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BIODIVERSITY RESEARCH

Analysis of the distribution of insectivorous bats in Israel

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Abstract. Data on localities from which insectivorous bats were collected or sighted in Israel were compiled into a Geographical Information System (GIS) in order to analyse patterns of species distribution. By intersecting precipitation and temperature data with spatially-referenced data on species observations stored in the GIS we determined the 'climatic envelope' of each species and constructed predictive maps which show the potential distribution of each species. Using cluster analysis, the bats were classified into three main biogeographic groups according to their distribution, namely desert, Mediterranean, and widespread in Israel. The potential distribution maps of all the species indicate that there are areas which have suitable bat habitats but from which bats have never been collected or observed. In the Mediterranean region of Israel, this is attributed to a large reduction in population size due to fumigation of caves, cave visitation and secondary poisoning.

Key words. Insectivorous bats, Israel, distribution, conservation.

INTRODUCTION

Studying rare and/or threatened species is a difficult task because, by definition, sample sizes are small. However, the identification of the various niche dimensions of such species is an important requirement for an effective study of their biology and to provide a future plan of conservation. Such identification is also helpful in studying the potential distribution of the species and thus provides a tool for determining conservation areas, as well as for studying the zoogeography of related species. Museum data can provide an insight into some of these niche dimensions. Although such data are often from areas far apart geographically and temporally, they are key for looking for other data which are essential for determining the physical conditions where the species lives. Knowing the exact locality of a collected specimen enables one to look for information about the climate and other physical and biological parameters of this locality, which can then be obtained from existing data banks.

In spite of its small size, Israel is exceptionally rich in plant and animal species. The main reasons for the high diversity are its location at a meeting point between Asia, Africa and Europe, a diverse topography and climate, and a long geological history. Because of these factors, the fauna of Israel comprises Mediterranean, European, Saharo-Arabic, Irano-Turanian and tropical (African and Oriental) species. This is equally true for the bats of Israel (Yom-Tov, 1993). There are ninety-four species of mammals in Israel (including one fruit bat *Rousettus aegyptius*), of which thirty (32%) are insectivorous bats (Microchiroptera), comprising the largest group of mammals in Israel (Mendelssohn & Yom-Tov, in press).

During the second half of the 20th century, the human population of the area of the former British Mandate of Palestine (currently Israel, the West Bank and the Gaza Strip) increased from 1.5 to about 8 million, with a concomitant increase in the standard of living, and a consequent adverse effect on many vertebrate species. Microchiroptera suffered most (particularly in the highly populated Mediterranean region of the country), due to secondary poisoning by eating contaminated insects, disturbance by visitors to caves and cave fumigation (Yom-Tov & Mendelssohn 1988). Several species of bats became extinct while the populations of others decreased by two orders of magnitude. Only two species, *Pipistrellus kuhli* and *Tadarida teniotis,* did not suffer such heavy losses, due to their habit of roosting in man-made structures. Hence, for most species of bats in the Mediterranean region of Israel the only available data are museum specimens which were collected before the 1960s. The bats which inhabit the desert half of Israel have not suffered to the same extent as the Mediterranean species, but very little data are available on this group, due to lack of collection effort (but see Yom-Tov, Makin & Shalmon, 1992 and Shalmon, 1993).

In the present study we used data on localities of insectivorous bats in Israel to study their conservation status and zoogeography.

MATERIALS AND METHODS

Data

Data on localities from which bats were collected were obtained from Tel Aviv University Zoological Museum, The Harrison Zoological Museum (Harrison, 1964; Harrison & Bates, 1991), and The Zoological Collections of the Hebrew University, Jerusalem. Additional localities were provided by various surveys, such as those of M. Dor during the 1940s and 1950s in the Mediterranean region of Israel (currently kept by Y. Yom-Tov), D. Makin during the early 1970s mainly in the Mediterranean region (Makin, 1987), and B. Shalmon throughout the country during the 1990s. The number of localities for different species varies greatly from ten or fewer per species (46% of the species), to between eleven and twenty (33%) and up to seventy (one species).

All localities were compiled into a geographical information system (GIS) in order to identify and analyse patterns of species distribution. The software ARC/INFO (ESRI Inc., 1996) was used as a platform for these analyses. We used the GIS for three main purposes: (1) to identify the geographical distribution of observations on each species, (2) to evaluate the potential distribution range of each species, and (3) to classify species into groups based on observed among-species overlap in distribution ranges.

Identifying the geographical distribution of species observations

Using the localities obtained from the various sources of information, a geographically-referenced database of all bat observations in Israel was compiled and stored as a ARC/INFO point coverage (ESRI Inc., 1996). Each row in this database represents a single observation characterized by name of the species and its *x*/*y* coordinates. A total of 472 localities on thirty species were compiled into the database. Geographical positions of these localities were determined to the nearest km using 1:50,000 topographical maps. Distribution maps were drawn for each species, on which all localities from where a species had been collected or reliably sighted were marked. In addition, areas with similar climatological characteristics (precipitation or temperature) were marked. Maps of individual species generated from this database enabled us to identify the observed distribution range of each species of bat in Israel.

Identifying potential distribution ranges

We used a bioclimatic modelling approach (Busby, 1986; Nix, 1986) to identify potential distribution ranges of individual bat species in Israel. Bioclimatic modelling relies on the assumption that regional patterns of species distribution are determined to a large extent by climatological factors, mainly precipitation and temperature (Root, 1988; Walker 1990; Lindenmayer *et al.* 1991; Repasky, 1991; Westman 1991; Brereton, Bennet & Mansergh, 1995). Precipitation is an important factor in determining species distribution, particularly in arid and semi-arid areas (such as Israel) where it is a limiting factor for primary production. Temperature is another important factor, particularly for bats, which are sensitive to cold temperature and either hibernate or migrate when temperatures drop below a certain level. Both factors have been shown to affect bat species distribution in Israel (Yom-Tov & Werner, 1996). In this study we used three climatological variables to determine potential distribution ranges: mean annual precipitation, mean temperature of the hottest month (August), and mean temperature of the coldest month (January). Digital maps of these variables were constructed by digitizing existing maps of precipitation (Dorfman, 1981) and temperature (Rosenan, 1970). By overlaying the three climatic maps with the map of the 472 localities we were able to determine, for each species, the minimum and maximum values of the three climatic variables defined above. The potential distribution range of a particular species was defined as the collection of all localities where rainfall and temperature values were within the climatic ranges documented for that species. Maps showing the distribution of the actual (point) records and the corresponding potential distribution ranges were produced for each species.

Classifying species into biogeographic groups

The bat fauna of Israel was classified into biogeographic groups using cluster analysis as a numerical classification method (van Tongeren, 1995). Two types of analyses were performed, one based on species co-occurrences within geographical zones defined by mean annual precipitation (a total of six zones: 0–200 mm, 201–400 mm, 401–600 mm, 601–800 mm, 801–1000 mm and 1001–1200 mm), and the other based on species co-occurrences in zones defined by mean temperature of the coldest month (a total of seven zones: 4–6°C, 6.1–8°C, 8.1–10°C, 10.1–12°C, 12.1–14°C, 14.1–16°C and 16.1–18°C). By overlaying the precipitation map with the map of the species localities we were able to determine the number of times each species was recorded in each precipitation zone. These counts were tabulated in the form of a matrix of thirty species by six rainfall zones. Similarly, by overlaying the temperature map with the map of species records we constructed a matrix of thirty species by seven temperature zones. Each of the two matrices was analysed using Ward's method of hierarchical cluster analysis. Preliminary analyses were performed using three different measures of dissimilarity: the Manhattan distance, the Euclidean distance and the squared Eucledean distance (Janson & Vegelius, 1981; van Tongeren, 1995). By generating dendograms using different dissimilarity measures we were able to evaluate the stability of the species groups obtained from the analysis. A comparison of the results obtained from the various clustering methods indicated that a classification of the thirty species into two or three groups resulted in a high level of agreement between the various clustering methods (Cohen's kappa statistics >0.68). In contrast, a classification of the species into four or more groups resulted in clustering solutions that were highly method-dependent. We therefore decided to categorize the species into three basic groups.

RESULTS AND DISCUSSION

The potential species distribution maps fall into three groups (Fig. 1): species which inhabit the southern deserts (Fig. 1a); those inhabiting the Mediterranean region (Fig. 1b); and those which are widespread in Israel (Fig. 1c). There is no species of bat which is confined to the area between the Mediterranean and desert regions (Irano-Turanian or steppic region; Yom-Tov & Werner, 1996), perhaps because this narrow area comprises only 10% of Israel. Four species (*Asellia tridens, Pipistrellus kuhli, Rhinolophus hipposideros* and *Tadarida teniotis*) were collected from a wide area in Israel and their potential distribution covers all or most of the country. In addition, two *Rhinopoma* species (*R. hardwickei* and *R. microphyllum*) which have a tropical distribution outside Israel, were found mainly along the Rift Valley, but also occurred in several places outside this area in the Mediterranean region, and their potential distribution maps show that they could occur throughout the country. Fifteen species (*Eptesicus serotinus, Miniopterus schreibersi, Myotis blythi, M. capaccini, M. emarginatus, M. myotis, M. mystacinus, M. nattereri, Nyctalus noctula, Pipistrellus pipistrellus, P. savi, Rhinolophus blasii, R. euryale, R. ferrum-equinum* and *Taphozous nudiventris*) occur in the Mediterranean region. Two of these species (*Pipistrelllus pipistrellus* and *P. savi*) were found only in the northern Galilee, close to the Lebanese border, indicating that this region is the southern limit to their distribution. Nine species (*Barbastella leucomelas, Eptesicus bottae, Nycteris thebaica, Otonycteris hemprichi, Pipistrellus bodenheimeri, P. rueppellii, Plecotus austriacus, Rhinolophus clivosu*s and *Taphozous perforatus*) occur in the desert region. Three of these desert species (*Barbastella leaucomelas, Nycteris thebaica* and *Taphozous perforatus*) were found only along parts of the Rift Valley, indicating a strong tendency to occur in the warmest region of Israel, where the mean August (the hottest month) temperature is 30°C and mean annual precipitation is lower than 300 mm (Jaffe, 1988). Single specimens of three desert species (*Plecotus austriacus, Otonycteris hemprichi* and *Pipistrellus rueppellii*) were found in the Mediterranean region and, if these localities are taken into account, their potential distribution is significantly enlarged and includes parts of the Mediterranean region. However, most of these single specimens were found during autumn and winter, which may reflect a tendency to find a cool hibernation site in the north rather than a potential breeding range.

The above grouping of the Microchiroptera is reflected in the results of the classification analysis (Figs 2 and 3), in which the various species are clustered according to their precipitation or temperature preferences. In both dendrograms, the species are very similarly grouped into desert, Mediterranean and widespread species. This is a logical outcome, because in Israel precipitation decreases and temperature increases

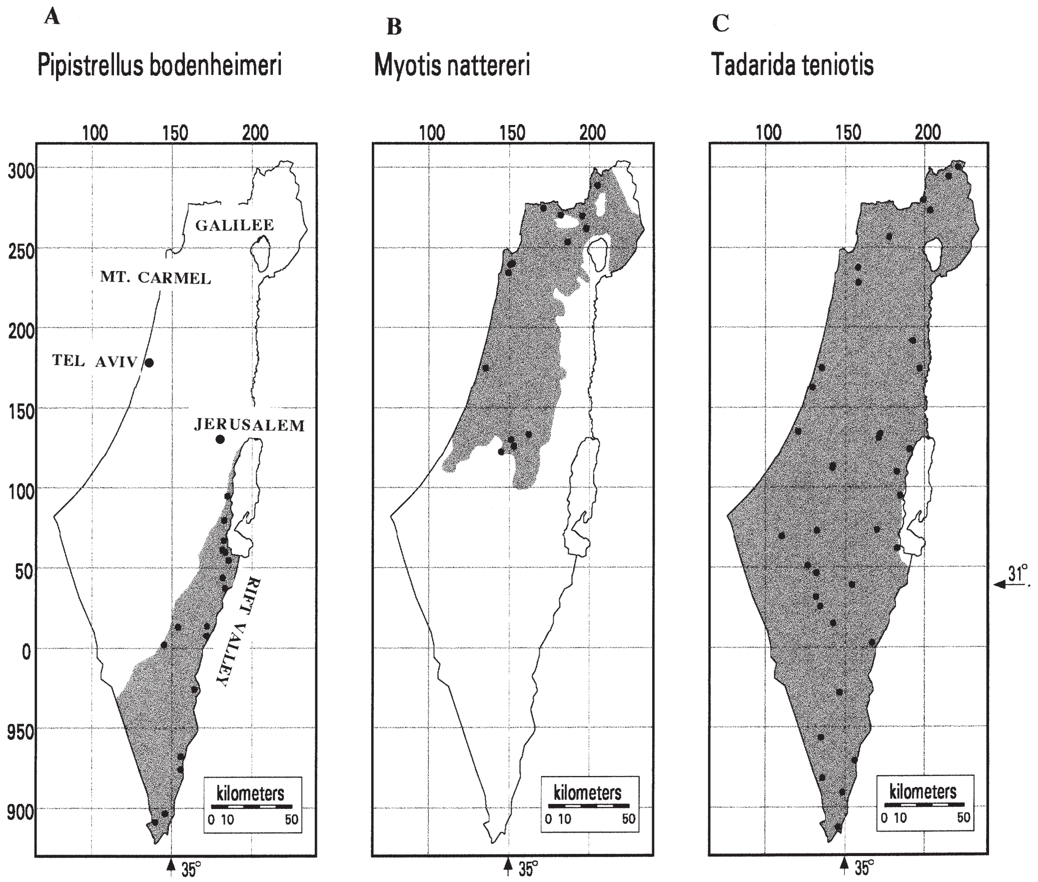

Fig. 1. Collection and sighting localities in Israel of three typical distribution patterns. The shaded area is the climatic envelope as generated using data on annual precipitation and mean temperature of the coldest and hottest months. (a) *Pipistrellus bodenheimeri*, a desert species. (b) *Myotis nattereri*, a Mediterranean species. (c) *Tadarida teniotis*, a widely distributed species.

from north to south, and dry places tend to be hot and vice versa. However, there are minor differences in the classification, which reveal details about the sensitivities of the species to temperature and precipitation. For example, the widespread species may be subdivided into two groups with respect to precipitation (Fig. 2): southern species penetrating north (*Rhinopoma hardwickei, R. microphyllum, Tadarida teniotis* and *Asellia tridens*), and northern species penetrating south (*Rhinolophus ferrum-equinum, R. hipposideros* and *Pipistrellus kuhli*). Using the parameter of temperature, *Asellia tridens* is omitted from the group widespread in the country (Fig. 2) and located among the desert species (Fig. 3), indicating that this species is more sensitive to cold temperatures than the other desert species which penetrated into the Mediterranean region. On the other hand, *Otonycteris hemprichi* which is located among the desert group using the parameter of precipitation (Fig. 2), is located among the Meditterranean group using temperature (Fig. 3), indicating that it is less sensitive to cold than other desert species.

In order to quantitatively evaluate our conclusion that the three groups of species defined by the cluster analysis differ from each other in their distribution along the precipitation gradient, the 472 localities were classified into three groups: localities of species classified as 'desert species', localities of species classified as 'Mediterranean species' and localities of species classified as 'widespread'. We then determined

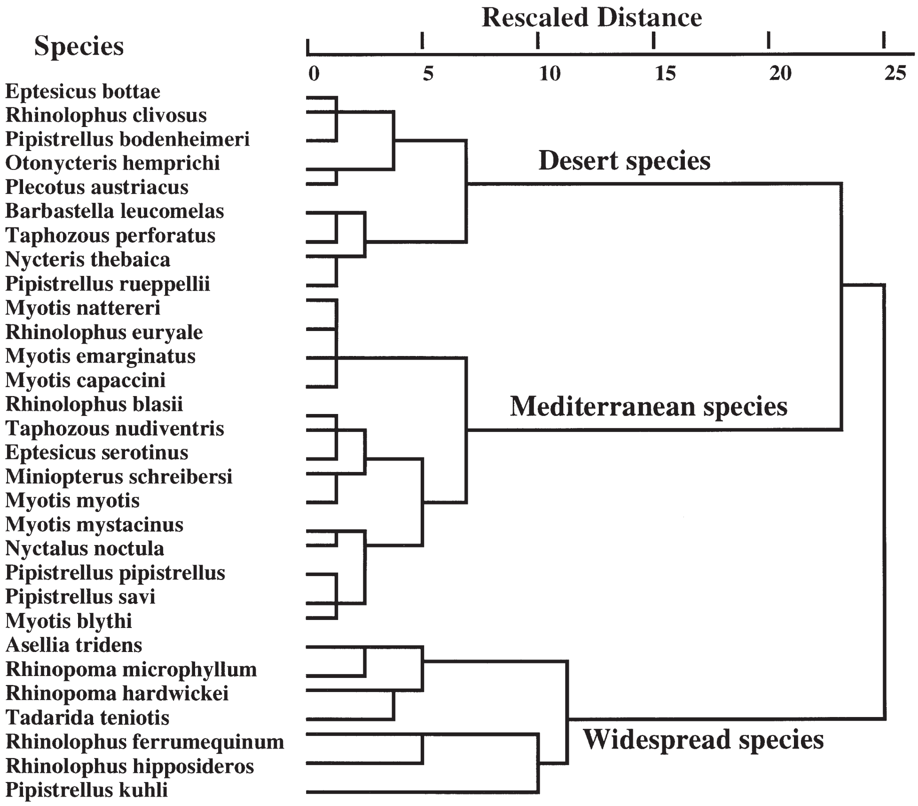

Fig. 2. A dendrogram of the bat fauna of Israel based on among-species similarity in distribution along a gradient of mean annual precipitation. Note the grouping into desert, Mediterranean and widespread species. The last group is sub-divided: southern species penetrating north (*Rhinopoma hardwickei, R. microphyllum, Tadarida teniotis* and *Asellia tridens*), and northern species penetrating south (*Rhinolophus ferrum-equinum, R. hipposideros* and *Pipistrellus kuhli*).

the mean and the variance of the precipitation values recorded for each group of localities. We expected that localities of species categorized into the desert group would show relatively low values of rainfall, localities of species categorized into the Mediterranean group would show relatively high values, and localities of species categorized as widespread would show intermediate values. We also expected that localities of species classified as widespread would show a higher variance of the precipitation values than those of either the desert or the Mediterranean species. All of these hypotheses were strongly supported by the results (Table 1). These findings indicate that our interpretation of the clusters as groups of desert, Mediterranean and widespread species was justified.

Four of the fourteen genera of Microchiroptera represented in Israel have vicarian species in both the Mediterranean and desert regions: *Eptesicus serotinus, Pipistrellus savi, P. pipistrellus, Rhinolophus blasii, R. euryale* and *Tapozous nudiventris* occur in the Mediterranean region while their respective congeners *Eptesicus bottae, P. bodenheimeri* and *P. rueppelli*, *Rhinolophus clivosus* and *Taphozous perforatus* occur in the desert.

The potential distribution areas of all species indicate that there are areas which could provide suitable habitats for bats, but from which bats have never been collected or observed. For example, no specimens of *Pipistrellus bodenheimeri* were collected west of the southern Rift (Arava) Valley, and no specimens of *Myotis nattereri* were collected in most in the central mountain ridges of Israel north of Jerusalem, although there areas are included in the climatic envelopes of these species (Fig. 1). This may be due to several

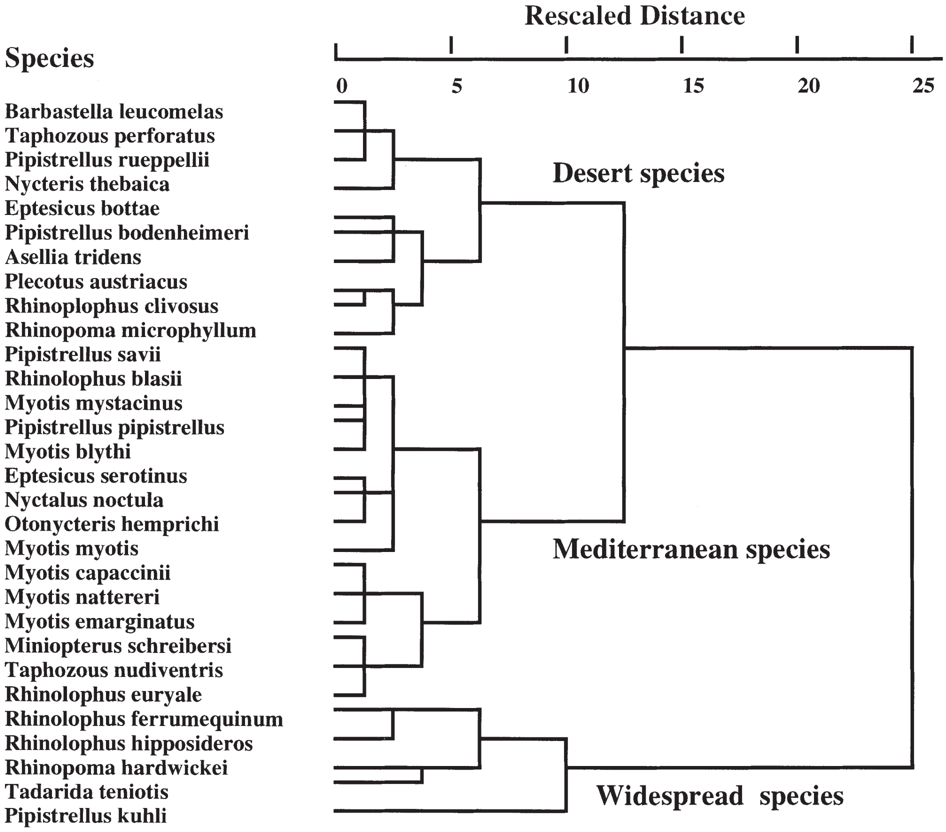

Fig. 3. A dendrogram of the bat fauna of Israel based on among-species similarity in distribution along a gradient of mean temperature of the coldest month (January). Note the grouping into desert, Mediterranean and widespread species.

Table 1. Precipitation characteristics (mean and variance) of localities representing species categorized into clusters interpreted as desert, Mediterranean and widespread species (see Fig. 2). Means of all clusters were significantly different from each other (P<0.01, independent samples t-tests).

Cluster	Mean (mm)	Variance (mm)	Interpretation
1	166.8	42,025	Desert species
2	605.3	49,062	Mediterranean species
3	418.7	63,504	Widespread species

factors, such as lack of suitable roosting sites (i.e. caves), lack of sampling or inadequate collecting efforts in the area. However, during the recent (1990s) survey carried out by B. Shalmon (personal communication) throughout the country in areas where potential roosting sites are not a limiting factor, hardly any new bat locations were found in the Mediterranean region, whereas several new ones were found in the desert. Moreover, many of the previously known roosting sites were devoid of bats or contained much fewer species and individuals than in the past. For example, in one cave on Mount Carmel where several thousands of bats belonging to six species where found during the 1940s (M. Dor, personal communication), only several hundred were counted by Makin (1987) during the early 1970s, and less than fifty individuals of one species in 1994 (B. Shalmon, personal communication). This serious decline is typical to the Mediterranean region of Israel, and is presumed to be the result of three factors: fumigation of caves against fruit bats (*Rousettus aegyptius*) that were considered to be agricultural pests, which affected mainly insectivorous bats inhabiting these caves, cave visitation and secondary poisoning (Yom-Tov & Mendelssohn, 1988). Hence, it seems that most bats of the Mediterranean group do not occupy their potential distribution area and may be considered as threatened species.

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Appendix

The distribution of the insectivorous bats of Israel.

Species	Distribution in Israel	Distribution outside Israel
Rhinopoma microphyllum	Widespread	Tropical, Africa and Asia
Rhinopopoma hardwicki	Widespread	Tropical, Africa and Asia
Taphozus nudiventris	Mediterranean	Africa and South Palearctic
Taphozus perforatus	Desert	Africa and South Palearctic
Nycteris thebaica	Desert	Africa
Rhinolophus ferrumequinum	Mediterranean	Southern Palearctic
Rhinolophus clivosus	Desert	Africa
Rhinolophus euryale	Mediterranean	Mediterranean
Rhinolophus blasi	Mediterranean	Mediterranean
Rhinolophus hipposideros	Widespread	Palearctic
Asellia tridens	Widespread	North Africa, Middle East
Tadarida teniotis	Widespread	South Palearctic
Myotis emarginatus	Mediterranean	South Palearctic
Myotis nattereri	Mediterranean	Palearctic
Myotis capaccini	Mediterranean	South Palearctic
Myotis myotis	Mediterranean	West Palearctic
Myotis blythi	Mediterranean	Palearctic
Myotis mystacius	Mediterranean	Palearctic
Eptesicus serotinus	Mediterranean	Palearctic
Eptesicus bottae	Desert	Saharo-Sindian
Pipistrellus kuhli	Widespread	South Palearctic, Africa
Pipistrellus pipistrellus	Mediterranean	Palearctic
Pipistrellus savi	Mediterranean	Palearctic
Pipistrellus bodenheimeri	Desert	Arabia
Pipistrellus rueppelli	Desert	Africa
Otonycteris hemprichi	Desert	Saharo-Sindian
Plecotus austriacus	Desert	South Palearctic
Miniopterus schreibersi	Mediterranean	Old World
Barbastella leucomelas	Desert	Palearctic
Nyctalus noctula	Mediterranean	Palearctic