Habitat use by female Geoffroy's bats (*Myotis emarginatus*) at its two northernmost maternity roosts and the implications for their conservation

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Abstract: Geoffroy's bat (*Myotis emarginatus*) has four known breeding colonies in the Netherlands. Two of these are the known most northerly maternity roosts of the species. Both colonies have received Natura 2000 status. In order to collect ecological data needed to develop a management plan of these two sites, seven female Geoffroy's bats from these two breeding colonies were radio tagged and tracked during their foraging trips. The animals used woods, stables of cattle and sheep, and tree lanes, to a distance of up to 8 kilometres from the maternity roosts. The animals used tree lanes to fly from their roosts to the hunting areas, but also to forage. They spent the most time in woods (36%), stables (32%), and in tree lanes (29%), the remaining time (2%) was spent in urban areas, open fields and orchards. We did not observe any movement of individuals between the two colonies. The percentage of the night spent in stables was negatively correlated with outside temperature. Based on the ecology of Geoffroy's bats and the data gathered in the telemetry study, we propose a number of recommendations for protecting these two colonies. These include conserving the breeding colony buildings and adapting management practices in an area of 8 kilometres around the colonies. The most important of these management practices are: conserving tree lines, insect-rich stables and woods In addition, the Dutch and German authorities should cooperate in controlling development projects (construction of roads or estate development) and other projects that may affect these landscape structures.

Keywords: temperature, weather, stables, cattle, lanes, woodland, Chiroptera, Limburg, the Netherlands.

Introduction

Geoffroy's bat (*Myotis emarginatus*) is a rare species in the northern part of its range and was evaluated as "Vulnerable" in 1996 (IUCN 2007). For this reason, Geoffroy's bat was included in Annexes II and IV of the Habitat Directive, giving it a special protection status in the European Union. Recently, the conservation status of the species has improved throughout much of Europe: in the European Mammal Assessment of 2006 (Temple & Terry 2007) it was evaluated as being of 'Least Concern'. In the Netherlands, however, only two maternity sites are known and it is considered 'Vulnerable' (Zoogdiervereniging VZZ 2007).

After arousing from hibernation in April and May, the females move to large mater-

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nity colonies, where the young are born. During the time of this study, there were two large maternity roosts, and two very small roosts (<10 individuals) in the Netherlands. The two large maternity roosts are located within 2 km of each other near Echt, Province of Limburg, with one each occurring in the attics of the Maria-Hoop Monastery and Lilbosch Abbey (Vergoossen 1992, Verheggen 2001). These maternity roosts are surrounded by agricultural land and woodlands, and at the time of this study were occupied by 985 and 85 adult animals respectively during summer (Vergoossen et al. 2009). The buildings in which the colonies are located have been assigned a Natura 2000 status (Ministry of Agriculture, Nature and Food Quality 2003).

However, to conserve the maternity roosts, the foraging areas must also be protected. This requires an understanding of the distances flown and the habitat types used by the bats. We gathered these ecological data by radio tagging and tracking seven females from the maternity roosts during their foraging flights in May 2007.

Materials and methods

Bats were captured between 17 and 23 May 2007 on flight paths using mist nets on the terrain surrounding the two maternity roosts and at a stable in the village of Montfort that was found to be a foraging site in an earlier study (J. Regelink, unpublished results). The captured bats were sexed, weighed, their forearm length was measured, and their reproductive condition was assessed. Non-reproductive females or females in early stages of pregnancy received a 0.42 g radio-transmitter (Model LB-2, Holohil Systems Ltd, Carp, Ontario, Canada) which was glued onto the fur, between the shoulder blades, using surgical glue (Sauer Hautkleber, Manfred Sauer GMBH, Lobbach, Germany). The recommended transmitter to body weight ratio of 5% (Aldridge and Brigham) was not exceeded. After the glue had dried, animals were released by placing them on a tree or other elevated object, so that they could fly away.

Animals were tracked using a directional antenna (type Y-6, Televilt, Lindesberg, Sweden) mounted on a car, and a receiver (Communication Specialist, Orange, California, USA). Each team, consisting of a driver and a tracker, tracked a single animal by car and whenever possible used close approach telemetry techniques to verify the location of the bat. If this was not possible, radio-triangulation was used to provide point locations. The positions of the animal were determined by homing in, but if animals hunted in an area for a longer period, an attempt was made to pinpoint this site by triangulation or by circling the site. If animals were hunting in stables for longer periods, we attempted to get a precise location by observation or by triangulation on foot. When this was not possible, because areas were inaccessible, the whole area that could be encircled was classified as being used, accepting a lower resolution.

During tracking, locations of the animal were entered in a voice-recorder and a GPS. The location of the animal was classified by habitat type, classified as ‘forest interior’, ’stable’, ’tree lane’, ’orchard’, ’urban’ or ’open field’. Animal locations on a forest edge were classified as ‘tree lane’. On the afternoon after each night of the fieldwork, the data were entered into a GIS and a spreadsheet. Stables that were used by the tracked animals were visited after the fieldwork period and their characteristics (type of cattle housed, type of flooring, and whether lights were left on or off at night) were recorded. Only animals that were tracked for more than two full nights were used in the habitat analyses.

We tested the effect of temperature, wind speed, and rainfall on the use of stables using Pearson correlation coefficients. Weather data was provided by Mr. Thieu Smeets (available from http://home.wxs.nl/~thieusm/limmet.htm) who maintains a weather station in Montfort. From his measurements, made at 10 minute intervals, we calculated sums (rain-

Table 1. Overview of the captures and days female Geoffroy's bats were tracked during the study in 2007. L: captured at Lilbosch. M: captured at Maria-Hoop. 1: 1st complete night tracked. 2: 2nd complete night tracked, ½: incomplete night. X: loss of transmitter.

Night of	L1	L2	L3	M1	M2	M3	M4
16 May	L						
17 May	1						
18 May	2	L	L				
19 May	-	1	1				
20 May	½	2	-	M	M	M	
21 May	½	-	-	-	1	1	
22 May	-	X	2	½	2	-	
23 May	X		-	-	-	-	
24 May			X	½	-	-	M
25 May				½	-	-	½
26 May				1	-	-	½

fall) or averages (wind, temperature) for the activity period of the bats, from 22:30 - 04:30 on the nights when bats were tracked.

The experiment was evaluated and approved by the Institutional Animal Care and Use Committee of Wageningen University as required by Dutch law (entry number 20070033). Exemption from the Dutch Flora and Fauna Act, which is required to capture and radio tag Geoffroy's bat, was given by the (then) Ministry of Agriculture, Nature and Food Quality.

Results

Four netting sessions resulted in the capture of ten female Geoffroy's bats. Of these, seven were radio tagged: three from the Lilbosch colony and four from the Maria-Hoop colony (table 1). Two tagged animals proved hard to track and could not be followed for two full nights. The data of these animals are included in the maps, but not used for habitat analyses. The animals lost the radio tags 4-6 days after tagging.

Two animals spent the day following capture outside the roost, one under a roof in Havert in nearby Germany, the other on the attic of a shed in Montfort in the Netherlands. One animal was caught near Maria-Hoop, but did not return to the colony at all. After two days, she was discovered roosting under an overhanging roof in Haaren, Germany. The next day, this animal roosted at a stable in Selsten, Germany.

All but one of the tracking days were dry. 4.4 mm of rain fell on the 18th of May in Montfort. The average temperature during the nights of the study ranged between 9.3 °C and 16.3 °C. Wind speeds remained below 1 Beaufort on all the nights of the study.

Spatial behaviour

During the study period, we were able to determine the emergence and return times of the 7 tagged animals a number of times. The radio tagged animals left the roost at 22:18 hours ± 0:12 sd (n=11), 44 minutes after sundown, and returned on average at 4:46 hours ± 0:14 sd (n=7), 53 minutes before sunrise.

Individual animals used similar flight paths and foraging areas on multiple days. Typically, after emergence from the roost, 2-3 stables were briefly visited during the commuting flight to the main hunting sites. A few times the tracked animals could be seen flying just under the canopy of tree-lined lanes,

Figure 1. Overview of all certain (solid lines) and probable (dotted line) flying routes and foraging areas (polygons and dots) used by the seven tracked female Geoffroy's bats. The two houses represent the two colonies. The dotted circle has a radius of 5 kilometres, the solid circle a radius of 8 kilometres.

although they occasionally crossed tens of metres of open fields as well as two-lane roads close to the colonies. One of these roads (the N274), was crossed at multiple locations along a 3 km portion of the road that passed through a woodland, while the second road (the N572) was crossed where isolated tree rows intersected the road. The animals crossed at canopy-height. The animals spent large part of the night flying in several hunting areas, located in forests and stables. When returning to the roost in the morning, they often briefly visited stables *en route* again. The animals did not venture farther than 8 kilometres from their maternity roost (figure 1); three of the bats regularly foraged in Germany.

The tracked individuals of the two roosts remained loyal to the roost where they were captured, with the only overlap occurring on the foraging grounds. One bat from each roost used the same stable near Montfort and this included simultaneous use.

Habitat use

Between leaving the roost and returning to it, the animals we tracked spent 36% of the time in woodland, 32% in stables, 29% in tree lanes, and 2% of the time in villages, orchards or open fields. Animals from the Maria-Hoop roost used tree lanes less often as their roost borders woodland.

There were clear individual differences in habitat use and although the animals used roughly the same range on consecutive

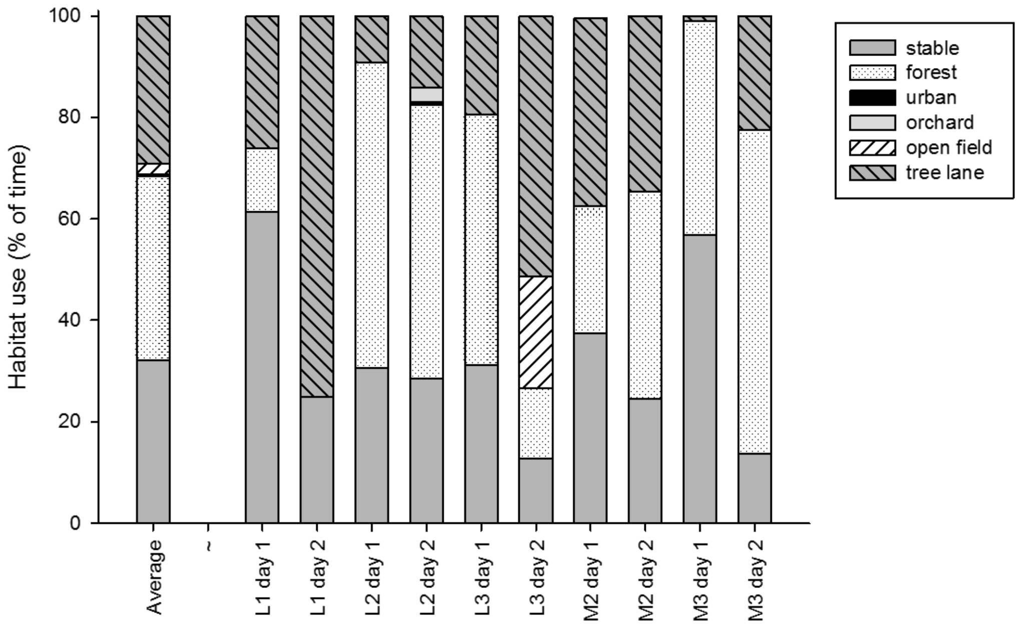

Figure 2. Habitat use by all animals and of individual animals per day, expressed as percentage of the time tracked.

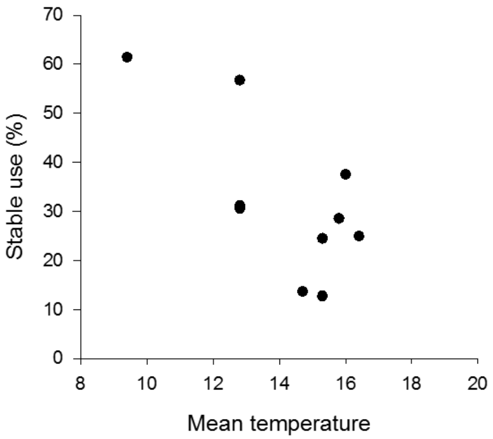

Figure 3. Use of stables and mean day temperature. Nightly use of stables was negatively correlated to night temperature (Pearson's correlation coefficient r=-0.70, P=0.02).

nights, some animals selected different habitats within these areas in the two nights they were tracked (figure 2). Nightly use of stables was negatively correlated to average temperature (figure 3; Pearson's r=-0.70, P=0.02).

Cattle were present in most (7 of 11) stables that were used, with one of these also housing sheep. One each of the remaining stables housed horses alone, sheep alone, horses and sheep together with the final stable containing only straw and machinery. All the stables had hard floors (concrete or tiles) where dung and straw is removed every few days, or had calves on straw in a corner. In 6 of 7 stables of which the owner could be interviewed, lights were kept off at night. The insides of stables and cowsheds were rich in insects, especially stable flies (*Stomoxys calcitrans*). We found no clear effect of the type of livestock housed on the amount of time a stable was used, but the stable used most and by several animals was a stable for cattle.

The animals hunted in several woodlands: Annendaalse Bos, Munningsbosch, 't Sweeltje, Taterbosch and a riparian woodland in Saefelen, Germany. The majority of these were mixed woods of Scots pine (*Pinus sylvestris*) and pedunculate oak (*Quercus robur*) crossed by open hiking paths. All but one of the woods used had a shrub layer of elder (*Sambucus nigra*), raspberry (*Rubus idaeus*) and rowan (*Sorbus aucuparia*).

Discussion

Only a small sample of the total population was studied: we tracked seven of the approximate 1000 animals inhabiting the two maternity roosts. However, the spatial patterns shown by these seven animals seemed to be similar to other Geoffroy's bats from these colonies that were observed using tree lanes and other linear elements as flyways, and woods and stables for hunting.

The insides of stables and cowsheds were relatively rich in insects, especially Diptera. They are sheltered from wind and rain and temperatures inside are usually higher than outside, especially when cattle are present. As such, stables may be an attractive foraging habitat for those species that can capture food by gleaning. Indeed, a large part of the diet of Geoffroy's bat in Germany and Belgium consists of insects that occur in stables (Krull et al. 1991, Moermans 2000, Steck & Brinkmann 2006, Kervyn 2012). The frequent use of stables and cowsheds by hunting Geoffroy's bats has also been found in other studies from the northern part of the species' distribution range (Krull et al. 1991, Brinkmann et al. 2001, Zahn et al. 2010). A study in south-eastern Germany resulted in similar findings to our own study, with tracked females spending 24.5% of the time in cow stables (Zahn et al. 2010). In Baden-Württemberg tracked females from a maternity colony spent up to 90% of the night in stables, while the two males tracked did not hunt in stables at all (Brinkmann et al. 2001). The study by Krull et al. (1991) does not give figures that specify foraging times in different habitats. In France and Spain tracking studies have shown no use of stables (Huet et al. 2002, Flaquer et al. 2008), but these study sites had only one or two stables (personal communication M. Lemaire, L. Arthur and C. Flaquer). We found that bats made more use of stables on colder nights and this supports the idea that the use of stables is related to climatological differences: in colder climates, the relatively warm and insect rich stables appear to be a more attractive alternative to natural foraging habitats, such as forests and orchards, whereas in warmer areas this advantage of stables is less prominent or absent.

In line with this, the use of stables and cowsheds by foraging Geoffroy's bats may be more frequent in the cooler months of spring and autumn than in summer: in spring and autumn their energy requirements are higher, and the temperature and insect density in natural habitats are lower (see for example Scanlon & Petit 2008). As such the sheltered stables will be more attractive hunting habitat than woodlands and tree lanes during autumn and spring, although in these periods the animals can also conserve energy by using torpor during inclement weather. The inter-relationship between temperature and food availability and their effect on Geoffroy's bats' choice of different foraging habitats over different temporal scales is an interesting subject for further study. This could be explored further by building predictive energy budget models and testing these models by determining the use of stables in spring, summer and autumn, using telemetry or autonomous bat call loggers and gathering local, more precise weather data and quantifying insect availability in stables and in alternative habitats.

Our data indicate that the animals fan out from the roost sites, to a distance of up to (at least) 8 kilometres. This range is similar to the maximum distance of 7.5 km found by Brinkmann et al. (2001) and 8 km reported by Zahn et al. (2010). Krull et al. (1991), however, report animals foraging as far as 10 km from the roost. Given the small number of bats tracked in our study, we recommend a conservation buffer of 10 km around all roosts of this species in the Netherlands.

Conservation measures

This study provides information on the amount of time female Geoffoy's bats spend in different habitats across the landscape around the only two known maternity roosts in the Netherlands. From the data gathered, several conservation measures have been proposed. Detailed plans are given in a separate Action Plan for Geoffroy's bat in the Netherlands (Dekker et al. 2008).

Geoffroy's bat uses tree lanes to commute between their roosts and foraging sites and for foraging. These lanes are important commuting routes and must be conserved. For commuting bats, these and other linear landscape elements are important in providing shelter from wind and predators, and provide orientation clues (e.g. Limpens & Kapteyn 1991, Verboom 1998). Even if the foraging areas and roosts are in prime condition, they will not be used if the animals cannot travel between them. Maintenance of tree lanes, especially the replacement of removed trees, is essential, to maintain connectivity across the landscape between foraging areas and roosts. The bats we saw during tracking flew in or above the canopy, and bats are sensitive to light during commuting (Stone et al. 2009). For this reason, streetlights in these areas should be placed sparingly. Attention needs to be given to providing bats with places to cross roads with substantial traffic (see Limpens et al. 2004).

Stables were an important foraging site. The stables used by the radio tracked animals mostly had livestock (and mostly cattle) housed on straw and an absence of lighting at night. It is vital for the wellbeing of maternity colonies to conserve these stables. Such stables are also used for hunting by common pipistrelle (*Pipistrellus pipistrellus*) (observations during our fieldwork), brown long-eared bat (*Plecotus auritus*) (Barataud 1990), grey long-eared bat (*Plecotus austriacus*) (Buys & Vergoossen 1997) and Natterer's bat (*Myotis nattereri*) (Simon et al. 2004). Stables can lose their value for foraging bats when insecticides or antiparasitic drugs are applied; this can reduce the number of insects, but also increases the risk of secondary poisoning. When stables are infested by insects that are harmful to the cattle, and must be treated, it is preferable to treat the cattle directly. The impact on bats can be minimised by treating stables early in the morning and by using insecticides that do not target mammals, such as pyrethrins. Other ways to minimise the impact on bats is by controlling insects using electrocution lights. We advocate avoiding deworming cattle with drugs that contain avermectins, as this compound remains active in dung for a long time, killing not only parasites, but also the insects inhabiting the stable (Ransome & Hutson 2000). Modern stables that do not have straw mixed with dung provide only few insects. This could become a problem, because "old-fashioned" stables seem to be becoming quite rare in the study area.

Woodlands used by the animals were mixed woods with a rich undergrowth. These woodlands should be conserved in this state. This can be done by retaining the undergrowth and leaving dead wood. The woodlands should be connected to tree lanes or other linear landscape structures, not only in the Netherlands, but also in neighbouring Germany.

Other studies have showed that *orchards* can also be an important habitat for Geoffroy's bats (Krull et al. 1991, Brinkmann et al. 2001, Zahn et al. 2010). There are very few orchards in our study area, but cultivation of these would surely benefit Geoffroy's bats, provided they are managed organically and are insect-friendly.

Conservation across borders. Three of the seven bats we tracked relied on areas in Germany for foraging and it is likely that the animals living in the Belgian maternity roosts close to the Dutch border have hunting areas in the Netherlands. For this reason, cross border landscape management plans are required that take the habitat requirements of Geoffroy's bat's into account. A first step could be to arrange meetings between bat specialists and local landscape planners and managers from Belgium, Germany and the Netherlands. In such meetings, known data of maternity roosts can be compiled and shared and any planned construction or landscape management projects in the direct surroundings of the roosts in the three countries can be reviewed, with a view to ensuring that compensation and/or mitigation measures to minimise the effects of such projects can be formulated.

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Samenvatting

Ingekorven vleermuizen in Nederland: habitatgebruik en bescherming van de twee noordelijkste kraamkolonies

Ten behoeve van beheer van twee kraamverblijven met een Natura 2000 status, Lilbosch en Maria-Hoop, werd het habitatgebruik van de daar levende ingekorven vleermuizen (*Myotis emarginatus*) onderzocht. Dit gebeurde door zeven dieren uit te rusten met een kleine zender en deze te volgen tijdens foerageertochten.

De dieren gebruikten bossen, stallen en bomenlanen, tot 8 kilometer van hun kraamverblijf. Bomenlanen werden gebruikt om de foerageergebieden te bereiken. De dieren besteedden de meeste tijd in bossen (36%), gevolgd door stallen (32%) en bomenlanen (26%). De resterende tijd (2%) werd besteed in stedelijk gebied, boven weilanden of akkers, of in boomgaarden. Geen van de gevolgde dieren wisselde tijdens de studie van kraamverblijf. Het percentage van de nacht dat in stallen werd besteed was omgekeerd evenredig aan de buitentemperatuur.

Op basis van de verzamelde gegevens in deze en andere studies kon een aantal beheermaatregelen worden geformuleerd. Hoewel enkele honderden meters rond de twee kraamverblijven zijn aangewezen als Natura 2000 gebied, gebruiken de ingekorven vleermuizen een groter gebied. Het advies is daarom om de soort in een groter gebied te beschermen dan nu het geval is. Aanbevelingen voor het

beheer zijn het behoud van bomenlanen, stallen en bos, alsmede samenwerking aan beide zijden van de Nederlands-Duitse grens tijdens projecten die het landschap beïnvloeden, zoals wegen- en stedenbouw.

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