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Ground-based and LiDAR-derived measurements reveal scale-dependent selection of roost characteristics by the rare tree-dwelling bat *Barbastella barbastellus*

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ABSTRACT

Bats use roosts for protection, sociality and reproduction. Lack of knowledge regarding the specific roost preferences of tree-dwelling bats means that roosts are regularly removed from woodland during felling and thinning interventions, even when woodlands are managed to promote biodiversity. The often-unintentional loss of roosts this way continues to constrain efforts to conserve many rare bat species.

We investigated roost selection by the barbastelle *Barbastella barbastellus* in fragmented oak woodlands in southwest England. Twenty-nine bats were radio tracked to 44 tree roosts between 2007 and 2015. Twenty-four different characteristics of roosts were measured using a combination of ground-based field surveys and airborne light detection and ranging (LiDAR) imagery, and roost characteristics were compared with those of random trees to determine selection.

Bats selected trees in ancient semi-natural broadleaved woodland over other woodland habitat types. Standing dead oak (*Quercus* spp.), while scarce, was positively selected over other tree types and supported significantly more suitable roost cavities. Roost selection was most strongly influenced by the number of cavities present on a tree and the openness of the canopy around the tree. The height of roost cavities and distance to water were also important features that influenced selection. Pregnant and lactating bats switched roosts less frequently than post-lactating and nulliparous bats and selected cavities higher on trees, most likely to facilitate the development of offspring and reduce the risk of predation.

Old growth woodland is vitally important to barbastelles and so the preservation and restoration of these habitats should be a conservation priority. While standing dead trees supported more preferred roost cavities than other tree types, our findings indicate that any tree supporting a suitable cavity may be used as a roost, irrespective of the size, condition or species, and should be retained wherever possible. Promoting the natural succession of younger woodland will help to deliver additional sustained benefits in the future.

1. Introduction

The availability of suitable roosts influences the distribution, diversity, social structure and reproductive fitness of bats (Kunz and Lumsden, 2003). Roosts provide protection from predation and shelter from ambient environmental conditions and are important sites for mating, hibernation and rearing young (Kunz and Lumsden, 2003; Lacki et al., 2007; Willis and Brigham, 2007). When woodlands are subject to human intervention e.g. to increase economic yield, promote recreational use or to improve ecological function after degradation has taken place, these interventions can affect the availability and suitability of roosts. By identifying characteristics of tree roosts that are most important to bats a more directed and effective approach to woodland management can be undertaken that delivers improved conservation outcomes.

Meta-analyses have identified a number of habitat features that are typically important to tree-dwelling bats, including tree height and diameter, canopy closure, tree trunk girth and the occurrence of standing deadwood (Lacki and Baker, 2003; Kalcounis-Ruppell et al., 2005; Fabianek et al., 2015a; Naďo and Kaňuch, 2015). The frequency,

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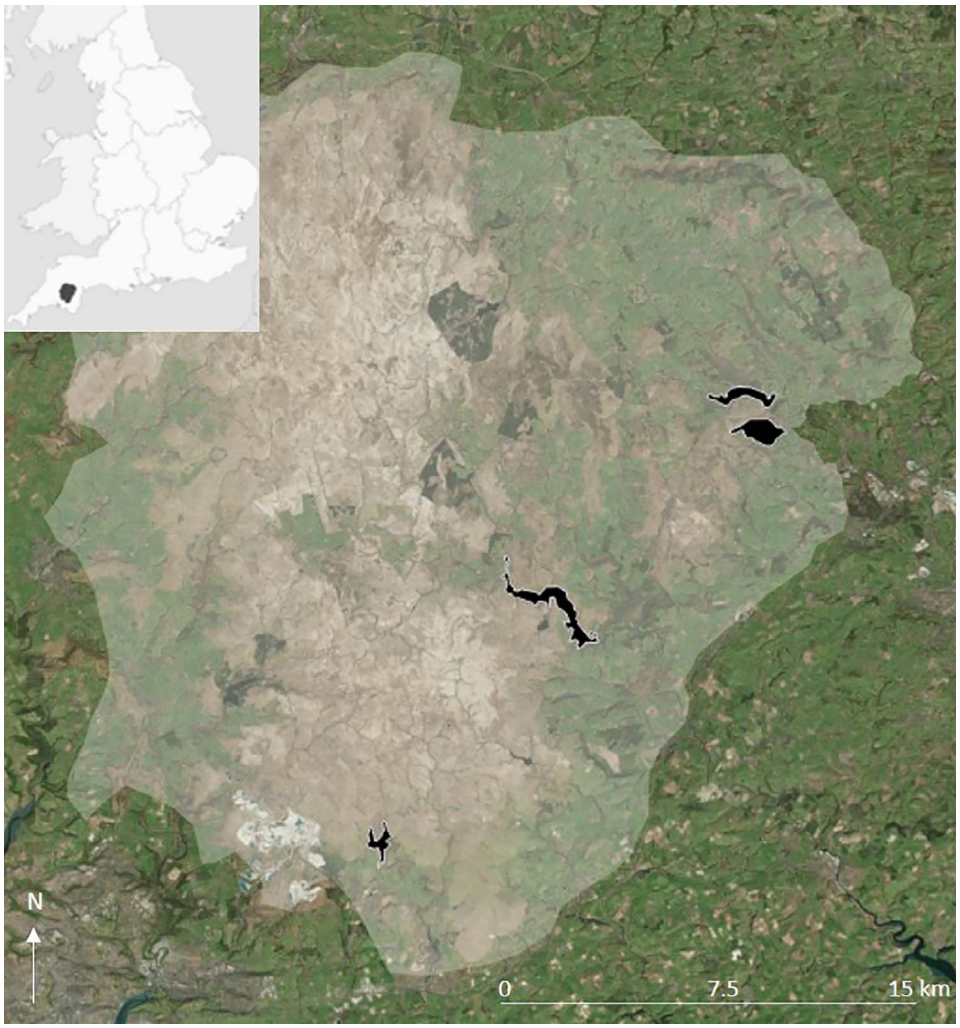

Fig. 1. Woodland study sites (black polygons) from top to bottom: Houndtor Wood (3°44′50″ W, 50°36′24″ N) (71 ha), Yarner Wood (3°43′35″ W, 50°35′41″ N) (150 ha), White Wood (3°51′40″ W, 50°31′56″ N) (241 ha), and Dendles Wood (3°56′59″ W, 50°26′13″ N) (50 ha), in Dartmoor National Park (grey polygon). Inset: location and boundary of Dartmoor National Park within the UK. Adapted from Ordnance Survey open data base map.

type and size of cavities has also been shown to influence roost selection (Russo et al., 2004; Lučan et al., 2009). In addition, bat presence within woodlands has been linked to the ruggedness (Froidevaux et al., 2016) and openness (Russo et al., 2004; Cox et al., 2016; Kortmann et al., 2017) of the upper canopy. Favourable microclimatic conditions may increase roost suitability (Boyles, 2007) and the phenomenon of social thermoregulation driven by roost characteristics indicates that bats do not rely passively on ambient temperature while roosting (Willis and Brigham, 2007; Russo et al., 2017a). In certain landscapes, topographical characteristics such as elevation, terrain aspect and distance to water have also been shown to be important (Cryan et al., 2000; Lacki and Schwierjohann, 2001; Lacki and Baker, 2003).

The importance of woodland characteristics can vary according to the sex and reproductive state of bats. Breeding female *Plecotus macrobullaris*, for example, predominantly roost in tree cavities at lower elevations than non-breeding females, while males select roosts in rock cavities and man-made structures (Alberdi et al., 2015). Understanding variability in roost selection by other species during different reproductive stages requires further work (Jachowski et al., 2016).

Many tree-dwelling bat species form fission-fusion societies, whereby individuals roost with one another interchangeably (Fleischmann and Kerth, 2014), and regular roost switching by bats in these societies is well documented (O'Donnell and Sedgeley, 1999; Russo et al., 2005; Trousdale et al., 2008; Ngamprasertwong et al., 2014). The primary function of roost switching remains unclear although reducing parasite load and risk of predation, minimising roost fouling, maintaining social cohesion among individuals, and maintaining knowledge of the locations of available roosts have all been proposed as drivers (Owen et al., 2001; Russo et al., 2005; Kühnert et al., 2016). Maintaining knowledge of existing roosts may be particularly important due to the ephemerality of tree roosts (Trousdale et al., 2008; Russo et al., 2005) and the temporal variation in the thermoregulatory requirements of bats (Russo et al., 2017a). While frequent roost switching is commonly exhibited by some species, these species typically express high inter-annual fidelity to roosting sites, returning to the same breeding site each year (Hillen et al., 2010; Silvis et al., 2014).

The barbastelle (*Barbastella barbastellus*; Schreber, 1774) is classified as 'Near Threatened' by the International Union for the Conservation of Nature (Piraccini, 2016), is listed under Annex II and IV of the EU Habitats Directive and is a UK Biodiversity Action Plan priority species (JNCC, 2010). Throughout Europe, barbastelles have retained a strong preference for roosting in trees and require old growth broadleaved forests that provide a high number of suitable roost cavities (Russo et al., 2004, 2010). Historic declines in populations have been associated with loss of old growth broadleaved forest habitat (Russo et al., 2004; Piraccini, 2016). To date, few studies have characterised the roosting requirements of the barbastelle. Russo et al. (2004, 2010) and Kortmann et al. (2017) documented roost preferences in breeding populations inhabiting extensive beech (*Fagus sylvatica*) and mixed upland