Short Note

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Into the light: atypical diurnal foraging activity of Blyth's horseshoe bat, *Rhinolophus lepidus* (Chiroptera: Rhinolophidae) on Tioman Island, Malaysia

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Abstract: Diurnal flight and foraging activity in insectivorous bats are atypical behaviours that have been recorded from islands with few avian predators and from locations with extended daylight hours. We present the first known observations of diurnal activity of *Rhinolophus lepidus* in forests on Tioman Island, Malaysia, recorded using visual surveys and acoustic monitoring. The bats were flying during the day and at night, and feeding buzzes detected suggest that they were actively foraging during the day. This appears to be a regular phenomenon on Tioman Island. The absence of resident diurnal avian predators that hunt below the forest canopy may account for the diurnal activity of *R. lepidus* in forests there.

Keywords: acoustic monitoring; daylight; foraging behaviour; tropical forest.

Regular diurnal flight and foraging activity in insectivorous bats is seldom reported, but has been previously noted to occur in Europe and Africa. In temperate Northern Europe, especially during summer, it is thought to occur because of night foraging shortfall or continuous daylight (Speakman 1990, Speakman et al. 2000). One species, *Pipistrellus pygmaeus* (Leach 1825) in Lazio and Molise National Park, Italy, has also been recorded emerging during daylight in summer to forage under closed canopy in an area with high insect abundance (Russo et al. 2011a). Bat populations displaying this behaviour have also been observed in tropical or sub-tropical areas with few diurnal avian predators, such as *Nyctalus azoreum* (Thomas 1901) on São Miguel of the Azores, Portugal, and *Hipposideros ruber* (Noark 1893) on São Tomé Island, West Africa (Moore 1975, Russo et al. 2011b).

In the equatorial tropics, such a phenomenon seems less likely to occur because of the relatively even durations of night and day, high insect diversity with low annual variation in abundance (Hails 1982, Stork 1988) and high avian biodiversity compared to temperate areas (Jetz et al. 2012). Speakman et al. (1994) suggested that hyperthermia might also limit diurnal activity in bats, especially in the tropics. However, diurnal heat stress is expected to be less severe for small bats (≤9 g) close to the equator, especially under foliage and cloud cover.

Since 2014, we have been observing small insectivorous bats to be active during the day in forests on Tioman Island, Peninsular Malaysia (2° 35′N, 104° 15′E; 133.6 km^2), 32 km off the eastern coast of Peninsular Malaysia (Abdul 1999). Every month during March–September 2015, these bats were encountered along the waterfall trail near the village of Juara (2° 47′N, 104° 12′E), during a study on the diet of the island flying fox *Pteropus hypomelanus* Temminck 1853 (Aziz et al. 2017). The trail, which starts next to the Juara Turtle Project, leads through a rubber plantation before continuing through coastal forest. Typically flying in pairs, these bats were always encountered in the coastal forest in the late morning or afternoon, not far from some large boulder formations. Day-flying bats were also occasionally observed in lowland forest along the Tekek-Juara trail located 4.8 km further north, although this did not occur every month. In July 2016, similar observations of diurnal bats were made again at the Tekek-Juara trail, and in the lowland secondary forest near Paya village (2° 47′N, 104° 07′E). Repeated visits in July and September 2017 allowed further observations with the aims of: 1) identifying the day-flying bat, 2) determining if it was a regular phenomenon and 3) describing their diurnal activity on the island.

Opportunistic observations took place in July 2017 in forests near Paya village on the west coast and in September 2017 in forests near Juara village on the east coast of Tioman Island (Figure 1). Much of the area consists of

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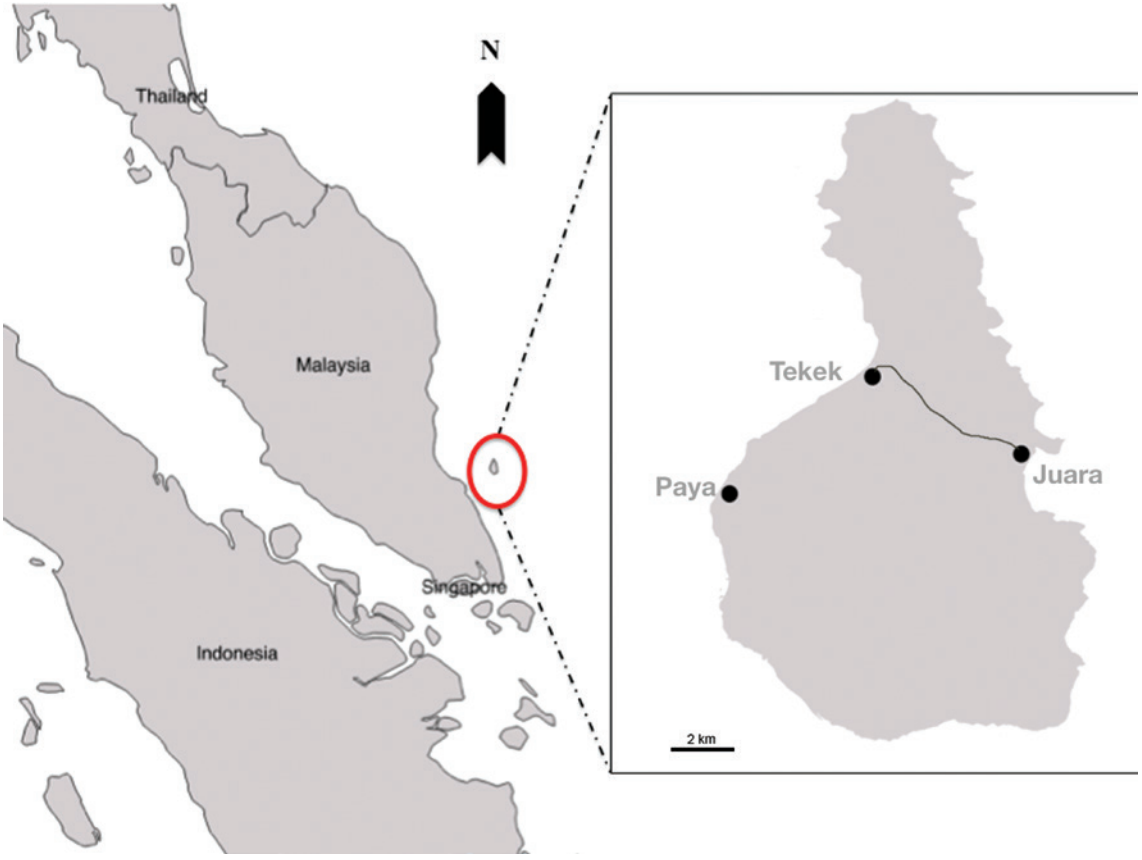

Figure 1: Map showing Tioman Island in the State of Pahang, Peninsular Malaysia, along with locations of villages and Tekok-Juara trail where day-flying *Rhinolophus lepidus* was recorded.

lowland secondary forest, with estuarine mangroves, and villages and tourist resorts next to the coast. Incidental sightings of bats outside the forest were also noted. Sunrise and sunset times on the island were approximately 07:00 h and 19:20 h, respectively. Observed bats were identified to species following the taxonomy of Simmons (2005), Kingston et al. (2009) and Lim et al. (2017). A heterodyne Batbox III D bat detector (Batbox Limited, West Sussex, UK) and an Echo Meter Touch (Wildlife Acoustics, Maynard, MA, USA) were used to determine the peak echolocation frequency of the bats. As the bats encountered were small, fast-flying and had highly directional calls, they were usually only within the detection profile of the bat detectors briefly. Often, the bats had to be first sighted and have the bat detectors pointed directly at them to pick up their echolocation signals.

From July 6 to 11, 2017, day-flying bats were encountered regularly on three separate forest trails near Paya, spanning the daylight hours of 09:00–18:00 h (Table 1). The bats were mostly seen flying close to the ground (about 0.3–1.8 m above ground) singly, but occasionally in pairs (Figure 2). Close observation of four individuals revealed that they generally took a wide circuitous flight path with a length of approximately 30 m but of variable width, usually with a portion over the forest trail. Ultrasonic frequencies with the greatest energy around 101 kHz, with some energy at 38 kHz and 27 kHz, were detected. This corresponds with the known peak echolocation frequency range of *Rhinolophus lepidus* Blyth 1844 (90.7–105.2 kHz), and the harmonics (Heller and von Helversen 1989, Kingston et al. 2000 [as *Rhinolophus refulgens* Andersen 1905], Pottie et al. 2005, Shi et al. 2009, Soisook et al. 2016 [as *R. refulgens*]). Feeding buzzes were also observed.

On July 8, 2017, a day-flying bat was seen flying in circuits along a forest trail and calling with the greatest energy around 100 kHz. An individual was caught at 17:20 h and was identified as *Rhinolophus lepidus* based on the echolocation frequency and morphology – particularly the pointed lancelet with concave sides, triangular connecting process and hair with light tips (Figure 2) (Francis 2008, Kingston et al. 2009). Some taxonomists (Francis 2008, Soisook et al. 2016) consider the population from Peninsular Malaysia and southern Thailand to be a separate species, *Rhinolophus refulgens*. The bat was released after a short examination.

Table 1: Observations of *Rhinolophus lepidus* on Tioman Island, Malaysia from July 6 to September 26, 2017.

Date	Time	No. of bats	Location (habitat)
July 6, 2017	16:45 h	3	Paya (forest)
	17:45 h	1	Paya (forest)
	19:00 h	>2	Paya (mangrove)
	21:00 h	≥1	Paya (forest)
July 7, 2017	17:30 h	1	Paya (forest)
	19:00 h	>2	Paya (mangrove)
July 8, 2017	09:30 h	2	Paya (forest)
	12:00 h	2	Paya (forest)
	15:30 h	1	Paya (forest)
	17:20 h	1	Paya (forest)
	22:00 h	≥1	Paya (forest)
July 9, 2017	10:45 h	2	Paya (forest)
	11:45 h	1	Paya (forest)
	15:30 h	2	Paya (forest)
	16:30 h	3	Paya (forest)
	17:45 h	2	Paya (forest)
	18:15 h	2	Paya (forest)
	19:00 h	1	Paya (coast)
July 10, 2017	09:00 h	1	Paya (forest)
	10:00 h	2	Paya (forest)
	19:00 h	1	Paya (coast)
	19:10 h	2	Paya (village)
July 11, 2017	17:15 h	2	Paya (forest)
	17:45 h	1	Paya (forest)
September 25, 2017	21:15 h	≥1	Juara (village)
September 26, 2017	12:00 h	2	Juara (forest)
	16:15 h	2	Juara (forest)
	16:45 h	1	Juara (forest)
	19:00 h	1	Juara (coast)

At least 5 day-flying bats identified as *Rhinolophus lepidus* were also recorded on September 26, 2017 from 12:00 to 17:00 h along the coastal forest trail at Juara village singly and in pairs (Table 1). These bats also flew in a circuitous flight path that was usually close to the ground. Feeding buzzes were heard and recorded (Figure 3).

Based on acoustic monitoring and morphology, the day-flying bats on Tioman Island were identified as *Rhinolophus lepidus*. During the day, the bats appeared to be most active in the late morning and late afternoon. The feeding buzzes observed suggest that the bats were actively foraging during the day. It was unlikely that the bats were flying and opportunistically foraging due to being disturbed from their roosts by the observer walking through the forest, as *R. lepidus* typically roosts in caves and abandoned buildings (Struebig et al. 2008, Kingston et al. 2009), structures that were not present in the immediate vicinity of the forest trails. Further, the bats were also often seen from a distance flying in the circuitous pattern along the trail ahead of the observers. However, there may be a possibility that some bats could be roosting in nearby boulder formations which are widespread across the island and which we encountered on the Juara waterfall trail. Based on echolocation calls, *R. lepidus* appears to be also active at night in the forest. In contrast, they were present at night next to the coast, in mangroves and in open areas adjacent to human settlement, but absent in those areas during the day. In Yunnan, China, this horseshoe bat is apparently strictly nocturnal, emerging from their roost about 9 min after sunset (Shi et al. 2009).

While day-flying by bats in temperate zones are associated mainly with food shortage (Speakman 1990, Speakman et al. 2000), the absence of resident diurnal avian predators that hunt bats in wooded areas on the tropical island of Tioman may account for the diurnal activity of *Rhinolophus lepidus* in forests there. Predation of bats by diurnal birds is considered an important factor influencing the rarity of day-flying activity in bats and a driver of the evolution of bat nocturnality (Speakman 1995, Mikula et al. 2016). On Tioman, the Japanese sparrowhawk (*Accipiter gularis*) is a northern winter migrant that is absent for most of the year, while other diurnal avian predators such as the changeable hawk-eagle (*Spizaetus cirrhatus*) and black-shouldered kite (*Elanus axillaris*) hunt predominantly in open areas or above the forest canopy (Sodhi et al. 1999, Wells 1999). Thus, we posit that on this island, release from island avian predators frees the bats from the predation pressure of daytime flight and foraging – similar to islands studied by Moore (1975) and Russo et al. (2011b). The absence of predators may allow *R. lepidus* to be active on Tioman during the day to exploit diurnal insect prey, and as such is the most likely explanation for its day-flying behaviour. It is unlikely that nighttime predation from birds is driving this phenomenon as the only nocturnal birds of prey on the island are owls (*Otus* spp.) that feed mostly on large insects (Wells 1999) and are neither a competitor nor a predator of insectivorous bats. Additionally, the small size (<9 g) of *R. lepidus* (Francis 2008, Kingston et al. 2009) is consistent with the prediction by Speakman et al. (1994) that "hyperthermia would almost never be a constraint" for daylight flying small bats at the equator. Consequently, the species appears to fly only in the day under forest cover, which could be for both predator avoidance and thermoregulatory reasons.

Although *Rhinolophus lepidus* is known to be present on Tioman Island, where the mammalian fauna is relatively well known (Medway 1966, Hill 1974, Csorba et al. 1997, Lim et al. 1999), this is likely the first published account of diurnal activity of insectivorous bats there, and in Asia. It remains to be determined whether activity

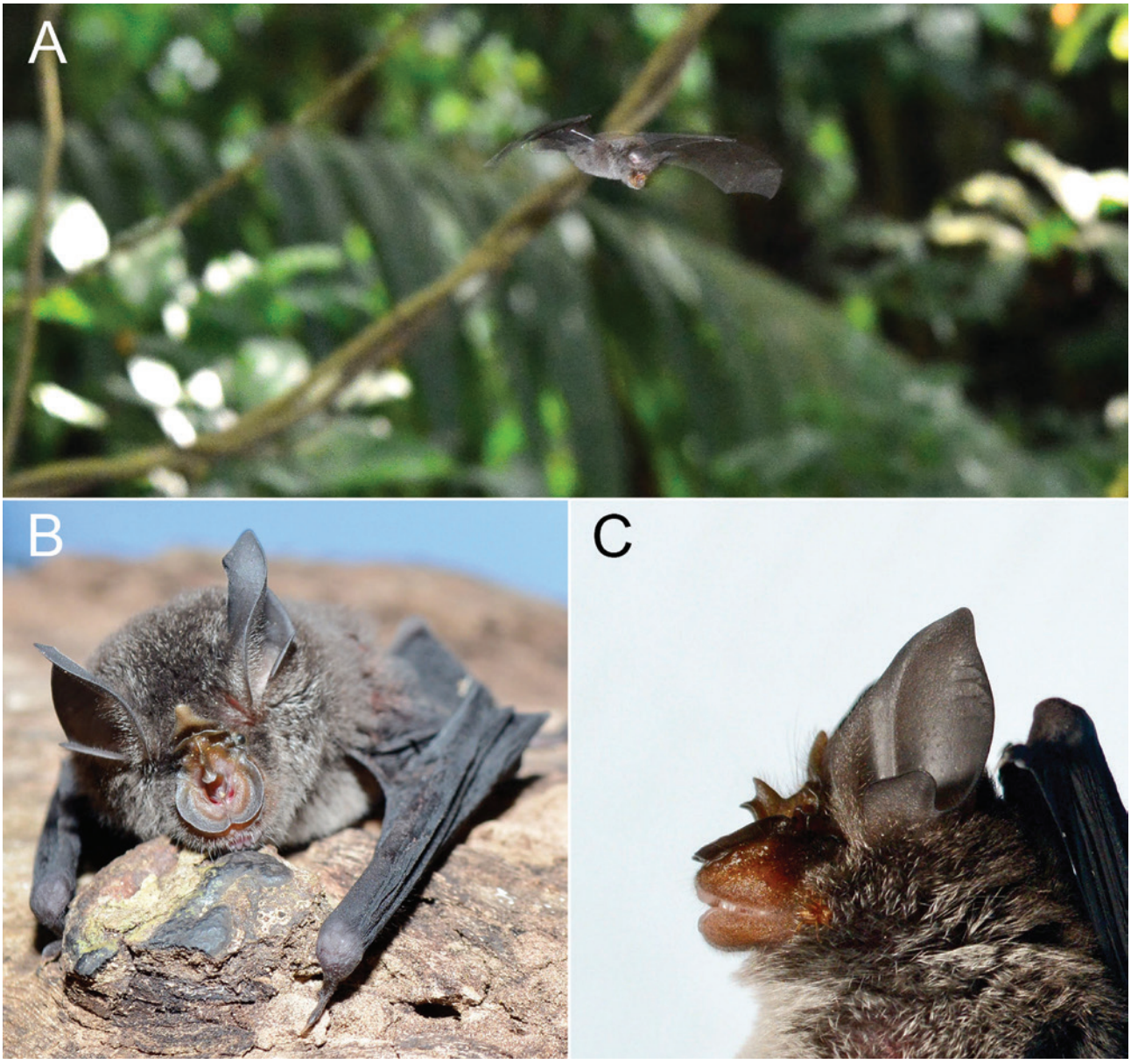

Figure 2: *In situ* image and characteristic features of the day-flying bats of Tioman Island, Malaysia.
(A) Day-flying insectivorous bat flying a low circuit in Paya, Tioman Island, Malaysia. (B and C) Frontal and lateral views of diurnal *Rhinolophus lepidus* displaying characteristic features of the species, i.e. pointed lancelet with concave sides, triangular connecting process and hair with light tips.

patterns and foraging ecology differ for the species by day and night, sex and spatially on the island. Temporally, it would be of interest to determine whether the diurnal activity of the species changes during the northern winter bird migration period (September–April), when the Japanese sparrowhawk, a forest avian predator, is present on Tioman (Sodhi et al. 1999). Also, further investigations could establish whether another resident small forest-dwelling bat, the least horseshoe bat (*Rhinolophus pusillus* Temminck 1834), is also active on Tioman during the day due to similar circumstances of release from avian predators.

This report provides support for the hypothesis that diurnal foraging activity in insectivorous bats is linked to the reduction of diurnal avian predators on isolated islands. However, it is only the third known example of this phenomenon in tropical or subtropical regions. Further research in the field could possibly focus on insectivorous bats on other islands that are known to be depauperate in diurnal birds of prey, to determine

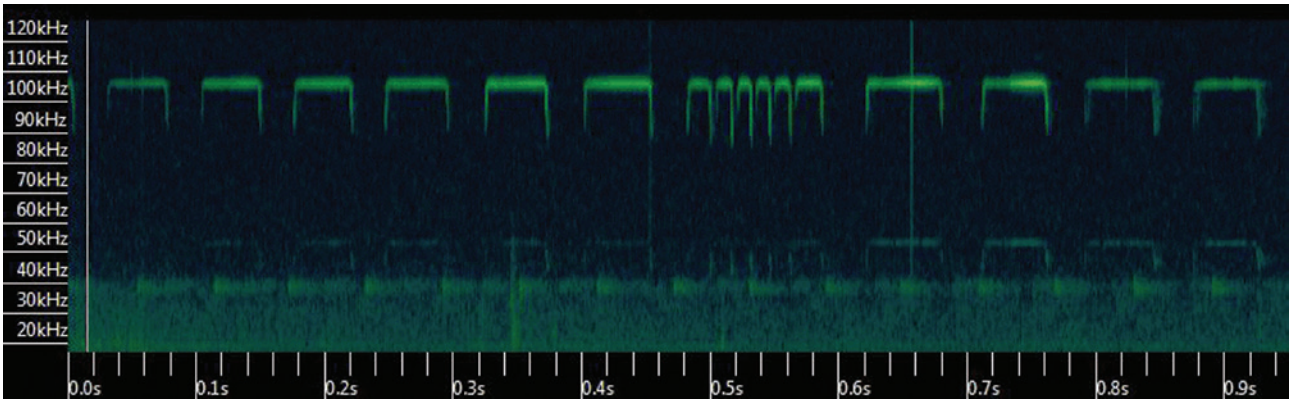

Figure 3: Spectrogram of echolocation calls of *Rhinolophus lepidus* recorded at Juara, Tioman Island, on September 26, 2017 at 11:59 h, showing a feeding buzz.

whether there is more widespread support for the hypothesis, or the particular conditions that permit such behaviour to occur.

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