classified under Annex II and IV of the EU habitats directive and is a UK Biodiversity Action Plan priority species (JNCC, 2010).

B. barbastellus has retained a preference for roosting in trees and requires old growth broadleaved woodland that provides an adequate amount of defoliating bark, rot holes and splits as roosts (Russo *et al*. 2004, 2010; Zeale, 2011). Old growth woodland (also termed ancient woodland in the UK) is a woodland that has progressed to a great age without significant disturbance and is a biodiverse climax community. Bouvet *et al*. (2016) has linked temperate bat presence with the proportion of standing deadwood present within a woodland, complementing findings that *B. barbastellus* disproportionally selects standing deadwood over available living trees (Zeale, 2011). Understanding preferences for woodland types, as well as tree and cavity types, is important to ensure favourable characteristics for the species are retained. It is also important to understand whether preferences change seasonally as temperature variation may dictate roost suitability.

For a breeding population to survive and remain stable, both suitable roosting sites and productive foraging grounds are required. Foraging 'patches' must provide suitable prey types; habitats should be structured to allow successful capture of prey, and be within an area that colony members can reach, both in terms of distance and the ability to traverse the landscape. Radio-telemetry studies are suitable for obtaining spatial information required to assess home range areas, foraging patches, and flight routes from roosts to foraging patches. *B. barbastellus* targets habitats associated with preferred moth prey, such as riparian habitats and broadleaved woodland (Davidson-Watts & McKenzie, 2006; Greenaway, 2008; Zeale *et al*. 2012). Field boundary features such as hedgerows and tree lines also provide important foraging habitat (Zeale *et al*. 2012). Variation in selected foraging patches within and between seasons is apparent, probably as a response to variation in prey availability (Greenaway, 2008), or, as observed by Zeale *et al*. (2012), influenced by reproductive status. *B. barbastellus* can travel long distances to foraging sites, with some individuals travelling over 20 km from roost to foraging area, consequently utilising large ranges with relatively small core foraging areas; most individuals typically travel shorter distances (8.4km) however (Zeale *et al*. 2012).

DNA barcoding and high throughput sequencing has been used successfully to identify consumed prey from bat faecal samples (Razgour *et al*. 2011; Zeale *et al*. 2011; Hope *et al*. 2014; Salinas-Ramos *et al*. 2015). A molecular approach for establishing prey from *B. barbastellus* faeces was first used in 2008 and subsequently refined (Zeale *et al*. 2011). It is now possible to identify consumed prey to species resolution with high accuracy. Understanding prey consumption at the species level allows researchers to consider preferred prey and dietary breadth, and enables managers to produce action plans to increase important prey species.

1.2 The Barbastelle in Bovey Valley Woods

In 2002 *B. barbastellus* was first recorded in the Dartmoor National Park. Subsequent radio-tracking located a maternity colony in Bovey Valley Woods in 2003 (Billington, 2002). The first and only concentrated research on the species in Bovey Valley Woods was undertaken in 2007 and 2008 (Zeale, 2011) and investigated roost use, ranging behaviour, foraging ecology and dietary composition. In addition to providing information to inform management, knowledge gaps in research were highlighted.

1.3 Objectives

This project was commissioned by the Woodland Trust and Natural England to fill current knowledge gaps in our understanding of the ecological requirements of *B. barbastellus* in Bovey Valley Woods. Research focused on examining seasonal variation in roosting and foraging behaviour of adult bats during the summer maternity period, and seasonal variation in prey choice. Research findings can then be used to inform the management of woodlands and the wider landscape, to promote conditions favourable for *B. barbastellus*.

The specific objectives covered by this report are to:

a) examine the seasonal roosting requirements of *B. barbastellus* in the Bovey Valley by using radio-tracking to locate roost features; to examine roost use, and survey roosts to record roost characteristics and to identify roost preferences from early spring until late autumn.

b) examine the seasonal ecological requirements of foraging adult female *B. barbastellus* in the Bovey Valley by using radio-tracking to identify ranging behaviour, habitat preferences and patterns of nocturnal activity of bats throughout the summer maternity period.

c) examine and compare the diet of adult female *B. barbastellus* in the Bovey Valley using a DNA-based approach.

d) provide evidence on which to base practical habitat enhancement and restoration measures within the colony range to ensure the long-term success of the species.

2 Methods

2.1 Study area

The study area covered a known roosting and ranging area used by a colony of *B. barbastellus* that has been previously researched (Zeale, 2009) and is currently monitored by acoustic methods (Angell and Mason, 2014). The colony utilises Bovey Valley Woods (3°44'W, 50°36'N) for roosting (hereafter termed the 'home wood') (Fig. 1). Home wood area was delimited retrospectively using all bat roost locations, and the boundary was defined using both woodland edge and, when contiguous, 250 metres from the nearest roost (the greatest distance recorded from a roost to a woodland boundary). Ranging area was delimited using combined MCP (maximum convex polygon) for all fixes recorded from all radio-tracked bats. The site is part of South Dartmoor Woods Candidate Special Area of Conservation (cSAC) and is within the East Dartmoor National Nature Reserve (NNR).

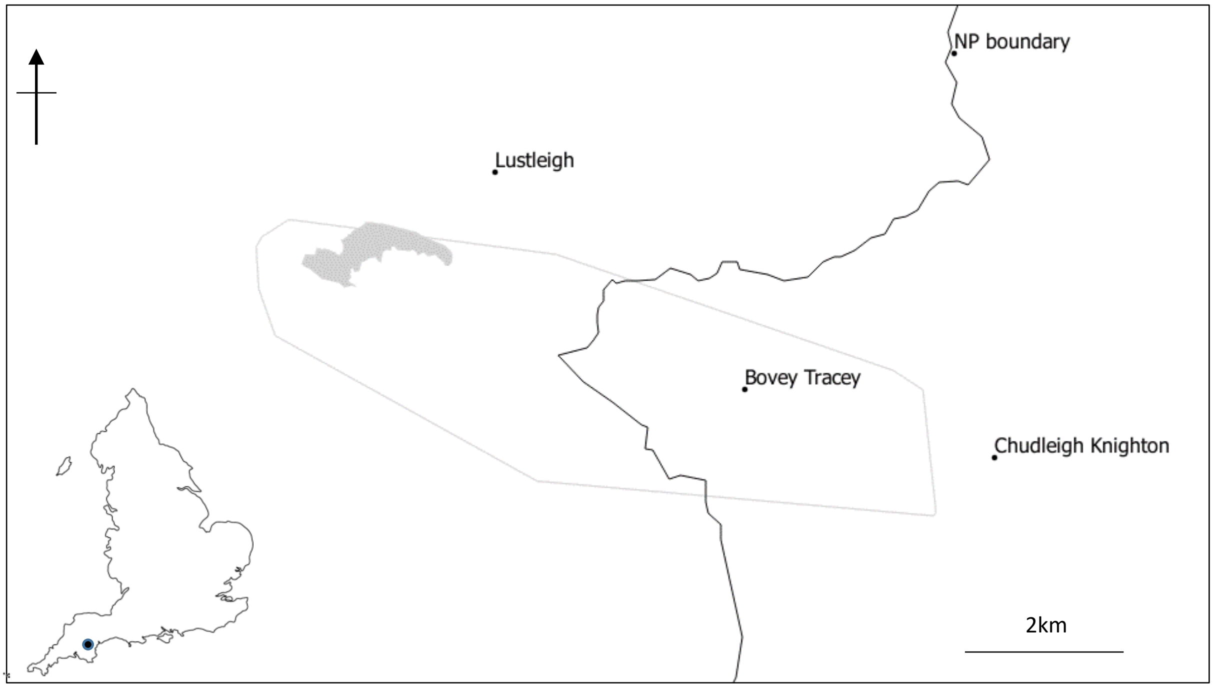

Figure 1 Map of Bovey Valley Wood study site within the East Dartmoor NNR showing the home wood (grey shaded polygon) and combined MCP ranging area for all radio-tracked bats combined (grey open polygon). NP boundary shows the boundary of the Dartmoor National Park.

2.2 Bat capture, tagging and radio-tracking

Bats were captured using mist nets (2.6 m & 6 m) (Avinet Inc, US) and harp traps (2 bank) (Faunatech Austbat, Australia) placed along woodland rides. Suitable woodland trapping sites were initially informed from past research (Zeale, 2009). To increase capture success (Hill and Greenaway, 2005; Scott and Altringham, 2014), Apodemus (Apodemus field equipment, Netherlands) and Sussex Autobat (University of Sussex, UK) acoustic lures broadcasting synthesised and direct recordings of *B. barbastellus* social and echolocation calls were used. Bats were also caught at roost sites during emergence on two occasions with three large hand-held butterfly nets (net diameter 47 cm, net depth 78 cm) attached to extendable aluminium poles. Acoustic lures were not used at roosts. Suitable individuals were measured and weighed, assessed for health and reproductive status and subsequently fitted with lightweight radio-transmitter tags (Pip3, 0.45 g) (Biotack Ltd, UK). Tags were attached to the clipped dorsal side of the animal between the scapulae using ostomy adhesive solution (Salts Healthcare Ltd, UK). All transmitters weighed < 5 % of the bats' body mass to avoid potential load-related changes in behaviour (O'Mara *et al*. 2014). Bats captured early in the study were fitted with aluminium wing bands (Porzana Ltd, UK) to ensure recaptured bats were identifiable throughout the project duration.

Radio-tracking followed the procedure adopted by Zeale (2009) to ensure data were comparable. Bats were tracked using r-1000 telemetry receivers (Communications Specialists Inc, US) and short three-element Yagi antennas (Wildlife Materials Inc, US). Bats were tracked continuously (Jones and Morton, 1992; Duvergé, 1996) using the homing-in method (White and Garrot, 1990). A bat was located to its roost during the day on foot and to foraging grounds at night by car. A tracking fix (surveyor location, direction of signal and distance from signal) was taken every five to ten minutes throughout a night. Activity type was determined through the nature of the signal. A rapid directional signal was classified as coming from a commuting bat; a fluctuating signal within a defined area was classified as belonging to a foraging individual; a static signal was recorded as roosting behaviour (Russo *et al*. 2004; Davidson-Watts and Mckenzie, 2006; Zeale, 2011). Any night on which a signal was lost for a period of time resulting in less than 95 % contact time was removed from analysis because the complete movements of the bat could not be described.

2.3 Habitat mapping

To inform habitat selection by foraging bats habitat data were obtained from Zeale (2009) and updated using GIS files (supplied by The Woodland Trust and taken from Defra magic map), aerial photographs (supplied by DigitalGlobe, Getmapping plc, Interfoterra Ltd & Bluesky, The Geoinformation Group) and through ground validation. Categories follow Phase 1 habitat classifications (JNCC, 2010) with modification (Zeale, 2009). Habitat maps were generated using Quantum GIS software 2.8.1 (Quantum GIS Development Team) using eleven dominant habitat types (Table 1).

Table 1 Description of habitat types used to assess habitat selection by foraging *B. barbastellus*.

Habitat type	Description
Broadleaved woodland	Ancient semi-natural broadleaf woodland, broadleaf plantation, active coppice, and young trees.
Mixed woodland	Ten percentage or more of both broadleaf and coniferous in canopy, includes plantation mixed woodland.
Coniferous woodland	Ten percentage or less broadleaf in canopy, includes both plantation and natural conifer woodlands.
Scrub	Dense forestry scrub, small shrubs and bracken.
Unimproved grassland	May be rank and neglected, mown or grazed grassland on enclosed land. Not treated with application of artificial fertiliser or herbicide, or have been so intensively grazed or drained, as to alter the sward composition significantly, including all unimproved areas, neutral, acidic or calcareous.
Improved grassland	Enclosed meadows and pastures which have been so affected by heavy grazing, drainage, or the application of herbicides and/or inorganic fertilisers that they have lost many species which one could expect to find in an unimproved sward. Includes permanent improved, semi-improved, and amenity grasslands.
Arable	Ploughed land, cropland and recently reseeded grassland. Includes arable land and grassland in rotation, horticultural land and nurseries, and recently planted and established orchards.
Riparian	Marginal vegetation around any water body, including riparian woodland, tall vegetation along water courses, swamp vegetation around pools and all types of fen and mire.
Open water	Open water, including rivers, streams, brooks, lakes, ponds (including operational ponds), reservoirs, aquaculture, and estuary and coastal waters.

Urban	Roads, houses and residential land, built-up areas, including areas of commercial retail, industry, high density residential (>40 % cover), agricultural buildings, transport areas, restored or active landfill sites, and active or inactive quarries.
Upland moor	Unenclosed areas of unimproved upland habitat, often grazed, including wet and dry shrub heath, heath grassland mosaic, gorse, bracken and acid grassland.

Hedgerows and minor tree lines, where present as secondary habitats, were included in grassland, arable, riparian and urban categories.

2.4 Analysis of roost preferences

To investigate whether *B. barbastellus* selected roosts with particular characteristics, the features recorded from roost trees were compared with those from randomly selected trees. Random trees were selected using a point-centred quarter method (Causton, 1988). The point was randomly selected using QGIS random point generator (Quantum GIS Development Team) within the home wood delimited during radio-tracking. Four quadrats were marked around each point (using bearings north, south, east and west) and the nearest potential tree in each quadrat selected and surveyed. A potential roost tree was at least equal or larger than the smallest DBH (Diameter at Breast Height) roost tree. The same quadrat method was repeated for roost trees (using the roost tree as the point centre) to provide comparable roost plots for random tree density analysis (Russo *et al*. 2004). Disturbance level was measured as distance to a footpath, road or building (whichever was nearer). To investigate roost cavity selection, 30 random cavities were located along a single transect within the home wood covering the areas in which most roost trees were located. The random cavities were located using binoculars at ground level and categorised as flaking bark, splits or rot holes (Andrews, 2013). A cavity was selected when features appeared comparable to those of the roost cavities. When more than one cavity was present on a tree, a single cavity was selected at random.

To examine whether roosting bats were selecting a particular woodland type, chi-square analysis was applied to test whether the proportion of use (number of roosts in each woodland category divided by total number of roosts located in the study area) departed from the expected proportion (area of corresponding woodland category divided by overall size of the study area) (Russo *et al*. 2004; Zeale, 2011). Two roosts that were located in an isolated area of woodland comprising only semi-natural broadleaved woodland were not included in this analysis as selection analysis requires at least two distinct woodland types to be present. Woodland categories were combined into 'semi-natural broadleaved woodland' and 'other woodland' categories to meet chi-square assumptions. The Z statistic was used to calculate Bonferroni's confidence intervals (Neu *et al*. 1974) and to establish statistically whether bats had positively or negatively selected a woodland category.

To examine whether roosting bats were selecting particular tree species, chi-square analysis was applied. Trees were classified as belonging to either 'Class 1 *Quercus*' live trees (*Q. robur* or *Q. petraea*) showing less than 80 % dead limbs and loss of foliage; 'Class 2 *Quercus*' dead trees showing 80 % or greater dead limbs and loss of foliage; 'other broadleaved spp.' (all live individuals); and 'conifer spp.' (all live individuals). To determine whether the features of roosts and random trees differed, univariate comparison analysis was used to test single variables. Roost plots were compared with random plots to determine differences in elevation, terrain exposure (when a plot was located on a slope the terrain exposure is the direction the slope faced), terrain slope, tree density, and distance from woodland edge, sources of water and disturbance. Roost trees were compared with random trees to determine differences in tree height, DBH, canopy closure and number of cavities. Roost cavities were compared with random cavities to determine differences in the frequency of cavities on trees, the height above ground and entrance direction of cavities (Table 2). All values of central tendency are means ± standard deviation unless otherwise stated.

Table 2 List of variables used to investigate roost preferences of *B. barbastellus*.

Scale	Variable	Description
Habitat	Type	Semi-natural broadleaved woodland (predominantly *Q. robur* and *Q. petraea*), plantation broadleaved woodland (mixed species), plantation conifer woodland (mixed species) and forestry scrub.
Roost plot	Disturbance	Distance from the roost tree or centre point of random plot to the nearest footpath, road or building in metres.
	Elevation	Height above sea level in metres.
	Tree density	Calculated in hectares as 10000/(mean of the four distances to nearest trees in metres)^2.
	Exposure	Direction, if present, of slope face.
	Slope	Clinometer measurement of slope from roost tree or random central point.
	Water	Distance from roost tree or random centre point to the nearest river, lake or reservoir in metres.
	Edge	Distance from roost tree or random centre point to the nearest woodland edge in metres.
Roost tree	Canopy	Degree of canopy closure around a tree assessed visually from the base of the tree.
	DBH	Diameter at Breast Height in metres.
	Cavity #	Number of cavities located visually from the ground with binoculars.
	Cavity type	Categorised as flaking bark, splits or rot holes.
	Tree height	Clinometer measurement of crown from a ten metre distance.
	Tree type	'Class 1 *Quercus*' species showing < 80 % dead limbs and loss of foliage. 'Class 2 *Quercus*', dead oak trees showing > 80 % or greater dead limbs and loss of foliage); 'other broadleaved spp.' (all live individuals); and 'conifer spp.' (all live individuals).

Variables and methods followed those described in Russo *et al*. (2004) and Zeale (2011).

2.5 Analysis of ranges and foraging areas

To improve the accuracy of radio-tracking fixes recorded from tagged bats, a radio-transmitter tag was placed in a fixed position in the field and measurements of signal strength were taken at varying distances and angles from the tag. This provided a reference for signal detection from which positional fixes of radio-tagged bats could be calibrated against. Radio-tracking fixes from bats were digitised using Quantum GIS software 2.8.1 (Quantum GIS Development Team) and the distance/azimuth python plug-in (0.9.1) (Paulo and Laplante, Technology One). Digitised fixes were analysed using Ranges 7 (Anatrack Ltd, UK) to calculate MCP home range areas and cluster cores. Cluster analysis is considered the best approach for quantifying the core areas used by free flying bats studied by radio tracking (Davidson-Watts *et al*. 2006; Zeale, 2009) as it produces a representative depiction of foraging grounds. Analysis of utilisation distribution discontinuities in intervals of 5 % found that 10 % of fixes from each bat disproportionately increased the range size. Examination of these fixes identified that they were from bats considered to be commuting. 90 % cluster cores were, therefore, used to describe foraging grounds. 100 % MCPs were used to determine total area covered (foraging, roosting and commuting) by individual bats (using all fixes obtained from the bat concerned) and total colony area (all fixes from all tracked bats). All values of central tendency are means ± standard deviation unless otherwise stated.

Habitat preferences were examined by comparing the habitat composition in which each *B. barbastellus* bat was recorded foraging (90 % cluster cores) with the habitat available to them (individual MCPs). Compositional analysis was used to determine whether habitats were used in proportion to availability, or if selection was occurring, and to determine the ranking of habitat types (Compositional Analysis Plus Microsoft Excel tool 6.2, Smith Ecology Ltd, UK) (Zeale *et al*. 2016). To satisfy the assumption that habitat categories should be one less than the number of tracked animals (Aebischer *et al*. 1993) the 11 habitat types (Table 1) were grouped into six broad habitat categories, including arable, moorland, pasture, urban, wetland, and woodland.

2.6 Analysis of diet

Captured bats were placed in sterilised hessian bags for 30 minutes or until they defecated. The deposited faecal pellet was placed in a sterile collection tube, dampened with 96 % ethanol and stored at minus 18 °C. DNA extraction and Polymerase Chain Reaction (PCR) was undertaken at Queen Mary University London (QMUL) using a QIAamp DNA Stool Mini Kit (Cat No./ID: 51504; Qiagen Ltd, UK) and a standardised top down approach following the technique used by Salinas-Ramos *et al*. (2015). Modified CO1 primers ZBJ-ArtF1c and ZBJ-ArtR2c (Zeale *et al*. 2011) were used for high throughout next generation sequencing using adaptors for Ion Torrent (Piñot *et al*. 2014). These primers have shown to be effective at amplifying arthropod prey while avoiding amplification of non-target DNA such as bat, bacteria and fungi (Zeale *et al*. 2011). The primers used may have low success with some taxa (e.g. Coleoptera), so absence in DNA records may not always mean absence in diet.

Sequences were analysed using Galaxy platform (Goecks *et al*. 2010). Reads were separated by forward and reverse MIDs (Multiplex Identifiers) (a maximum of two mismatches were allowed). All sequences shorter than 147 bp or longer than 167 bp (target amplicon length was 157 bp) were filtered out and collapsed into unique haplotypes. Singleton sequences (a sequence occurring only once) were excluded from analysis. Sequences were compared to BLAST (Basic local assignment search tool) (http://blast.ncbi.nlm.nih.gov/Blast.cgi) and interpreted using taxonomic hierarchy with MEGAN6 software (Husan, 2016) using 281 BLAST score and a 99.3 % sequence similarity threshold for species diagnosis (Zeale *et al*. 2011).

3 Results

3.1 Capture data

Bat captures were attempted on 28 nights between May and September 2015, recording 53 bats from nine species, including UK BAP priority species *B. barbastellus, Pipistrellus pygmaeus, Plecotus auritus, Rhinolophus ferrumequinum* and *Rhinolophus hipposideros* (Appendix 1). Eighteen *B. barbastellus* were captured (Table 3). One individual was caught from a roost box within Yarner Wood (a previously unrecorded roosting site). This individual roosted alone and was a female. No juveniles were captured despite capture events continuing through and beyond the time when they would be flying. Emergence counts revealed a minimum colony size of 15 *B. barbastellus*. The colony was confirmed as a breeding population by the presence of pregnant and lactating females, and contained a pregnant female radio-tracked in 2008 (identified by ring no. Y1417).

Table 3 Summary of *B. barbastellus* captures in order of date captured. An 'unsure' status was documented when the bat could not be definitively classed as pregnant or non-breeding. An evaluation of breeding status of males was not made. Dark grey represents bats tracked to roosts and foraging grounds. Light grey represents bats tracked to roosts only.

ID	Date	Age	Sex	Status	Forearm length (mm)	Body mass (g)	Droppings obtained
8	22/04/2015	Adult	male		39.50	8.10	Yes
11	22/04/2015	Adult	male		39.99	6.00	No
12	22/05/2015	Adult	female	pregnant	39.27	9.80	Yes
13	26/05/2015	Adult	female	unsure	39.35	7.90	Yes
1	27/05/2015	Adult	female	pregnant	38.25	8.50	Yes
2	27/05/2015	Adult	female	unsure	38.29	8.60	Yes
3	27/05/2015	Adult	female	pregnant	39.04	8.60	Yes
4	27/05/2015	Adult	female	pregnant	37.15	8.70	Yes
14	27/05/2015	Adult	male		34.28	6.70	Yes
15*	02/07/2015	Adult	female	pregnant	37.15	8.70	Yes
16**	14/07/2015	Adult	female	pregnant	39.70	11.20	No
17*	14/07/2015	Adult	female	pregnant			No
10	14/07/2015	Adult	female	lactating	39.37	10.00	Yes
5	30/07/2015	Adult	female	lactating	39.19	11.30	Yes

6	30/07/2015	Adult	female	lactating	39.80	9.60	Yes
7	20/08/2015	Adult	male		38.85	9.40	No
18	05/08/2015	Adult	male		36.55	9.00	No
9	13/09/2015	Adult	female	nulliparous	39.83	10.00	No

* recapture from the same tracking period. Identified by the presence of ring (early season) or clipped fur.

** recapture from 2008. Identified by the presence of a ring (ring no. Y1417).

3.2 Roost selection and preferences

During the five-month data collection period ten *B. barbastellus* (nine females: four pregnant, three lactating, one nulliparous, one unsure; and one male) were tracked to 13 roost trees. Average number of roosts used per bat was 1.5 ± 0.7 (range 1-3). Bats were tracked daily for 6.7 ± 3.2 days (range 3-11). Average time in the roost before roost switching was 2.4 ± 1.3 days (range 1-4, *n* = 5 bats), although five bats did not switch roosts despite being tracked for the life of the radio tag. Two roosts were used by multiple bats and one of these roosts was used by two bats during the same period. This roost was used for 21 days in total by all the bats tracked there. Emergence surveys were performed on 17 of the 21 days and recorded 14 bats consistently at this roost. The roost that was used most frequently was confirmed as a maternity roosts with newborn dependant young (non-volant juveniles) because the bats tracked to this roost were heavily pregnant or lactating. Overall, the average emergence count was 9.4 ± 6.02 bats (range 1-15, *n* = 31 emergence surveys). Two roosts were classified as maternity roosts as the bats tracked to these roosts were lactating. Average colony size at these two roosts was 13.6 ± 1.2 (range 9-15, *n* = 23 emergence surveys). In all other roosts (*n* = 11) the average emergence count was 1.2 ± 0.7 bats (range 1-4, *n* = 21 emergence surveys). The maximum recorded number of bats in a single roost was 15.

Roost selection at the habitat scale showed that *B. barbastellus* disproportionately selected trees in semi-natural broadleaved woodland (Fig. 2) over trees in plantation broadleaved woodland where only one roost tree was located (Table 4).

Figure 2 Map of roost locations and habitat types within (a) Houndtor Wood and (b) Yarner Wood. The two woodlands are within 1 km of each other and separated by upland heath. 'Other woodland type' includes plantation broadleaved woodland, plantation conifer and forest scrub.

Table 4 Results of chi-square and selection analyses (Bonferroni's confidence intervals) for woodland habitat type by roosting *B. barbastellus*. Proportion of use expected = area of 'woodland type'/overall size of the study area; proportion of use observed = number of roosts occurring in the corresponding woodland type/number of roosts in the study area. To satisfy assumptions of chi-square, data for roosts within Yarner Wood (*n* = 2) (Fig. 2) are removed. Yates correction has been applied.

Woodland type	Area (ha)	Number of roosts	Proportion of use expected	Proportion of use observed	Chi square value	Selection
Semi-natural broadleaved	33.37	10	0.54	0.91	2.14	Positive
Other woodland categories*	28.47	1	0.46	0.09	4.11	Negative
Total	61.84	11	1	1	ƚ 6.25	

* includes plantation broadleaved woodland, plantation conifer and forestry scrub. ƚ $p<0.02$

Roost plots (*n* = 13) had greater tree density (108.8 ± 57.7 ha; range 24.02-123.5 ha) than random plots (*n* = 13) (t = 3.8, df = 16, p = 0.001) and were located closer to potential disturbance ($\bar{x}$ = 47 ± 40.6 m; range 6-125 m) than random sites (W = 41, p = 0.02) (Fig. 3). The type of potential disturbance in all cases was a footpath. There was no significance between distance to water (W = 60, p = 0.2), distance to woodland edge (W = 75, p = 0.6), terrain slope (W = 85, p = 1.0), elevation (t = 0.5, df = 23, p = 0.5) or terrain exposure (χ^2_3 = 12, p = 0.2).

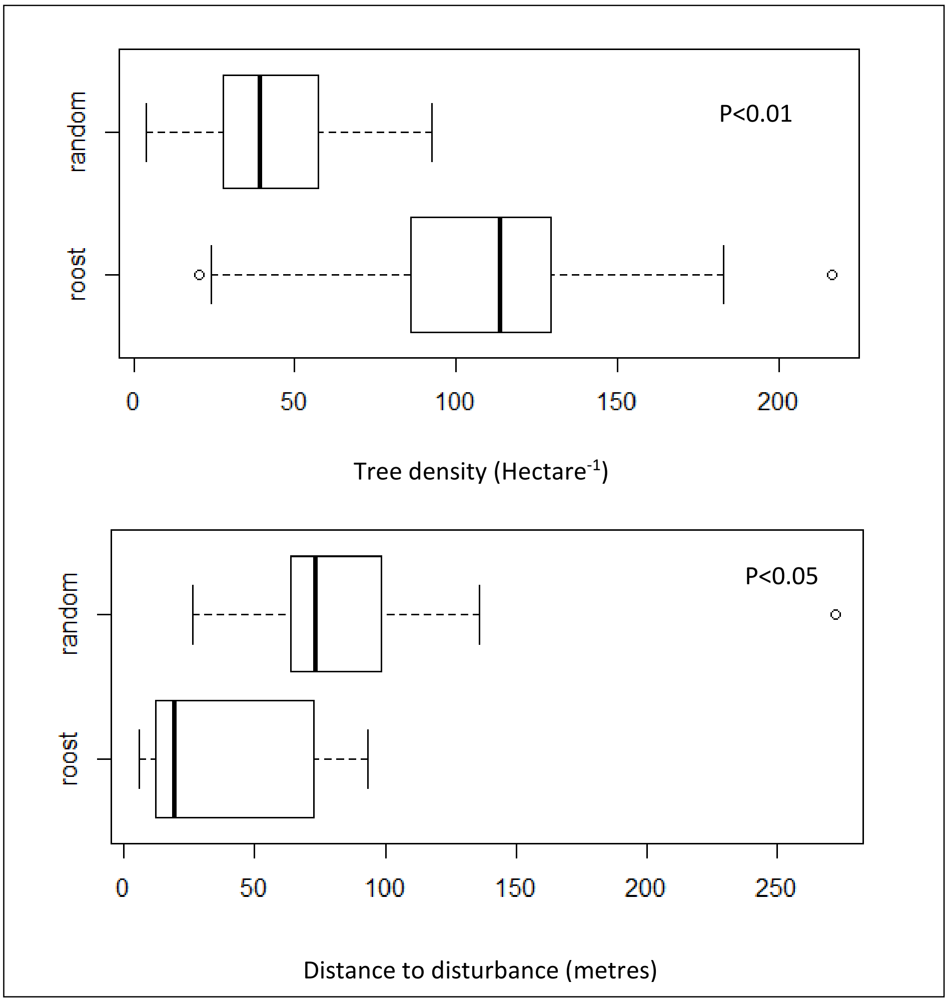

Figure 3 Box plot showing median, upper and lower quartiles and range of tree density and distance to footpath for roost plots, and results of Mann-Whitney and t-tests. Outliers are represented by circles.

The majority of roost trees (9 out of 13) were class 1 (live) *Quercus* trees. The remaining four roosts were found in class 2 (dead) *Quercus* trees. No other tree species was used for roosting. The majority of random trees (32 out of 52) were class 1 *Quercus* trees. The remainder consisted of nine class 2 *Quercus* trees, five 'other broadleaved' trees and six 'conifer' trees. To meet assumptions of chi-square analysis, and because these tree classes were not selected, conifer and other broadleaved trees were removed from analysis. Class 1 *Quercus* and class 2 *Quercus* trees were used in line with availability (Table 5) i.e. selection did not occur.

Table 5 Results of chi-square and selection analyses (Bonferroni's confidence intervals) for tree class according to tree species and condition. Proportion of use expected = number of random trees in each tree class/total number of random trees. Proportion of use observed = number of roost trees in each tree class/total number of roost trees. Class 1 represents live *Quercus* trees showing < 80 % of dead limbs and loss of foliage; Class 2 represent dead *Quercus* showing trees > 80 % or greater of dead limbs and loss of foliage. Both include *Q. robur* and *Q. petraea*.

Tree class	Roost trees	Random trees	Proportion of use expected	Proportion of use observed	Chi-square value	Selection
Class 1 *Quercus*	9	32	0.78	0.70	0.30	absent
Class 2 *Quercus*	4	9	0.22	0.30	0.20	absent
Total	13	41	1	1	ɫ 0.41	

ɫ not significant.

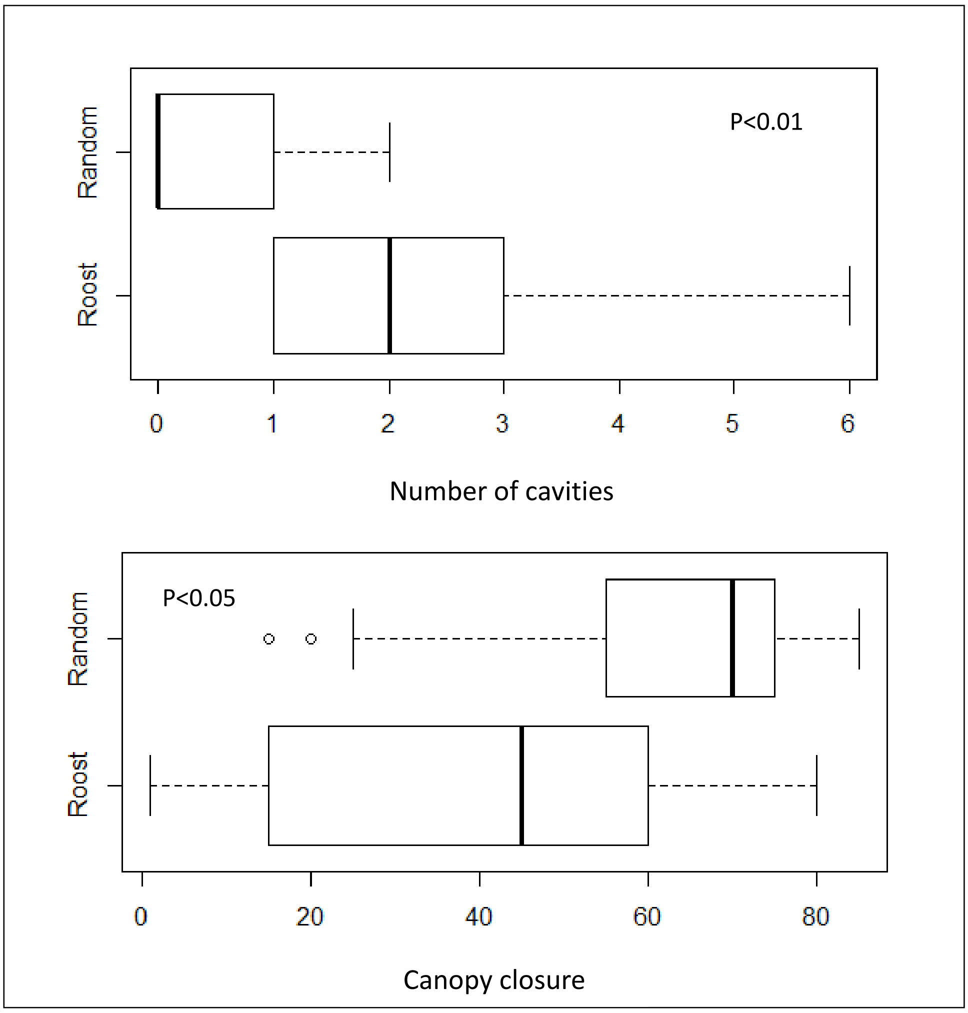

Figure 4 Box plot showing median, upper and lower quartiles and range of canopy closure and cavity frequency of roost (*n* = 13) and random trees (*n* = 52). Data are taken from all roost and random tree species including class 1 *Quercus*, class 2 *Quercus*, 'other broadleaved' and conifer spp.

Roost trees (*n* = 13) had a greater number of cavities ($\bar{x}$ = 2.3 ± 1.5; range 1-6) than random trees (*n* = 52) (W = 608.5, p <0.01), and had a more open canopy ($\bar{x}$ = 42 ± 28.2 %; range 1-80 %) than random plots (W = 185.5, p = 0.01) (Fig. 4). No significant difference was recorded for DBH (W = 425.5, p = 0.15) or height (t = -0.739, df = 19, p = 0.47) between roost and random trees.

All roost trees used (*n* = 13) were surveyed for roost cavities. Bats roosted within splits (*n* = 7), rot cavities (*n* = 2) and under defoliating bark (*n* = 4). Potential available roost cavities (*n* = 30) located during transects were splits (*n* = 5), rot cavities (*n* = 4) and defoliating bark (*n* = 21). Chi-square analysis shows cavity types were not used at random (Table 6). Splits were positively selected, rot cavities were used in proportion to perceived availability, and flaking bark was least preferred. Roost height (14.4 ± 6.2 m) did not differ between roost and random cavities (W = 0.98, p = 0.9 m).

Table 6 Results of chi-square and selection analyses (Bonferroni's confidence intervals) for cavity type.

Cavity type	Roost trees	Random trees	Proportion of use expected	Proportion of use observed	Chi-square value	Selection
Flaking bark	4	21	0.70	0.30	2.86	Negative
Rot cavity	2	4	0.13	0.15	0.04	Absent
Split	7	5	0.17	0.54	10.78	Positive
Total	13	30			ǂ 13.68	

ǂ *p* < 0.001

When comparing our data on roost use to that in previous research in the same area (Zeale, 2011) differences are evident for some variables (Table 7). Frequency of roost switching is lower and average time in roost is higher in our study. Habitat type selection for roosting bats agrees with previous research but our study observed individual tree selection for live *Quercus* species which disagrees with findings of Zeale (2011), who found a positive selection for dead *Quercus* species. The main cavity type selected in 2007/8 was flaking bark whereas a positive selection for splits was documented in our study. Roost height was greater in our study and the lower maximum colony count implies that the colony may have reduced in size since 2007/8.

Table 7 Comparison of roosting data obtained between 2015 (this study) and 2007/8 (Zeale, 2011). *B. barbastellus* sampled in 2015 consisted of four pregnant and three lactating bats, one adult female (reproductive status unknown), one nulliparous female and one adult male. *B. barbastellus* sampled in 2007/8 consisted of nine post-lactating and five non-breeding adult females. 2015 sampling period was April – August. 2007/8 sampling period was July-September. SD = standard deviation.

Variable	2015	2007/8
Maximum colony count (number of bats)	15	23
Main roosting location	Becky Falls	Houndtor Wood
Switching frequency*	0.24	0.44
Average time in roost (days)	4.13 ± 3.27 SD	2.30 ± 2.00 SD
Main roosting habitat	Semi-natural broadleaf	Semi-natural broadleaf
Main tree selection	Live *Quercus* species	Dead *Quercus* species
Main cavity type	Split	Flaking bark
Roost height (metres)	14.42 ± 6.21 SD	7.19 ± 6.03 SD

*roost switching frequency was calculated as the number of switching events by each bat tracked continuously for at least three days divided by the number of tracking days.

3.3 Ranging and foraging

Seven female bats (three pregnant, three lactating and one unsure) were successfully radio-tracked for an average of 2.7 days (range = 2-3 days). The average number of fixes per individual was 139 ± 38 fixes. Bats showed considerable variation in MCP size and maximum range (Table 8). MCP size varied from 56.9-1293.3 ha (Fig. 5). Maximum range varied from 1.2-8.3 km. On average, lactating bats (*n* = 3) had larger MCPs (642.4 ha) and travelled further (5.3 km) than pregnant bats (251.2 ha, 4.2 km, *n* = 3), though differences could not be tested statistically because of small sample sizes. When comparing our data with Zeale (2009) it is evident that ranging behaviour is different between studies (Table 9).

Cluster cores were less variable (5.7-27.9 ha) than MCPs, and on average pregnant bats had larger core areas (17.8 ha) than lactating bats (16.5 ha). Core foraging areas were on average only 5.8 ± 3.7 % of MCP areas. The majority of core foraging areas were away from the home wood with the exception of those of bat three (Fig. 6), which foraged almost exclusively within the home wood. Lactating females regularly returned to the home wood throughout the night (range 2-3 times in a single night). Pregnant bats returned occasionally (range 1-2 times in a single night) and not on every night tracked. Bats showed high site fidelity over the periods in which they were tracked ($\bar{x}$ = 6 days (range = 3-8 days), both for MCPs and 90 % cluster cores.

Table 8 Maximum Convex Polygons (MCP), mean maximum range travelled, and 90 % cluster cores for seven tracked *B. barbastellus*. Mean maximum range was calculated from the known roost used that day to the furthest point travelled for that night.

Bat ID	Date tracked	Days tracked	Status	Foraging area (ha)		Mean max. range (km)
				100 % MCP	90 % Core	
1	27/05/2015	2	Pregnant	218.9	19.7	3.8
2	27/05/2015	2	Unsure	477.6	14.7	5.2
3	27/05/2015	3	Pregnant	56.9	5.7	1.2
15	02/07/2015	3	Pregnant	575.7	27.9	7.7
5	14/07/2015	3	Lactating	1293.3	22.6	8.3
6	30/07/2015	3	Lactating	171.5	16.6	2.2
10	30/07/2015	3	Lactating	462.5	10.2	5.4
Mean ± SD				465.2 ± 410.7	16.8 ± 7.5	4.8 ± 2.7

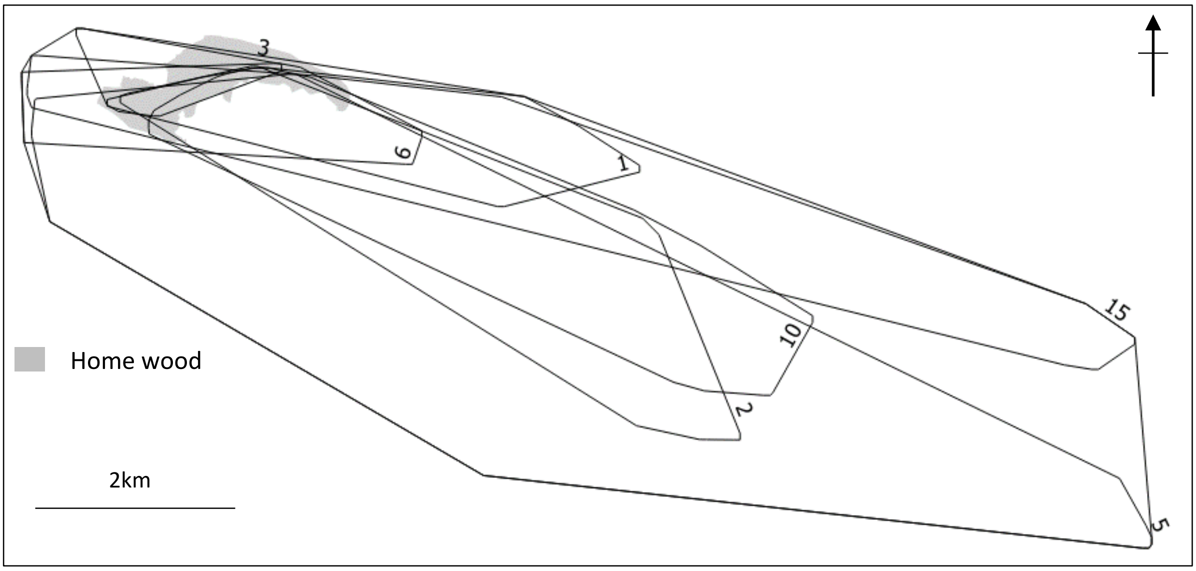

Figure 5 Individual MCP areas for all *B. barbastellus* (numbered) and combined MCP for all bats ($n = 7$).

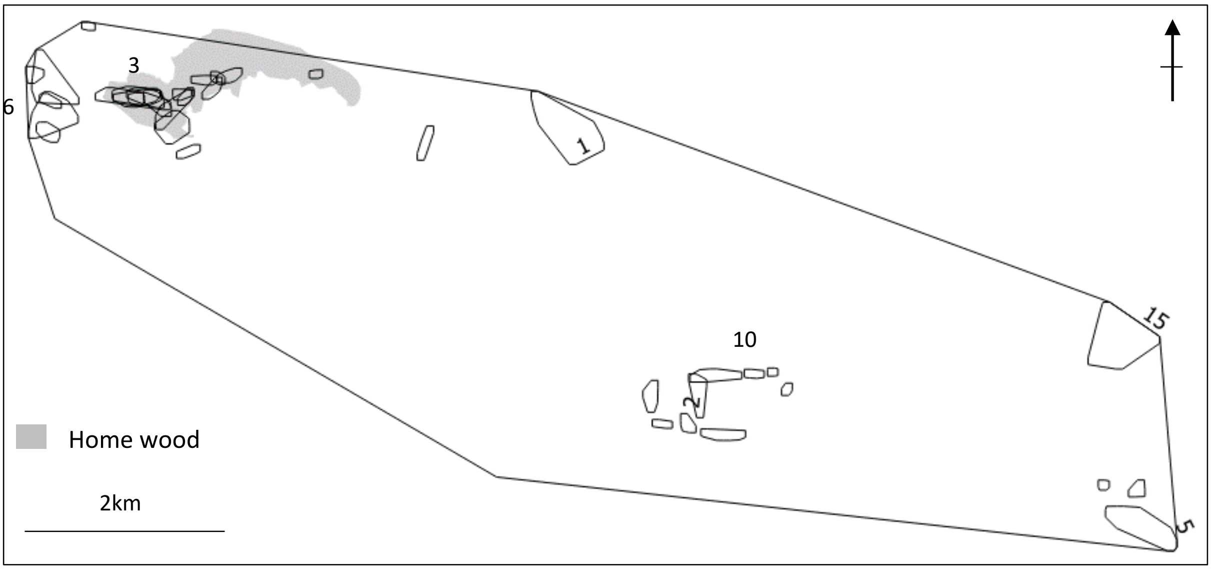

Figure 6 Individual 90 % cluster cores for all *B. barbastellus* (numbered) and combined MCP for all bats (n = 7).

Table 9 Comparison of radio-tracking data between 2015 and 2007/8. *B. barbastellus* sampled in 2015 consisted of three pregnant, three lactating and one adult female bat (reproductive status unknown). *B. barbastellus* sampled in 2007/8 consisted of nine post-lactating and five non-breeding adult females. 2015 sampling period was April - August. The 2007/8 sampling period was July-September. SD = standard deviation.

Variable	2015 (mean ± SD)	2007/8 (mean ± SD)
Mean maximum range (metres)	4.9 ± 2.7	8.5 ± 4.9
100 % MCP (hectares)	465.2 ± 410.6	1587.9 ± 1214.9
Cluster cores (hectares)	16.8 ± 7.5	82.5 ± 21.9

The composition of habitats used by radio-tracked *B. barbastellus* (*n* = 7) was significantly different from that available (weighted mean Wilk's = 0.0123, χ^2_5 = 30.7747, P < 0.01). A ranking matrix (Table 10) shows the order of selected habitats as wetland > woodland > pasture > arable > urban >>> moorland (where > was preferred to that immediately following and where a >>> shows significant selection between the two adjacent habitat categories).

The overall composition of available habitats (combined MCP = 1970.7 ha) was 39.1 % improved grassland, 19.9 % broadleaved woodland, 13.7 % upland moorland, 11.0 % urban, 4.4 % arable, 4.1 % riparian, 3.0 % unimproved grassland, 2.0 % scrub, 1.6 % coniferous woodland, 0.9 % mixed woodland and 0.3 % open water. In comparison the composition of used habitat (mean % habitat within 90 % cluster cores; *n* = 7) was 24.8 % improved grassland, 48.6 % broadleaved woodland, 0.0 % upland moor, 1.4 % urban, 3.0 % arable, 10.7 % riparian, 2.5 % unimproved grassland, 4.1 % scrub, 3.8 % coniferous woodland, 1.4 % mixed woodland and 0.0 % open water (Figure 7).

Table 10 Simplified ranking matrix for *B. barbastellus* (*n* = 7) comparing proportions of habitat within used habitat (90% cluster cores) and available habitat (100% minimum convex polygons). The table shows preference for each category on every row compared to the corresponding habitat in each column. A significant difference between two habitats is shown as +++ (positive) and --- (negative), + or – shows a nonsignificant selection trend. Rank order = five being the most selected and zero being the least selected.

	Arable	Moorland	Pasture	Urban	Wetland	Woodland	Rank
Arable		+	-	+	-	-	2
Moorland	-		---	---	---	---	0
Pasture	+	+++		+	---	-	3
Urban	-	+++	-		---	---	1
Wetland	+	+++	+++	+++		+	5
Woodland	+	+++	+	+++	-		4

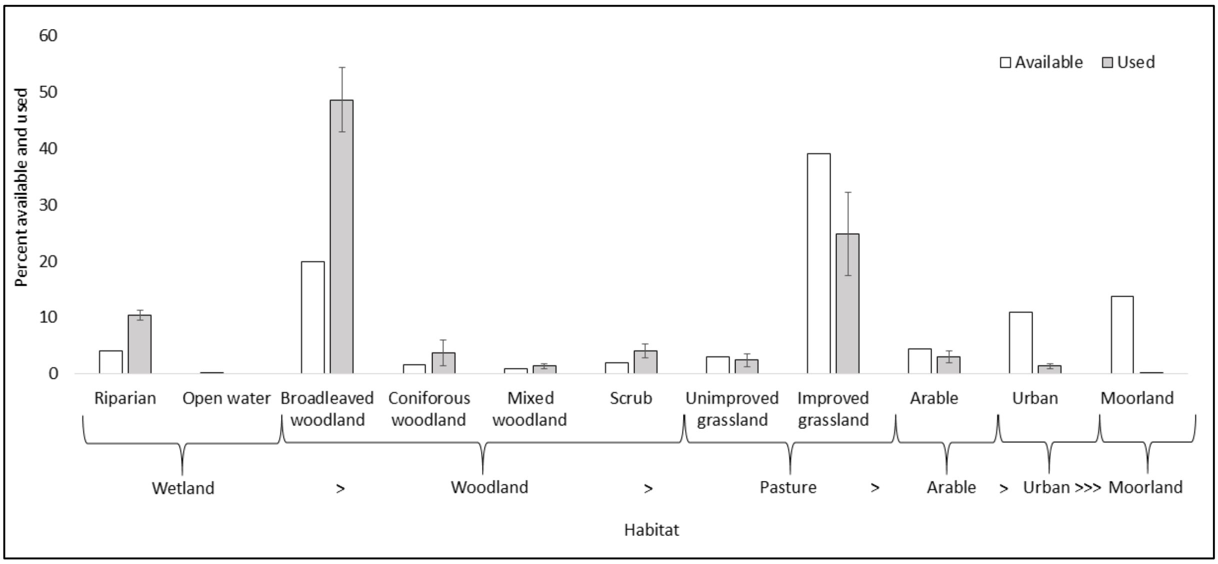

Figure 7 Comparison of 11 available habitat types (combined MCP) and habitat used (90 % cluster cores) (mean % of area used) by *B. barbastellus* (*n* = 7) ± standard error in selection rank order of six broad habitat types where > shows a habitat preferred to that immediately following, and where >>> shows significant selection between the two adjacent habitat categories.

3.4 Diet

Prey DNA was successfully extracted from 12 faecal pellets collected between April and September from both female and male *B. barbastellus* (Table 2). Bioinformatics reprocessing and manual verification confirmed 51 prey species belonging to two insect orders (Diptera and Lepidoptera) and five families (Crambidae, Geometridae, Noctuidae, Pyralidae, Scathophagidae) (Table 11). The average number of prey species consumed per bat was 5.8 ± 4.6. When combining these findings with those of Zeale (2011), of the 51 prey species identified ten were consumed by more than one bat and five were consumed by bats in both studies (Table 12).

Table 11 List of prey identified in the faeces of 12 *B. barbastellus* by DNA analysis. Similarity of closest matches to reference sequences on BOLD are shown as a Bit score and similarity %. Total number of sequences assigned to species is 1732. Recovery refers to frequency of occurrence of prey items among bats.

Order	Family	Species	Common name	Recovery (*n* bats)	Similarity %	Frequency (*n* sequences)	Bit score
Diptera	Scathophagidae	*Scathophaga stercoraria*	yellow dung fly	1	99.4	9	283
Lepidoptera	Crambidae	*Eudonia lacustrata*		1	99.4	10	281
		Scoparia basistrigalis		1	99.4	3	285
	Geometridae	*Aethalura punctulata*	grey birch	1	100	100	289
		Asthena albulata	small white wave	1	100	1	289
		Cabera pusaria	common white wave	2	100	38	291
		Catarhoe rubidata	ruddy carpet	1	99.4	3	283
		Chloroclysta miata	autumn green carpet	1	99.4	2	283
		Cosmorhoe ocellata	purple bar	1	100	3	291
		Cyclophora annularia	The mocha	1	99.4	1	285
		Dysstroma truncata	common marbled carpet	1	99.4	4	285
		Ectropis crepuscularia	The engrailed	1	100	1	291
		Epirrhoe alternata	common carpet	2	99.4	7	285
		Eulithis prunata	The phoenix	1	100	104	291
		Eupithecia abbreviata	brindled pug	3	99.4	24	285

Eupithecia plumbeolata	lead-coloured pug	1	99.4	13	281
Eupithecia subfuscata	grey pug	1	100	45	291
Eupithecia vulgata	common pug	1	99.4	28	285
Gymnoscelis rufifasciata	double-striped pug	1	99,4	46	285
Hydriomena furcata	July highflyer	1	100	20	289
Hydriomena impluviata	May highflyer	1	100	96	291
Idaea aversata	riband wave	1	99.4	19	281
Idaea biselata	small fan-footed wave	1	100	4	291
Lampropteryx suffumata	water carpet	1	99.4	16	285
Lomaspilis marginata	clouded border	1	99.4	18	283
Odontopera bidentata	scalloped hazel	4	100	455	291
Peribatodes rhomboidaria	willow beauty	1	99.4	13	281
Perizoma affinitatum	The rivulet	1	99.4	2	283
Petrophora chlorosata	brown silver-line	2	99.4	11	285
Scopula floslactata	cream wave	2	100	14	291
Selenia dentaria	early thorn	1	99.4	12	285
Trichopteryx carpinata	early tooth-striped	1	100	2	289
Xanthorhoe designata	flame carpet	1	99.4	13	285

	Xanthorhoe fluctuata	garden carpet	1	99.4	7	285
	Xanthorhoe montanata	silver-ground carpet	2	100	43	289
Noctuidae	*Abrostola tripartita*	The spectacle	1	99.4	1	285
	Agrotis exclamationis	heart and dart	3	100	150	291
	Agrotis ipsilon	dark sword-grass	1	99.4	20	285
	Anaplectoides prasina	green arches	1	99.4	29	285
	Apamea monoglypha	dark arches	1	99.4	39	285
	Autographa gamma	silver y	1	99.4	19	281
	Cerastis rubricosa	red chestnut	1	99.4	27	285
	Conistra vaccinii	The chestnut	1	99.4	7	285
	Diarsia rubi	small square-spot	1	99.4	4	285
	Lithophane socia	pale pinion	1	99.4	17	281
	Mesapamea secalis/didyma	common/lesser common rustic	2	99.4	3	285
	Noctua janthe/pronuba	Langmaid’s/large Yellow Underwing	1	99.4	1	283
	Ochropleura plecta	flame shoulder	1	99.4	15	285
	Orthosia incerta	clouded drab	2	99.4	185	281
	Phlogophora meticulosa	angle shades	1	99.4	14	283
Pyralidae	*Endotricha flammealis*		1	99.4	14	283

Table 12 Comparison of prey identified in the faeces of *B. barbastellus* by DNA analysis in 2007/8 and 2015. Recovery refers to the frequency of occurrence of a prey item in a faecal sample. Data from 2015 (*n* = 12) and 2007/8 (*n* = 51) (Zeale, 2011) are included to show difference in prey species consumption between years.

Order	Family	Species	Common name	Recovery 2015 (*n* bats)	Recovery 2007/8 (*n* bats)*
Lepidoptera	Geometridae	*Cabera pusaria*	common white wave	2	2
		Epirrhoe alternata	common carpet	2	1
		Eupithecia abbreviata	brindled pug	3	0
		Odontopera bidentata	scalloped hazel	4	3
		Petrophora chlorosata	brown silver-line	2	1
		Scopula floslactata	cream wave	2	0
		Xanthorhoe montanata	silver-ground carpet	2	0
	Noctuidae	*Agrotis exclamationis*	heart and dart	3	2
		Mesapamea secalis/didyma	common/lesser rustic	2	0
		Orthosia incerta	clouded drab	2	0

* Data from *B. barbastellus* captured at several sites throughout the UK including the Bovey Valley.

4 Discussion

4.1 Roost use

B. barbastellus selected roosts within old growth semi-natural woodland. Of the 13 roosts recorded, 12 were in this habitat, and there was significant positive selection of semi-natural broadleaved woodland and significant negative selection of other available habitat. This agrees with previous research at the site (Zeale, 2009) and strengthens the view that old growth woodland is important for *B. barbastellus*, and that loss of such woodland throughout Europe has contributed to population declines (Russo *et al*. 2004; Piraccini, 2011; Zeale, 2011). Retention of semi-natural broadleaved woodland in the Bovey Valley should be ensured as a main priority, as should the protection of veteran trees and standing deadwood.

It is evident that the colony roosted in trees that were spatially close to each other, with nine of the 13 roosts located in one specific area of the valley. This location differs from a similar clustering of roosts found in 2007/8 (Zeale, 2011). Although still within semi-natural broadleaved woodland, the main colony roosting area has moved approximately 750 metres east. This may agree with the observations of Greenaway (2008) who suggested that a colony will gradually change its spatial patterns of occupancy in a woodland over several years. One reason for this is that roosting opportunity changes over time as trees age (although it may also be the result of surveying bats at different times of the season). More roosting opportunity is present at one point in time than was previously or will be in the future. This temporal behavioural change has implications for the carrying capacity of woodland for *B. barbastellus*. Expanding suitable habitat by encouraging the promotion, development and conservation of important roost characteristics observed in this study in the relevant sections of plantation broadleaved woodland could increase the carrying capacity of the woodland and ensure future sustainability of the colony. Improving the value of plantation broadleaved woodland is advised by the Joint Nature Conservancy Council (JNCC, 2010) and appears a suitable consideration for Bovey Valley Woods. Our research found that *B. barbastellus* avoided conifer stands and so replacement of these with broadleaved species, as proposed by the Woodland Trust, will further improve the area of *B. barbastellus*.

As found by Russo *et al*. (2004) roost plots had significantly greater canopy openness when compared to random plots. Roosts positioned in areas of greater canopy gaps will benefit from increased sunlight which will raise the temperature within the roost. Zeale (2011) did not find significance in canopy openness between roost and random plots indicating canopy gaps are important for pregnant and lactating bats and less so for the post-lactating bats studied by Zeale (2011). Lactating females have dependant pups that are less able to regulate body temperature and so would benefit from exposure of the roost to sunlight (Kunz and Fenton, 2005; Camaclang, 2006). Post-lactating and nulliparous females have reduced energy demands compared with pregnant and lactating females, and can use cooler roosts where bats can enter torpor to conserve energy. Roosts used by pregnant and lactating females are of high importance for conservation as the quality and availability will influence the productivity of the population. If canopy openness also reduces humidity (Latif and Blackburn, 2009), our research indicates that high humidity is not as important for roosting by B. *barbastellus* in the Bovey Valley.

The importance of understorey for *B. barbastella* is unclear. Greenaway (2001) and Russo *et al*. (2004) described preferred roosting habitat as typically surrounded by a relatively dense understory (it should be noted that the research by Russo *et al*. (2004) was undertaken in *Fagus sylvatica* dominant woodland, and that the amount of standing deadwood and lack of understorey where correlated); Zeale (2009) found a lack of dense understory around roosts. Our study agrees with the findings of Zeale (2009) as although understorey was present close to roosts it was typically sparse. Further quantitative measurements are needed to fully assess the understorey at this site.

In contrast to Zeale (2011), our study did not find a positive selection for dead trees. Bats used both dead and live trees for roosting. This further strengthens the conclusions by Zeale (2011) that any tree that provides roosting opportunities (e.g. by possessing a split, rot hole or flaking bark) is important, and any attempt to establish guidance promoting just the retention of standing deadwood may remove important roosting opportunities. There were significantly more cavities in roost trees than in random trees. This is in agreement with the findings of Zeale (2011), and indicates the importance of trees containing several cavities.

Roost plots were significantly closer to footpaths than random plots. In addition, roosts were clustered near footpaths with regular pedestrian traffic (visitors to a popular tourist site – Becky Falls). These footpaths were considered as potential disturbance, but do not appear to influence roost selection. If roosting opportunities are present in all semi-natural areas in the valley, there are many other areas that are relatively free from human disturbance. As roosting *B. barbastellus* can sometimes be disturbed by an approaching person while tracking bats to roost sites (Alex Sams pers. comm.), this information is of interest as it may indicate that bats can habituate to disturbance.

Analyses of roost type showed that *B. barbastellus* selected splits over flaking bark and rot cavities were used in line with availability. This is in contrast to the results of Zeale (2011) who found a significant positive selection for flaking bark. The difference in findings between the two studies may be associated with differences in roost availability at the time of study (a large selection of roosts with flaking bark found in earlier research were no longer available), or differences in the reproductive status of tracked individuals. As the bats avoided flaking bark despite this roost type being present, a lack of availability of this roost type is unlikely. The maternity colony studied selected splits, which probably provide relatively large cavities, stable temperature and better security from predation.

The average height of roost entrances (14.42 m) did not differ from random cavities but was significantly higher than that found by Zeale (2011) (7.19 m). The reason for this may be a change in the availability of suitable roosts, or that pregnant and lactating females are selecting roosts relatively close to the canopy. In conjunction with the finding that bats selected sites with relatively low canopy cover, the bats in our study may be selecting roosts that are exposed to relatively high levels of sunlight and consequent increased temperatures. Russo *et al*. (2004) found that *B. barbastellus* roost cavities were significantly higher than random cavities.

Russo *et al*. (2004) proposed that thermal properties play an important role in roost selection by lactating female *B. barbastellus*. Lactating females would be expected to select south-facing roosts to optimise conditions for dependant pups. Although not statistically tested seven of the 13 roosts in our study faced south. Furthermore, the roost used predominantly through the lactation period was south facing and positioned high in the canopy. Such a roost aspect and height is likely to provide warmth, promoting growth of young.

Roost switching by tree-dwelling bats is well established (O'Donnell and Sedgeley, 1999), and switching by *B. barbastellus* follows similar patterns to those seen in other tree-dwelling bat species (Russo *et al*. 2005; Greenaway, 2008; Zeale, 2011). Roost switching was recorded at half the rate found by Zeale (2011), and time in roost before switching was double. This may be due to variation between years, but more probably is due to differences in the reproductive status of females monitored. Pregnant and lactating females may show relatively low rates of roost switching and any benefits of switching, such as parasite load reduction, avoiding roost fouling and minimising predation risk (Owen *et al*. 2001; Russo *et al*. 2004; Zeale, 2009) may be of relatively low importance compared with the advantages associated with remaining in one roost when dependant young are present. Mothers may experience difficulties carrying non-volant young, the thermal roost properties may be less suitable in other roosts, or perhaps movement in lactation would fragment the maternity colony and reduce any associated social or thermoregulatory benefits.

Prior to this research, the maximum colony size recorded in the study area from a single roost was 23 individuals (Zeale, 2011). *B. barbastellus*, as with other tree dwelling bats, show fission-fusion behaviour (Fleischmann and Kerth, 2014), with subgroups fragmenting and reassembling repeatedly. As such, 23 should be taken as an absolute minimum and it is likely that the colony (in terms of number of breeding females) is likely to have been higher in number. Our study found a maximum colony size of 15 individuals from a single roost. There was no evidence to indicate that the colony was split during this period, but this cannot be confirmed. Whether this suggests the colony has reduced in size since 2008 is unclear as this study, in contrast, monitored the colony before juveniles were volant and so a smaller colony size would be expected in comparison with counts made during the post-lactation period. To establish trends in colony numbers, medium to long-term monitoring should be continued as proposed by Angell and Mason (2014). Trends in frequency of activity may indicate increases or decreases in colony numbers over several years. In addition, radio-tracking could be repeated in future years.

4.2 Ranging behaviour

The large variability in individual MCP and foraging distances found in our study has been observed in other studies on *B. barbastellus* (Davidson-Watts and Mckenzie, 2006; Greenaway 2008; Zeale *et al*. 2012). The size of cluster cores, which are likely to be important foraging areas, were less variable in size, as observed by Zeale (2009). MCP size shows considerable variability across study sites (Davidson-Watts and Mckenzie, 2006; Greenaway 2008; Zeale *et al*. 2012) and, in part, reflects the ability of the species to commute long distances on occasion. The relatively small size of the combined MCP in our study should be viewed with caution as the number of bats tracked is also small compared with other studies, and the combined MCP size will be related to the number of bats tracked if bats forage in different areas (which was observed). The likely reasons for the relatively small size of individual MCPs in our study, however, is that the relatively high wing loading of pregnant bats will restrict foraging range, and lactating females need to revisit the roost to suckle pups through the night. All lactating bats tracked in our study returned to the maternity roost periodically through the night. Zeale *et al*. (2012) documented post-lactating and nulliparous bats having a greater mean MCP (1587 ha) than a study by Greenaway (2008) (1235 ha) that included pregnant and lactating females. An additional theory is that post lactating bats forage at greater distances from the roost to reduce competition with volant juveniles foraging closer to the home wood, though this is considered unlikely if prey are superabundant. More research is needed to investigate these theories.

One bat surveyed in this study foraged almost exclusively within the home wood during the period in which it was tracked. This was not observed among bats tracked from this colony in 2007/8 (Zeale, 2009). This behaviour was observed at the nearby Dendles Wood site early in the 2007/8 season. Foraging within the home wood has been observed in *B. barbastellus* (Davidson-Watts and Mckenzie, 2006) and other insectivorous bats (Duvergé and Jones, 1994). Seasonal changes in foraging behaviour may be affected by changes in ambient temperature (Greenaway, 2008), prey behaviour and availability, intraspecific competition (Zeale, 2011), reproductive status, or a combination of these factors. Data obtained from the colony at Bovey Valley Woods indicates that reproductive status may be an important factor influencing foraging range, but other factors cannot be discounted.

Our study agrees with previous findings (Hillen *et al*. 2009; Zeale, 2009) that *B. barbastellus* foraging areas have little or no overlap between individuals. This spatial organisation is evident across populations (Greenaway 2008, Davidson-Watts and Mckenzie, 2006) with Zeale (2009) proposing that *B. barbastellus* may be territorial. Spatial segregation of individual foraging areas has implications for population ecology and the spatial scale for successful management of the landscape.

We found foraging *B. barbastellus* positively selected (in order) wetland, woodland and pasture for foraging, and arable areas, urban areas and moorland where least preferred. This is in agreement with Zeale (2009) and indicates that despite variation in distance travelled, size of MCP and cluster cores, these habitat types are selected throughout the active period and is not influenced by reproductive state. As proposed by Zeale (2012) the habitats selected are associated with high insect abundance, particularly riparian vegetation and oak woodland which support diverse populations of moths. In agreement with Zeale *et al*. (2012) the protection and restoration of bankside vegetation, wet meadows, wet woodland, and semi-natural deciduous woodland is important.

Pasture may contain relatively few potential prey resources (see section 4.3) yet the habitat is selected by *B. barbastellus*. This positive selection has been explained by the presence of features at boundaries such as hedgerows and the edges of broadleaved woodland (Zeale, 2009). Our study confirms this, as bats found in these habitats were located at the boundaries near to adjoining woodland or within close proximity to hedgerows. Although the telemetry procedure used lacks fine spatial resolution, we believe the consistent location of fixes deemed to be close to boundaries confirms that the boundaries rather than the grassland itself is being used.

Moorland was not a preferred habitat. This may be due to the exposed nature of upland moor habitat, as suggested by Zeale (2009). Steps to improve moorland for foraging *B. barbastellus* would be a waste of resources unless it is shown that the diet consists of prey that are associated with moorland habitat for at least part of their life cycle. *Rhinolophus euryale* has shown to consume adult lepidotera which have a larval stage outside the bats foraging ground (Arrizabalaga-Escudero *et al*. 2015). Coniferous woodland, mixed woodland, open water, scrub and urban areas are of low importance to the Bovey Valley population and although foraging may occur in these habitats, it is probably opportunistic rather than targeted. Arable habitat was not a preferred foraging area but steps could be taken to retain, establish and improve field boundaries within this habitat which may provide increased opportunity for *B. barbastellus* in the future. Urban expansion that encroaches on riparian habitat, broadleaved woodland and grassland is predicted to negatively affect the colony by removing foraging opportunities.

A core sustenance zone (defined as the area surrounding a bat roost within which habitat availability and quality will have a significant influence on the resilience and conservation status of the colony using the roost) around the home wood should be created in which important habitat types, as highlighted by this report, can be conserved or enhanced for *B. barbastellus*. The most suitable way to establish a sustenance zone is to create a buffer around the home wood using the radius of the mean maximum range of the radio-tracked bats. In combination with Zeale (2009) and our research, the mean maximum range of all *B. barbastellus* radio-tracked from the Bovey Valley colony is 6.5 km (*n* = 21 bats).

4.3 Diet

Sampled *B. barbastellus* consumed lepidopteran prey belonging to four families. The majority of prey species belonged to the families Geometridae and Noctuidae. It is likely these prey species were consumed more frequently because of chance encounters with more abundant species. Management should focus on maintaining and, if possible, increasing consumed moth species within the home wood and observed surrounding sustenance zone. As an example *Cabera pusaria* larvae are known to feed on *Butula* species and so ensuring an adequate amount of birch trees will provide at least one prey source for *B. barbastellus*. *Epirrhoe alternate* larvae feed on Galium species and so ensuring an adequate amount of goosegrass will provide at least two potential prey species. Depending on the resources available this can be applied to the more commonly eaten prey, or the entire confirmed prey list found during our study.

5 Conclusion

Our study identified several features of importance to the roosting and ranging ecology of the population of *B. barbastellus* in the Bovey Valley Woods. By focusing on these features the scale of management needed to ensure the conservation of the colony can be achieved.

Roost trees were located almost exclusively in semi-natural mature woodland despite other woodland types being available. Site fidelity was high for a defined area within the home wood with use for both roosting and foraging. The minimal intervention management strategies in place for this area should be continued and any changes proposed reviewed for the impact to the current woodland structure. Allowing individual trees to mature within the areas classified as plantation broadleaved woodland will ensure suitable roosting sites in the future and increase the suitability for the colony to move further around the home wood between years. The erection of *B. barbastellus* style roost boxes in these areas will ensure suitability for roosting in the short term. It will be important to ensure the provision of trees that provide roosting opportunities, including live mature trees and standing deadwood with splits, rot holes and flaking bark. The coniferous stands within the home wood were not utilised for roosting and are considered to be of limited value for foraging. Their conversion to broadleaved stands would be positive for the colony. Further features found to be important for selection of roost trees and roost areas by *B. barbastellus* include canopy openness and a high tree density.

Important foraging habitat includes riparian habitats, broadleaved woodland, and field boundary features such as broadleaved woodland edge, hedgerows and tree lines found in grassland habitat and/or around arable fields. The protection and restoration of bankside vegetation, wet meadows, wet woodland, semi-natural deciduous woodland and hedgerows is advised. All of the above habitats within a 6.5 km sustenance zone around the home wood should be identified and conserved. Proposed urban development within this zone should be reviewed in terms of encroachment on the above habitat types and features.

Our research highlighted that *B. barbastellus* bats in the Bovey Valley eat many moth species. Ensuring or increasing the abundance of Lepidoptera within the population's sustenance zone will directly benefit the population.

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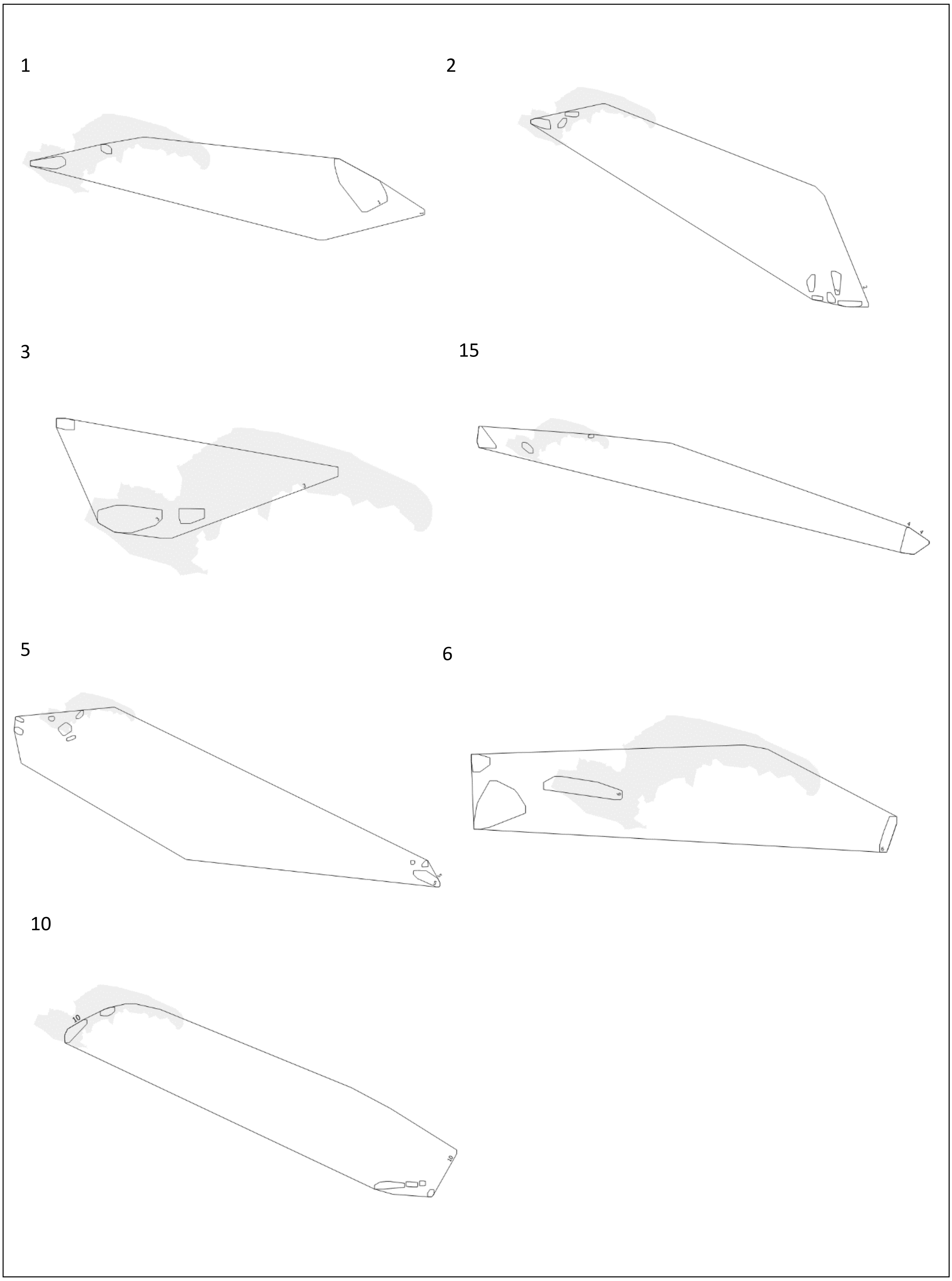
Appendix 1 Summary of all bat captures in order of capture date.

#	Date	Species	Age	Sex	Status	FAL (mm)	Bodymass (g)
8	22/04/2015	*Barbastella barbastellus*	adult	male		39.5	8.1
11	22/04/2015	*Barbastella barbastellus*	adult	male		39.99	6
19	22/04/2015	*Myotis mystacinus*	adult	female			
20	22/04/2015	*Myotis daudentonii*	adult	male			
21	11/05/2015	*Myotis nattererii*	adult	female		28.19	4
22	11/05/2015	*Rhinolopus hipposideros*	adult	male		36.23	
23	13/05/2015	*Myotis nattererii*	adult	male		38.8	6.4
24	14/05/2015	*Myotis species* (small)	adult	female			
25	15/05/2015	*Pipistrellus pipistrellus*	adult	female			
12	22/05/2015	*Barbastella barbastellus*	adult	female	pregnant	39.27	9.8
26	22/05/2015	*Myotis nattererii*	adult	female			
27	22/05/2015	*Pipistrellus pipistrellus*	adult	male			
28	22/05/2015	*Pipistrellus pipistrellus*	adult	male			
29	22/05/2015	*Pipistrellus pipistrellus*	adult	female			
30	22/05/2015	*Pipistrellus pipistrellus*	adult	female			
13	26/05/2015	*Barbastella barbastellus*	adult	female	unsure	39.35	7.9
1	27/05/2015	*Barbastella barbastellus*	adult	female	pregnant	38.25	8.5
2	27/05/2015	*Barbastella barbastellus*	adult	female	unsure	38.29	8.6
3	27/05/2015	*Barbastella barbastellus*	adult	female	pregnant	39.04	8.6
4	27/05/2015	*Barbastella barbastellus*	adult	female	pregnant	37.15	8.7
14	27/05/2015	*Barbastella barbastellus*	adult	male		34.28	6.7
31	15/06/2015	*Pipistrellus pipistrellus*	adult	female			
32	15/06/2015	*Pipistrellus pipistrellus*	adult	male			
33	16/06/2015	*Pipistrellus pygmaeus*	adult	male			
34	16/06/2015	*Myotis mystacinus*	adult	female			

35	18/06/2015	*Myotis mystacinus*	adult	female			
36	18/06/2015	*R. ferrumequinum*	adult				
15	02/07/2015	*Barbastella barbastellus*	adult	female	pregnant		
16	02/07/2015	*Barbastella barbastellus*	adult	female	pregnant	39.7	11.2
17	02/07/2015	*Barbastella barbastellus*	adult	female	pregnant		
10	14/07/2015	*Barbastella barbastellus*	adult	female	lactating	39.37	10
5	30/07/2015	*Barbastella barbastellus*	adult	female	lactating	39.19	11.3
6	30/07/2015	*Barbastella barbastellus*	adult	female	lactating	39.8	9.6
37	30/07/2015	*Pipistrellus pipistrellus*	adult	female			
38	30/07/2015	*Myotis species* (small)	adult	female			
39	30/07/2015	*Myotis mystacinus*	adult	female	lactating		
40	30/07/2015	*Myotis species* (small)	adult	female	lactating		
41	30/07/2015	*Pipistrellus pipistrellus*	adult				
18	05/08/2015	*Barbastella barbastellus*	adult	male		36.55	9
42	17/08/2015	*Myotis species* (small)	adult	male		32.42	4.1
43	17/08/2015	*Myotis brandtii*	adult	male		33.48	4
7	20/08/2015	*Barbastella barbastellus*	adult	male		38.85	9.4
44	25/08/2015	*Plecotus auritus*	adult	male		32	7
45	25/08/2015	*Myotis mystacinus*	adult	female	p. lactating	34.41	5.2
46	26/08/2015	*Myotis mystacinus*	adult	male		27.28	4.2
47	26/08/2015	*Plecotus auritus*	adult	male		39.93	8
48	26/08/2015	*Myotis mystacinus*	adult	male		34.04	4.1
49	27/08/2015	*Myotis brandtii*	juvenile	male		34.12	4.3
50	27/08/2015	*Pipistrellus pipistrellus*	adult	female		33.24	8
51	27/08/2015	*Plecotus auritus*	adult				
52	01/09/2015	*Plecotus auritus*	adult	female		34.86	8.7
53	01/09/2015	*Myotis nattererii*	adult	male		37.65	7
9	13/09/2015	*Barbastella barbastellus*	adult	female	N. breeding	39.83	10

Appendix 2 Comparison of individual MCPs (large open polygon), 90 % cluster cores (small open polygons) and home wood (grey polygon). *n* = bat ID number (refer to table 3 for additional bat information).



Appendix 3 Aerial images with individual MCPs and 90 % cluster cores for all bats.

(a) Aerial image* with individual MCP (large open polygon), 90 % cluster cores (small open polygons) and home wood (grey polygon) for bat 1

(b) Aerial image* with individual MCP (large open polygon), 90 % cluster cores (small open polygons) and home wood (grey polygon) for bat 2.

(c) Aerial image* with individual MCP (large open polygon), 90 % cluster cores (small open polygons) and home wood (grey polygon) for bat 3.

(d) Aerial image* with individual MCP (large open polygon), 90 % cluster cores (small open polygons) and home wood (grey polygon) for bat 15.

(e) Aerial image* with individual MCP (large open polygon), 90 % cluster cores (small open polygons) and home wood (grey polygon) for bat 5.

(f) Aerial image* with individual MCP (large open polygon), 90 % cluster cores (small open polygons) and home wood (grey polygon) for bat 6.

(g) Aerial image* with individual MCP (large open polygon), 90 % cluster cores (small open polygons) and home wood (grey polygon) for bat 10.

* Aerial imagery taken from Google Earth; supplied by DigitalGlobe, Getmapping plc, Interfoterra Ltd & Bluesky, Lansat, The Geoinformation Group and Google plc.