Short Note

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Free-ranging Van Gelder's bat *Bauerus dubiaquercus* (Chiroptera: Vespertilionidae) preying on dung beetles in southern Mexico

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Abstract: We report the first prey species consumed by the free-ranging Van Gelder's bat *Bauerus dubiaquercus*. We trapped four pregnant individuals of this species carrying freshly captured dung beetles. We describe the wing morphology and flight descriptors (wing loading and wing aspect ratio) of the species, which presents wings more suitable for capturing insects by aerial hawking, although the evidence suggests that is able to capture dung beetles of nearly 10% of its body mass in flight close to the ground. The species could obtain their prey while foraging on uncluttered pasture near forest edges.

Keywords: Antrozoini; feeding ecology; insectivorous bat; montane cloud forest; wing loading.

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The Neotropical Van Gelder's bat *Bauerus dubiaquercus* (1959), is an insectivorous species of the Vespertilionidae family, and closely related to *Antrozous pallidus* (Moratelli and Burgin 2019). It is a tree-roosting species (Fenton et al. 2001), considered locally rare, with a disjunctive distribution from Mexico to Costa Rica (Moratelli and Burgin 2019; Reid 2009). This species occurs in a wide variety of tropical forested-areas, including lowland, deciduous, pre-montane, and montane evergreen forests, at elevations ranging from 100 to 2300 m a.s.l. (Engstrom et al. 1987). Females are larger than the males (Engstrom and Wilson 1981; Reid 2009). Cranial traits include broader zygomatic arches, a well-developed sagittal crest (Van Gelder 1959), relatively shorter and wider rostrum and short thick jaws and a strongly built mandible (Engstrom et al. 1987), suggesting a strong bite force related to the consumption of hard-shelled insects such as beetles (Freeman 1979). However, no information is available regarding the diet of free-ranging individuals. In captivity, *B. dubiaquercus* is reported to glean insects and feed on cockroaches and katydids (Reid 2009).

The foraging behaviour of *B. dubiaquercus* is virtually unknown. It has been proposed that this bat is anatomically unable to capture prey from the ground, with its pelvic girdle that is less robust, and hence less muscular, than that of *A. pallidus*, which does glean insects from the ground and from tree surfaces (Czaplewski et al. 2018; Martin and Schmidly 1982). Foraging patterns in bats have been related to wing shape, described by wing aspect ratio, body size and wing loading (Norberg and Rayner 1987; Thollesson and Norberg 1991), variables that have not been measured in *B. dubiaquercus*. In the sister species *A. pallidus* these flight descriptors have been related to slow flight in open areas or around vegetation and suggest that the bat could obtain prey directly from the ground as a gleaner (Norberg and Rayner 1987).

During a study of the bat fauna presents in the region of Los Tuxtlas (September 2018), in south-eastern Mexico, we documented individuals of *B. dubiaquercus* carrying

recently captured dung beetles in their mouths. The site (18°32′3.55″ N, 95°8′18.54″ W; 1034 m a.s.l.) is located on the San Martín Tuxtla volcano, part of the Los Tuxtlas Biosphere Reserve, Veracruz. The climate is temperate and humid, and the vegetation is tropical montane cloud forest, within a matrix of pasture-land (Guevara et al. 2004).

We sampled bats using mist-nets ($3 \times 6 \times 12$ m) placed near vegetation and across possible bat flight paths (i.e., gaps and corridors within the vegetation) for approximately 4 h after sunset. Captured individuals were identified using the field guide of Reid (2009). We recorded species, time of capture, sex, forearm length, weight, age category and reproductive condition of the individuals. In the field, we used a sheet of millimetre graph paper on which we took photographs of the extended bat wing in order to obtain (1) wing loading (WL), which is calculated by dividing the body mass by wing area; (2) wing aspect ratio (WAR), calculated by dividing the wingspan by the mean wing chord; and (3) the tip-shape index (I) of the wing (Norberg and Rayner 1987). Wing measurements were taken exclusively from the right wing and multiplied by two for the calculation of flight descriptors considering both wings. This was carried out to allow direct comparison of these measurements with previously reported values in other insectivorous bats.

Insect prey items captured in the net at the same time as the bat were collected and identified by Martha Madora Astudillo, the curator of the arthropod collection of the Biological Station Los Tuxtlas, Universidad Nacional Autónoma de México (UNAM).

To describe functional traits in cranial morphology, previously recognized in insectivorous bats (Freeman 1979, 1984), we obtained photographs of the lateral view of the skull and mandible for two specimens deposited in the mammal collection of the Instituto de Investigaciones Biológicas, Universidad Veracruzana (IIB-UV). The specimens examined were: IIB-UV4164, male from Plan de San Luis, Oaxaca; IIB-UV3560, male from Parque de Flora y Fauna, Pipiapan, Veracruz. Digital images were taken with a Nikon D5600 camera with an adapted macro lens (Nikkor 60 mm 2.8 F). The molar and total teeth areas were measured in digital photographs using the program ImageJ 1.53 (Schneider et al. 2012). Two cranial measurements, previously used as descriptors in the study of diet in bats (Freeman 1984), were obtained from these specimens using a digital caliper (Mitutoyo CD-6″ Mitutoyo U.S.A.) on the right side of the skull: (1) zygomatic breadth (ZB) – greatest width across the zygomatic arches, (2) condylocanine length (CCL) – from occipital condyle to anterior edge of the canine.

We captured five adult individuals of *B. dubiaquercus* during different sampling nights (Figure 1A), always in the lower portion of the net, (*ca.* 50 cm from the ground in all cases). Four of the five individuals were females, of which three were pregnant. All individuals were captured between 90 and 120 min after sunset, during the first quarter of the moon phase. Each of the four female bats had a live beetle in their jaws when captured (Figure 1B and 1C).

The beetles were identified as *Dichotomius amplicolis* (Scarabaeidae: Scarabaeinae; Figure 1C), a dung beetle from the Gulf of Mexico. The beetles recovered from the mouth of *B. dubiaquercus* weighed 2.12 ± 0.19 g, for a head and body length of 30–35 mm.

Dichotomius is one of the most diverse and abundant dung beetle genera in the Neotropics, represented in Mexico by only seven species (Chamé-Vázquez et al. 2020). *D. amplicolis* is a nocturnal digger dung beetle (C. Cultid, pers. comm.), previously recorded in Veracruz at forest-pasture edges and near live fences (Díaz et al. 2010).

Beetles are commonly reported in the diet of insectivorous bats, some bat species are even referred to as durophagous (Aguirre et al. 2003; Freeman 1979) due to their high consumption of hard-bodied prey, such as beetles (Aguirre et al. 2003). Nevertheless, a few insectivorous bats have been reported to take dung beetles as prey, including Vespertilionidae and Molossidae (see Young 2015) and, to a lesser extent, the closely related species *A. pallidus* (Czaplewski et al. 2018; Johnston and Fenton 2001; Lenhart et al. 2010; Rambaldini and Brigham 2011).

Since bats can be prey selective (Agosta et al. 2003), it is interesting to note that we captured pregnant females carrying dung beetles. It is possible that they may select an abundant and nutritious prey to address the high energy demands of the reproductive season (Anthony and Kunz 1977).

A strong relationship has been found between insect size and exoskeleton hardness, with beetles being 3.3 times harder than moths of the same size (Freeman and Lemen 2006). Bat species with the most robust skulls (including *A. pallidus*, *Eptesicus fuscus*, and *Molossus* spp.; Freeman 1981) prey on hard-bodied insects. A beetle of 13 mm in length can be pierced with a force of 1.2 N (Freeman and Lemen 2006). For comparison, *A. pallidus*, a species of similar size to *B. dubiaquercus*, has a bite force of 6.4 N (Freeman and Lemen 2006) and we would expect *B. dubiaquercus* to at least match this bite force. In this sense, the effectiveness of the killing bite of this species could be appreciated in the prey carried and pierced by the bat (Figure 1B and 1C).

Beetle-eating bats have thick jaws, well-developed cranial crests associated with larger masticatory muscles,

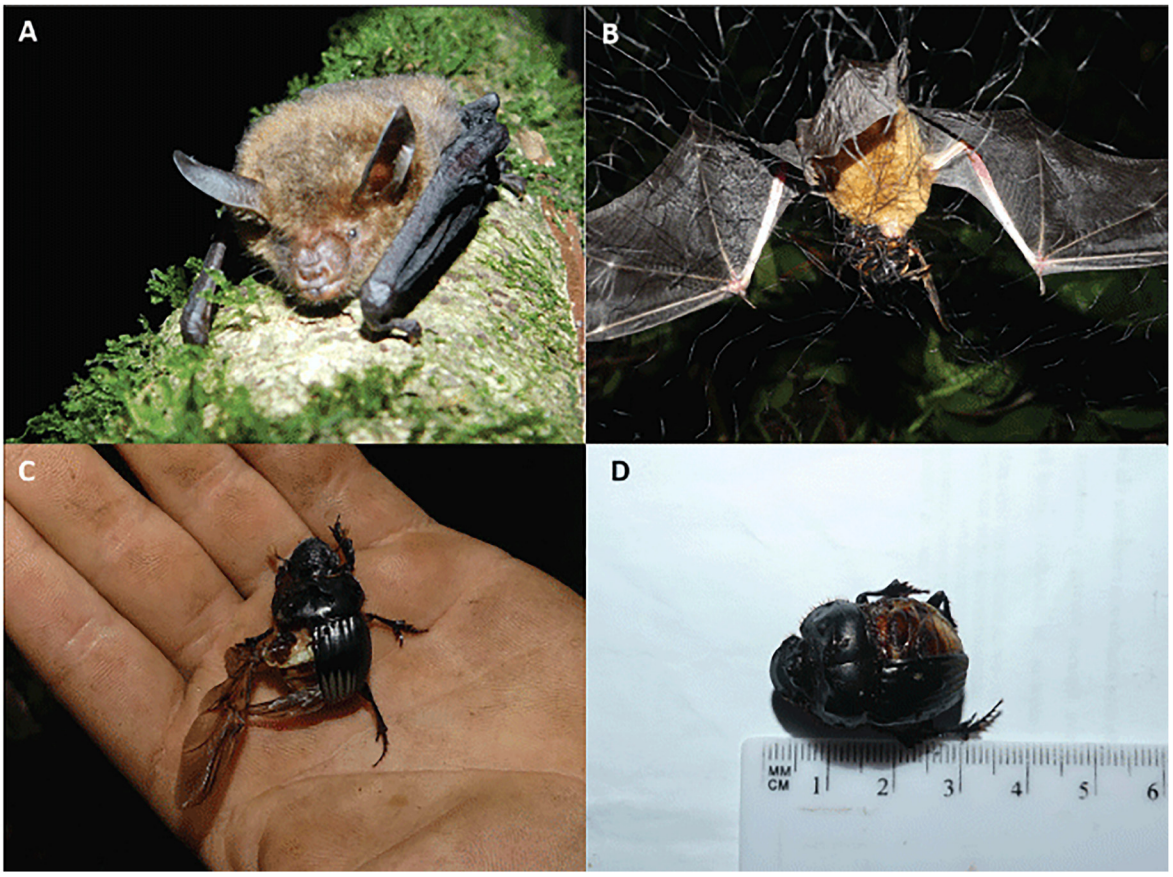

Figure 1: (A) An adult individual of *Bauerus dubiaquercus*; (B) captured female *B. dubiaquercus* carrying a dung beetle; (C) the dung beetle preyed by the bat; (D) another dung beetle preyed upon by another individual bat. Photo credits: (A) Pedro A. Aguilar, (B) Martín Alarcón, (C) and (D) Pedro Díaz.

and bigger teeth (Freeman 1979). All of these characteristics are present in *B. dubiaquercus* (Figure 2A and 2B). Bats include hard prey items in their diet and have well developed canines and upper third molars (M^3), with the M^3 occupying at least 8% of the total area of teeth, and a ZB/CCL ratio of around 80% (Freeman 1984). These traits are present in *B. dubiaquercus* (average ZB/CCL ratio: 81%, average percentage of M^3 area: 8.13%, Figure 2C), and support the notion that it is a consumer of hard prey.

The forest floor at the study site was cluttered with twigs, rocks, ferns and other obstacles, making it more likely that *B. dubiaquercus* captures these beetles by flying at a low height in the nearby grazed pasture (as in *Eptesicus*; Catto et al. 1996). A cluttered understory makes it difficult to access insects for ground foraging bats (Rainho et al. 2010), while pasture with cattle present ensures the supply of dung-associated beetles, favouring the foraging of the bat (Anderson et al. 2020).

The wing morphology of *B. dubiaquercus* (n = 3, WAR: 5.29 ± 0.38, WL: 13.58 ± 0.53 N/m^2, I: 1.03 ± 0.13) corresponds to a bat that can forage close to the edge of the forest, considering the close values of aspect ratio and wing tip index observed in *A. pallidus* (WAR: 6.1 and I: 1.52; Norberg and Rayner 1987). However, the more pointed wings (values of I close to 1) and the high WL observed in *B. dubiaquercus* suggest that it can fly fast and perform open turns, which are manoeuvres typical of open-space aerial forager bats (Thollesson and Norberg 1991). The values of the flight descriptors for this species, according to body mass, are more similar to vespertilionid bats foraging in open areas, which present poor manoeuvrability and probably hawk flying insects (e.g., *Lasiurus borealis*, Norberg and Rayner 1987).

Vespertilionid species with greater dispersal abilities, having broader distribution range than poor dispersers, are expected to have higher wing loading and aspect ratio, as is the case of *L. borealis* (Luo et al. 2019). These expectations could be fulfilled in *B. dubiaquercus*, in view of its WL and WAR values close to *L. borealis*, nevertheless the current distribution of *B. dubiaquercus* is highly fragmented and is

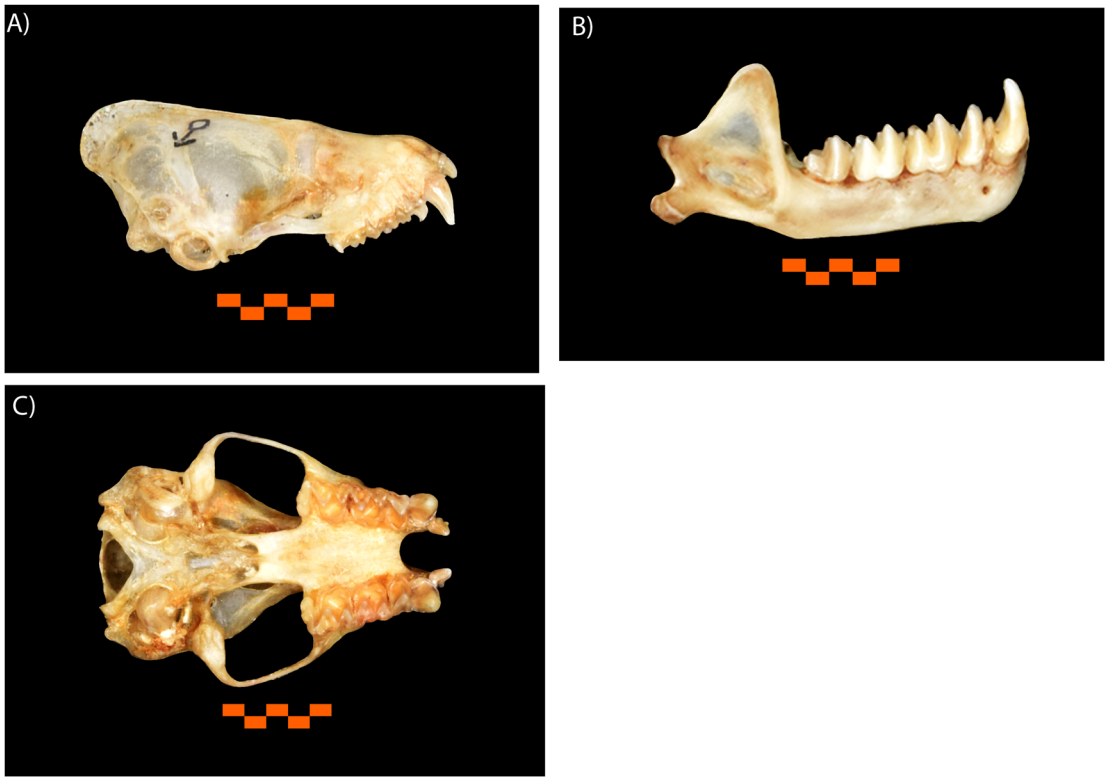

Figure 2: Photographs of the skull and mandible of *Bauerus dubiaquercus* IIB-UV4164, with a scale of 5 mm. (A) Lateral view of the skull; (B) lateral view of mandible, and (C) ventral view of skull. ZB, zygomatic breadth; CCL, condylocanine length; M^3, upper third molar.

considered a rare species (Moratelli and Burgin 2019; Reid 2009). This suggests that *B. dubiaquercus* could be constrained to the edge space but forages in open space, behaviour that renders its capture difficult.

Taking these observations together, we suggest that *B. dubiaquercus* is probably an open forager, with wing morphology, size and bite force suitable for capturing a beetle of *ca.* 10% of its body mass in close proximity to the ground or during flight near the forest edge. Dung beetles could constitute an important prey when available, especially during the reproductive season of this understudied bat species, representing an energetic reward to pregnant females.

Research ethics: The authors used the Secretaría del Medio Ambiente y Recursos Naturales permit (SGPA/DGVS/003071/18) for capturing individuals. No voucher specimens were collected.

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