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# Foraging habitats of *Myotis emarginatus* in Central Europe

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**Abstract** We radio-tracked *Myotis emarginatus* in Upper Bavaria, Germany to identify the key-foraging habitats and to enable an adequate habitat management for this endangered species. The studied females foraged at a distance of up to 8.1 km around their colony roost. The average distance of the foraging area was 3.7 km, where 70% of foraging areas were located within a distance of 5 km and 90% within 6 km of the nurseries. Moreover, these bats spent about 75% of their foraging time within 5 km and 85% within a 6-km radius. To reach the foraging areas, the bats usually used riparian woodlands, hedges and tree lines as flight paths. Specifically, 46.9% of the foraging areas were located in forests, 24.5% in cow sheds, 18.4% in riparian woodlands along streams and 10.2% in fields, villages, orchards, hedges and groves on open land. On average, the bats foraged in forests for 56.2% of the time, during which habitat allocation was possible. In cow sheds the percentage was 29.2%, in riparian deciduous woodland 11.5% and in the other habitats 3.1%. Within forests *M. emarginatus* avoided foraging in spruce monocultures. Pure stands of spruce covered 45% of the total forest area, but only 10% of the foraging areas were located in this forest type. Deciduous forests on the other hand were much more common as foraging sites (40%

versus 11%). Therefore, the availability of native deciduous forest and of fly-infested stables within a radius of 6 km around the colony roosts should be the focus of conservation concepts for *M. emarginatus*.

**Keywords** Radio tracking · Deciduous forests · Spruce monoculture · Behaviour · Cow shed

## Introduction

*Myotis emarginatus* is regarded as an endangered species in Europe and listed in appendix II of the Fauna Flora Habitat (FFH) Directive of the European Union. To enable adequate conservation measures for *M. emarginatus*, the requirements concerning foraging habitats have to be considered. In central Europe, the species is at the northern limit of its distribution and depends on human settlements for reproduction (attic roosts), whereas it is naturally cave dwelling in southern Europe. While the roosting ecology of *M. emarginatus* is largely known (Zahn and Henatsch 1998; Friemel and Zahn 2004), many aspects concerning foraging activity remain unclear. It is a gleaning species (Schumm et al. 1991), and it performs second best after *Myotis nattereri* in detecting prey close to clutter (Siemers and Schnitzler 2004). Based on these studies, it can be assumed that the bats forage near and within foliage (Schumm et al. 1991; Siemers and Schnitzler 2004). Radio tracking revealed that woodlands are used as hunting grounds, and woody elements outside forests are utilised both for foraging and for commuting flights (Krull et al. 1991; Brinkmann et al. 2001). Crossing of open areas is avoided, indicating the importance of linear landscape elements for the species (Friemel and Zahn 2004). It is also known that cow sheds are regularly

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attended to catch flies (Krull et al. 1991; Brinkmann et al. 2001; Steck and Brinkmann 2006).

However, the available knowledge is not sufficient to suggest species-specific habitat management measures (Kretzschmar 2003). It is not known, for example, which types of forest habitats are preferred by notch ear bats and in which radius around the roosts most hunting activity takes place. Also, the extent of foraging outside forests remains to be investigated.

To elucidate the role of woodland versus other habitats and to study the influence of forest structure and composition on the habitat use of this species, we radio-tracked *M. emarginatus* in Upper Bavaria, Germany. In this area, the population density is comparatively high (Rudolph 2000), indicating a high quality of foraging habitats. This situation allows identification of key-foraging habitats and their location relative to the colony sites of notch ear bats. Type, structure and distribution pattern of the preferred habitats are investigated in this study and will have implications for management plans, e.g. according to the EU Habitats Directive (Rudolph 2000) for the area surrounding the colonies.

## Materials and methods

### Study area

We radio-tracked bats from two attic dwelling colonies in Mühlberg (12°46' east, 47°56' north) and Kirchanschöring (12°50' east, 47°57' north) in Upper Bavaria, Germany. The Mühlberg location consisted of about 400 adult females, while Kirchanschöring consisted of about 200. The study area is located in the foothills of the Alps, near lake “Waginger See” and is composed mainly of hilly landscapes, forests, fields and meadows. The open areas are highly structured by linear woody elements such as riparian woodlands or hedges. In the forests, spruce (*Picea abies*) monocultures are predominant. However, where forestry is difficult, such as on slopes, Beech forests (*Fagus sylvatica*) are still abundant and constitute the naturally prevailing forest type. Along streams and at moist stands, the tree diversity is higher and includes ash-tree (*Fraxinus excelsior*), oak (*Quercus spec*), willow (*Salix spec*), maple (*Acer spec*), black alder (*Alnus glutinosa*) and several shrub species.

### Radio tracking

We got data from all 11 radio-tracked individuals, including 10 adult females and one male (Table 1). Six females and the male were tracked in 2003 and four females in 2004. We glued 0.35 g radio transmitters (Titley Electronics, Ballina, NSW, Australia) between the shoulders of the bats using skin

bond cement. The lifespan of the battery reached up to 10 days. Signals were received by Regal 2000 receivers (Titley Electronics, Australia) operated with three-element Yagi antennae. We estimated our bearings to be exact to about  $\pm 5^\circ$ . Tracked animals could be detected in woodlands up to a distance of 500 m away and in open areas up to 1 km (Holzhaider et al. 2002).

Bats were handled with permits by the Government of Upper Bavaria. All females were caught in the morning at the roost entrances (windows), when they returned to the colony roost after foraging. The male bat was caught in a cow shed near Kirchanschöring. Each animal was tracked for two to five nights in a row. However, in many cases tracking was successful only during parts of the night. The duration of tracking varied between 296 and 1,457 min in the 11 animals (Table 1). Observers followed bats by car and located the position of each individual by taking cross bearings every 1–5 min. The bearings were synchronised using walkie-talkies. A fluctuation in intensity and a change of direction of the received signal indicated a flying bat. The bat was assumed to be stationary when the signal was stable. The cross bearings were mapped on topographic maps (1:25,000). Whenever possible, we tried “homing in” on the animal in order to come as close as possible to the bat when it showed sustained flight activity within a forest area or another habitat where foraging could be inferred. Locations where the bats were continuously active for at least 5 min after successful homing in were defined as foraging sites (according to Güttinger 1997). In addition, we defined an area as a foraging site if more than five cross bearings of moving bats were located from a small area (150-m radius) within 15 min.

At each centre of the foraging site, we determined the land use pattern (settlement, cow sheds, forest, meadows or fields, woody elements outside forests as hedges or orchards), and in the case of forests, we described tree composition and the spatial structure in a radius of 30 m, taking the following parameters by visual estimation:

- Percent area of spruce forest (more than 90% spruce trees in upper and middle stratum), percentage area of deciduous forest (more than 90% beech or other deciduous trees) and percentage area of mixed forest (rest).
- Percent area covered by upper, middle and lower stratum; as an index of the “foliage density” over all strata, we added up the coverage figures of upper, middle and lower stratum (sum of all strata).
- Percent area covered of different tree densities (classes of average distance between trees: 1–3, 3–5 and >5 m) and percent area covered by very dense “thicket-like” stands (mainly young trees, diameter at breast height <12 cm, distance <1 m)
- Presence of bodies of water (streamlets, creeks and lakes)

**Table 1** Number of tracking nights and hours and duration of stay in different habitat types

	Nights	Duration of tracking (min)	Habitat allocation (min)	Duration of stay in cow sheds (min)	Duration of stay in woodlands (min)	Duration of stay in riparian woodland (min)	Duration of stay in fields, villages, orchards hedges or groves (min)	Distance (km) and types of foraging areas
F 1 (K) preg	2	991	382	124	258	0	0	2.4 (c), 3.1 (w), 0.6 (w)
F 2 (K) preg	3	1,071	143	32	72	31	8	0.5 (o), 7.3 (c), 8.0 (w), 1.3 (w), 1.9 (o), 5.3 (o)
F 3 (M) lac	2	595	9	0	0	0	9	3.5 (o), 8.1 (w)
F 4 (M)	4	841	486	176	185	90	35	5.6 (c), 5.6 (o), 4.4 (c), 5.8 (w), 5.0 (w), 5.4 (o), 4.5 (w)
F 5 (M) lac	3	660	64	0	50	14	0	0.1 (w), 7.2 (w), 7.6 (w), 7.4 (o)
F 6 (M) lac	4	1,457	809	507	287	15	0	3.0 (c), 3.3 (w), 3.1 (w), 1.6 (o)
M 1	3	819	736	236	500	0	0	0.0 (c), 0.6 (w)
F 7 (K)	2	262	128	0	128	0	0	2.7 (w)
F 8 (K) preg	4	1,263	799	293	391	115	0	1.4 (w), 2.2 (w), 2.6 (w), 3.6 (w), 2.2 (c), 2.4 (c), 2.1 (o), 2.9 (o)
F 9 (K) preg	5	486	319	129	82	108	0	1.4 (w), 2.3 (w), 3.4 (o), 3.1 (o), 1.6 (c), 2.3 (c)
F 10 (K) null.	7	1,237	885	261	442	20	162	2.4 (w), 4.2 (w), 4.6 (w), 5.2 (o), 5.3 (o), 5.4 (c) 5.4 (c)
Summ.	39	9,682	4,760	1,758	2,395	393	214	

The open areas include riparian, linear woodland (nine), field (one), village (one), orchard (one), hedges (one) and groves on open land (one) *Duration of tracking* time during which the animals could be tracked, *Habitat allocation* times where the presence of the bat in a given habitat type could be confirmed by homing in or cross bearings, *F* female, *M* male, *(K)* Kirchanschöring, *(M)* Mühlberg, *c* cow shed, *w* woodland, *o* open areas

To compare the foraging sites in woodlands with general forest appearance in respect to these parameters, we selected four “reference forest areas” for each site at a distance of 150 m (angle between the directions of the reference areas 90°, the direction of the first area was chosen by chance). In case a reference area determined by this method was located outside the forest, no data were taken. We assessed the same data at reference areas as at the foraging sites and calculated the means of all reference areas belonging to a given foraging site. These pairs (data from foraging area–means of the data from reference area) were compared by a paired sample test (Wilcoxon signed rank test; Siegel and Castellan 1988). In some cases, foraging activity in one of the habitat types (settlement, cow sheds, forest, meadows or fields and woody elements outside forests) could be proven by cross bearings or homing in, but the data were not sufficient to locate a “foraging site” as defined above. In these cases, only the distance between roost and foraging area and the duration of the stay in the given habitat type were considered for further analyses.

Using aerial photographs (1:25,000; obtained from the Bavarian State office for Survey and Geo-information), we additionally determined the forest composition (percentage of spruce forest, deciduous forest and mixed forest) in all woodlands within a rectangle including all foraging sites (165 km<sup>2</sup>; “total forest area”). We concentrated on the exact location of foraging sites by homing in to characterise the bats use of spatial structure on a lower scale, and therefore, we did not obtain enough cross bearings to calculate the total size of foraging areas.

## Results

We had contact to the 11 bats after they had left their roost for 161.4 h and an exact habitat allocation was possible during 79.3 h (Table 1). The bats foraged in a distance of up to 8.1 km around their colony roost. The average distance of the female foraging areas ( $n=47$ ) was 3.7 km (SD 2.2). Seventy percent of the foraging areas were located within a distance of 5 km and 90% within 6 km of the nurseries.

Correspondingly, these bats spent about 75% of their foraging time within the 5 km and 85% within the 6 km radius of the nurseries. However, four nonreproductive or postlactating females also used alternative day roosts during the tracking period, probably as a reaction to capture. We found three of these day roosts, and they were located at farm buildings in 3.0-, 4.9- and 5.2-km distance from the colony roost. Individual bats returned to the same foraging areas on consecutive nights. The male bat roosted in a farmhouse next to the cow shed (where it was caught) and foraged in this shed and in a woodland 600 m away. The bats were flying continuously for the periods that we had contact with them (dusk to dawn), except for lactating females which returned to the nursery for up to 1 h, two to three times each night.

Of all 49 foraging areas, 23 were located in forests (46.9%), 12 in cow sheds (24.5%) and 14 outside forests (28.6%). Within the last group, linear riparian woodlands along streams were the most important habitats (nine sites, 18.4%). In each of the following habitat types, one foraging site was found: field, village, orchard, hedge and groves on open land. On average, the bats foraged in forests for 56.2% of the time during which habitat allocation was possible. In cow sheds the percentage was 29.2% and in riparian deciduous woodlands 11.5%, and 3.1% of the time was spent in fields, villages, orchards, hedges and groves on open land (female 3, in which habitat allocation was possible only for 9 min, was excluded for this calculation). This indicates a strong preference of wood habitats, which cover only about 20% of the total study area.

Within forests *M. emarginatus* avoided foraging in spruce monocultures (Fig. 1). Pure stands of spruce covered 45% of the total forest area, but only 10% of the foraging areas were located in this forest type. Deciduous forests, on the other hand, were much more common as foraging sites (40% of the foraging sites versus 11% cover). Additionally, the comparison between the reference areas (located near the foraging sites) and the total forest area showed that in the woodlands around the foraging sites, pure coniferous forests are relatively rare (Fig 1). This indicates that *M. emarginatus* does not make use of foraging sites within extensive spruce monocultures.

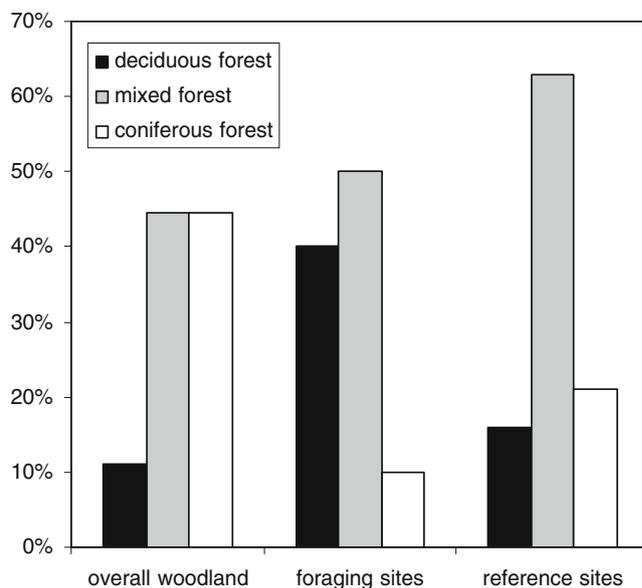
The avoidance of the coniferous forests was not caused by the high foliage density, which was often observed in younger stands of spruce. *M. emarginatus* even prefers dense woodlands for foraging. The foliage cover (sum of all strata) was significantly higher at foraging sites than in the reference areas (38.3% versus 30.1%, Wilcoxon test,  $p=0.01$ ). Additionally, dense stands (tree density 1–3 m) were significantly more abundant in the foraging areas than in the nearby reference areas (57.1% versus 39.2%,  $p=0.046$ , Fig. 2), whereas stands of low tree densities (>5 m) were comparatively rare (12.6% versus 32.3%,  $p=0.031$ ). How-

ever, very dense, thicket-like stands were obviously avoided. These stands covered on average less space at sites where foraging bats could be found than in the reference areas (6.5% versus 26.1%,  $p=0.010$ , Fig. 2).

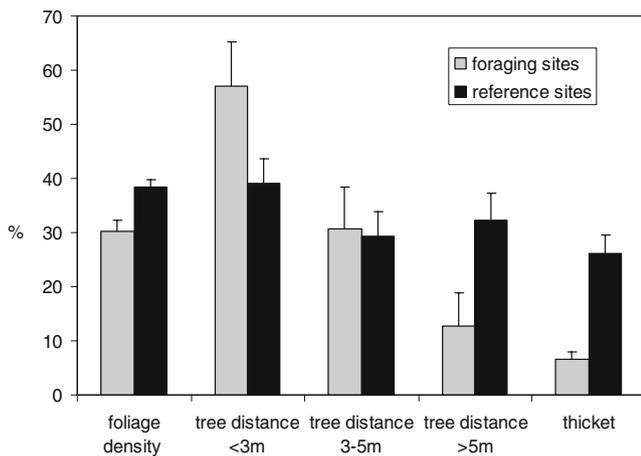
Seven out of the 11 bats used sheds as foraging sites. It is noteworthy that the bats obviously preferred cow sheds to horse stables. In the latter, we never recorded foraging activity. In one case a bat ignored all stables of a horse-farm except a tiny shed where a few Galloway cattle lived besides the horses. Cow sheds were used by pregnant or lactating females as well as by nonreproductive individuals. The bats did not use these stables more intensively during rainy and cold nights than during more favourable conditions. However, they visited the cow sheds several times during the night, and most visits occurred during the second half of the night.

The tracked females foraged on average in five (SD 2.5) different foraging areas (maximum eight), and per night they used between one and eight (on average two or three) areas. On average they stayed 49 min (min 5, max 258 min) in forest-foraging areas, 45 min (7–175 min) in cow sheds and 18 min (5–118 min) in open areas.

To reach the foraging areas, the bats usually used riparian woodlands, hedges and tree lines as flight paths but open areas were not completely avoided. The cross bearings taken while the bats conducted commuting flights ( $n=58$ ) indicated that 24% of flight time was spent over open land without any buildings or vegetation, and 9% of the cross-points were located close to isolated trees or groves. However, 57% of the bearings were taken at linear landscape elements like riparian woodlands, hedges or tree



**Fig. 1** Forest composition in the whole area, at foraging sites (in % of all foraging sites) and at reference sites (in % of all reference sites)



**Fig. 2** Structural parameters of foraging sites and reference sites (means and standard error)

lines and 10% in settlements, which also offer structured flight paths.

While one bat flew non-stop to foraging areas in a distance of 8 km within 29 min, the other bats often interrupted their commuting flights for short foraging breaks, especially while they moved along the riparian woodlands.

## Discussion

In spite of the fact that habitat allocation was only possible during 49% of the time during which the bats could be tracked, our data probably show a realistic picture of the foraging habitat use by *M. emarginatus*. There was no habitat type where the bats “disappeared” extraordinarily often or were more difficult to locate compared to others. However, in respect to the commuting flights, our data might not give the usage of linear landscape elements correctly. Cross bearing of the bats in the woody valleys of streams was extremely difficult. The direction of the signals regularly indicated an orientation along such streams (e.g. the signal of bat 5 could be continuously received by two cars moving along both sides of the deep valley of a small stream, lined by deciduous woodland [50–200 m wide]). The bat used this flight path over 3 km in several nights, but exact cross bearings were not possible. Considering this difficulty, we estimated that 90% of all commuting flights outside forests and villages were conducted along linear woody landscape elements.

Cow sheds and dense deciduous or at least mixed woodlands were the most important foraging habitats of the studied *M. emarginatus* population. Cow sheds were somewhat less intensively used than in western Germany, where females spent on average 75% of their foraging time

in these stables (Brinkmann et al. 2001). In any case, in Bavaria cow sheds also belong to the key-foraging habitats of the species (Krull et al. 1991).

We did not find a strong impact of weather on the usage of stables as Brinkmann et al. (2001), but the increasing presence of the bats in the cow sheds during the second half of the night may indicate a reaction to climatic conditions. If ambient temperatures decreased, then the insect activity would decrease in other foraging habitats and make the sheds an even more attractive site.

## Consequences for conservation

The occupied cow sheds were typically old-fashioned buildings for dairy cattle or fat stock. Our observations indicate that in modern, clean cow sheds or stables used for horses, the density of flies was much lower, and consequently, their value for bats was lower. Due to modernisations of buildings and the usage of insecticides (Lengerken et al. 2006), a decline in the number of suitable cow sheds is predicted. Additionally, the increasing trend of alternative forms of cattle ranching in Bavaria (e.g. suckler cattle farms), where stables are less important, contributes to this reduction (Faulhaber 2005). Up to now, colony sizes of *M. emarginatus* in Bavaria have been stable or are increasing (Friemel and Zahn 2004), which suggests that these changes have not harmed the population. Nevertheless, the availability of stables that are a favourable fly habitat has to be considered in conservation concepts for notch-eared bats.

Forests are most likely the natural foraging habitats of *M. emarginatus*. We showed that pure stands of coniferous (spruce) forest are avoided, a trend that has been reported for other bat species as well (Zahn and Krüger-Barvels 1996; Holzhaider et al. 2002). Considering the distance between foraging sites and nursery roost, our study indicates that conservation measures within a radius of 6 km would cover most of the foraging areas of a colony. Within this area, the use of native, broad-leave tree species in forestry and the avoidance of pure stands of dense young trees (a consequence of clear-cutting forestry) provide advantageous foraging areas for notch-eared bat populations.

However, *M. emarginatus* uses its nursery roosts shorter than other attic dwelling species (Friemel and Zahn 2004). The bats begin to abandon the attics in July. It is still an unsolved question how the population is distributed afterwards and where foraging occurs in late summer and autumn.

Interestingly, 59% of all foraging sites but only 28% of all reference sites in forests were located near streamlets or streams, and outside forests the riparian, deciduous woodlands were the main foraging habitat next to cow sheds.

This might indicate a preference for moist woody vegetation as foraging habitat. However, the usage of linear, riparian woodlands as flight paths may increase the probability of foraging along streams. The avoidance of spruce monocultures may have the same effect, because at moist stands along streams pure spruce monocultures are rarer than elsewhere. On the other hand, the availability of emerging aquatic insects and the higher diversity of trees and shrubs on moist soils might indeed enhance the food supply for *M. emarginatus* in riparian woodlands. Even if the reason for the preference of moist woodland is not fully understood, our findings suggest that the management of riparian woodlands (usage of native trees, avoidance of clearings, re-establishment of woodland along streams) should be considered in the habitat management plans for this bat species.

The ecological niche of *M. emarginatus* in Central Europe

It is noteworthy to mention, that according to the usage of dense forests and the ability to catch prey close to clutter, the notched ear bat is ecologically similar to *M. nattereri* and, to a lesser extent, to *Myotis bechsteinii* (Siemers et al. 1999; Siemers and Schnitzler 2004; Siemers and Swift 2006). Analyses of the diet indicated a large niche overlap in *M. emarginatus* and *M. nattereri* (Beck 1991, 1995; Krull et al. 1991; Siemers and Swift 2006; Steck and Brinkmann 2006). However, both species occur sympatrically in Bavaria, and little is known about resource partitioning in the wild. *M. nattereri* used similar foraging habitats (Smith and Racey 2008) whereby bats that were studied in Baden-Wuerttemberg (where *M. emarginatus* also occurs) used coniferous forest types, which are avoided by *M. emarginatus* (Siemers et al. 1999). Situations where both species occur sympatrically are interesting from the background of a Holocene colonisation of the alpine foothills by notched eared bats. *M. nattereri*, a tree-hole-dwelling species is native to the Central European deciduous woodlands, whereas *M. emarginatus*, an originally cave-dwelling species (Topál 2001), depends on buildings for reproduction in Central Europe. Sympatry of these species in the study area is therefore of recent origin and niche separation might be low. A comparative study, including radio tracking and diet analyses of colonies living in close vicinity, could help to resolve the ecological differences in these similar species.

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