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HABITAT USE BY BATS IN A MEDITERRANEAN ECOSYSTEM IN ISRAEL—CONSERVATION IMPLICATIONS

Yohay Carmel* & Uriel Safriel

Department of Evolution, Systematics and Ecology, The Hebrew University of Jerusalem, Jerusalem 91904, Israel

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Abstract

Conservation programs for insectivorous bats should be based on protecting their foraging habitats as well as their roosts. In this paper we present a method for assessing habitat use of a bat community using a bat detector. We found distinct patterns of habitat use for seven bat species in Mt Meron Nature Reserve, Israel. Using these patterns, we recommend conserving and fostering riparian vegetation, since several endangered species forage mainly in this increasingly threatened habitat. © 1998 Elsevier Science Ltd. All rights reserved

Keywords: bats, habitat use, conservation, nature reserve management, Israel.

INTRODUCTION

Insectivorous bats form a diverse group (some 600 species world-wide, Hill and Smith, 1984) with unique biological characteristics. Many species have become endangered, mainly due to destruction and degradation of their foraging habitats and roosts. In Israel, of the 17 species in the Mediterranean region, 10 are endangered and 5 other species are rare (Shalmon, 1994).

Knowledge about foraging behaviour and habitat use of the bats is of primary importance to establish conservation practices for endangered species (Stebbings, 1988). Using this knowledge, one can manage nature reserves to increase the extent of these habitat types, and protect them. In the last decade, due to technological advances in bat detectors and in telemetry, habitat use data for more and more species are accumulating. Most studies provide data for a single species (Racey and Swift, 1985; Rydell, 1986; Jones and Rayner, 1989; Brigham *et al.*, 1992; Navo *et al.*, 1992; Duverge and Jones, 1994; Burford and Lacki, 1995), or data for the bat fauna as a whole, without distinguishing between species (Thomas, 1988; Krusic *et al.*, 1996; Walsh and Harris, 1996). Exceptions to this are the works of Rydell in Sweden (1992) and Rydell *et al.* in Scotland (1994), where habitat use data for several bat species were gathered in a single study.

In this paper we follow and modify Rydell's method, and describe a method for assessing habitat use of a bat community. The habitat use patterns of each individual species are assessed. The data collected by this method are used to construct a management program for a nature reserve designed to promote protection of its insectivorous bat species.

METHODS

Study area

The study was carried out in the 100 km^2 Mt Meron Nature Reserve, in the Upper Galilee Mountains (32° N, 35° E, 700 to 1200 m a.s.l.), the largest reserve in the Mediterranean region of Israel. The climate is Mediterranean, with cold, rainy winters (mean annual rainfall 1000 mm, mean January temperature 6°C) and cool dry summers (mean August temperature 24°C) (Markus, 1994).

In the middle of the reserve lies the village of Beit Jan, whose inhabitants have traditional cultivation rights in the reserve, and maintain orchard plots there. A few settlements and their agricultural lands (mainly orchards) are located outside the reserve border.

Habitat types

We distinguished six habitat types in the reserve:

1. Tall scrub: the Mediterranean woodland scrub in Mt Meron is composed of broadleaved trees, 3–12 m high, dominated by the oaks *Quercus calliprinos* and *Quercus boissieri*.
2. Batha: low shrubs and grasses up to 0·7 m high, dominated by *Sarcopoterium spinosum*.
3. Water: open bodies of water devoid of adjacent vegetation cover, such as ponds and sewage farms.
4. Riparian vegetation: spring or stream surrounded by trees (often 10–15 m).

*To whom correspondence should be addressed. Fax: 972-2-6584741; e-mail: yochaym@zebra.bot.huji.ac.il

5. Orchards: apples, pears, plums, and olive groves.
6. Settlements: small rural villages.

Detecting foraging activity

Identification of bat species by their echolocation sounds has been often used in field studies (e.g. Ahlen, 1981, 1990; Fenton and Bell, 1981; Jones, 1993; Kalko and Schnitzler, 1993; Rydell, 1994). We used an Ultrasound bat-detector (D-940, Pettersson Elektronik, Uppsala, Sweden) which transforms the bats' echolocation calls to sounds within the audible range. The detector was used in frequency-division (broad-band) and heterodyne (tuned) modes.

We used Ahlen's booklet and tape (1990), which includes recordings of most species in the study area, for a preliminary acquaintance with species-specific sounds. A survey was then made, in which several roosts and foraging habitats were visited (Carmel, 1993). Sounds of foraging bats were recorded, and then these bats were captured by a mist net. In this way we confirmed the identification of sounds of all species in the study area, except *Tadarida teniotis* and *Nyctalus noctula*, which were not captured. Both species, however, use clear distinctive sounds.

Discrimination between species of the same genus could not be made by the call structure alone. Distinction between *Rhinolophus ferrumequinum* and *Rhinolophus hipposideros* can only be made by their unique call frequencies (in the study area these were 83 Khz for the former species and 104 Khz for the later). Thus, a positive identification was made only when the rhinolophid bat was heard long enough to allow an assessment of the precise frequency. The same is true for the identification of pipistrelle species. The echolocation calls of these species were heard best at 37, 42 and 50 Khz for *Hypsugo savii, Pipistrellus kuhli* and *Pipistrellus pipistrellus*, respectively. The only difference between *Myotis nattereri* and *Myotis capaccinii* calls is that calls of the latter species are much stronger, while those of the former can only be heard from a distance of a few metres. An identification of these species was only made when the bat was seen and heard at the same time.

Sampling activity level in different habitat types

In previous works, bat activity was measured using several different methods, such as counting the number of minutes in which bats were heard (McAney and Fairley, 1988) or the number of bats present at the site (Rydell, 1992; Rydell *et al.*, 1994) or the number of passes heard in the bat detector during a specified time (Bell, 1980; Thomas, 1988; Barclay, 1991; Krusic, 1996), or while sampling specific transects (Walsh and Harris, 1996). These methods do not discriminate between commuting passes, where the bat is just flying through the site, and passes made where the bat is actually foraging in the site.

In this study we measured the cumulative time-length (in seconds) of echolocation sounds heard in the detector. A sample constituted of listening to the detector for a specified period in a site, and recording the cumulative time-length of echolocation sounds. All samples were recorded on tapes to allow later identification or confirmation of sounds under question. Notes were taken on frequencies and characteristics of sounds. During a sample, we regularly used the frequency division system, and when a sound was heard, we switched to the heterodyne system to assess the frequencies of the call (Rydell, 1992). Using this method, we were able to characterize habitat use of several species in a single study.

Activity level was defined as the accumulated activity time divided by total sample time. Sample length was usually 10 min in most sites, but up to 75 min in habitats with low or no activity. In a sampling night, two or three habitat types were sampled. Each site was visited three times in a sampling night: early (until 2200), in the middle of the night (2200–0200) and late (0200–dawn). The order of habitats to be sampled was randomly determined for each sampling night, to minimize time-dependence between samples. All habitat types were visited at least one night (three times) every month during the summer (April-October) and at least one night every two months during the winter (November-March), for 12 months starting January 1991 (Table 1). During the study, we noticed that two habitat types—scrub and riparian vegetation—are used by several endangered species. Therefore, these habitats received more sampling effort, in terms of both number of samples and time lengths. However, the relation between sampling effort in different habitat types was kept constant during the sampling period to avoid seasonal variation in sampling effort between habitat types.

Data analysis

Activity-level data were proportions, so the distribution of the data was not normal, neither could it be transformed to normal distribution due to the large number of zeros. Also, sample times were uneven, so parametric methods could not be used. We therefore calculated ratio estimates instead of means (Cochran, 1977) for comparing activity in different habitat types. The ratio estimate ($\hat{R}$) is the sum of activity time-lengths of a single species in a specific habitat, divided by the sum of

Table 1. Sampling dimensions

Habitat type	No. of sites	No. of samples	Total sample time (min)
Scrub	18	72	1170
Batha	6	27	466
Water bodies	5	27	291
Riparian vegetation	10	44	1213
Agriculture	6	27	425
Settlements	7	27	336
Total	52	224	3901 (65 h)

sample times in that habitat. Here, $\hat{R}$ is expressed in percent:

$$\hat{R} = \frac{\sum_{i=1}^{n} Yi}{\sum_{i=1}^{n} Xi} \times 100 \qquad (1)$$

where Xi is length of sample i, Yi is length of species activity in that sample and n is number of samples in that habitat.

Analytical methods for calculating the variance of a ratio estimate are not suitable for sample sizes < 30 (which is the case in some of the habitat types), therefore the variance of the ratio estimate was calculated using the bootstrap technique (Crowley, 1992). The results formed a pool from which a pair of data (Xi, Yi) were drawn each time, with returns. $\hat{R}$ was recalculated using n pairs. We repeated the process 10000 times, using a computer program written for the task. The variance was calculated using these 10000 ratio estimates. Ratio estimates of activities of a species in different habitats were tested for significance using Behernes-Fisher t test, where variances are not assumed equal (Sokal and Rohlf, 1981):

$$Z = \frac{\hat{R}1 - \hat{R}2}{\sqrt{\hat{V}(\hat{R}1) - \hat{V}(\hat{R}2)}} \qquad (2)$$

where $\hat{V}(\hat{R})$ is the estimated variance of the ratio estimate $\hat{R}$. We used the Bonferroni adjustment for multiplied comparisons (Hochberg and Tamhame, 1987) and found that when $Z \geq 2{\cdot}5$ then $p < 0{\cdot}1$ for all 15 possible comparisons of pairs of habitats. We used the same method to compare activity level in different seasons for each species. We also compared habitat use in winter and in summer for each species, to test for a possible interaction between season and habitat use.

RESULTS

We heard bat calls in 134 of 224 samples. Thirty samples (22%) included calls that could not be identified to the species level. There was a significant deviation from randomness in foraging activity in different habitats, for seven of the species that were found in the study area:

P. kuhli foraged most frequently in settlements near street lights (Fig. 1(a)), and was the only species here. It also foraged above open water and above scrub. *P. pipistrellus* foraged mostly above riparian vegetation and open water (Fig. 1(b)). *M. capaccinii* foraged almost exclusively above water pools (Fig. 1(c)) where it flew a few centimetres above water, in long straight lines. *M. nattereri* was heard always very close to vegetation (mostly riparian) in dense scrub (Fig. 1(d)). *T. teniotis* always flew high above the ground (> 10 m), in long straight lines, foraging mostly above settlements (Fig. 1(e)).

Rhinolophus spp. calls were heard in 36 samples, but in 20 cases they were heard too briefly to allow identification of the species. *R. ferrumequinum* and *R. hipposideros* were heard in eight samples each, both only in riparian vegetation. Data of all *Rhinolophus* calls were therefore pooled for statistical analysis (Fig. 1(f)).

All these species were more active in summer (April–October) than in winter (November–March) (Fisher and Beherens t-test, $p < 0{\cdot}02$, Fig. 2). We did not detect any noticeable differences between winter and summer in habitat-use pattern for any of these species.

Five other species, *Eptesicus serotinus, Nyctalus noctula, Miniopterus schreibersii, Myotis myotis* and *Hypsugo savii* were heard only a few times, and their habitat use could not be determined.

DISCUSSION

The method described above is capable of assessing habitat use for several species in one study. However, it is limited to areas where bat populations are small to moderate, like our study area, where more than one bat is seldom heard at the same time. When many bats (and presumably several species) are present at the site at the same time, the cumulative activity time for each species can not be assessed accurately.

Species in the study area can be classified according to their habitat use pattern into three major groups:

1. Scrub and riparian vegetation species. *R. ferrumequinum, R. hipposideros* and *M. nattereri* foraged only near woody vegetation, mainly in riparian vegetation. *M. nattereri* was confined to woody vegetation in the Netherlands (Baagoe, 1987), in Czechoslovakia (Gregor and Bauerova, 1987) and in England (P. Richardson, pers. comm.). Both *R. ferrumequinum* and *R. hipposideros* were confined to woody vegetation in previous field studies (Griffin and Simmons, 1974; Jones and Rayner, 1989; Duverge and Jones, 1994). The pattern of habitat use by *R. hipposideros* in Ireland (McAney and Fairley, 1988) resembles our findings for rhinolophid species. It was most active in aquatic habitats near riparian woody vegetation and near farmyards, less active near trees and hedgerows, and rarely heard in open areas.

   These three species are endangered in Israel (Shalmon, 1994), with populations currently a few hundred each (B. Shalmon., pers. comm.). Habitat loss may be a main cause for the decline of their populations. During recent decades, this habitat has suffered more human pressure than other habitats in the region, since springs in most streams have been captured in pump houses.
2. Water body species. *M. capaccinii* forages mainly above ponds, lakes, and sewage farms. Its trawling behaviour seems to be suitable for catching insects

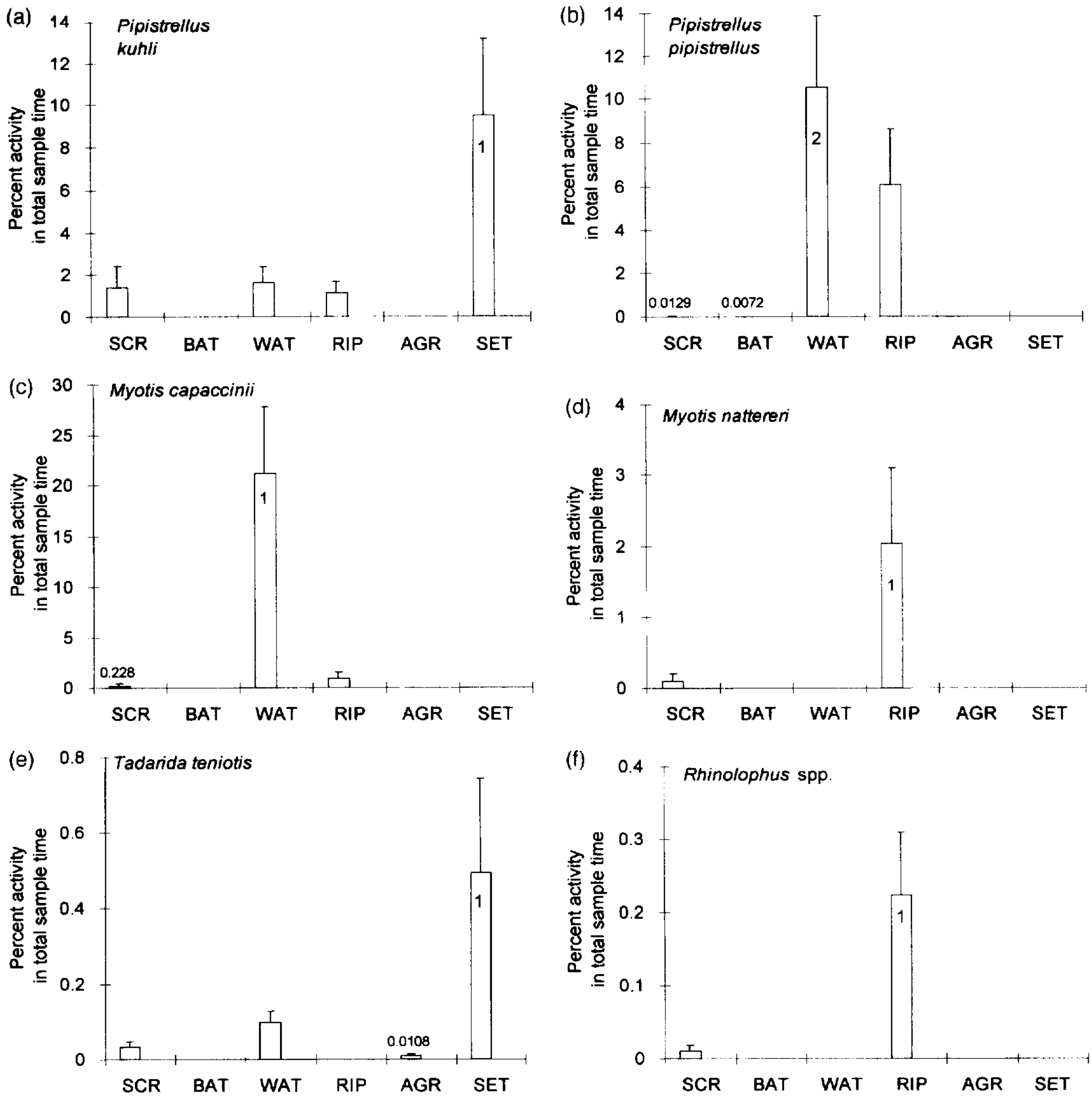

Fig. 1. (a)–(f) Habitat use of insectivorous bats. The percentage ratio estimate $\hat{R}$, (proportion of activity time in total sample time) is shown for each habitat with the estimated standard error for each ratio estimate shown above each bar. Total sample time in each habitat is given in Table 1. (1) $\hat{R}$ for that habitat differs significantly from all other habitat $\hat{R}$ s. (2) $\hat{R}$ differs significantly from all other habitat $\hat{R}$ s except riparian vegetation. SCR—scrub, BAT—batha, WAT—water, RIP—riparian vegetation, AGR—agriculture, SET—settlements.

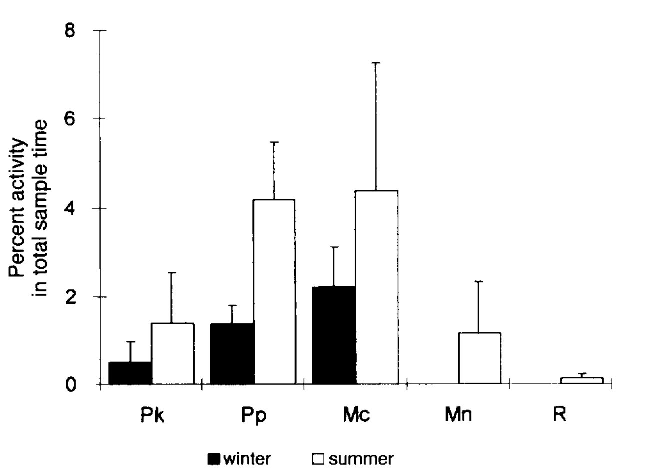

Fig. 2. Activity in winter and summer. Pk—*P. pipistrellus kuhli*; Pp—*p. pipistrellus*; Mc—*M. capaccinii*; Mn—*M. nattereri*; R—*Rhinolophus* spp.

from water surface. This species is relatively abundant in the Mediterranean region, where it takes advantage of such artificial habitats.

3. Species of several habitat types. *P. pipistrellus* foraged above water bodies, scrub and riparian vegetation, while *P. kuhli* used all these habitats, but preferred settlements. These findings are consistent with the suggestion by Haffner and Stutz (1986) that *P. kuhli* displaces *P. pipistrellus* around street lights in areas where they coexist. The pattern of habitat use by *P. pipistrellus* in Scotland (Racey and Swift, 1985) is very similar to the one found in this study: habitats preferred were (in descending order) riparian vegetation, water bodies and around trees. It avoided open hills and moorland (the equivalent of our Batha). There is no information on habitat use of *P. kuhli* in other regions.

T. teniotis also foraged above a variety of habitat types, but always high in open areas, above scrub canopy, settlements and water bodies. There is no information on its habitat use elsewhere. *P. kuhli* and *T. teniotis* are currently the most common species in the Mediterranean region of Israel. We assume that use of several habitat types and exploitation of human-made habitats can explain their relative abundance. *P. pipistrellus* is rare in the region (Shalmon, 1994). The Upper Galilee mountains are the species' southern distribution limit and this may account for its sparse populations.

No bat species used the agricultural land within the reserve, as in studies by MacDonald *et al.* (1990) and Gaisler and Kolibac (1992), while Rydell *et al.* (1994) found limited use of farmland, only by *P. pipistrellus*. We found that during our study period insecticides were intensively used in orchards from April to September. Thus, the avoidance of orchards by bats may be a result of their lack of nocturnal insects, destroyed by pesticides. There is also evidence from other countries (e.g. Brosset *et al.*, 1988) that insecticides accumulated in bat tissues are a major cause of increased death rates.

Our findings are similar to those of Walsh and Harris (1996), who found that habitats associated with broad-leaved woodland and water in England were most preferred by vespertilionid bats, but least abundant in the landscape, while widespread arable land, moorland and grassland were strongly avoided. Since habitat use data for all species were pooled together in that study, this conclusion is probably true for the common species there (*P. pipistrellus*), but it may not be valid for the rare ones.

A general trend emerging from the results is that large portions of the Mt. Meron Nature Reserve are not used by bats, while the habitats intensively used by several species are only minor fractions of the reserve area (Fig. 3). The patterns of habitat use found in this study allow us to suggest a management program for the reserve, which includes three elements.

First, since riparian vegetation is the major habitat for at least three endangered species, and further loss of this already diminishing habitat could lead to their extinction, we recommend increasing the extent of riparian vegetation in the reserve. This could be done by allowing treated sewage water of a village close to the reserve to flow into the reserve's dry streams. Second, a restricted use of pesticides in the reserve might initiate a positive feedback—with bats visiting orchards and reducing the insects. This in turn would encourage the expansion of organic agriculture at the expense of pesticide-dependent agriculture, and further promote bat conservation. The use of insecticides to control mosquito populations in water bodies should likewise be reviewed in nature reserves, to ensure that only those of low persistence and low mammalian toxicity are used (Clawson, 1991). Third, since the Batha was almost totally avoided by all bat species, the transformation of open areas to woodland scrub should improve the reserve's value for bats. The natural succession processes act in this direction, and could be accelerated by afforestation.

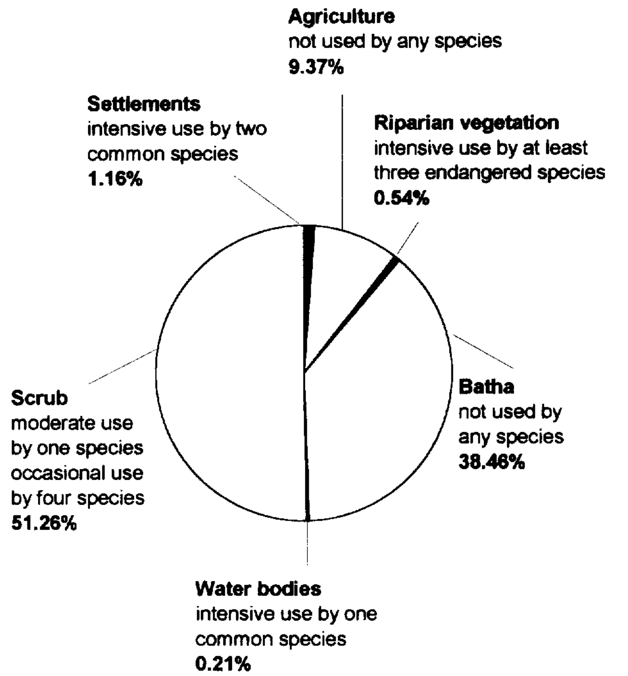

Fig. 3. The distribution of habitat types in Mt Meron Nature Reserve and their value for foraging bats.

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