

Web-building spiders and blood-feeding flies as prey of the notch-eared bat (*Myotis emarginatus*)

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ABSTRACT. Conservation of the endangered notch-eared bat (*M. emarginatus*) requires a specific action plan based on precise ecological requirements of this species. The analysis of the diet of three colonies in southern Belgium revealed: (1) spatial and seasonal variations of the diet; (2) the consumption of web-building spiders (*Araneus diadematus*, *Araneus triguttatus*, *Cyclosa conica*, *Enoplognatha* sp., *Larinioides patagiatus*, *Neriene emphana*); (3) the predominance of blood-feeding dipterans in the diet (*Stomoxys calcitrans* and *Musca autumnalis*). Since the populations of these two ectoparasitic flies are sensitive to the use of antiparasitic drugs, these drugs should be used with caution by farmers and veterinarians in the vicinity of maternity colonies.

KEY WORDS: Food, spiders, *Stomoxys calcitrans*, *Musca autumnalis*, Geoffroy's bat.

INTRODUCTION

Bat populations are declining world-wide as a result of a growing number of factors, including habitat loss and fragmentation, disturbances to roosts, exposure to toxins and introduced predators (RACEY, 1998). Relatively little attention has been devoted to the ecology of the notch-eared bat although this species is considered as endangered in Belgium and Luxembourg (HARBUSCH et al., 2002; VERKEM et al., 2003; LAMOTTE, 2007; KERVYN et al., 2009). The habitats used by this species must be conserved in accordance with the Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora. The implementation of pertinent conservation measures requires information on its foraging habits.

Five studies have documented the food habits of the notch-eared bat in Europe (BAUEROVÁ, 1986; KRULL et al., 1991; BECK, 1995; STECK & BRINKMANN, 2006; GOITI et al., 2011). These studies pointed out the importance of spiders

and flies in the diet of the notch-eared bat, but they failed to identify most of these arthropods to a specific level, which is, however, required in order to build a species-specific action plan for the conservation of this species.

The aims of this paper are (1) to describe in detail the diet of the notch-eared bat in southern Belgium, especially regarding spiders; (2) to point out intra-specific dietary differences in relation to the seasonal and geographical conditions; (3) to focus on implications of the diet for the conservation of this bat species.

MATERIALS AND METHODS

Three bat colonies were studied in southern Belgium (Figure 1). The first colony consists of about one hundred breeding females roosting in the church of Bolland, Province of Liège, a village situated in the Herve upland in a bocage landscape dominated by pastures and orchards. The second colony of about fifty breeding females occupies the attic of a private house

in Rochefort, Province of Namur, a small town in the Famenne region surrounded mainly by broad-leaved and coniferous forests, pastures and arable land. The third colony consists of circa thirty breeding females roosting in the church of Guirsch, Province of Luxembourg, a village situated in the Belgian Lorraine region in a landscape dominated mainly by broad-leaved and coniferous forests, and pastures.

Polythene sheets were placed on the attic floor, beneath the roosting bats, from the end of April to October 1999. Faecal pellets were collected every two weeks in Bolland and monthly in Rochefort, air-dried and stored in plastic bags. Due to access restriction, only one sample was collected in June 1999 in Guirsch. From these collections, pellets were taken at random, in order to reduce the number of pellets originating from the same individual. The sample size was determined *a posteriori* by examining the variation of prey proportions related to the number of analysed pellets (KERVYN, 1998). Large samples with a high diversity were analysed. This clearly indicated that after the analysis of approximately 10 droppings, inclusion of more droppings did not significantly alter the composition of the sample.

A sample of 20 droppings allowed detection of all the identifiable taxa. Each faecal pellet was soaked in water on a microscope slide and teased apart under a binocular microscope using a pair of dissecting needles. Identification of insect pieces was facilitated by the general descriptions of SHIEL et al. (1997) WHITAKER (1988), MCANEY et al. (1991) and specialised documents (LOCKET & MILLIDGE, 1953; VAN EMDEN, 1954; D'ASSIS FONSECA, 1968; VAN HELSDINGEN, 1969; LECLERCQ, 1971; ROBERTS, 1985; SMITH, 1986; RANSY & BAERT, 1987; ROBERTS, 1987, 1998). Species of Araneae were only identified by genitalia (epigynes for females and palps for males), although the majority of the prey remains were legs or chelicerae. Insect fragments were also compared with specimens stored in the entomological collections of the Zoological Museum of Liège and the Royal Belgian Institute of Natural Sciences of Brussels. No attempt was made to accurately estimate the frequency of fragments or percentage volume of prey taxa within a dropping, because most fragments could not be attributed to any taxon. Moreover, the remains of a single prey are distributed among many droppings (ROBINSON & STEBBINGS, 1993). Results are expressed in relative frequency



Figure 1 – Location of study sites in Belgium.

of occurrence, which represents the number of pellets containing the item among a sample of 20 pellets, divided by the total number of items. To detect possible variations, a goodness-of-fit test (SOKAL & ROHLF, 1981) was performed to compare the frequency distribution of prey items. A Newman-Keuls test was used to identify the origin of the variations.

RESULTS

Diet Composition

A total of 873 insect fragments were recorded from 320 droppings (Table 1). Of these, 788 items were identified and 85 were not. The mean number of prey taxa per dropping was 2.67 ± 1.44 , with maximum of 9.0. Diptera accounted for the majority of identified prey, with a large proportion of stable fly (*Stomoxys calcitrans*) and face fly (*Musca autumnalis*) (Table 1 and Figure 2). These two species accounted for 53.4% of the prey in Bolland and 72.1% in the sample from Guirsch. However, the most striking difference between sites was the absence of stable and face flies in Rochefort. In contrast to this, Araneae – the second most important taxon – accounted for 29.4% in the diet from Rochefort, while this prey appeared in reduced proportion in Bolland (22.4%) and Guirsch (23.3%). The identified spiders in Bolland (7 items) were Araneidae with *Araneus diadematus* (n = 1), *Cyclosa conica* (n = 2), and Theridiidae (n = 3) with *Enoplognatha* sp. (cf. *ovata*) (n=1). In Rochefort (17 items), spiders were also mainly Araneidae, with *Araneus diadematus* (n = 1), *Araneus triguttatus* (n = 2), *Cyclosa conica* (n = 12), *Larinioides patagiatus* (n = 1) and Linyphiidae with *Neriene emphana* (n = 1). Other prey found in Bolland and Rochefort belong to the taxa Lepidoptera, Hymenoptera Apocrita – mainly Ichneumonidae, Coleoptera, Neuroptera, Thysanoptera and Psocoptera (Table 1).

Seasonal variations

Variation in consecutive samples was low

(Figure 2). Samples were homogenous among sampling periods in Bolland (G-test global: $G = 36.7$; $df = 30$; ns) and Rochefort (G-test global: $G = 17.88$; $df = 21$; ns), but lepidopterans in Bolland were more numerous in May (G partial = 11.33; $df = 5$; $p < 0.05$).

DISCUSSION

Diet

Relevance and limitations of the method have been evaluated by several authors (RABINOWITZ & TUTTLE, 1982; KUNZ & WHITAKER, 1983; DICKMAN & HUANG, 1988; ROBINSON & STEBBINGS, 1993). Faecal analysis does not provide the exact composition of the ingested food. However, it allows an estimation of the food composition, especially for the most common prey items. Its use is valuable for seasonal or geographical comparisons of the diet. Results usually overestimate the proportion of large insects and of those prey items leaving easily identifiable pieces even after ingestion and digestive transit. Soft-bodied insects may be underrepresented.

Since notch-eared bats may forage up to 10 km from the roost (KRULL et al, 1991) and the transit time in bats is rapid (KOVTUN & ZHUKOVA, 1994), faeces collected in the roost may contain a higher proportion of insects caught near the roost (RABINOWITZ & TUTTLE, 1982).

This study provides, for the first time, species-level identification for the main prey of this bat in three Belgian colonies. Although the sampling period was limited to one single year, results may be considered as representative since intra-annual variation appears to be low. This gives a more comprehensive concept of the foraging behaviour and the foraging habitats of the notch-eared bat. The diet composition of these bats studied in Germany (KRULL et al., 1991; BECK, 1995; STECK & BRINKMANN, 2006) was also dominated by species of Diptera (*Muscidae*) and spiders, as we found in the colonies of Bolland

and Guirsch. The diet described by BAUEROVÁ (1986) and GOITI (2011) is somewhat similar to the food composition of the colony settled in Rochefort where spiders constitute a large part of the diet. The six species of spiders identified as prey items are all web-building spiders, usually found on bushes and trees (ROBERTS, 1995).

Foraging behaviour

A diet composed of spiders and nocturnally non-flying insects, such as muscids, supports the gleaning behaviour of the notch-eared bat, as

predicted by NORBERG & RAYNER (1987) and observed by KRULL et al. (1991) and SCHUMM et al. (1991). The prey items identified here are shared in Europe with other foliage-gleaner or surface-gleaner bats such as *Plecotus auritus* and *Myotis nattereri* (BAUEROVÁ, 1982; GREGOR & BAUEROVÁ, 1987; SHIEL et al., 1991; SWIFT & RACEY, 2002; MOTTE, unpublished results). It is now well documented that the notch-eared bat forages in forests, in orchards or along forest edges (KRULL et al., 1991; BARATAUD, 1993; BRINKMANN et al., 2001; HUET et al., 2004; FLAQUER et al., 2008; ZAHN et al., 2010; GODIN, unpublished results), but this bat can

Table 1

Food composition of the notch-eared bat at three study sites.

Taxa	Bolland											Total	%
	99-05-13	99-05-29	99-06-12	99-06-26	99-07-12	99-07-24	99-08-08	99-08-23	99-09-05	99-09-18	99-10-29		
ARACHNIDA Araneae	15	10	6	11	12	9	11	8	13	18	12	125	22,4%
INSECTA Coleoptera	-	2	-	1	-	-	-	-	-	-	-	3	0,5%
INSECTA Coleoptera Carabidae	1	-	-	-	-	-	-	-	-	-	-	1	0,2%
INSECTA Coleoptera Chrysomeloidea Cerambycidae	-	-	-	-	-	-	-	-	-	-	-	-	0,0%
INSECTA Coleoptera Scarabeoidea Scarabeidae	-	1	-	1	-	1	-	-	1	1	-	5	0,9%
INSECTA Coleoptera Staphylinidae	1	-	-	-	-	-	-	-	-	-	-	1	0,2%
INSECTA Diptera	-	-	-	1	-	1	1	1	1	-	1	6	1,1%
INSECTA Diptera Anisopodidae	2	1	1	2	-	-	-	-	-	-	-	6	1,1%
INSECTA Diptera Calliphoridae	-	-	-	-	-	-	-	-	-	-	-	-	0,0%
INSECTA Diptera Chironomidae or Ceratopogonidae	-	-	-	-	-	-	-	-	-	-	-	-	0,0%
INSECTA Diptera Culicidae	-	-	-	-	-	-	-	-	-	-	-	-	0,0%
INSECTA Diptera Empididae	1	-	-	-	-	-	-	-	-	-	-	1	0,2%
INSECTA Diptera Muscidae	3	-	1	-	-	-	-	-	-	1	-	5	0,9%
INSECTA Diptera Muscidae <i>Musca autumnalis</i>	3	12	10	13	12	11	15	14	15	9	7	121	21,7%
INSECTA Diptera Muscidae <i>Stomoxys calcitrans</i>	8	12	18	14	20	19	19	19	18	15	15	177	31,7%
INSECTA Diptera Nematocera	-	-	-	-	1	-	-	-	-	-	-	1	0,2%
INSECTA Diptera Psychodidae	1	4	3	-	-	1	3	-	1	-	-	13	2,3%
INSECTA Diptera Scatophagidae	4	1	-	1	2	-	-	1	1	2	-	12	2,2%
INSECTA Diptera Syrphidae	-	-	-	1	-	-	-	-	-	-	-	1	0,2%
INSECTA Diptera Tipulidae	3	1	1	-	-	-	-	-	-	-	-	5	0,9%
INSECTA Hymenoptera Apocrita	-	1	-	-	-	-	-	-	-	-	1	2	0,4%
INSECTA Hymenoptera Apocrita Ichneumonidae	2	2	1	-	1	-	-	-	1	-	-	7	1,3%
INSECTA Lepidoptera imago	1	4	4	4	2	-	2	3	1	1	-	22	3,9%
INSECTA Lepidoptera larvae	5	2	-	-	-	-	-	-	-	-	-	7	1,3%
INSECTA Psocoptera	-	-	1	-	1	-	-	-	-	-	-	2	0,4%
INSECTA Neuroptera Chrysopidae	-	-	-	-	-	-	-	-	-	-	-	-	0,0%
INSECTA Neuroptera Hemerobiidae	2	-	-	-	-	-	-	-	-	-	-	2	0,4%
INSECTA Thysanoptera Thripidae	-	-	-	-	-	-	-	-	-	-	-	-	0,0%
Undetermined	2	1	3	5	3	3	4	5	1	3	3	33	5,9%
Total	54	54	49	54	54	45	55	51	53	50	39	558	100%

also opportunistically feed inside cowsheds (KRULL et al., 1991; SCHUMM et al., 1991; VERGOOSSEN & BUYS, 1997; BRINKMANN et al., 2001; DEKKER et al., 2008). A large consumption of spiders has seldom been documented in bats. It is known from only a few other gleaning-bat species worldwide: *Kerivoula papuensis* in Australia (SCHULZ, 2000) and *Myotis keeni* in Canada (BURLES et al., 2008).

Prey detection

Bats that capture animal prey from substrates often emit characteristic echolocation calls that are short-duration, frequency-modulated (FM) and broadband. Such calls do not seem effective for finding prey among cluttered backgrounds

because echoes reflecting from the substrate mask the acoustic signature of prey (ARLETTAZ et al., 2001). Hence, like many other surface-gleaning bats, the notch-eared bat presumably detects its prey by listening for prey-generated sounds, in flight or sometimes from a perch (VERGOOSSEN & BUYS, 1997; BRINKMANN et al., 2001; DEKKER et al., 2008). Muscids are expected to be detected by their fluttering or buzzing noise, presumably initiated by the bat’s flight movement near the substrate. Spiders are presumably captured on their web, since webs are often found among the notch-eared bat droppings, as a result of fur cleaning after foraging (BODIN et al., 2002). Spiders could be detected by echolocation or through the buzz generated by spider prey in the web.

Guirsch			Rochefort						Total	%	% of identified	Taxa
99-06-20	Total	%	99-05-22	99-06-20	99-08-22	99-09-21	Total	%				
10	10	23,3%	20	20	20	20	80	29,4%	215	24,6%	27,3%	Araneae
-	-	0,0%	-	1	-	-	1	0,4%	4	0,5%	0,5%	Coleoptera
-	-	0,0%	-	-	1	-	1	0,4%	2	0,2%	0,3%	Coleoptera Carabidae
-	-	0,0%	2	1	1	-	4	1,5%	4	0,5%	0,5%	Coleoptera Chrysomeloidea Cerambycidae
-	-	0,0%	1	-	1	-	2	0,7%	7	0,8%	0,9%	Coleoptera Scarabeoidea Scarabeidae
-	-	0,0%	-	-	-	-	-	0,0%	1	0,1%	0,1%	Coleoptera Staphylinidae
-	-	0,0%	4	7	2	6	19	7,0%	25	2,9%	3,2%	Diptera
-	-	0,0%	-	1	-	-	1	0,4%	7	0,8%	0,9%	Diptera Anisopodidae
-	-	0,0%	-	-	1	-	1	0,4%	1	0,1%	0,1%	Diptera Calliphoridae
-	-	0,0%	4	-	1	2	7	2,6%	7	0,8%	0,9%	Diptera Chironomidae or Ceratopogonidae
-	-	0,0%	-	-	1	-	1	0,4%	1	0,1%	0,1%	Diptera Culicidae
-	-	0,0%	-	1	-	1	2	0,7%	3	0,3%	0,4%	Diptera Empididae
-	-	0,0%	-	1	-	1	2	0,7%	7	0,8%	0,9%	Diptera Muscidae
15	15	34,9%	-	-	-	-	-	0,0%	136	15,6%	17,3%	Diptera Muscidae <i>Musca autumnalis</i>
16	16	37,2%	-	-	-	-	-	0,0%	193	22,1%	24,5%	Diptera Muscidae <i>Stomoxys calcitrans</i>
-	-	0,0%	-	-	-	-	-	0,0%	1	0,1%	0,1%	Diptera Nematocera
-	-	0,0%	-	-	-	3	3	1,1%	16	1,8%	2,0%	Diptera Psychodidae
-	-	0,0%	1	1	1	2	5	1,8%	17	1,9%	2,2%	Diptera Scatophagidae
-	-	0,0%	1	-	-	-	1	0,4%	2	0,2%	0,3%	Diptera Syrphidae
-	-	0,0%	5	4	3	-	12	4,4%	17	1,9%	2,2%	Diptera Tipulidae
-	-	0,0%	-	-	-	-	-	0,0%	2	0,2%	0,3%	Hymenoptera Apocrita
-	-	0,0%	7	4	1	4	16	5,9%	23	2,6%	2,9%	Hymenoptera Apocrita Ichneumonidae
2	2	4,7%	5	4	9	3	21	7,7%	45	5,2%	5,7%	Lepidoptera imago
-	-	0,0%	8	6	1	1	16	5,9%	23	2,6%	2,9%	Lepidoptera larvae
-	-	0,0%	-	-	-	-	-	0,0%	2	0,2%	0,3%	Psocoptera
-	-	0,0%	-	-	-	1	1	0,4%	1	0,1%	0,1%	Neuroptera Chrysopidae
-	-	0,0%	5	3	4	3	15	5,5%	17	1,9%	2,2%	Neuroptera Hemerobiidae
-	-	0,0%	-	2	1	6	9	3,3%	9	1,0%	1,1%	Thysanoptera Thripidae
0	0	0,0%	15	11	13	13	52	19,1%	85	9,7%	---	Undetermined
43	43	100%	78	67	61	66	272	100%	873	100%	100%	Total

Conservation

The importance of stable and face flies in the diet of this endangered bat raises an interesting conservation issue, since it provides a new example of human dependency among bats (STEBBINGS & ROBINSON, 1991). These flies are considered as pests and locally strongly controlled because of their impact on cattle health and related economic damage (LECLERCQ, 1971; CAMPBELL et al., 2001; RODRÍGUEZ-BATISTA et al., 2005). Larvae of these prey species develop in decaying organic matter, such as horse and cow dung (GRABOVAC & PETRIC, 2003; RODRÍGUEZ-BATISTA et al., 2005), in cowsheds but also on pastures and orchards around cattle feeding sites of hay in round bales (BROCE et al., 2005). As well as by sanitary measures in cowsheds, these insects are mainly destroyed by the application of antiparasitic drugs (MADSEN et al., 1990; MC CRACKEN, 1993). This practice should be banned or strongly reduced for the cattle around summer roosts of the notch-eared bat (EUROBATS, 2010). This management measure is also recommended for the conservation of the serotine bat (KERVYN & LIBOIS, 2008) and the endangered greater horseshoe bat (*Rhinolophus ferrumequinum*) (RANSOME & HUTSON, 2000), which regularly share roosts with the notch-eared bat. Both species feed on a key-prey, the dung beetle *Aphodius*, a non-target species also affected by antiparasitic treatments.

Conservation measures devoted to areas neighbouring notch-eared bat colonies should therefore take the problem of antiparasitic administration into account (DOWNS & SANDERSON, 2010), particularly in Special Areas of Conservation of the Natura 2000 network, around forests and orchards but also in and around cowsheds. Amazingly, since cowsheds are a privileged foraging area, the presence of cattle within cowsheds in summertime seems to be of great importance to maintaining or restoring the local population of the notch-eared bat. The impact of livestock welfare regulations – imposing larger, cleaner and better ventilated cowsheds, in opposition to the ecological

requirements of flies – would be interesting to analyse, since it presumably reduces the quality of this feeding area for notch-eared bats.

On the evolution of blood-suckling in bats

Many papers have presented hypotheses concerning the intermediate stages involved in the origin of the blood feeding strategies present in bats (MONTEIRO & NOGUEIRA, 2011). The consumption of blood-feeding ectoparasites is considered as a first step in the development of blood feeding behaviour from the ancestral, insect-eating behaviour (FENTON, 1992; BAKER, 2010). Our results on the diet of notch-eared bats illustrate the feasibility of this step in a vespertilionid bat. Further research would be worthwhile to test whether bats take significant advantage of ectoparasite meals.

CONCLUSIONS

Our results confirm that the diet of notch-eared bats (*Myotis emarginatus*) in southern Belgium is characterized by flies, but also spiders and other nocturnal non-flying insects. Local differences in diet composition can be explained by an opportunistic foraging behaviour. The importance of web-building spiders in the diet suggests that bats might be able to pluck spiders from their webs. These bats presumably detect their prey by the sounds they produce. The consumption of stable and face flies is congruent with the observations of individuals foraging within cowsheds. The present-day agricultural practice of eliminating flies with insecticides or transforming cowsheds may be hazardous for the survival of this bat. Thus, action plans designed for this Natura 2000 species should avoid such agricultural practices affecting the prey availability of this human-dependant bat.

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