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Dietary analysis confirms that Rickett's big-footed bat (*Myotis ricketti*) is a piscivore

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Abstract

The diet of *Myotis ricketti* was examined by faecal analysis, and foraging behaviour was observed in the field. Scales from at least three species of small fish were found in the droppings, together with fragments of insects from six orders. This study demonstrates that *M. ricketti* is a fish-eating bat. As with other trawling bats in the genus *Myotis*, *M. ricketti* emits short, broadband echolocation sounds. The sounds recorded from bats released from the hand swept downward from *c*. 70 to 28 kHz in 4 ms, and contained most energy at 41 kHz.

Key words: *Myotis ricketti*, diet, piscivore, insectivore, echolocation, Beijing

INTRODUCTION

Myotis ricketti (Vespertilionidae) has long been regarded as an endemic species from China. Recent surveys have found the species also in Laos (Francis, Lhounboline & Asprey, 1996) and in north-east India (A. Thabah & G. Jones, pers. obs.). *Myotis ricketti*, is a relatively large-sized bat for the genus (forearm length 53–58 mm) (Ma *et al*., 2003) and is sometimes known as *M. pilosus* (e.g. Koopman, 1994). Thomas (1894) obtained a skull and skin of a bat from C. B. Rickett, which became the type specimen from Foochow, Fukien Province. Allen (1936) discussed in detail the status of *M. ricketti*. The prominent characteristics of this species are the well-developed feet and claws. Similar features occur in the piscivorous bats *Noctilio leporinus* and *M. vivesi* (Allen, 1936; Bloedel, 1955). *Myotis ricketti* has long been suspected to be a fishing bat simply because of its large feet and claws (Allen, 1936; Bloedel, 1955). In 1936, Allen captured a specimen of *M. ricketti* from Suzhou, China, and examined the stomach and intestines. However, the alimentary tracts were empty and diet could not be determined. A limited study on five droppings of *M. ricketti* in Laos found fish as the dominant feature in the sample (Robinson & Webber, 1998). The present examination focuses on the diet of this species in China. Evidence is provided that the species is piscivorous, and some of the fish species are identified from the structure of their scales. In addition, a brief description of the echolocation sounds of *M. ricketti* is provided.

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METHODS

Field studies were conducted at Sihe village (39.72°N, 115.98°E), which lies in Fangshan County, 100 km south-west of Beijing. The village is in a mountainous region, and includes 1 large cave where the bats roost. Surrounding vegetation is classified as warm temperate zone forest. Most of the native forest is Chinese pine *Pinus tabulaeformis*, arborvitae *Sadina chinensis* and oaks *Quercus mongolica* and *Q. liaotungensis*. There is 1 reservoir (*c*. 15 000 m^2) 8 km away from the cave. Most bats in the main cave are individuals of *M. ricketti*, together with *Rhinolophus ferrumequinum*, *Murina leucogaster*, and *Myotis myotis* in smaller numbers.

Between late August and mid-October 2002, *M. ricketti* (6–25 bats each sample) were captured by mist netting at the entrance of the cave when bats returned from foraging at *c*. 22:00. Faeces were sampled every 2 weeks by holding these bats in small clear cotton bags overnight. The bats were released in the same cave next morning; and faeces from each bat were collected (5–10 droppings) and deposited in 70% alcohol for detailed examination with a microscope. Species-specific patterns of scales enabled identification of fish (Chu, 1935). Scales from faeces were compared under a microscope with scales

Table 1. Measurements of *Myotis ricketti* ($n = 40$; individuals of both sexes included), *M. daubentonii* and *M. adversus*. Measurements of *M. daubentonii* are taken from Schober & Grimmberger (1989), except for hindfoot length, which is from Bates & Harrison (1997). Measurements for *M. adversus* are from Churchill (1998)

Parameters	*M. ricketti*	*M. daubentonii*	*M. adversus*
Body mass (g)	22.5 ± 3.5	7–15	5–15
Forearm length (mm)	55.2 ± 0.9	35–42	36–43
Hindfeet length (mm)	18.4 ± 1.8	7.9	8.3–10.1
Body length without tail (mm)	67.8 ± 1.5	45–55	35–50
Tail length (mm)	57.5 ± 2.7	31–44.5	33–42
Ear length (mm)	18.5 ± 2.5	10.5–14.2	8.9–15.6
Wingspan (cm)	34.8 ± 1.3	24–27.5	26.7–29.2
Mid-toe with claw length (mm)	11.3 ± 2.4	–	–

from a reference collection of fish that were caught with throw and dip nets from the reservoir. Reference fish were identified to species and deposited in the Institute of Zoology, Chinese Academy of Sciences. Identification of insects was made to order based on a reference collection of insects captured by hand-net around the cave and reservoir (Zheng & Gui, 1999). Visual estimates were made of the percentage volume of each food category (Whitaker, 1987) for each sample and we also measured the percentage occurrence of each food type in the droppings sample from each bat. The foraging bats were watched with a digital infrared video camera (Sony DCR-TRV27E) and by naked eye while listening simultaneously with an ultrasonic Detector D240x (Pettersson Elektronik) set in heterodyne mode tuned to 40 kHz around the cave and the reservoir. The scales of fish, wings of insects, and anatomical measurements of the bats including the length of forearms, ears, tails, feet and mid-claws were measured with a vernier calliper to an accuracy of 1 mm. Body mass was assessed using a spring balance to an accuracy of 0.5 g. The morphology of *M. ricketti* was compared with *M. adversus* and *M. daubentonii*. Echolocation sounds were recorded from 5 bats captured at a cave in Guilin, Guangxi Province. One call per bat was analysed, that call being the furthest (> 10 m) from the release point with a good signal : noise ratio. Recordings were made with a Pettersson D980 bat detector (time-expansion 10×) onto a Sony TCD-D8 DAT recorder. Analysis was performed using the software BatSound (Pettersson Elektronik), with FFT size 512 points and a Hanning Window.

RESULTS

The bat *Myotis ricketti*, compared with *M. daubentonii* and *M. adversus*, is a large-sized *Myotis* with forearm length *c.* 55.2 mm and a wingspan close to 34.8 cm. The feet are characteristically large, measuring *c.* 18.4 mm (Table 1).

In total, 43 bats were captured, and pellets were pooled from each bat for analysis (Table 2). Fish and insects were found in faecal samples, and fish scales were easily distinguished by their silver colour. Three fish species and at least six orders of insects were found in the droppings (Table 2). Most of the identifiable insect parts were from Homoptera (about 70% of all insect remains). The wings of Coleoptera and Diptera were 2–4 mm, and some of them were from beetles in the families Cantharidae and Chrysomeloidae. The wings of Hemiptera were 2–5 mm. Additionally, the remains of Ephemeroptera and Odonata were found occasionally. Three species of fish were eaten by *M. ricketti*: *Zacco platypus* (Cyprindidae, Leuciscinae), *Carassius auratus* (Cyprindidae, Cyprininae) and *Phoxinus lagowskii* (Cyprindidae, Leuciscinae). The diameter of the scales was 1.5–3.5 mm for *Z. platypus* and *C. auratus*, *c.* 1.0–2.0 mm for *P. lagowskii*. The three fish species were encountered 25 times in all 43 faecal samples. Insects were encountered 21 times including twice in mixed food samples, and 19 samples consisted entirely of fish remains (Table 2). The scales of *Z. platypus* were most abundant, and occurred 17 times in 43 faecal samples (Table 2). The visual estimates of the volume of each food for individual samples, and the percentage occurrence of each food are shown in Table 3. The scales of *Z. platypus* were usually present and the average per cent volume and the per cent frequency were 32.7% and 40%, respectively.

The echolocation sounds of *M. ricketti* were broadband, sweeping from 70.84 ± 1.71 (mean ± SD) kHz to 27.68 ± 1.08 kHz (Fig. 1). The frequency with most energy (measured from the power spectrum, FFT size 512 points) was 40.56 ± 2.65 kHz. Call duration averaged 4.08 ± 0.66 ms, and pulse interval varied considerably, with a mean value of 108.80 ± 52.75 ms.

During the field study in the Sihe village, *M. ricketti* were observed flying back and forth above the water

Table 2. Food of *Myotis ricketti*, based upon 43 faecal samples collected from the end of August to mid-October 2002. Prey included fish and insects, and insects belonged to six orders described in the text. Date for collection, time when the faecal samples were collected from the cave; *n*, total number of faecal samples collected from the cave every time; total, total frequency of each food type found in all samples. Mixed fish included *Z. platypus* and *P. lagowskii*, and mixed food comprised *Z. platypus* and insects

Date for collection	*Z. latypus*	*C. auratus*	*P. lagowskii*	Mixed fish	Only insects	Mixed food	*n*
31 Aug 2002	2	0	0	0	4	0	6
14 Sep 2002	2	0	0	1	2	1	6
28 Sep 2002	4	1	0	0	1	0	6
13 Oct 2002	6	5	1	0	12	1	25
Total	14	6	1	1	19	2	43

Table 3. The average per cent volume (the average percentage by volume of each food type) and per cent occurrence (the percentage of *Myotis ricketti* eating each food type) in 43 faecal samples

Food items	Average per cent volume (%)	Per cent frequency (%)
Zacco platypus	32.7	40
Carassius auratus	12.6	14
Phoxinus lagowskii	6.4	5
Diptera	5.3	12
Coleoptera	4.5	9
Hemiptera	0.5	2
Homoptera	29.0	37
Other[a]	9.1	23

[a] Unidentified fragments in faecal samples.

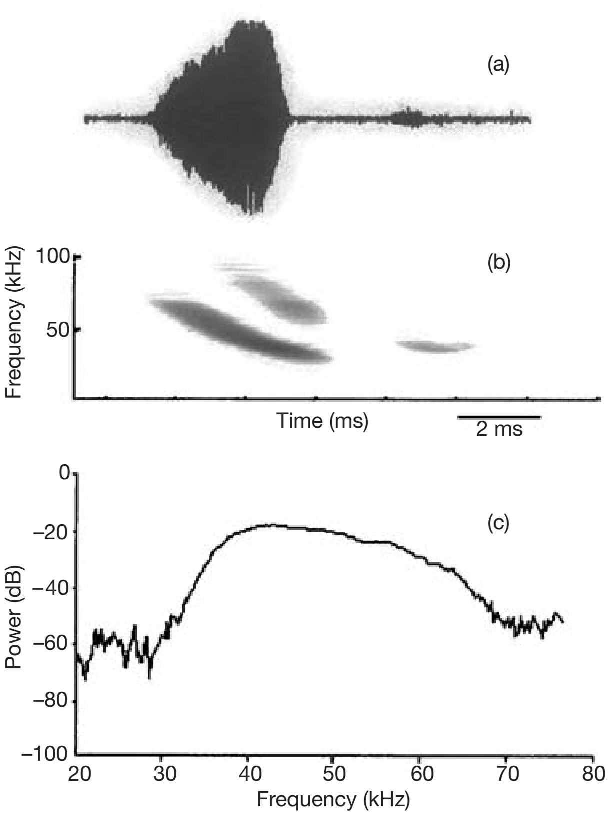

Fig. 1. Waveform (a), sonogram (b) and power spectrum (c) of an echolocation sound from *Myotis ricketti*.

surface of the reservoir and near the cave with the digital infrared video camera four times. Also, sounds of the foraging bats were detected and listened to by earphones with an ultrasound detector located at the bank of the reservoir. The detector indicated that the characteristic frequency of the sounds emitted from the foraging bats on the surface was *c*. 40 kHz. This frequency is consistent with that of *M. ricketti*.

DISCUSSION

Based on our data, we confirm the suspicion that *M. ricketti* is a piscivore. The bat ate mainly fish of the species *Z. platypus* during our study. *Zacco platypus*, is a small pelagic fish with an adult body length *c*. 11 cm. In the field, *Z. platypus* was easily observed when it broke the water surface and sometimes leapt clear of the water. *Noctilio leporinus* rakes the water surface with its hind feet, and sometimes performs a 'pointed dip' taking prey directly from the water surface, spearing fish with its claws (Bloedel, 1955; Brooke, 1994; Schnitzler *et al*., 1994). Fish-eating bats detect fish by echolocation, detecting ripples produced by fish on the surface of water or sometimes the exposed body of prey (Suthers, 1965, 1967; Wenstrup & Suthers, 1984). The small pelagic fish (silversides, ballyhoo and sardines; Brooke, 1994), which are prey of *N. leporinus*, are pursued at night by barracuda (Sphyraenidae) and escape these predators by migrating to the water's surface and leaping out. These small fish are easily caught by *N. leporinus* (Brooke, 1994). Therefore, it is probable that leaping by *Z. platypus* increases the opportunity of *M. ricketti* catching it using its large claws. *Carassius auratus* and *P. lagowskii* were less commonly found in the diet of *M. ricketti* because they usually live on the bottom. In natural conditions, these benthic fish sometimes visit the water surface, especially when weather changes affect oxygen pressure in the water. Some fish move on the surface, especially on summer mornings. Benthic fish may also occasionally catch insects floating on the water surface.

Apart from the small fish, aerial insects were commonly found in the diet of *M. ricketti*. Thus, this bat is both an insectivore and a piscivore. *Noctilio leporinus*, the best-researched fish predator, also eats insects in the dry season (Brooke, 1994). This species has a flexible foraging strategy, and it can adjust to local foraging conditions.

The echolocation sounds of *M. ricketti* are similar to those of trawling insectivorous bats in the genus *Myotis* in that they are brief and broadband (e.g. *M. daubentonii*, Jones & Rayner, 1988; *M. adversus*, Jones & Rayner, 1991; *M. dasycneme*, Britton *et al*., 1997; *M. capaccinii*, Siemers, Stilz & Schnitzler, 2001). All trawling *Myotis* bats studied to date use short broadband echolocation sounds, though similar sounds are shared by most *Myotis* species, and may reflect phylogenetic constraints on sound design in this genus. In comparison with other recordings of trawling bats *M. daubentonii* and *M. capaccinii* released from the hand (see Parsons & Jones, 2000; Russo & Jones, 2002), the echolocation calls of *M. ricketti* are longer, lower in frequency, and have longer pulse intervals. These characteristics are expected because *M. ricketti* is larger than trawling insectivorous bats found in Europe. We expect that calls and pulse intervals will be even longer when the bat is flying in open spaces above the water surface, as is the case in trawling species studied to date (compare results in Jones & Rayner, 1991 with those in Parsons & Jones, 2000). It now seems that large-footed *Myotis* bats, formerly placed in the subgenus *Leuconoe* by Findley (1972), evolved morphology adapted to piscivory several times independently in a number of evolutionary lineages (Ruedi & Mayer, 2001).

Myotis ricketti is more dependent on fish than smaller trawling *Myotis* species, and must travel considerable distances to forage. *Myotis daubentonii* (forearm length *c*. 36 mm) is able to catch small fish when offered them in the laboratory (Siemers, Dietz *et al*., 2001), although it is insectivorous under natural conditions (Vaughan, 1997), perhaps occasionally catching dead fish on the water surface (Brosset & Delamare Debouteville, 1966). *Myotis adversus* (forearm length *c*. 39 mm) takes a few fish under natural conditions (Robson, 1984). *Myotis ricketti* is relatively large, and represents a trend towards greater piscivory associated with larger body size, leading to almost exclusive piscivory exhibited by *N. leporinus* (forearm length *c*. 87 mm). There are acoustic advantages associated with the echolocation of prey on the water surface (Siemers, Stilz *et al*., 2001), and energetic benefits from the ground effect (Jones & Rayner, 1988, 1991) and these advantages may have driven the evolution of trawling for insect prey on the water surface, which may in turn have led to the evolution of piscivory.

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