

Roost selection by non-breeding Leisler's bats (*Nyctalus leisleri*) in montane woodlands: implications for habitat management

MARTINA SPADA¹, SUSANNE SZENTKUTI², NICOLA ZAMBELLI³, MARZIA MATTEI-ROESLI³, MARCO MORETTI⁴, FABIO BONTADINA², RAPHAËL ARLETTAZ², GUIDO TOSI¹, and ADRIANO MARTINOLI^{1, 5}

¹Dipartimento Ambiente-Salute-Sicurezza, Università degli Studi dell'Insubria, Via J. H. Dunant 3, 21100 Varese, Italy

²Conservation Biology, Zoological Institute, University of Bern, Baltzerstrasse 6, CH-3012 Bern, Switzerland

³Centro Protezione Chiroteri Ticino (CPT), CH-6714 Semione, Switzerland

⁴WSL Swiss Federal Research Institute, Sottostazione Sud delle Alpi, Via Belsoggiorno 22, CH-6501 Bellinzona, Switzerland

⁵Corresponding author: E-mail: adriano.martinoli@uninsubria.it

We investigated roost selection by Leisler's bat (*Nyctalus leisleri*) before and after hibernation in 2005 in a mountain area of southern Switzerland. The study area is dominated by deciduous trees and characterised by the presence of previously managed chestnut (*Castanea sativa*) orchards that are now partly abandoned. In March–May and August–October, 15 radio-tracked bats (seven males and eight females) used 28 roost trees. We analysed roosts used by *N. leisleri* at three different levels: (i) micro-scale: features of roost cavities; (ii) meso-scale: characteristics of selected roost trees and (iii) macro-scale: structure of woodland surrounding roost trees. Selection at meso and macro-scales was obtained comparing characteristics of roost trees and surrounding woodland with potentially available trees and woodlands. Bats roosted mainly in live chestnut trees, with large diameter and absence of vegetation near the entrance. Roost trees were located closer to streams, in woodlands with a higher percentage of sweet chestnut trees and a lower tree density than random trees. Multifunctional forest management in abandoned chestnut stands, comprising recreation (chestnut harvesting) and preservation of a semi-natural habitat and its related biodiversity, would recreate the traditional woodland features – in particular an open forest structure with low tree density and presence of ancient chestnut trees – and provide suitable roosting sites to migratory *N. leisleri*.

Key words: *Nyctalus leisleri*, chestnut stands, forest composition, roost selection, Switzerland

INTRODUCTION

Understanding factors that affect roost selection is of primary importance in the study of biology, ecology and conservation of bats. Roosting habits influence local and global distribution, population density, foraging and mating strategies, social structure and seasonal movements (e.g., Findley, 1993; Altringham, 1996; Vonhof and Barclay, 1996; Fenton, 1997; Kunz and Lumsden, 2003). The thermo-physical characteristics of roosts also affect bat physiology (Altringham, 1996; Kerth *et al.*, 2001). Almost two-thirds of the European bat species use tree cavities to roost in during part of their life cycle, and some of them rely on these roosts for reproduction and hibernation (e.g., Stebbings, 1988; Agnelli *et al.*, 2004; Russo *et al.*, 2004, 2005). Deforestation, causing loss of habitat, is a major threat for these species (Hutson *et al.*, 2001), while damaging forest management

techniques, for example the removal of old or dead trees, can destroy valuable habitat for tree-dwelling bats (Hutson *et al.*, 2001; Russo *et al.*, 2004). In these changing landscapes, studies on micro- and macro-habitat selection by bats are fundamental to provide guidelines for a sustainable forest management which aims to preserve biodiversity.

Leisler's bat, *Nyctalus leisleri* (Kuhl, 1817) is a medium sized migratory bat (forearm length 40–47 mm, body mass 11–20 g — Agnelli *et al.*, 2004; Bogdanowicz and Ruprecht, 2004) of the family Vespertilionidae. In general, such bats give birth in the northern part of Europe but hibernate in southern Europe. Being a migratory species (Olioso, 1999; SECEMU, 1999; Ohlendorf *et al.*, 2000; L. Rodrigues, T. Ivanova and M. Uhrin, in litt.) that presents vagrant but also sedentary populations (Bogdanowicz and Ruprecht 2004; Hutterer *et al.* 2005), it is protected by the Bonn Convention

and the European Habitat Directive 92/43/CEE. Leisler's bat is widespread in Ireland but has a patchy distribution in the rest of Europe (McAney and Fairley, 1990; Mitchell-Jones *et al.*, 1999). In Switzerland it is not common but seems more frequent in the central and northern part of the country (Hausser, 1996; Moretti *et al.*, 2003). According to the IUCN red list of threatened species (Chiroptera Specialist Group, 1996), *N. leisleri* is at lower risk (near threatened), but there are little data to assess its status accurately (Stebbing, 1988). Little is known about the foraging or reproductive ecology of the species. Foraging habitats include open areas, over rivers, lakes or pastures, and also deciduous and coniferous woodlands and around streetlights (Vaughan *et al.*, 1997; Shiel *et al.*, 1999; Waters *et al.*, 1999; Russ *et al.*, 2003; Russo and Jones, 2003). Leisler's bat is considered a forest dwelling species roosting mainly in tree cavities. However, roosts also occur in buildings (Mitchell-Jones *et al.*, 1999; Shiel *et al.*, 1999; Waters *et al.*, 1999) and bat boxes are readily used in both coniferous and deciduous forests (Corbet and Harris, 1991; Hausser, 1996). Ruczyński and Bogdanowicz (2005) described roosting preferences of *N. leisleri* and *N. noctula* in Białowieża Primaeval Forest (Poland) during the reproductive season (May–August), but there is no information about tree roost selection by *N. leisleri* in Southern Europe during autumn (before onset of hibernation) and early spring (after emergence from hibernation), when bats are wintering.

In the foothills of the southern Alps, sweet chestnut stands are among the most common woodland types, and trees were planted for their important role as food source for humans and animals. These groves, present for centuries, are characterised by considerable numbers of old trees (some older than 100 years) with decay, hollows, cavities and deeply furrowed bark that offer habitat to many species, including bats (Bull *et al.*, 1997; Mazurek and Zielinski, 2004). In this environment we examined roost selection by Leisler's bat at three levels: roost-cavity, roost-tree, and woodland surrounding the roost tree. Our aim was to identify woodland characteristics useful to produce guidelines for conservation and forest management in order to preserve an environment suitable for this sensitive bat species. This study is part of the SELPI ('Selve e Pipistrelli' — Chestnut orchards and Bats) project that aims to evaluate the effect of chestnut stands management on the population of *N. leisleri*.

MATERIALS AND METHODS

Study Area

The study was conducted in Alto Malcantone, Cantone Ticino, Switzerland (46°03'N, 8°53'E). The area is mountainous, with an altitude ranging from 560 to 1,636 m a.s.l. and extends over 15 km² (1,507 ha). It is largely covered with woodlands (67%), dominated by sweet chestnut (*Castanea sativa*), durmast oak (*Quercus petraea*) and birch (*Betula* sp.) below 800 m a.s.l., while beech (*Fagus sylvatica*) and pastures dominate at higher elevations. Traditional chestnut orchards, that played an important role in economic activities until the first part of the twentieth century, occur close to villages. These stands are semi-natural environments characterised by the presence of sparse old chestnut trees (low tree-density), grafted to obtain edible fruits of good quality, surrounded by meadows that are managed with pruning, grazing and/or mowing. In the last decades, many stands have been abandoned and are not managed, with the result that old chestnuts have been surrounded by dense woody vegetation.

Trapping and Handling Bats

Leisler's bats overwinter in Cantone Ticino, with two active seasons between hibernation, from March to May and from the end of August to the beginning of October. Bats were captured in both seasons in 2005 from bat boxes located in both managed and unmanaged chestnut stands throughout the study area. Each animal was removed from the box and temporarily held in cotton bags until handling. It was weighed to the nearest 0.1 g with an electronic scale (Maul Tronic, Germany), and forearm length (from wrist joint to elbow joint) was measured using precision callipers (± 0.1 mm). Sex was assessed by inspecting external genitalia (Racey and Swift, 1981) and wings were observed by back-lighting and visually examined to distinguish juveniles from adults, the former showing cartilage epiphyseal plates in finger bones (metacarpal-phalangeal joint of the fourth finger; Kunz, 1988; Stebbing, 1988). Bats were fitted with 0.47 g Holohil LB-2 or 0.62 g Holohil BD-2 transmitters, attached between the scapulae with Skinbond® surgical glue after trimming the fur.

Location of Roosts

Radio tracking was conducted on foot, mainly during day time, using a JDS Executive 2000 radio-receiver (Wildlife Materials, Inc., Carbondale, USA) and a three-element handheld directional Yagi antenna. Roosts were located daily by homing-in to the signal when the transmitter was active. After identification of the roost-tree, the cavity used by the animal was identified by assessing radio-signal strength and direction and, when possible and safely accessible, by inspecting the cavity or observing emerging bat(s) at dusk. Roost tree position was taken with a GPS (Garmin) and mapped (scale 1:25,000). Roosts chosen by bats were checked every day while the tag was active (on average 10 days).

Characterisation of Roosts

Roost use was investigated at three different levels scaling from (i) roost features, (ii) roost tree characteristics, and (iii)

forest structure surrounding the roost trees. When the cavity was located we recorded six characteristics: type (woodpecker hole, loose bark, rot cavity, mechanical break), roost position (branch or trunk); height of the cavity from the ground using a meter or an ipsometer (Leiss, BL 6); aspect (using a compass); cavity size (entrance height and width, inner height as the total height of the inner space, inside cross section and inner volume, the latter calculated approximating the shape of the cavity to the closest geometric figure — Table 1). In addition, to obtain information about the accessibility of the cavity by bats, we estimated visually the proportion of vegetation in front of and surrounding the hole. At tree-level we identified the species, life stage, diameter at breast height (DBH) and overall tree height using an ipsometer. Life stage was determined using four classes: (1) living trees with < 50% dead limbs; (2) living trees with > 50% dead limbs; (3) dead trees with < 50% bark and limbs absent; (4) dead trees with > 50% bark and limbs absent. Height of the tree nearest to the roost tree was measured for comparison with the roost tree. The vegetation surrounding the roost tree was characterised in four sampling plots (15 × 15 m): the first centred around the roost tree and the remainder identified inside the woodland, centred along a random 50 m transect starting from the roost tree. In each plot we visually estimated the percentage cover of herbs (0–150 cm height), shrubs (151–500 cm), and trees (> 5 m); canopy structure and woodland density (overall tree number per hectare), while the three dominant tree species were recorded. We also recorded tree life stage and diameter at breast height of the trees present in all the plots to compare them with those of the roost tree and obtain information about the characteristics of the trees present (= available) in the same area. To estimate woodland composition at random points (= available habitat), we also recorded the same woodland variables in three 15 × 15 m sampling plots located in 28 random areas (Table 2). Random points were generated using the Animal movement 2.04 program in ArcView 3.2 (ESRI, 1996; Hooge and Eichenlaub, 1997). These points were laid over the Malcantone vegetation map to identify different types of available woodland and compare them with woodlands used by bats. For every roost and random point, data about elevation, aspect (using Swiss digital elevation model DHM 25), distances to main roads, dust roads, streams and buildings, (using geographic layer Vector 25) were extrapolated using ARC/INFO 8.2 workstation. To allow selection evaluation for a particular aspect of mountainsides hosting a roosting tree, aspect data were compared with a random sample of 84 points generated as described above.

Statistical Analysis

Data were analysed with SAS v 8.0 (SAS, 1999). Relative abundance of tree species, herb cover, shrub cover and tree-canopy cover were expressed as proportions (p_i). All proportional data were transformed using the arcsine (p_i) transformation

to improve normality (Sokal and Rohlf, 1995). Descriptive statistics ($\bar{x} \pm SD$ and range) of habitat variables are shown in Table 2. Univariate inferential procedures, student *t*-test for normally distributed variables and Kruskal-Wallis tests for those that did not meet assumptions of normality, were used to test for differences between habitat variables in sample plots with roosts and random plots. For circular variables analysis, we used Rayleigh test (cavity aspect) and the circular analysis of variance (roost neighbourhood aspect). Parameters which described roost trees were compared with those of the nearest tree (height) and those sampled in the roost plots (DBH and life stage) using paired-*t* test when the variable was normally distributed and Wilcoxon-matched-paired signed-ranks test when it was not (Sokal and Rohlf, 1995). Multivariate discriminant function analysis (MDA) with cross-validation was applied to determine habitat variables that were related with woodland around roost trees, by exploring habitat differences between the 84 plots in woodlands used by bats (3 random plots along a 50 m transect for each woodland) and 84 plots in random areas. Exploratory data analyses showed that several habitat variables co-varied: (percentage of chestnut correlated with herb cover and canopy structure; herb cover with tree density; elevation with percentage of beech and distance to buildings; distance to main roads with distance to buildings and dust roads; elevation with distance to buildings and main roads; distance to dust roads with distance to buildings and main roads; all $r > 0.37$, $P < 0.01$). Therefore, in order to reduce multicollinearity in MDA models, a stepwise forward method (Proc stepdisc, SAS, 1999) was used to select variables to be included in the multivariate discriminant analysis model (MDA), with significance level to enter and stay set at $\alpha = 0.10$ (Table 3). Our dataset did not conform to multivariate normal distribution, but MDA tests are robust to departures from normality (Dillon and Goldstein, 1984). Wilk's lambda values were obtained with a MANOVA to test for statistical significance of the selected MDA model (Proc stepdisc — SAS, 1999).

RESULTS

Bats Tagged

A total of 18 adult Leisler's bats were radio-tagged, five females and four males in spring and three females and six males in autumn. We detected signal from tagged bats for 10 ± 8 days (range 2–21). Mean forearm length was 43.6 ± 2.3 mm for males and 44.6 ± 1.0 mm for females; mean weight was 14.9 ± 2.9 g for males and 15.3 ± 1.6 g for females. Since three animals could not be detected after release, roost selection was investigated for 15 bats (eight females and seven males).

TABLE 1. Mean and SD of cavity parameters for each cavity type

Variables	Loose bark ($n = 6$)	Mechanical breaks ($n = 4$)	Rot cavity ($n = 3$)	Woodpecker hole ($n = 2$)
Entrance height (cm)	44 ± 76	44.5 ± 32	14 ± 9.5	6.0 ± 1.4
Entrance width (cm)	2.5 ± 1.3	2.4 ± 0.5	4.7 ± 1.5	6.0 ± 1.4
Inner height (cm)	41.3 ± 37	44.8 ± 24.3	261 ± 17	6.0 ± 1.4
Inside cross section (cm ²)	26.4 ± 28.7	61.2 ± 23.8	882 ± 1316	60 ± 14
Volume (dcm ³)	2.4 ± 0.03	2.7 ± 2.0	330 ± 545	0.3 ± 0.2

TABLE 2. Mean, SD and range of woodland variables recorded for roosts and random plots

Parameters (unit)	Random ($n = 84$)		Roost ($n = 84$)	
	$\bar{x} \pm \text{SD}$	Range	$\bar{x} \pm \text{SD}$	Range
Chestnut (%)	70 \pm 26	15–95	53 \pm 35	5–100
Beech (%)	51 \pm 34	3–100	83 \pm 22	45–100
Birch (%)	7.5 \pm 3	2–10	15.5 \pm 11.5	1–35
Other (%)	18 \pm 26.5	1–70	46.5 \pm 38	2–100
Tree cover (%)	53 \pm 30	9–93	72 \pm 19	20–97
Shrub cover (%)	7 \pm 6.5	0–23	10 \pm 14	0–52
Herb cover (%)	47 \pm 34.5	0–90	17 \pm 24	0–83
Density (n/ha)	300 \pm 200	70–0.96	700 \pm 400	700–400
Distance houses (m)	154 \pm 124	19–509	238 \pm 185	17–720
Distance rivers (m)	80 \pm 55.5	8–188	102 \pm 85	0.3–387
Distance main roads (m)	27 \pm 38	0–152	76 \pm 82	11–411
Distance dust roads (m)	158 \pm 219	0–1094	3434 \pm 381	29–1405
Elevation (m)	833 \pm 139	660–1281	906 \pm 194	613–1309

Twenty-eight trees in which Leisler's bats roosted, and 15 roost cavities were identified. Roosts were always located daily during the time the transmitters were active (mean 10 ± 8 days, range 2–21). Single bats used an average 1.9 ± 1.3 (range 1–5) roosts during the time radio transmitters stayed attached, with mean inter-roost distance of 465 ± 524 m (range 31–1749 m). Bats switched roost frequently, each roost being occupied on average during 2.6 ± 3.7 days (range 1–17 days). Tagged bats never roosted together and inspection of the cavities showed they were either solitary or rarely in small groups (of maximum three individuals). Bats were also found roosting in bat boxes ($n = 6$) and wall crevices in houses ($n = 6$).

Roost Use at Cavity and Tree Level

Leisler's bats roosted more frequently in mechanical breaks (40% of total roost sites), but some also roosted beneath loose bark (27%), in rot cavities (20%) or woodpecker holes (13%; see Table 1 for descriptive statistics of cavity parameters). Eleven out of these 15 cavities were in the trunk, and in 13 cases the entrance was not sheltered by vegetation ($\chi^2 = 8.07$, $d.f. = 1$, $P < 0.01$). Eleven roost cavities were in living parts of trees, four in dead limbs. Tree density around roosts in live trees was lower than around those found in dead limbs (Mann-Whitney U -test: $z = 2.11$, $P < 0.05$). Mean roost height from the ground was 5.2 ± 2.9 m (range 0.5–10 m). Cavities used by bats were not facing a particular direction (Rayleigh test: $r = -0.15$, $P = 0.78$).

Out of 28 roost trees, 21 were sweet chestnut, three beech and one sycamore (*Acer pseudoplatanus*),

green alder (*Alnus viridis*), bird cherry (*Prunus avium*) and one exotic pine (*Pinus wallichiana*). Roost trees had larger DBH than the trees found in roost and woodland plots (mean \pm SD: roost trees 66.8 ± 30.6 cm; random trees 39.6 ± 16.0 cm; Wilcoxon signed rank test: $P < 0.001$). Most roost trees were live ones (19 out of 28), with less than 50% of dead limbs (life stage class 1), while seven belonged to class 2 and only two were dead trees (class 4). Mean overall height of roost trees was 20 ± 6 m, not significantly different from the overall height of available trees (18 ± 5 m; paired t -test: $t = 1.35$, $d.f. = 26$, $P = 0.19$). Predominant aspect on mountainsides where roost trees were located showed no significant differences if compared to the same measure carried out on a random sample covering the entire study area (roosts trees $\mu = 323$, $k = 0.41$; random points $\mu = 247$, $k = 0.76$; Circular analysis of variance: $F_{1, 111} = 2.31$, $P = 0.13$).

Woodland Selection

Woodland areas including tree-roosts had a lower tree density, a higher proportion of chestnut, wider herb cover (all $P < 0.001$) and a lower forest cover index ($P < 0.01$) than random plots within the study area (Table 2). Areas including roosts were also closer to main roads, dust roads and buildings (all $P < 0.05$) than random ones (Table 3). The MDA explained 59% of variation in woodland structure between areas with and without roosts, and showed that woodland around roosts was less dense and with wider herb cover, more chestnut trees and fewer beeches than random sites. Sites with roosts were also closer to main roads and streams than random sites (Table 4).

TABLE 3. Significance levels of single candidate variables for the stepwise discriminant analysis in the MDA model

Variables	$F_{1,54}$ -value	P -value	R^2
% Chestnut	18.17	< 0.001	0.25
% Beech	1.77	0.19	0.03
% Birch	0.40	0.53	0.01
Shrub cover	0.12	0.73	0.00
Herb cover	15.60	0.0002	0.22
Forest cover index	8.21	0.006	0.13
Tree density	19.10	< 0.001	0.26
Basal area	0.91	0.34	0.02
Distance buildings	4.03	0.05	0.07
Distance rivers	1.29	0.26	0.02
Distance main roads	8.31	0.006	0.13
Distance dust roads	4.99	0.03	0.08
Elevation	2.64	0.11	0.05

DISCUSSION

In this study, *N. leisleri* showed marked tree and habitat preferences for roosting during the non-breeding season. Cavity selection was not investigated because sample size was too small (number of located cavities = 15), cavities were of four different types (mechanical breaks, rot cavities, loose bark and woodpecker holes) and to investigate selection it would be necessary to compare a higher number of used cavities with random ones for each type. Radio-tracked bats used different types of roosts characterised by a narrow entrance width (all cavities less than 7 cm — 66% less than 4 cm); such findings are comparable with those by Ruczyński and Bogdanowicz (2005) in Poland (less than 6 cm). Forepart from rot cavities, the remaining roost cavities had small inner cross sections and volumes than those found in Poland: bats seemed to favour small crevices where to roost alone or in small groups, while during the breeding season they may require larger roost cavities to form maternity colonies.

Seasonal differences in cavity use may also be related to micro-habitat characteristics of roosts. A warmer roost is important during the reproductive period, when females need to maintain homeothermy during pregnancy and lactation (Racey, 1973; Racey and Swift, 1981; Grinevitch *et al.*,

1995; Altringham, 1996; Russo *et al.*, 2004). In contrast, in spring and autumn bats may save energy during the day by entering torpor, thus preferring cooler roosts (e.g., Grinevitch *et al.*, 1995; Altringham, 1996). In our study area, in spring and autumn 2005, Leisler's bats roosting in bat boxes select those with a lower daily temperature (S. Szentkuti, unpublished data). Temperature inside a natural cavity is also influenced by several factors, i.e.: cavity entrance, the health state of the tree in which the cavity is found, tree diameter, canopy cover, and mean ambient temperature and its daily fluctuations (Law and Anderson, 2000; Sedgely, 2001; Wiebe, 2001; Paclík and Weidinger, 2007). In particular, live and large trees provide a more stable temperature, live trees being warmer than dead ones at low ambient temperature (below 0°C), but colder in warmer days (Paclík and Weidinger, 2007). During spring and autumn (present study), at mean ambient temperatures > 5°C, most roosts were in live trees with large stem diameters, probably provide cool and stable temperatures during the day.

In our study area, most cavities, located in live parts of trees, were also situated in open stands (mainly chestnut orchards) and all without vegetation in front of and around the entrance. These features may favour movements of bats flying to and from the roost, important for Leisler's bats

TABLE 4. Significance levels of variables selected in the MDA model. * Order of selected variables according to their entry in stepwise procedure with Proc stepdisc implemented in SAS (1999). ASCC = Average squared canonical correlation (all $P < 0.001$)

* Selected variables	F -value (partial R^2)	P -value	ASCC
Tree density	19.10 (0.26)	< 0.001	0.26
Distance main roads	10.16 (0.16)	0.002	0.38
Herb cover	5.24 (0.09)	0.026	0.44
% Beech	3.46 (0.06)	0.068	0.47
% Chestnut	9.78 (0.16)	0.003	0.56
Distance rivers	3.73 (0.07)	0.059	0.59
Wilks' Lambda final model	$F_{6,49} = 0.410$	< 0.001	

whose high wing loading allows fast flight but also determines poor manoeuvrability (Norberg and Rayner, 1987).

Mean cavity height was lower than in other studies (e.g., 18.7 m in Ruczyński and Bogdanowicz, 2005) on *N. leisleri* and *N. noctula* (Heerdt and Sluiter, 1965; Stratmann, 1978; Kronwitter, 1988; Schmidt, 1988). This difference with other habitats and/or regions may be related to: (i) lower average tree height (20 m) and canopy height (Faliński, 1986; Vonhof and Barclay, 1996); (ii) occurrence of different species and/or lower abundance of predators (Rydell *et al.*, 1996; Sedgeley and O'Donnell, 1999; Ruczyński and Bogdanowicz, 2005); or (iii) bats actively choosing lower cavities with a cooler temperature (Sedgeley, 2001).

In common with other tree-dwelling bat species, Leisler's bats showed marked preference for deciduous trees with a larger DBH for roosting (Gaisler *et al.*, 1979; Boonman, 2000; Jung *et al.*, 2004; Russo *et al.*, 2004; Sedgeley and O'Donnell, 2004). Apart from their influence on cavity microclimate (see above), trees with large stem diameters may be preferred simply because they bear more cavities suitable for roosting (Sedgeley and O'Donnell, 2004). The avoidance of conifers for roosting is common among many bats, although they are preferred by some species, mainly Nearctic (e.g., *Myotis sodalis* — Britzke *et al.*, 2003). The reasons of this behaviour are unknown. Boonman (2000) found pine trees to have less available cavities than broadleaves, maybe due to a different wood quality and structure. In a study on *N. noctula*, Schmidt (1988) showed that only 16% of bats roosted in coniferous trees though they covered 90% of the forest. In our study area broadleaves were dominant and small patches of coniferous woodlands were cluttered with a closed canopy and low canopy height. These habitat characteristics may be avoided by Leisler's bats which prefer open surroundings with roosts located in woodlands with a low tree density. Open areas are also important for foraging as they fly primarily away from clutter, relying on agility to hawk flying insects (Norberg and Rayner, 1987). In a study carried out in Southern Italy (Russo and Jones, 2003) 28 out of 40 *N. leisleri* passes recorded in ten habitat types were detected in sweet chestnut woodlands, showing that this habitat may also be important for foraging.

Woodlands used as roosting sites by *N. leisleri* were characterised by a higher herb cover and a higher percentage of sweet chestnut trees than expected, suggesting that the choice of chestnut

trees for roosting was not casual. In our study area, managed chestnut stands, where trees are spaced and grazing reduces understorey growth, formed the majority of open woodlands with a well-developed herb cover, thus representing the habitat most used by Leisler's bats for roosting. Chestnut orchards also have an open canopy structure that favour bats in searching and accessing the right cavity for roosting (Barclay *et al.*, 1982; Vonhof and Barclay, 1996). Woodland structure also affects the thermal conditions of roosts: an open structure prevents the retention of humidity and heat (Constantine, 1966; Sedgeley, 2001), while solar radiation can penetrate easily and warm roosts. Although these are the general habitat conditions, roost type plays an important role. Deep cavities located in large trees can maintain a more constant temperature because of the thick bark providing a good insulation against weather conditions (e.g., Sedgeley and O'Donnell, 2004), while other types of roosts like exfoliating bark maintain a thermal gradient, from which bats can select optimal conditions through the day by adjusting their position (Rabe *et al.*, 1998). So, within limits determined by macro-habitat (wood-structure) characteristics, bats can choose different types of cavities that allow them to maintain the best conditions for day roosting.

Finally, we found that woodlands with roost trees were closer to roads and water sources than random woodland areas. Proximity to foraging sites is an important factor for roost selection and Leisler's bats often forage over water bodies and in proximity of riparian zones (Vaughan *et al.*, 1997; Shiel *et al.*, 1999; Waters *et al.*, 1999; Russ *et al.*, 2003). The vicinity of roosts to main and/or dust roads in the Malcantone forests is most likely related to previous and/or current management of the chestnut stands which were created near roads to have easy access with chariots and vehicles.

We conclude that Leisler's bats in Alto Malcantone select roosts with particular features at tree level but mainly respond to stand-level characteristics. In particular, managed chestnut stands represent one of the most suitable roosting habitats for Leisler's bat and their preservation appears of great importance. Therefore, restoration of unmanaged chestnut orchards is desirable, especially of those characterised by low naturalness: removal of trees other than chestnuts, as well as the creation of a herb cover through clearing of the understorey and grass sowing are the first actions to be taken. The remaining chestnut trees should be maintained in good health by pruning, with special attention to ancient

trees. However, it is also desirable to preserve some decaying or dead trees that may offer suitable roosts to bats as well as to other animal species. Finally, long-term management of chestnut-dominated stands should also include planting young trees and maintaining a low tree density.

ACKNOWLEDGEMENTS

We wish to thank S. Bologna, Francesca Sozzi and Sara Valoroso for assistance with fieldwork. L. Wauters, D. Preatoni and D. Russo gave useful comments on an earlier version of the ms. The study was partially financed by Project 'PRIN 2003' from the MIUR (Italy). We are also indebted to the Editor-in-Chief W. Bogdanowicz and two anonymous referees who contributed to improve the manuscript.

LITERATURE CITED

- AGNELLI, P., A. MARTINOLI, E. PATRIARCA, D. RUSSO, D. SCARAVELLI, and P. GENOVESI. 2004. Guidelines for bat monitoring: methods for the study and conservation of bats in Italy. Quaderni di Conservazione della Natura, 19 bis, Ministero dell'Ambiente — Istituto Nazionale per la Fauna Selvatica, Rome and Ozzano dell'Emilia (Bologna), Italy, 193 pp.
- ALTRINGHAM, J. D. 1996. Bats biology and behaviour. Oxford University Press Inc., Oxford, 262 pp.
- BARCLAY, R. M. R., C. E. THOMASON, and F. J. S. PHELAN. 1982. Screech owl, *Otus asio*, attempting to capture little brown bats, *Myotis lucifugus*, at a colony. Canadian Field-Naturalist, 96: 205–206.
- BOGDANOWICZ, W., and A. L. RUPRECHT. 2004. *Nyctalus leisleri* (Kuhl, 1817). Pp. 717–756, in Handbuch der Säugetiere Europas (F. KRAPP, ed.). Bd 4/II, Teil II. Aula-Verlag, Wiebelsheim, 582 pp.
- BOONMAN, M. 2000. Roost selection by noctules (*Nyctalus noctula*) and Daubenton's bats (*Myotis daubentonii*). Journal of Zoology (London), 251: 385–389.
- BRITZKE, E. R., M. J. HARVEY, and S. C. LOEB. 2003. Indiana bat, *Myotis sodalis*, maternity roosts in the southern United States. Southeastern Naturalist, 2: 235–242.
- BULL, E. L., C. G. PARKS, and T. R. TORGENSON. 1997. Trees and logs important to wildlife in the interior Columbia Basins. U.S. Forest Service General Technical Report PNW-391, 57 pp.
- CHIROPTERA SPECIALIST GROUP. 1996. *Nyctalus leisleri*. In IUCN red list of threatened species. <http://www.iucnredlist.org>. Downloaded on 27 February 2008.
- CONSTANTINE D. G. 1966. Ecological observations of lasiurine bats in Georgia. Journal of Mammalogy, 47: 1347–1358.
- CORBET, G. B., and S. HARRIS. 1991. Handbook of British mammals, 3rd edition. Blackwell, Oxford, 602 pp.
- DILLON, W. R., and M. GOLDSTEIN. 1984. Multivariate analysis: methods and applications. Wiley and Sons, New York, 608 pp.
- ESRI. 1996. Using ArcView GIS. Environmental Systems Research Institute, Inc., Redlands, California, 340 pp.
- FALIŃSKI, J. B. 1986. Vegetation dynamics in low temperate lowland primeval forest: ecological studies in Białowieża forest. Pp. 39–111, in Geobotany 8 (J. B. FALIŃSKI, ed.). Dr. W. Junk Publishers, Dordrecht, 537 pp.
- FENTON, M. B. 1997. Science and the conservation of bats. Journal of Mammalogy, 84: 1–14.
- FINDLEY, J. S. 1993. Bats. A community perspective. Cambridge University Press, Cambridge, 167 pp.
- GAISLER, J., V. HANÁK, and J. DUNGEL. 1979. A contribution to the population ecology of *Nyctalus noctula* (Mammalia: Chiroptera). Acta Scientiarum Naturalium Academiae Scientiarum Bohemoslovacae, Brno, 13: 1–38.
- GRINEVITCH, L., S. L. HOLROYD, and R. M. R. BARCLAY. 1995. Sex differences in the use of daily torpor and foraging time by big brown bats (*Eptesicus fuscus*) during the reproductive season. Journal of Zoology (London), 235: 301–309.
- HAUSSER, J. 1996. Säugetiere der Schweiz: Verbreitung, Biologie, Ökologie. Im Auftrag der Schweizerischen Gesellschaft für Wildtierbiologie. Denkschriftenkommission der Schweizerischen Akademie der Naturwissenschaften, Basel and Birkhäuser, Berlin, 501 pp.
- HEERDT, P. F., and J. W. SLUITER. 1965. Notes on the distribution and behaviour of the Noctule bat (*Nyctalus leisleri*) in Netherlands. Mammalia, 29: 463–346.
- HOOGE, P. N., and B. EICHENLAUB. 1997. Animal movement extension to ArcView, version 1.1. U.S. Department of the Interior, Geological Survey. Alaska Biological Science Center, Anchorage, 28 pp.
- HUTSON, A. M., S. P. MICKLEBURGH, and P. A. RACEY (comp.). 2001. Microchiropteran bats: global status survey and conservation action plan. IUCN, Gland, 256 pp.
- HUTTERER, R., T. IVANOVA, C. MEYER-CORDS, and L. RODRIGUES. 2005. Bat migrations in Europe. A review of banding data and literature. Bundesamt für Naturschutz, Bonn, 176 pp.
- JUNG, T. S., I. D. THOMPSON, and R. D. TITMAN. 2004. Roost site selection by forest-dwelling male *Myotis* in central Ontario, Canada. Forest Ecology and Management, 202: 325–335.
- KERTH, G., K. WEISSMAN, and B. KÖNIG. 2001. Day roost selection in female Bechstein's bats (*Myotis bechsteini*): a field experiment to determine influence of roost temperature. Oecologia, 126: 1–9.
- KRONWITTER, F. 1988. Population structure, habitat use and activity patterns of the noctule bat *Nyctalus noctula* Schreb., 1774 (Chiroptera, Vespertilionidae) revealed by radio-tracking. Myotis, 26: 23–85.
- KUNZ, T. H. (ed.). 1988. Ecological and behavioral models for the study of bats. Smithsonian Institution Press, Washington D.C., 533 pp.
- KUNZ, T. H., and L. F. LUMSDEN. 2003. Ecology of cavity and foliage roosting bats. Pp. 3–90, in Bat ecology (T. H. KUNZ and M. B. FENTON, eds.). The University of Chicago Press, Chicago, 789 pp.
- LAW, B. S., and J. ANDERSON. 2000. Roost preferences and foraging ranges of the eastern forest bat *Vespadelus pumilus* under two disturbance histories in northern New South Wales, Australia. Australian Ecology, 25: 352–367.
- MAZUREK, M. J., and W. J. ZIELINSKI. 2004. Individual legacy trees influence vertebrate wildlife diversity in commercial forests. Forest Ecology and Management, 193: 321–334.
- MCANEY, C., and J. FAIRLEY. 1990. Activity of Leisler's bat *Nyctalus leisleri* at a summer roost in Ireland. Myotis, 28: 83–91.
- MITCHELL-JONES, A. J., G. AMORI, W. BOGDANOWICZ, B. KRYSZTUFEK, P. J. H. REJINDERS, F. SPITZENBERGER, M. STUBBE, J. B. M. THISSEN, V. VOHRALÍK, and J. ZIMA. 1999. The atlas of European mammals. Academic Press, London, 496 pp.

- MORETTI, M., M. ROESLI, A. S. GAMBONI, and T. MADDALENA. 2003. I pipistrelli del Cantone Ticino. *Memorie della Società Ticinese di Scienze Naturali*, 6: 1–9.
- NORBERG, U., and J. RAYNER. 1987. Ecological morphology and flight in bats (Mammalia, Chiroptera): wing adaptation, flight performance, foraging strategy and echolocation. *Philosophical Transactions of the Royal Society of London*, 316B: 335–427.
- OHLENDORF, B., B. HECHT, D. STRASSBURG, and P. AGIRRE-MENDI. 2000. Fernfund eines Kleinabendseglers (*Nyctalus leisleri*) in Spanien. *Nyctalus*, 7: 239–242.
- OLIOSO, G. 1999. Une nouvelle Noctule de Leisler, *Nyctalus leisleri*, baguée trouvée en France. *Arvicola*, 11: 9.
- PAČLÍK, M., and K. WEIDINGER. 2007. Microclimate of tree cavities during winter nights — implications for roost site selection in birds. *International Journal of Biometeorology*, 51: 287–293.
- RABE, M. J., T. E. MORREL, H. GREEN, J. C. DE VOS, and C. R. MILLER. 1998. Characteristics of Ponderosa pine snags used by reproductive bats in northern Arizona. *Journal of Wildlife Management*, 62: 612–621.
- RACEY, P. A. 1973. Environmental factors affecting the length of gestation in heterothermic bats. *Journal of Reproduction and Fertility, Supplement*, 19: 175–189.
- RACEY, P. A., and S. M. SWIFT. 1981. Variations in gestation length in colony of pipistrelle bats (*Pipistrellus pipistrellus*) from year to year. *Journal of Reproduction and Fertility, Supplement*, 19: 175–189.
- RUCZYŃSKI, I., and W. BOGDANOWICZ. 2005. Roost cavity selection by *Nyctalus noctula* and *N. leisleri* (Vespertilionidae, Chiroptera) in Białowieża primeval forest, Eastern Poland. *Journal of Mammalogy*, 86: 921–930.
- RUSS, J. M., M. BRIFFA, and W. I. MONTGOMERY. 2003. Seasonal pattern activity and habitat use by bats (*Pipistrellus* spp. and *Nyctalus leisleri*) in Northern Ireland, determined using a driven transect. *Journal of Zoology (London)*, 259: 289–299.
- RUSSO, D., and G. JONES. 2003. Use of foraging habitats by bats in a Mediterranean survey: conservation implications. *Ecography*, 26: 197–209.
- RUSSO, D., L. CISTRONE, G. JONES, and S. MAZZOLENI. 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., D. ALMENAR, J. AIHARTZA, U. GOITI, E. SALSAMENDI, and I. GARIN. 2005. Habitat selection in sympatric *Rhinolophus mehelyi* and *R. euryale* (Mammalia: Chiroptera). *Journal of Zoology (London)*, 266: 327–332.
- RYDELL, J., A. ENTWISTLE, and P. A. RACEY. 1996. Timing of foraging flights of three species of bats in relation to insect activity and predation risk. *Oikos*, 76: 531–535.
- SAS. 1999. SAS STAT users guide, version v. 8.0. SAS Institute Inc., Cary, North Carolina.
- SCHMIDT, A. 1988. Beobachtungen zur Lebensweise des Abendseglers, *Nyctalus noctula* (Schreber, 1774), im Süden des Bezirkes Frankfurt/O. *Nyctalus (N.F.)*, 5: 389–422.
- SECEMU (SOCIEDAD ESPAÑOLA PARA LA CONSERVACIÓN Y EL ESTUDIO DE LOS MURCIÉLAGOS). 1999. Informe sobre la campana de anillamiento de murciélagos en España. Año 1998. *Ecologia*, 13: 459–461.
- SEdgeLEY, J. A. 2001. Quality of activity microclimate as factor influencing selection of maternity roosts by a tree-dwelling bat, *Chalinolobus tuberculatus*, in New Zealand. *Journal of Applied Ecology*, 38: 425–438.
- SEdgeLEY, J. A., and C. F. J. O'DONNELL. 1999. Roost selection by the long-tailed bat *Chalinolobus tuberculatus*, in temperate New Zealand rainforest and its implication for the conservation of bats in managed forests. *Biological Conservation*, 88: 261–276.
- SEdgeLEY, J. A., and C. F. J. O'DONNELL. 2004. Roost use by long-tailed bats in South Canterbury: examining predictions of roost-site selection in a highly fragmented landscape. *New Zealand Journal of Ecology*, 28: 1–18.
- SHIEL, C. B., R. E. SHIEL, and J. S. FAIRLEY. 1999. Seasonal changes in the foraging behaviour of Leisler's bats (*Nyctalus leisleri*) in Ireland as revealed by radio-telemetry. *Journal of Zoology (London)*, 249: 347–358.
- SOKAL, R. R., and F. J. ROHLF. 1995. *Biometry: the principles and practice of statistics in biological research*, 2nd edition. Freeman, New York, 880 pp.
- STEBBINGS, R. E. 1988. *Conservation of European bats*. Christopher Helm, London, 246 pp.
- STRATMANN, B. 1978. Faunistisch-ökologische Beobachtungen an einer Population von *Nyctalus noctula* im Revier Ecktannen des StFB Waren (Müritz). *Nyctalus*, 1: 2–22.
- VAUGHAN, N., G. JONES, and S. HARRIS. 1997. Habitat use by bats (Chiroptera) assessed by means of broad-band acoustic method. *Journal of Applied Ecology*, 34: 716–730.
- VONHOF, M. J., and R. M. R. BARCLAY. 1996. Roost-site selection and roosting ecology of forest-dwelling bats in southern British Columbia. *Canadian Journal of Zoology*, 74: 1797–1805.
- WATERS, D., G. JONES, and M. FURLONG. 1999. Foraging ecology of Leisler's bat (*Nyctalus leisleri*) at two sites in southern Britain. *Journal of Zoology (London)*, 249: 173–180.
- WIEBE, K. 2001. Microclimate of tree cavity nests: is it important for reproductive success in northern flickers? *The Auk*, 118: 412–421.

Received 22 August 2007, accepted 07 March 2008