Journal of Threatened Taxa

The international journal of conservation and taxonomy

www.threatenedtaxa.org

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

ARTICLE

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26 July 2016 | Vol. 8 | No. 7 | Pp. 8953–8969
10.11609/jott.2785.8.7.8953-8969

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 July 2016 | 8(7): 8953–8969

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OPEN ACCESS

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Abstract: Bat communities of mainland Southeast Asia can be highly diverse. Many are under threat. Despite this, regional faunal composition is not well documented for many areas, including regions of Vietnam. We assessed the biodiversity of bats in a watershed protection forest in the southeastern Truong Son (Annamite) Mountains, southwestern Quang Ngai Province, Vietnam in 2011–2013. Twenty species of insectivorous bats were documented including a high diversity of *Murina* species Tube-nosed Bats. Diversity and abundance indices were compared with that recorded previously in two nature reserves and one national park in Vietnam, and were higher or comparable in several measures despite the lack of a karst substrate for roosts. Reproduction in the insectivorous bat fauna coincided with the early rainy season. In the late dry season, pregnant females of several species were observed but volant juveniles were not present, whereas in the early wet season adult females were lactating or post-lactating and volant juveniles of nine species were detected. We recorded echolocation calls of 14 bat species; for each species, we compared features of calls with those reported previously in other Asian localities. For some species we found discrepancies in call metrics among studies, perhaps suggesting a greater hidden biodiversity of bats in Southeast Asia.

Keywords: Bats, Chiroptera, diversity, echolocation, reproduction, Vietnam.

DOI: http://dx.doi.org/10.11609/jott.2785.8.7.8953-8969 | **ZooBank:** urn:lsid:zoobank.org:pub:CF64B7A1-5162-4101-80FF-32CCB4217BC6

Editor: Paul Bates, Harrison Institute, Kent, United Kingdom. **Date of publication:** 26 July 2016 (online & print)

Manuscript details: Ms # 2785 | Received 11 May 2016 | Final received 30 June 2016 | Finally accepted 07 July 2016

Citation: Son, N.T., T.J. O'Shea, J.A. Gore, C. Gabor, V.T. Tu, T. Oshida, H. Endo & M. Motokawa (2016). Bats (Mammalia: Chiroptera) of the southeastern Truong Son Mountains, Quang Ngai Province, Vietnam. *Journal of Threatened Taxa* 8(7): 8953–8969; http://dx.doi.org/10.11609/jott.2785.8.7.8953-8969

Funding: Wildlife At Risk, Vietnam Academy of Science and Technology, JSPS Ronpaku Program, and SYNTHESYS Project, financed by the European Community Research Infrastructure Action under the FP7 "Capacities" Program, Hungarian Scientific Research Fund (OTKA).

Conflict of Interest: The authors declare no competing interests.

For **Vietnamese abstract, Author Details** and **Author Contribution** see end of this article.

Acknowledgements: Nguyen Vu Khoi and Wildlife At Risk sponsored and guided the field work, and the director and researchers of IEBR provided support. We thank biologists in other disciplines who participated in field work, including C. Abercrombie, R. D. Babb, L. V. Cuong, P. Moler, B. H. Manh C. Hope, W. Van Devender, T. A. Vu; E. J. Sterling (New York), K. Kevin (Berkeley), and B. H. Manh provided the study area map. Fieldwork was approved and supported by FPD of Quang Ngai Province and the Ministry of Agriculture in Hanoi. Precipitation data were obtained from the NASA Langley Research Center POWER Project. Nguyen Truong Son was supported by JSPS RONPAKU Program ID No. VAST–11125 and JSPS Core-to-Core Program B. Asia-Africa Science Platforms (2014-2016). Gabor Csorba received support from the SYNTHESYS Project, financed by the European Community Research Infrastructure Action under the FP7 "Capacities" Program and the Hungarian Scientific Research Fund (OTKA) K112440. N.V. Khoi and R. D. Babb kindly contributed photographs.

INTRODUCTION

Bat communities in Southeast Asia are among the most diverse in the world but are threatened by habitat loss and other factors (Kingston 2010). Despite high diversity, there is little descriptive documentation available on the faunal composition of regional bat communities in mainland Southeast Asia, including a lack of basic information on echolocation patterns and the timing of reproduction of species within these bat communities. The Truong Son Mountains of Vietnam and the adjacent Lao People's Democratic Republic (Lao PDR) have high faunal biodiversity in general (Tordoff et al. 2003), but little is known about bat diversity in this mountain range. Therefore, our study had three objectives: (1) to document the bat fauna of the southeastern Truong Son Mountains and to compare its diversity with that reported previously in other localities of Vietnam (Hendrichsen et al. 2001; Furey et al. 2010); (2) to sample characteristics of echolocation calls of a subset of the insectivorous bats of the southeastern Truong Son Mountains, and to qualitatively compare their echolocation traits with those reported previously in other localities in Asia; (3) to assess the timing of reproduction in female bats in the late dry season and in the early wet season. This region is influenced by a predictable rainy season following the dry winter season (Sterling et al. 2006; NASA 2012). Seasonal patterns in reproduction of tropical insectivorous bats wherein the birth and fledging of young occur during rainy seasons when primary productivity and insect abundance are high have been observed in other tropical regions (e.g., Fleming et al. 1972; Bernard & Cumming 1997; Racey & Entwistle 2000), including one reserve in northern Vietnam (Furey et al. 2011).

MATERIALS AND METHODS

Study area

We sampled bats in southwestern Quang Ngai Province, Vietnam. The study area is a Watershed Protection Forest administered through the Quang Ngai Forest Protection Department, Vietnam Ministry of Agriculture and Rural Development, which facilitated our study. The forest is located in central Vietnam in the southeastern Truong Son (Annamite) Mountains, Ba To District, southwestern Quang Ngai Province (Fig. 1). The study area is near the borders with Gia Lai Province, Kon Tum Province, and Binh Dinh Province.

We based our work at two campsites (Fig. 1): Camp 1 was at 750m elevation, and was sampled in late May – early June 2011 (early rainy season) and March 2013 (late dry season); Camp 2 was at 930m elevation and was sampled in March 2012 (late dry season). Camp 1 was in a cleared grassy area at coordinates 14.6602^{0}N & 108.6075^{0}E. The surrounding forest was mainly secondary regrowth after logging about 40 years earlier. Camp 2 was located at 14.6206^{0}N 108.5865^{0}E and was also covered by secondary forest but had a greater number of mature and large diameter trees compared to those of Camp 1. Both sites are in a region that experiences highly seasonal rainfall (Fig. 2).

We compare our results with previous studies on bat biodiversity conducted at three other localities in Vietnam that have higher conservation status: Kon Cha Rang Nature Reserve (14.567^{0}N & 108.567^{0}E) and Kon Ka Kinh National Park (14.333^{0}N & 108.367^{0}E) in Gia Lai Province (Hendrichsen et al. 2001) and Kim Hy Nature Reserve in Bac Kan Province in northern Vietnam (Furey et al. 2010). The studies in Gia Lai Province took place for 2-3 weeks in each reserve during March and April 1999; Kon Ka Kinh National Park and Kon Cha Rang Nature Reserve are about 42km and 10km away from our study area, respectively. Estimation of assessment effort and relative abundance are not available for the Gia Lai studies (Hendrichsen et al. 2001), limiting quantitative comparisons. However, we also compare our results with the study by Furey et al. (2010) at Kim Hy Nature Reserve, the most comprehensive study of a bat community in Vietnam. Unlike our study area, Kim Hy Nature Reserve has a karst substrate (Furey et al. 2010).

Bat sampling, identification, and reproductive assessment

We captured bats using mist nets and harp traps set from ground level. We set nets across trails in forest, over small ponds and streams in forest or near forest edges, and at openings at the forest edges. We set harp traps at similar locations and in dry stream beds that could function as travel corridors for bats. We deployed two different harp traps in 2011. One was a 4-bank trap 1.5x1.5 m in area (2.25m^2) and the other was a 2-bank trap 0.9x1.1 m in area (1.0m^2). In 2012 we deployed the same size traps and a larger 4-bank trap 2m x 2m in area (4m^2). Mist nets ranged from 6.0 to 12.8 m in length. We sampled for bats near the lower elevation Camp 1 at 33 geo-referenced locations on 11 nights between 28 May and 9 June 2011 inclusive, and on five nights 16 to 20 March 2013 inclusive. In 2011 most (90%) sampling localities were within 800m of Camp 1 with a maximum

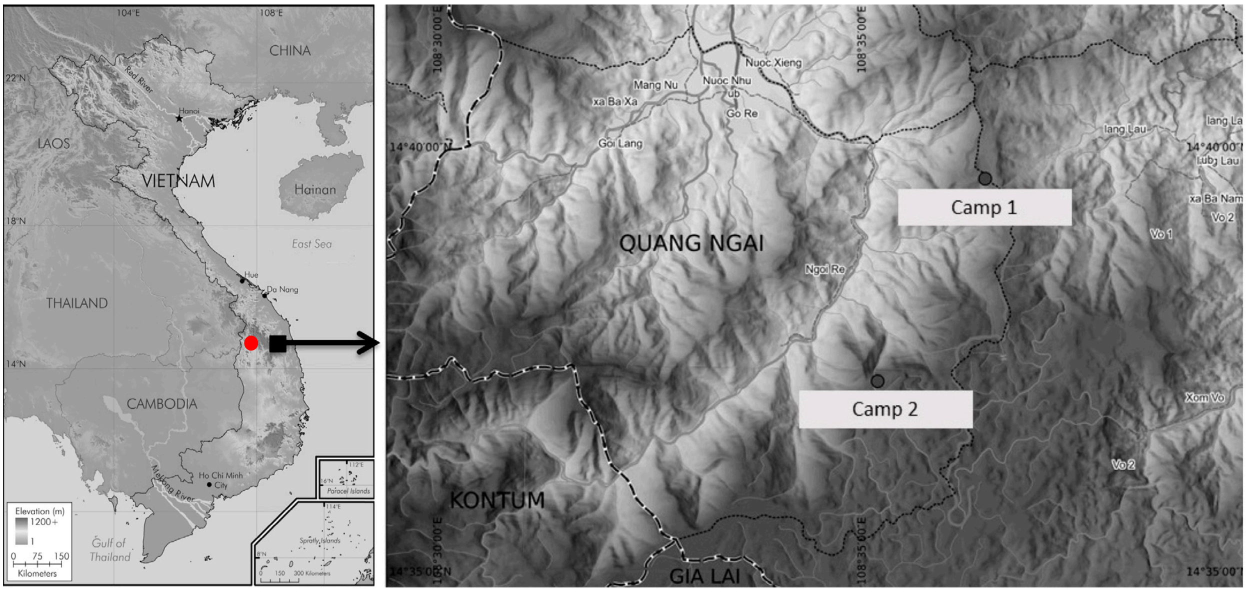

Figure 1. Locations of bat sampling camps in southeastern Truong Son Mountains, Ba To District, Quang Ngai Province, Vietnam, May–June 2011 and March 2012, March 2013. Sources: Wildlife At Risk/Bui H. Manh -2016

distance of 1.25km between localities; elevations at netting sites in 2011 varied from 712m to 772m. At Camp 2 we sampled at 52 geo-referenced locations on nine nights between 12 and 20 March 2012 inclusive. Most of these sampling locations (45 of 52) ranged from 883 m to 991 m in elevation and were within 800m of Camp 2, but for two nights nets were set at 330–650 m elevation. In March 2013 we sampled for five nights using the same-sized mist nets as during prior trips and two 2.25m^2 harp traps. All capture and handling procedures for bats were approved by the Institute for Ecological and Biological Resources, Vietnam Academy of Sciences.

We relied on the following sources for identifications of bats in the field based on external characters: Borissenko & Kruskop (2003), Francis (2008), and Kruskop (2013). We also compared specimens in the field with recent descriptions of new taxa that appeared in Kruskop & Eger (2008) and Furey et al. (2009b). In the laboratory we also compared voucher specimens with descriptions of new *Murina* species by Csorba & Bates (2005), Csorba (2011), Csorba et al. (2007, 2011), Eger & Lim (2011), Francis & Eger (2012), Soisook et al (2013a,b), and Son et al. (2015a, b). We preserved voucher specimens in 95% ethanol. We also took liver or wing tissue in 95% ethanol for future DNA analysis (Son et al. 2015a). All samples and voucher specimens are in collections at the Institute for Ecological and Biological Resources, (IEBR) at the Vietnam Academy of Sciences and Technology, Hanoi.

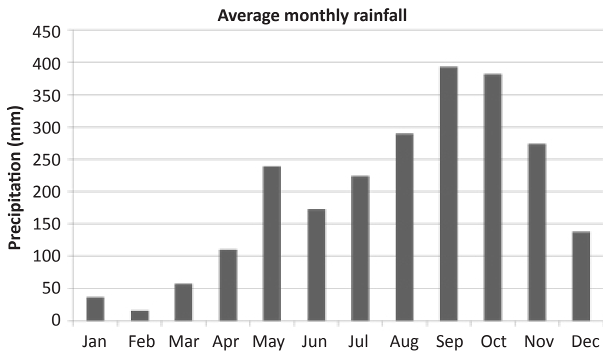

Figure 2. Average monthly rainfall in the region of the study area in the southeastern Truong Son Mountains, Ba To District, Quang Ngai Province, Vietnam, 1997–2009. (Data courtesy of NASA Langley Research Center POWER Project; NASA 2012.)

We categorized adult female bats as pregnant, lactating, post-lactating, and non-reproductive according to criteria of Racey (2009). We recorded number of visible embryos per female when pregnancy was detected in voucher specimens. Age was categorized as volant juvenile or adult based on fusion of the phalangeal epiphyses (Brunet-Rossinni & Wilkinson 2009).

Echolocation recordings

We recorded echolocation sounds of bats in 2011 and 2012, including individuals prepared as voucher specimens. We compared our results with those reported in the literature for the same species recorded elsewhere in Asia. Such comparisons can be useful for future species identification, particularly for cryptic taxa that may be members of species complexes that are not yet well understood (Francis 2008). We recorded calls in three situations: (1) single bats flying in an enclosure made with mosquito nets (2m high x 2m wide x 3m long); (2) single bats hanging freely on the sides of the enclosure; (3) single bats held in our hands. Recordings of bats in flight in enclosures or in hand are commonly employed in bat studies in Asia (e.g., Kingston et al. 1999; Kingsada et al. 2011; Hughes et al. 2011) but some measurements can be biased compared to recordings of free-flying bats. However, given the low capture success (see Results) and need for voucher specimens we chose not to release bats for recordings in the open.

In 2012 we sampled echolocation calls as WAV files using an Echometer EM 3 digital ultrasonic recorder (Wildlife Acoustics 2012). The EM3 allows recording at sampling rates of 256 and 384 kHz (providing analysis of calls up to frequencies of about 192 kHz). We set the recording amplitude threshold at 18 db. We analyzed properties of calls recorded in 2012 in Hanning windows using spectrograms, oscilloscope tracings, and power spectra features of Call Viewer software set at 10 db background threshold and 256-point FFTs (Skowronski & Fenton 2008). We analyzed time and frequency characteristics for 12 representative calls per individual. For bats with predominantly constant frequency (CF) calls we calculated the frequency of maximum energy (FMAXE, kHz), the frequency range of the preceding upsweep (FM rise, kHz), the frequency range of the terminal downsweep (FM tail, kHz), and the sound duration (ms). For bats with predominantly frequency modulated (FM) calls we calculated mean ± SD and ranges for start frequency (kHz), end frequency (kHz), FMAXE (kHz), midpoint (kHz) and duration (ms). We did not measure interpulse intervals because of the confined recording context. In 2011 recordings were made with AnaBat II bat detectors with programmable zero-crossing analysis interface modules (AnaBat™ CF Storage ZCAIM; Titley Electronics, NSW, Australia). We used AnalookW software, version 3.8.13 (http://users.lmi.net/corben/WinAnalook.htm) to view and describe the calls recorded in 2011. This system allows time and frequency measurements of fundamental harmonics, but does not allow more thorough acoustic analysis (Fenton et al. 2001). The Anabat system also does not allow reliable measurements of the upper ranges of echolocation calls of species that utilize very high frequencies. In our study areas these were primarily bats of the genera *Murina* and *Kerivoula*. *Murina* species produce calls that are faint in intensity, making upper frequencies difficult to record. We provide results from Anabat recordings for those species of *Murina* that were recorded only in 2011 with the caveat that start frequencies are likely underestimates. For comparative purposes we also tabulate these same metrics from the echolocation calls of the same species reported previously elsewhere in Asia.

Computations and statistical analyses

We provide original data and simple descriptive summary statistics: means, standard deviations (SD), ranges, and coefficients of variation (CV; SD/mean). We calculated metrics for insectivorous bat species diversity for comparison with the insectivorous bat communities described in the three other bat diversity assessments in Vietnam noted above following methods given by Kingston (2009) and Furey et al. (2010). We calculated assessment effort based on total surface areas of mist nets and harp traps multiplied by the number of hours nets or traps were set, and estimated the success rates by dividing total number of individuals or total number of species captured per unit effort. We provide species richness (S) as the total number of species in a community. We calculated species diversity indices, measures of evenness of distribution of individuals among species, predicted species richness, and inventory completeness using program SPADE (Chao & Shen 2010). We calculated the inverse Simpson Index of Diversity as 1/D where $D = [\Sigma n\ (n-1)]/\ [N\ (N-1)]$, where n is the number of individuals in each observed species, and N is the total number of individuals captured (Magurran 1988). Evenness of the distribution of individuals among species is expressed by the formula $(1/D)/S$, where S is the number of observed species. We followed Furey et al. (2010) and used program SPADE to calculate predicted species richness based on a hypothetical increase in sampling effort that was double the number of bats captured; we estimated predicted species richness with two methods (Solow & Polasky 1999; Shen et al. 2003), and then measured inventory completeness as the range in the ratio of observed species richness to predicted species richness x 100% based on the two estimation computations.

RESULTS

Species diversity

We detected 20 species of bats among the 166 individuals captured at the study area (Table 1). We collected 98 entire specimens with corresponding tissue

Table 1. Sampling effort and numbers of bats captured by mist nets and harp traps at the southeastern Truong Son mountains study area in southwestern Quang Ngai Province, Vietnam, May–June 2011, March 2012, and March 2013. N unique species is the number captured only in harp traps or only in mist nets. Abbreviations: m^2nh = square-meter net-hour; m^2hth = square-meter trap-hour; NA = not applicable.

	2011			2012			2013			Total in		Total
	Mist Nets	Harp Traps	Total	Mist Nets	Harp Traps	Total	Mist Nets	Harp Traps	Total	Mist Nets	Harp Traps	
Effort	2,845 m^2nh	174 m^2th	NA	9,487.5 m^2nh	770.5 m^2 th	NA	1,332	216 m^2 th	NA	13,654.5 m^2nh	1,160.5 m^2th	NA
Nights Sampled	10	10	11	9	8	9	5	5	5	19	18	25
Hours Sampled	114	102	NA	378.5	322	NA	60	60	60	492.5	424	NA
Species												
Rhinolophus affinis (Image 1)	0	4	4	37	10	47	1	18	19	38	32	70
Rhinolophus shameli (Image 2)	0	0	0	0	0	0	0	1	1	0	1	1
Rhinolophus pearsonii (Image 3)	0	0	0	1	0	1	0	0	0	1	0	1
Rhinolophus pusillus (Image 4)	5	5	10	3	5	8	4	5	9	12	15	27
Hipposideros cineraceus (Image 5)	0	0	0	0	0	0	0	3	3	0	3	3
Hipposideros larvatus (Image 6)	1	4	5	1	0	1	0	2	2	2	6	8
Hipposideros pomona (Image 7)	2	0	2	2	1	3	0	3	3	4	4	8
Megaderma lyra (Image 8)	0	0	0	2	0	2	0	0	0	2	0	2
Glischropus bucephalus	1	0	1	0	0	0	0	0	0	1	0	1
Murina annamitica (Image 9)	10	1	11	0	0	0	0	1	1	10	2	12
Murina beelzebub (Image 10)	0	1	1	1	0	1	0	0	0	1	1	2
Murina cyclotis (Image 11)	2	4	6	0	0	0	0	0	0	2	4	6
Murina eleryi (Image 12)	0	1	1	0	0	0	0	1	1	0	2	2
Murina fionae (Image 13)	1	1	2	1	1	2	0	0	0	2	2	4
Myotis ater (Image 14)	6	0	6	0	0	0	0	0	0	6	0	6
Myotis muricola	0	0	0	1	0	1	0	0	0	1	0	1
Hypsugo cadornae	0	0	0	0	0	0	0	1	1	0	1	1
Kerivoula hardwickii (Image 15)	0	1	1	0	1	1	0	0	0	0	2	2
Scotomanes ornatus (Image 16)	0	0	0	2	0	2	1	0	1	3	0	3
Scotophilus heathii	0	0	0	0	0	0	6	0	6	6	0	6
Total Bats Captured	28	22	50	51	18	69	12	35	47	91	75	166
Bats per night	2.8	2.2	4.5	5.7	2.25	7.7	2.4	7	9.4	4.8	4.2	6.6
Bats per hour	0.25	0.22	NA	0.135	0.056	NA	0.2	0.583	0.783	0.185	0.177	NA
Bats per m^2nh or m^2th	0.01	0.126	NA	0.005	0.023	NA	0.009	0.162	NA	0.007	0.065	NA
N Species	8	9	12	10	5	11	4	9	10	15	13	20
N Unique Species	3	4	NA	6	1	NA	2	7	NA	7	5	NA
Species m^2nh or m^2th	0.003	0.057	NA	0.001	0.006	NA	0.003	0.042	NA	0.001	0.012	NA

samples (muscle or liver). We also took wing tissue from another 15 specimens. Seven species were captured only in mist nets, five only in harp traps, and eight in both (including four of the five species of *Murina*; Table 1). Abundance of bats and number of species detected per unit of mist netting effort were about a tenth of those detected per unit of harp trapping effort (Table 1).

At the Camp 1 area we captured 97 bats of 17 species (Table 1) at 15 sampling locations in 4,177 m^2nh of mist net and 390 m^2th of harp trap sampling (both years combined, Table 1). The number of species detected and individuals detected per unit effort was lower at the higher elevation sites sampled at Camp 2 in 2012, where *Rhinolophus affinis* was preponderant (Table 1). We captured 69 bats in 2012, and 65 of these were captured within the 883–991 m elevation range. The respective numbers of individuals and species detected per effort unit were lower at Camp 2 localities than at Camp 1

Table 2. Bat species diversity statistics for insectivorous bats among samples from the southeastern Truong Son Mountains, Quang Ngai Province, Vietnam. Predicted species richness and inventory completeness was calculated with Program Spade (Chao & Shen 2010) based on a hypothetical doubling of sampling effort (numbers of individuals captured). Estimates are ± 1 SE.

	All sites	2011, 2013 Sites, (lower elevation)	2012 Sites, (higher elevation)
Number of species observed	20	17	11
Predicted Species Richness Solow & Polasky (1999)	23.0 ± 2.8	23.6 ± 4.9	14.8 ± 3.4
Predicted Species Richness Shen et al. (2003)	23.6 ± 2.2	23.4 ± 4.5	15.3 ± 2.9
Inventory Completeness	85–87%	72–73%	72–74 %
Simpson's Diversity Index (1/D)	4.54 ± 0.23	7.59 ± 0.19	2.07 ± 0.42
Evenness ($E_{1/D}$)	0.227	0.448	0.188

localities (Table 1).

Individuals of the five species of *Murina* captured at Camp 1 in 2011 were taken at locations within 630m horizontal distance of each other, with three species of *Murina* taken at the same trap or net site. Although no fruit bats (Pteropodidae) were captured or seen in the study area, on 21 March 2012 we observed bat-expressed fruit pulp on the ground beneath a fruiting tree at 825m elevation and in June 2011 *Cynopterus* bats were observed near the village of Ba To, elevation 53m, about 17km from our study area.

Simpson's Inverse Index of Diversity and Index of Evenness were higher at the lower elevation areas near Camp 1 sampled in 2011 and 2013 in comparison with areas near Camp 2 sampled in 2012 (Table 2). Inventory completeness at the Quang Ngai study area was estimated to be 85–87 %, with a predicted 23–24 species likely to be detected with a doubling in numbers of bats captured (Table 2). More species were predicted at the Camp 1 lower elevation sites than at the Camp 2 higher elevation sites, with similar inventory completeness estimates (72%) for both (Table 2).

Seasonality in female reproduction

In late May and June 2011 (early in the rainy season), we captured volant juveniles of nine species and adult females of six species; most of the adult females were

Table 3. Sex, age, and reproductive condition of bats captured at the southeastern Truong Son Mountains, Quang Ngai Province, Vietnam during the early wet season in late May-June 2011 and near the end of the dry season in March 2012 and 2013.
Ad = adult; L = lactating; ND = not determined; NR = non-reproductive; P = pregnant; PL= post-lactating; VJ = volant juveniles.

Species	May–June 2011		March 2012, 2013	
	Males	Females	Males	Females
Megaderma lyra	0	0	1 Ad	0
Rhinolophus affinis	0	1 Ad-L, 2 VJ, 1 Ad-NR	35 Ad	25 Ad-P, 1 Ad-ND, 5 Ad-NR
Rhinolophus pearsonii	1 Ad	0	0	0
Rhinolophus pusillus	0	7 Ad-L, 3 Ad-P, 1 VJ	5 Ad	7 Ad-P, 4 Ad-NR
Rhinolophus shameli	0	0	1 Ad	0
Hipposideros cineraceus	0	0	0	1 Ad-P, 2 Ad-NR
Hipposideros larvatus	3 Ad	2 VJ	0	2 Ad-NR
Hipposideros pomona	2 Ad	0	5 Ad	1 Ad-P
Glischropus bucephalus	0	1 Ad-L	0	0
Hypsugo cadornae	0	0	0	1 Ad-NR
Kerivoula hardwickii	1 VJ	0	0	1 Ad-P
Murina annamitica	2 VJ, 1 Ad	4 Ad-L, 1 Ad-PL, 2 VJ	0	1 Ad-NR
Murina beelzebub	1 VJ	0	1 Ad	0
Murina cyclotis	1 Ad	1 Ad-L, 2 Ad-PL, 2 VJ	0	0
Murina eleryi	1 VJ	0	0	1 Ad-NR
Murina fionae	0	2 Ad-L	2 Ad	0
Myotis ater	4 Ad 1 VJ	1 VJ	0	0
Myotis muricola	0	0	0	1 Ad-P
Scotomanes ornatus	0	0	3 Ad	0
Scotophilus heathii	0	0	3 Ad	3 Ad-NR

Table 4. Echolocation call characteristics of bats with frequency modulated (FM) calls sampled at the Truong Son Mountains study area, southwestern Quang Ngai Province, Vietnam. Call characteristics are also provided for the same species as documented in the literature. Values are means +/- 1 SD and ranges in parentheses. NR = not reported, NA = measurement not applicable.

Species and location	Reference	N bats	N calls	Start Frequency (kHz)	End Frequency (kHz)	Duration (ms)	FMAXE (kHz)	Midpoint Frequency (kHz)
Kerivoula hardwickii: Quang Ngai, Vietnam, 2012	This study	1	12	169.5 ± 19.9 (147–192)	95.2 ± 9.1 (90–124)	1.4 ± 0.56 (0.8–2.2)	149.3 ± 26.5 (126–190)	132.3 ± 12.4 (119–158)
Kerivoula hardwickii: Thailand	Hughes et al. 2011	88	88	169.6 ± 28.8	90.7 ± 8.1	3.1 ± 2.7	118.3 ± 11.9	NR
Murina annamitica: Quang Ngai, Vietnam, 2011	This study	3	36	> 131.0 ± 7.0 (122.1–152.4)	70.4 ± 15.5 (46.2–113.5)	1.2 ± 0.0 (0.5–1.9)	NA	>100.7 ± 8.5 (84.7–125.1)
Murina beelzebub: Quang Ngai, Vietnam, 2012	This study	1	12	146.0 ± 8.3 (127.0–156.5)	74.3 ± 7.1 (66.3–86.0)	1.4 ± 0.7 (0.9–3.1)	124.5 ± 8.4 (102.4–131.9)	110.1 ± 5.0 (102.8–118.9)
Murina eleryi: Quang Ngai, Vietnam, 2011	This study	1	12	>127.9 ± 6.6 (121.2–141.6)	84.7 ± 6.3 (75.5–94.2)	0.6 ± 0.1 (0.4–0.8)	NA	>106.3 ± 5.1 (99.3–114.3)
Murina cyclotis: Quang Ngai, Vietnam, 2011	This study	3	36	>127.1 ± 5.8 (118.5–149.5)	56.9 ± 13.4 (35.0–111.9)	2.3 ± 0.5 (1.0–3.4)	NA	>92.0 ± 7.1 (82–121)
Murina cyclotis: Thailand	Hughes et al. 2011	28	28	121.4 ± 44.6	57.4 ± 25.9	1.8 ± 1.2	93.8 ± 7.6	NR
Murina fionae: Quang Ngai, Vietnam, 2012	This study	1	12	152.8 ± 7.8 (135.8–163.1)	66.8 ± 7.5 (51.6–76.1)	1.05 ± 0.2 (0.9–1.6)	112 ± 21.3 (72.0–133.4)	109.8 ± 6.9 (93.7–116.7)
Myotis ater: Quang Ngai, Vietnam, 2011	This study	2	24	105.0 ± 7.0 (95.8–117.7)	53.4 ± 4.9 (44.8–60.4)	2.3 ± 0.7 (1.4–3.9)	NA	79.2 ± 4.2 (73.4–87.3)
Myotis ater: Bac Kan, Vietnam	Furey et al. 2009a	2	4	104.7 (95.4–110)	57.5 (53.7–60.1)	1.4 (1.0–1.7)	66.7 (64.3–71.3)	62.5 (60.4–64.1)
Myotis muricola: Quang Ngai, Vietnam, 2012	This study	1	12	115.5 ± 7.3 (102.4–127.2)	49.9 ± 2.2 (45.7–53.1)	3.1 ± 0.9 (1.7–4.5)	65.4 ± 2.8 (59.9–69)	82.7 ± 3.5 (76.8–88.6)
Myotis muricola: Thailand	Hughes et al. 2011	49	49	118.0 ± 17.1	55.6 ± 10.1	5.2 ± 2.5	82.3 ± 16.6	NR
Myotis muricola: Bac Kan, Vietnam	Furey et al. 2009a	2	4	97.8 (75.3–114.1)	54.5 (51.5–59.2)	1.9 (1.0–2.4)	66.2 (62.0–73.6)	59.7 (57.0–63.6)
Scotomanes ornatus: Quang Ngai, Vietnam, 2012	This study	1	12	104.6 ± 6.3 (98–122.6)	20.1 ± 0.7 (19.2–21.4)	3.3 ± 0.9 (2–4.8)	63.8 ± 3.0 (56.2–67.1)	62.4 ± 3.2 59.1–71.3
Scotomanes ornatus: Bac Kan, Vietnam	Furey et al. 2009a	6	6	54.1 ± 7.0 (43–62)	21.0 ± 1.9 (18.6–23.1)	3.4 ± 0.8 (2.2–4.4)	31.7 ± 2.5 (29.7–35.9)	28.8 ± 1.8 (26.6–31.3)
Scotomanes ornatus: Mianyang, China	Liu et al. 2011	NA	NA	73.9 ± 11.5	22.9 ± 2.6	NA	57.9 ± 1.4	NA

lactating or post-lactating (19 of 23) with three pregnant and one non-reproductive (Table 3). In March 2012 and 2013 (prior to the rainy season), no female bats were lactating or post-lactating, no volant juveniles of either sex were captured, and most female bats taken were either pregnant (36 of 56) or had no discernible evidence of pregnancy or lactation (Table 3). A single embryo was found in each of the pregnant females saved as voucher specimens; the following species and number of pregnant individuals (in parentheses) were examined for number of embryos by dissection: *Hipposideros cineraceus* (1), *H. larvatus* (1), *Kerivoula hardwickii* (1), *My. muricola* (1), *R. affinis* (4), and *R. pusillus* (6).

Echolocation calls

We recorded echolocation calls of 14 species of bats in the southeastern Truong Son Mountains (Tables 4 and 5). To our knowledge, calls of four species (*M. annamitica*, *M. beelzebub*, *M. eleryi*, and *M. fionae*) have not been previously reported. FM calls of four species (*K. hardwickii, M. cyclotis, Myotis ater,* and *My. muricola*) were generally concordant with those reported previously (Table 4). Differences with calls reported in the literature for some but not all localities were found for *Scotomanes ornatus* and four species with CF calls*: R. affinis, R. pearsonii, R. pusillus,* and *H. larvatus* (Table 5; see Discussion).

Table 5. Characteristics of echolocation calls of bats with predominantly constant frequency (CF-FM and FM-CF-FM) calls sampled at the Truong Son Mountains study area, southwestern Quang Ngai Province, Vietnam. Characteristics are also provided for the same species as documented in the literature. Values are means +/- 1 SD and ranges in parentheses. NA = measurement not applicable, (~) value estimated from published sonogram. Blanks appear where data were not reported in the original reference.

Species	Reference	N bats	N calls	CF component FMAXE (kHz)	FM rise (kHz)	FM tail (kHz)	Duration (ms)
Rhinolophus affinis: Quang Ngai, Vietnam, 2012	This study	18	216	80.6 ± 0.77 (79.3–82.5)	11.0 ± 6.1 (0–58.9)	19.2 ± 4.9 (2.2–59.9)	30.6 ± 7.0 (13.9–52)
Rhinolophus affinis: Bac Kan, Vietnam	Furey et al. 2009a	18	18	71.1 ± 0.9	ca. 14.2	ca. 14.5	43.2 ± 10.4 (17.6–55.4)
Rhinolophus affinis: Kon Tum, Vietnam	Thong 2011 *in* Kingsada et al. 2011	1		84.5			
Rhinolophus affinis: Hainan, Guangdong, Guangxi (China)	Zhang et al. 2009			(70–74.3)			
Rhinolophus affinis: Jiangxi, China	Zhang et al. 2009			(88.1–88.5)			
Rhinolophus affinis: Yunnan, China	Zhang et al. 2009			(82.6–83.7)			
Rhinolophus affinis: Fujian, China	Zhang et al. 2009	10		(71.9–86.1)			
Rhinolophus affinis: unspecified, China	Wu et al. 2015	6	1 per bat	86.57 ± 0.44			
Rhinolophus affinis: Peninsular Malaysia	Kingston et al. 2000	4	24	77.6		~10	~25
Rhinolophus affinis: Cambodia	Kingsada et al. 2011	8	≥ 40	(76.1–79.9)			
Rhinolophus affinis: Thailand	Robinson 1996	6		(75–80)			
Rhinolophus affinis: Lao PDR	Francis 2008; Francis & Habersetzer 1998			(73–78)			
Rhinolophus affinis: Myanmar	Francis & Habersetzer 1998			78.4			
Rhinolophus affinis: Central Java	Ith et al. 2016	6	1 per bat	81.8 ± 0.4 (81.2–82.3)			
Rhinolophus affinis: Borneo	Ith et al. 2016	1	1 per bat	68.9			
Rhinolophus affinis: Sumatra	Ith et al. 2016	5	1 per bat	74.2 ± 0.5 (73.2-74.6)			
Rhinolophus affinis: Southern Malay Peninsula	Ith et al. 2016	16	1 per bat	77.8 ± 1.3 (75.4–79.3)			
Rhinolophus affinis: Northern Malay Peninsula	Ith et al. 2015	31	1 per bat	70.9 ± 0.7 (69.5–72.6)			
Rhinolophus affinis: Tarutao islands, Thailand	Ith et al. 2016	10	1 per bat	65.1 ± 1.3 (63.6–66.6)			
Rhinolophus pearsonii: Quang Ngai, Vietnam, 2012	This study	1	12	64.0 ± 0.3 (63.7–64.4)	11.1 ± 1.9 (8.4–13.6)	13.2 ± 4.2 (6.9–18.4)	38.3 ± 2.9 (33.9–43.1)
Rhinolophus pearsonii: Thailand	Robinson 1996	9		65			
Rhinolophus pearsonii: Thailand	Hughes et al. 2010	12	12	60.0			ca. 40
Rhinolophus pearsonii: Bac Kan, Vietnam	Furey et al. 2009a	18	18	53.0 ± 1.5 (51.1–55.4)	ca. 10.1	ca. 12.1	41.5 ± 9.7 (26.7–59.7)
Rhinolophus pearsonii: multiple locations, China	Zhang et al. 2009		89	57.6–70			
Rhinolophus pearsonii: unspecified, China	Wu et al. 2015	10	1 per bat	67.70 ± 3.08			
Rhinolophus pusillus: Quang Ngai, Vietnam, 2012	This study	8	96	99.7 ± 0.7 (97.9–101)	14.9 ± 4.8 (2–22.5)	17.5 ± 4.8 (5–26.7)	35.8 ± 9.8 (13.5–52.3)
Rhinolophus pusillus: Bac Kan Province, Vietnam	Furey et al. 2009a	10	10	105.0 ± 1.2 (102.3–106.1)	ca. 14.8	ca. 18.2	31.6 ± 8.9 (20.5–47.6)
Rhinolophus pusillus: China	Zhang et al. 2009			(100.3–111.2)	~15	~15	
Rhinolophus pusillus: Guangxi, China	Zhang et al. 2009			111.2			
Rhinolophus pusillus: unspecified, China	Wu et al. 2015	6	1 per bat	107.52 ± 1.63			
Rhinolophus pusillus Eleven locations across southeastern China	Jiang et al. 2010	199	30–40 per bat	Means 102 to 114, variable by sex and location			
Rhinolophus pusillus: Thailand	Hughes et al. 2010	174	174	112.5 (ca. 107–127)			
Rhinolophus pusillus: Thailand	Robinson 1996	9		(90–95)			
Rhinolophus pusillus: Thailand	Soisook et al. 2016	40		107.3–115.2			
Rhinolophus pusillus: Lao PDR	Francis & Habersetzer 1998			100			
Rhinolophus pusillus: Lao PDR	Francis 2008			(108–110)			

Species	Reference	N bats	N calls	CF component FMAXE (kHz)	FM rise (kHz)	FM tail (kHz)	Duration (ms)
Hipposideros larvatus: Quang Ngai, Vietnam, 2011–2012	This study	2	24	93.2 ± 0.3 (92.6–93.8)	0.0	14.8 ± 4.0 (9.4–21.7)	5.8 ± 1.8 (3.5–13.0)
Hipposideros larvatus: Bac Kan, Vietnam	Furey et al. 2009a	32	32	86.5 ± 1.8 (83.8–89.3)	ca. 0.2	ca. 11.3	7.8 ± 1.4 (5.2–11.2)
Hipposideros larvatus: Hainan, Guangdong, Guangxi (China)	Zhang et al. 2009			(83.2–88)	0.0	~12	~11
Hipposideros larvatus: Yunnan, China	Zhang et al. 2009			(79.2–84)	0.0	~12	~11
Hipposideros larvatus: Thailand	Robinson 1996	5		85			
Hipposideros larvatus: Thailand	Hughes et al. 2010	(many)	(many)	94.7 (ca. 87–100)	0.0	~12	~10
Hipposideros larvatus: Peninsular Malaysia	Kingston et al. 2000	5	30	100.0		~14	~10
Hipposideros larvatus: Myanmar	Thabah et al. 2006	30 males 21 females	30 21	92.6 ± 1.5 (male) 93.0 ± 1.0 (female)			
Hipposideros larvatus: Myanmar	Struebig et al. 2005	51	51	92.7 ± 1.4 (89.2–95.2)			
Hipposideros larvatus: Malaysia	Thabah et al. 2006	12 males 7 females	12 7	100.6 ± 0.8 (male) 100.6 ± 0.6 (female)			
Hipposideros larvatus: Myanmar	Francis & Habersetzer 1998			97.7			
Hipposideros larvatus: India (Phonic group 1)	Thabah et al. 2006	12 males 10 females	12 10	83.7 ± 1.8 (male) 85.1 ± 0.7 (female)			
Hipposideros larvatus: India (Phonic group 2)	Thabah et al. 2006	22 males 15 females	22 15	96.7 ± 2 (male) 98.0 ± 2 (female)			
Hipposideros larvatus: Guangxi, China	Wei et al. 2011			85.2 ± 0.5			7.8 ± 0.9
Hipposideros larvatus: Peninsular Malaysia	Francis 2008			(97–100)			
Hipposideros larvatus large form: Lao PDR	Francis 2008			(93–97)			
Hipposideros larvatus medium form: Lao PDR	Francis 2008			(86–89)			
Hipposideros larvatus small form: Lao PDR	Francis 2008			(99–102)			
Hipposideros pomona: Quang Ngai, Vietnam, 2012	This study	2	24	128.6 ± 4.2 (124.3–134.1)	0.0	10.7 ± 4.1 (5.3–18.4)	5.3 ± 1.0 (3.1–6.7)
Hipposideros pomona: Bac Kan, Vietnam	Furey et al. 2009a	7	7	125.1 ± 2.3 (122–127.7)	~ 0.1 kHz	~ 21 kHz	7.0 ± 2.3 (3.7–9.3)
Hipposideros pomona: Yunnan, China	Zhang et al. 2009			120.8–125.6			
Hipposideros pomona: Guangdong, China	Zhang et al. 2009			125–129			
Hipposideros pomona: Hainan, China	Zhang et al. 2009			121			
Hipposideros pomona: Hong Kong, China	Shek and Lau 2006 in Zhang et al. (2009)			129.6 (125.7–132.5)			
Hipposideros pomona: Lao PDR	Francis and Haberstetzer (1998)			125			
Hipposideros pomona: Lao PDR	Francis (2008)			120–126			
Hipposideros pomona: central Thailand	S. Puechmaille pers. comm.) in Douangboubpha et al. (2010)			125.6–128.2			
Hipposideros pomona: Myanmar	Struebig et al. (2005)	22	22	134.9 ± 1.4 (132.1–137.2)			
Hipposideros pomona: Myanmar	S. Puechmaille (pers. comm.) in Douangboubpha et al. (2010)			(131.8–135.4)			
Hipposideros pomona: Thailand	Douangboubpha et al. (2010)	23 males 15 females	230 150	133.3 ± 3.9 (127.3–139.3) 139.3 ± 3.7 (127.7–140.2)			

Image 1. ***Rhinolophus affinis***

Image 2. ***Rhinolophus shameli***

DISCUSSION

Comparisons with three protected areas in Vietnam (Furey et al. 2010; Hendrichsen et al. 2001) suggest that the bat fauna of the southeastern Truong Son Mountains in Quang Ngai Province is diverse for a region that does not have a karst geological substrate (karst provides many potential roosting sites). Greater species richness of insectivorous bats was found at our study area than in Kon Cha Rang Nature Reserve and Kon Ka Kinh National Park (15 and 13 species, respectively; Hendrichsen et al. 2001) in nearby Gia Lai Province, but overall diversity was lower than at the more intensively sampled, karst-dominated Kim Hy Nature Reserve (28 species of insectivorous bats, four pteropids, 90% inventory completeness, Simpson Index 10.91 ± 0.18, Evenness 0.341; Furey et al. 2010). Abundance of bats per unit of mist-netting effort was twice as high at Kim Hy Nature Reserve (0.014 bats per m^2nh, Furey et al. 2010) than at our area, but results per unit trapping were similar (0.047 bats per m^2th; Furey et al. 2010). Species detected per unit of mist-netting was nearly identical (0.0009; Furey et al. 2010), but species detected per unit trapping (0.006 at Kim Hy; Furey et al. 2010) was higher at our study area overall. The number of species and individuals detected per unit effort at the lower elevation site we sampled in 2011 and 2013 were comparable to or higher than at Kim Hy overall, and comparable to or higher than two of the three forest types at Kim Hy Nature Reserve (Furey et al. 2010). Lower evenness and diversity was especially pronounced at our higher elevation sites sampled during 2012; diversity comparisons are more similar among our lower elevation sites sampled during 2011/2013 and the sites at Kim Hy Nature Reserve.

It is noteworthy that we documented five species of tube-nosed bats (genus *Murina*) sympatrically

Image 3. *Rhinolophus pearsonii*

Image 4. *Rhinolophus pusillus*

distributed at the study area. Son et al. (2015a) provided a detailed overview of the genus *Murina* in Vietnam, and established that Vietnam has the greatest number of species of *Murina* in Southeast Asia. In contrast, however, we did not detect fruit bats at our study area. At least two species of fruit bats were captured at Kon Cha Rang and Kon Ka Kinh National Park in nearby Gia Lai Province (Hendrichsen 2001), and four species of fruit bats were present at Kim Hy Nature Reserve in Bac Kan Province (Furey et al. 2010). Pteropodid bats may utilize the southeastern Truong Son Mountains study area at other times of the year if fruit is more abundant than in the dry or in the early wet seasons when we sampled the bat fauna. Evidence for the presence of fruit bats of unknown species was detected below a fruiting tree near the 2012 study area, and in 2011 an unidentified *Cynopterus* was seen about 17km from our camp at a lower elevation.

We found a higher diversity of bats at the lower elevation site. Only *M. eleryi* was taken exclusively in a harp trap at this site, suggesting that differences in sampling techniques cannot explain the higher diversity at the lower elevation. Two ecological factors may contribute to the differences in diversity between lower and higher elevations in the southeastern Truong Son Mountains. In other tropical and subtropical areas, the diversity of bats declines with increasing elevation (e.g., Graham 1983; Patterson et al. 1998). Additionally,

Image 5. *Hipposideros cineraceus*

Image 6. *Hipposideros larvatus*

Image 7. *Hipposideros pomona*

Image 8. *Megaderma lyra*

some differences in diversity between lower and higher elevations at our study area might reflect seasonal movements of bats. In northern Vietnam Furey et al. (2010) suggest that some species of bats may be unique to each season. They found only about half of the total documented species in both dry and wet seasons (40–52 % depending on habitat type), and fewer species were recorded in each unique habitat type during the wet season than during the dry season (Furey et al. 2010).

We found evidence for seasonal differences in reproduction of female bats at our study area. In much of Vietnam there is a predictable rainy season following a dry winter season, but with the monthly patterns of precipitation varying regionally (Sterling et al. 2006). In many other tropical and subtropical parts of the world the reproductive season of insectivorous bats is timed to coincide with predictable rainy seasons: young are born and become independent when community productivity and insect abundance is high (Fleming et al. 1972;

Image 9. *Murina annamitica*

Image 10. *Murina beelzebub*

Image 11. *Murina cyclotis*

Image 12. *Murina eleryi*

Bernard & Cumming 1997; Racey & Entwistle 2000). Furey et al. (2011) found strong evidence to support the existence of this pattern in the insectivorous bat fauna at Kim Hy Nature Reserve, and suggested that the pattern may hold for a wider region in Southeast Asia. Rainfall in the southeastern Truong Son Mountains is lowest in January through March, then increases and remains relatively higher from May to November (Fig. 2). Our findings strongly support Furey et al.'s (2011) suggestion of rainy season reproduction of bats in Vietnam. In March prior to the rainy season, we found that many females were pregnant, no females were lactating or post-lactating, and no volant juveniles of either sex were captured (Table 3). In late May and June, most adult females were lactating, a few were pregnant, and volant juveniles of 10 species were captured (Table 3). Given the longer period of seasonal rainfall at our study area compared to the Kim Hy Nature Reserve, it is possible

Image 13. *Murina fionae*

Image 14. *Myotis ater*

Image 15. *Kerivoula hardwicki*

Image 15. *Scotomanes ornatus*

that the reproductive season for some species of bats also may be more prolonged than in areas with shorter rainy seasons.

Echolocation call measurements of the two *Murina* species recorded in 2012 (Table 4) are concordant with those reported previously for other species in this genus. Kingston et al (1999) and Thong et al. (2011) reported that echolocation calls of different *Murina* species tend to be similar to one another, showing short durations and faint intensity, sweeping a broad bandwidth with high frequency starting points, typically at about 150kHz. These characteristics match those we recorded for *M. beelzebub* and *M. fionae*. Calls for the *Murina* sampled at Camp 1 in 2011 also match these characteristics, but our start frequency estimates may have been limited by the equipment used at that time. For these species, the maximum values in the range of the start frequencies are most reliable. Midpoint values may also be biased low. However, our measurements of calls of *M. cyclotis* in 2011 are very similar to those of *M. cyclotis* from Thailand (Hughes et al. 2011; Table 4). Our measurements of echolocation calls of the other species of vespertilionid bats are consistent with those reported previously. Echolocation calls of *Scotomanes ornatus* were recorded from a hand-held individual in our study, and the start and end frequencies are higher than those reported by Furey et al. (2009a) for free-flying *S. ornatus*. This is most likely because the free-flying individuals emphasized the first harmonic, whereas our peak energy measurements of the hand-held bat were all in the second harmonic. Measurements of calls of *S. ornatus* recorded by Liu et al. (2011) at Mianyang, China had lower start frequencies than our results, but showed similar FMAXE and end frequencies (Table 4).

Greater discrepancies in echolocation call measurements are observed when we compare CF calls of rhinolophid and hipposiderid bats recorded in the southeastern Truong Son Mountains with those previously reported in other parts of Asia (Table 5). It is suspected that several currently recognized species of these Asian bats, such as *H. larvatus* and some species of *Rhinolophus*, may consist of complexes of several species with very similar morphological characteristics (Francis 2008). Further research will be required to resolve the causes of geographic variation in echolocation calls of rhinolophid and hipposiderid bats in relation to their systematic status. Such geographic variation is found in FMAXE measurements of *R. affinis* (Table 5). In *R. affinis*, the coefficient of variation was <1% for FMAXE of 216 calls from 18 bats recorded at our study area in Quang Ngai, whereas calls recorded previously in Vietnam, China, Lao PDR, Myanmar, Malaysia, Borneo and Sumatra (but not central Java) were generally outside of the range of minimum-maximum values from our study area (Table 5; Ith et al. 2015). In our study area the higher FMAXE of echolocation calls of *R. affinis* (*sensu lato*) did not follow the geographic trend suggested by Ith et al. (2016) of lower frequencies north of the Kangar-Pattani Line across the Thai-Malay Peninsula. Discrepancies also are found between calls of *R. pusillus* in the present study and those from some locations in China, Thailand, Lao PDR, and Vietnam (Table 5). Jiang et al. (2010) show that resting frequencies in *R. pusillus* across southeastern China vary by sex, location and mean annual rainfall. However, the mean frequencies in that study are outside the range of call measurements taken at our study area (Table 5). Considering this variability in echolocation calls, our findings support Zhang et al. (2009) and Soisook et al.'s (2016) suggestions that cryptic species of an *R. pusillus* complex might be present in Asia based on differences in echolocation calls. Values of FMAXE for *R. pearsonii* also showed some discrepancies as well as similarities among localities. Among hipposiderids, we found overlap with our range of estimates of FMAXE for *H. pomona* and published reports from elsewhere, including China, Lao PDR, Myanmar and Thailand (Table 5). In contrast, great variation is seen in FMAXE of bats referred to as *H. larvatus* across Asia, with results reported from Myanmar more consistent with those of bats we recorded than from many other locations (Table 5). Thabah et al. (2006) suggested that bats from Myanmar with echolocation frequencies similar to the bats we sampled may be a species other than *H. larvatus*. *Hipposideros larvatus* seems to present another case where additional research on variability in echolocation and systematics is needed. There is a possibility that some of the discrepancies that we highlight among various published studies by others could be an artifact of misidentification of bats, circumstances of recording (e.g., in free-flying vs. in-hand), or variability in equipment among studies. Nonetheless the number of differences suggests a real biological basis for this variation and the need for further study.

CONCLUSION

This study revealed significant biodiversity in the insectivorous bats of the southeastern Truong Son Mountains in Quang Ngai Province, Vietnam. Enhanced conservation and protection planning for the watershed protection forests within this area will be critical for maintaining the diversity of bats and other wildlife of the region in the future.

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Vietnamese abstract: Việt Nam được đánh giá là một trong những trung tâm đa dạng dơi trong khu vực Đông Nam Á cũng như của thế giới. Các nghiên cứu gần đây cho thấy, Việt Nam còn chứa đựng tiềm năng đa dạng các loài dơi cần tiếp tục được nghiên cứu. Từ 2011 đến 2013, chúng tôi đã điều tra đánh giá mức độ đa dạng các loài dơi tại khu rừng phòng hộ khu vực đông nam dãy Trường Sơn, trên địa bàn tỉnh Quảng Ngãi và đã ghi nhận được 20 loài dơi ăn côn trùng với mức độ đa dạng cao của các loài dơi mũi ống giống *Murina*. So sánh với một số khu vực khác của Việt Nam, các chỉ số đa dạng và phong phú các loài dơi ghi nhận tại vùng nghiên cứu tương đương hoặc cao hơn, mặc dù tại đây không phải là khu vực núi đá vôi, nơi trú ngụ thích hợp cho các loài dơi. Mùa sinh sản của các loài dơi muỗi được ghi nhận diễn ra vào đầu mùa mưa khi ghi nhận được đa phần các cá thể cái đang nuôi con hoặc đang cai sữa và con non có thể bay được. Trong khi cuối mùa mưa, không bắt gặp con non mà chỉ ghi nhận được số ít cá thể cái vẫn đang mang thai. Tín hiệu siêu âm của 14 loài dơi đã được ghi nhận và so sánh với những dẫn liệu công bố trước đây tại khu vực khác nhau ở châu Á mà một số điểm bất thường trong các chỉ số tín hiệu siêu âm của một số loài có thể chỉ ra rằng, sự đa dạng dơi tại Đông Nam Á còn ẩn chứa nhiều điều cần tiếp tục được nghiên cứu.

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Author Contribution: Thomas J. O'Shea and Nguyen Truong Son worked with the team in fieldwork, data analysis, species indentification, writing, and correcting the proof: Gabor Csorba and Vuong Tan Tu: species identification; Jeffery A.Gore participated in field sampling, data collection, and reviewing manuscript; Hidedi Endo, Tatsuo Oshida, Masaharu Motokawa: reviewing manuscript.

OPEN ACCESS

ISSN 0974-7907 (Online); ISSN 0974-7893 (Print)

July 2016 | Vol. 8 | No. 7 | Pages: 8953–9052
Date of Publication: 26 July 2016 (Online & Print)
DOI: 10.11609/jott.2016.8.7.8953-9052
www.threatenedtaxa.org