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Short Communication

The first record of European free-tailed bat, *Tadarida teniotis* Rafinesque, 1814, and note on probable elevational movement from Nepal

Basant Sharma [a,b,*], Rohit Chakravarty [c], Pushpa Raj Acharya [a,d]

[a] Nepal Bat Research and Conservation Union, Pokhara, Nepal
[b] Faculty of Science Health and Technology, Nepal Open University, Lalitpur, Nepal
[c] Department of Evolutionary Ecology, Leibniz Institute for Zoo and Wildlife Research, Berlin, 10315 Germany
[d] Central Campus of Science and Technology, Faculty of Science, Mid-western, University, Surkhet, Nepal

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ABSTRACT

Out of the four *Molossidae* species from South Asia, the distribution of the European free-tailed bat, *T. teniotis* is most poorly known. This species has been occasionally reported from Afghanistan, Bangladesh, Bhutan, and India; however, no records exist in Nepal. Here we report the first record of *T. teniotis* from Nepal and comment on its possible elevational movement in the Himalaya. Active acoustic surveys were conducted in the Kali Gandaki canyon during autumn and winter seasons at two elevational zones, 800–1200 m and 2100–2500 m, in three habitat types (forest, agricultural land, and human settlements). Echolocation calls of *T. teniotis* were easily distinguished by their low frequency, shallow frequency modulation, and long duration. During autumn, the activity was recorded only at 2100 to 2500 m and varied significantly from winter activity, while *T. teniotis* was observed at both elevational zones during winter. The result confirms the presence of *T. teniotis* from Nepal. Based on our observations of differential activity at different elevation zones in two seasons, we recommend more intensive studies to confirm seasonal migration and to understand seasonal demographics along the Kali Gandaki landscape and in the entire Himalayan range at large.

Introduction

The family *Molossidae* of bats consists of 18 genera and 130 species, of which the genus *Tadarida* consists of 8 species worldwide (Simmons and Cirranello 2020). Only four species of *Molossidae* are reported from South Asia; *T. teniotis* Rafinesque, 1814; *Tadarida aegyptiaca* E. Geoffroy, 1818; *Chaerephon plicatus* Buchannan, 1800; and *Otomops wroughtoni* Thomas, 1913 (Bates and Harrison 1997; Srinivasulu et al 2020). Of these four species, *T. aegyptiaca* has a wide distribution across South Asia, *C. plicatus* and *T. teniotis* are uncommon, while *O. wroughtoni* is rare and has only two recorded locations (Bates and Harrison 1997; Deshpande and Kelkar 2015; Srinivasulu et al 2010).

T. teniotis is widely distributed in southern Europe and parts of northern Africa, and its distribution further extends to the Indo-Malayan region of Asia (Benda and Piraccini 2016). It has been recorded from sea level to 3000 m in the Alps (Arlettaz et al 2000; Benda and Piraccini 2016). In the Indian Subcontinent, it was earlier occasionally recorded from Afghanistan, Bangladesh, Bhutan, and India (Bates and Harrison 1997; Benda and Piraccini 2016; Deshpande and Kelkar 2015; Hill 1963) hence, formerly considered as a rare migrant (Molur et al 2002). However, a recent study from Uttarakhand, a part of the western Himalaya adjoining Nepal, reported its occurrence from numerous areas and suggested it may be widespread in other parts of the Himalaya (Chakravarty 2017). Its occurrence from Nepal's geographical limits was hitherto undocumented.

T. teniotis is largely solitary and sedentary, but occasionally and seasonally, it is found in colony sizes ranging from 5 to 400 individuals (Bates and Harrison 1997; Benda and Piraccini 2016). It emerges late in the evening and forages 10–50 m above ground level across a large variety of temperate and semi-desert habitats (Benda and Piraccini 2016; Russo and Jones 2003). High-flying species like *T. teniotis*, are difficult to capture either in mist nets or in harp traps (Kunz et al 2009; Voigt and Holderied 2012; Walters et al 2012). Moreover, literature from Europe suggests that

* Corresponding author. Tel.: +977 9849952120.
E-mail address: b.s.sharma237@gmail.com (B. Sharma).

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it prefers to roost in small caves and rock crevices in high cliffs that are inaccessible to humans and in artificial structures such as bridges and buildings (Benda and Piraccini 2016). Hence, non-invasive acoustic monitoring is an excellent method to identify high-flying bat species and to understand their feeding behavior and habitat use (Davy et al 2007; Georgiakakis and Russo 2012; Papadatou and Russo 2014; Russo and Jones 2002). Although echolocation calls are still being documented for most South Asian bat species, the calls of Molossids are well-documented and readily identified to species level (Deshpande and Kelkar 2015). In this paper, we used acoustic sampling to document the occurrence of *T. teniotis* in Nepal for the first time. We also report differences in activity in autumn and winter at different elevational zones, which may provide evidence for the seasonal migration of this species in the Himalaya.

Material and methods

Study site

The study was conducted in the Kali Gandaki canyon (28°42′24″N, 83°38′43″E), the deepest gorge in the world that separates the major peaks of Dhaulagiri on the West and Annapurna on the East (Carosi et al 2014). Kali Gandaki River flows through the upper Mustang to Myagdi, Baglung, and Parbat districts (Figure 1). The upper region (2100–2500 m above sea level) of the study site i.e. Ghasa to Lete, lies within the Annapurna Conservation Area in Mustang district, whereas the lower region (800–1200 m) lies within Parbat, Baglung, and Myagdi districts (Carosi et al 2014). The climate of the upper region is sub-alpine and temperate; desiccated by strong winds and high solar radiation; the maximum temperature reaches up to 23°C in summer and a minimum of −2.5°C in winter (MoAD 2018). The climate of the lower region is sub-tropical; the maximum temperature reaches up to 30°C in summer and a minimum of 8°C in winter (MoAD 2018). Dominant vegetations are *Pinus wallichiana*, *Thuja* sp., and *Juglans regia* in the higher elevation and *Dalbergia sissoo*, *Diploknema butyraceae*, *Pinus roxburgii*, *Toona ciliata*, *Alnus nepalensis*, *Shorea robusta*, *Ficus bengalensis*, *Ficus cunia* and *Dendrocalamus* sp. in the lower elevation (Sharma et al 2020).

Acoustic survey

The Kali Gandaki canyon was divided into two elevational regions; lower (800–1200 m) and upper (2100–2500 m) regions, and from each elevational region, three habitat types (forest, agriculture land and human settlements) of an approximately equal area were selected randomly on the basis of terrain property and presence of road trails for transect walk. The geographical location of each selected site was marked using Garmin E-Trex 10 and plotted using QGIS 3.12.2 (QGIS Development Team 2020). One person with Echometer Touch 2 Pro (Wildlife Acoustics 2020) walked constantly on the road trail of approximately 2 km in each selected site (6 sites) and performed spot counts (3–5 minutes) covering the whole area (Bat Conservation Trust 2016). The survey was conducted from 6:00 PM to 9:00 PM in autumn (September–October 2019) and in winter (January–February 2020) season. Each selected site was surveyed thrice in each season randomly, thereby spending a total of 36 days of field visits.

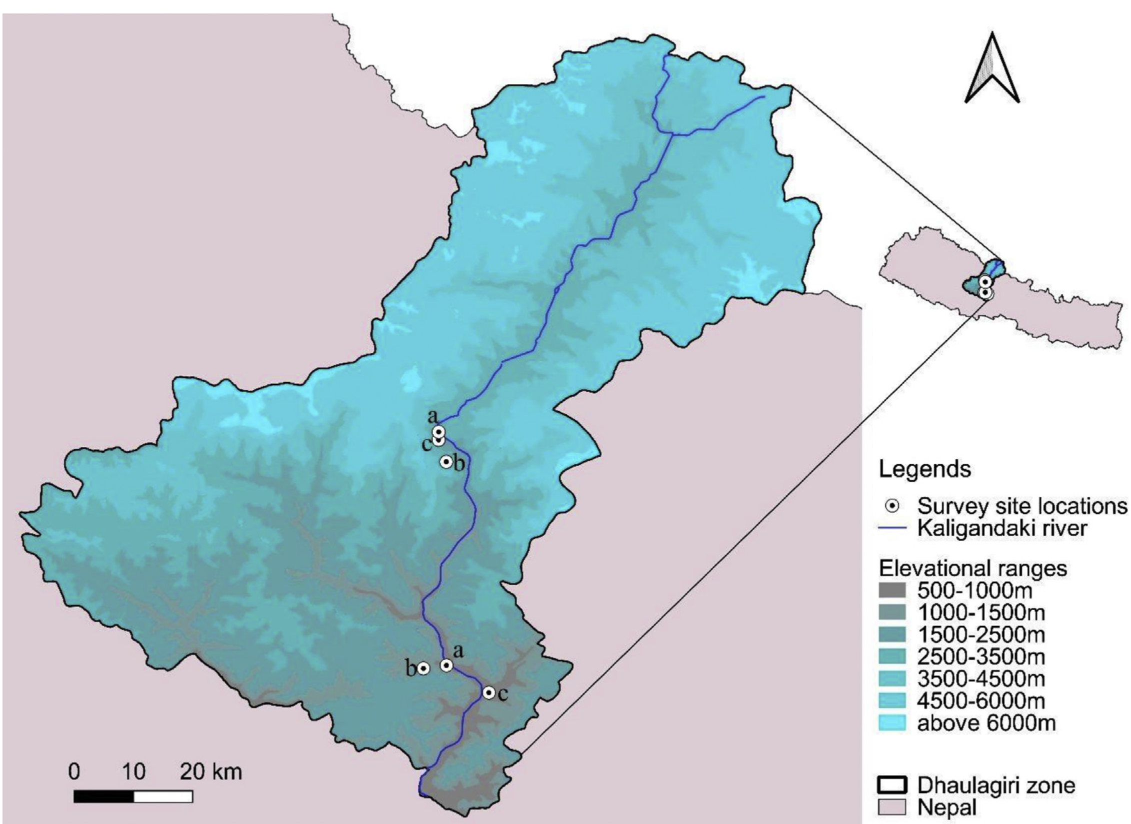

Figure 1. Map of study area showing elevational ranges and three surveyed habitat types (a = agriculture land, b = forest and c = human settlements) in the Kali Gandaki canyon, Nepal.

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Data analysis

The recorded echolocation call recordings were analyzed using Raven Pro software (Charif et al 2010) and identified by comparing with reference published echolocation parameters of South Asia's *Molossidae* species (Deshpande and Kelkar 2015).

Generally, bat activity is calculated by dividing the total number of bats passes by total time spent per night (Appel et al 2017); however, as we consider the number of passes of a single species with constant sampling time per night (3 hours) throughout the survey, in this paper, we use the total number of passes as a measure of *T. teniotis* activity. We defined bat passes as each recorded file (3–10 s) where two or more echolocation pulses were identified as *T. teniotis*. From each file, we selected 2 to 3 good quality representative echolocation signals randomly for measurement. The mean and standard deviation of echolocation parameters and activity were calculated and compared. The Shapiro-Wilk test was performed to check the normality of the data and Levene's test of homogeneity of variance to assess the equality of variances. A paired t test was calculated to compare mean *T. teniotis* activity between autumn and winter season at 2100–2500 m, and an independent t test was calculated to compare mean activity between 800–1200 m and 2100–2500 m during the winter season. All statistical analyses were performed using SPSS version 25 (International Business Machines 2017).

Results

We recorded 420 representative echolocation signals of *T. teniotis* that ranged from a start frequency of 16.2 ± 2.1 kHz to an end frequency of 10.9 ± 0.9 kHz, with a peak frequency of 13.0 ± 1.0 kHz (Table 1, Figure 2). The calls were of long duration (20.7 ± 4.1 ms) (Table 1, Figure 2).

A total of 199 *T. teniotis* passes were recorded during our study period, of which, the maximum number of passes were recorded in autumn season at an elevation of 2100–2500 m (52.76%) followed by winter season at 800–1200 m (25.63%), and minimum was recorded during winter season at 2100–2500 m (21.61%) while, no passes were recorded in the autumn season at 800–1200 m (Table 2, Figure 3). Elevationally ($n = 18$), the mean activity of *T. teniotis* was higher at 2100–2500 m (8.1 ± 3.90) than at 800–1200 m (2.7 ± 3.21), whereas seasonal ($n = 18$) activity remained fairly constant (autumn = 5.7 ± 6.3 and winter = 5.1 ± 2.1) (Table 2). The mean activity of *T. teniotis* was higher and nearly equal on both agricultural land (8.44 ± 3.42, $n = 9$) and human settlements (8.11 ± 3.93, $n = 9$), while little lower in the forest (5.56 ± 3.27, $n = 9$) (Table 2, Figure 4)

Paired t test showed significant difference on activity of *T. teniotis* between autumn and winter season at an elevation of 2100–2500 m ($t = 16.98$, $df = 8$, $p = 0.00$), while independent t test showed no significant difference between elevations of 800–1200 m and 2100–2500 m during the winter season ($t = 1.15$, $df = 8$, $p = 0.28$) (Table 3).

Discussion

This study presents the first record of *T. teniotis* from Nepal and provides evidence for differential elevational activity in two different seasons, which may be linked to seasonal migration. *T. teniotis* calls were of low frequency (audible to human ears) with shallow frequency modulation and relatively long duration. Compared to other Molossid species found in South Asia, the echolocation frequencies of *T. teniotis* are the lowest (peak frequency = 11–15 kHz) (Table 1). The call parameters measured from our recordings match with published echolocation calls of *T. teniotis* (Table 1). Like other free-tailed bat species, the low frequency, shallow frequency modulation, and high duration of *T. teniotis* suggest that it is also an open-air forager that feeds high above the ground or trees (Jung et al 2014; Rydell and Yalden 1997; Schnitzler and Kalko 2001; Voigt and Holderied 2012; Zbinden and Zingg 1986). This habitat use and the scarce surveys in Nepal may explain why *T. teniotis* has been overlooked in the Nepal Himalayas during previous trapping surveys of bats or mammal inventories.

Although no activity was recorded at 800–1200 m during autumn, the activity of *T. teniotis* was high during winter. Further, activity between autumn and winter season at 2100–2500 m also varied significantly. This hints at an elevational movement during two seasons and possible seasonal movement from higher to lower elevational regions in the Kali Gandaki canyon. Generally, *T. teniotis* is sedentary; however, occasionally, it exhibits seasonal movement e.g. in Malta (Benda and Piraccini 2016). Seasonal migration is common in some temperate bat species such as *Nyctalus noctula*, *Nyctalus leisleri*, and *Barbastella* sp., and mainly occurs to escape from seasonally harsh weather conditions and scarcity of food (Cryan 2003; Cryan et al 2004; Fleming and Eby 2003; Furmankiewicz and Kucharska 2009). The average temperature of the higher elevation region of our study site reaches a minimum of −2.5°C during the peak winter season (MoAD 2018); hence, elevational movement of *T. teniotis* also might have been driven by such extreme cold temperature. Despite their movements to the lower region in winter, the activity of *T. teniotis* between lower and

Table 1. Echolocation parameters of *T. teniotis* recorded in the Kali Gandaki canyon, Nepal, compared with several literatures and other *Molossidae* species from South Asia.

Species	Start frequency (kHz)	Peak frequency (kHz)	End frequency (kHz)	Duration (ms)	Sources
T. teniotis	16.2 ± 2.1	13.0 ± 1.0	10.9 ± 0.9	20.7 ± 4.1	This study, n = 420, bandwidth 5.0 ± 1.4 kHz
	23.8 ± 4.3	14.9 ± 0.73	12.7 ± 0.9	12.8 ± 2.3	(Chakravarty 2017), n = 34
	14.3 ± 4.0	12.8 ± 1.3	10.1 ± 1.3	19.5 ± 12.9	(Deshpande and Kelkar 2015), n = 67
	14.6 ± 5.0	11.8 ± 2.3	10.6 ± 1.5	15.0 ± 3.5	(Walters et al 2012)
	14.8 ± 1.8	11.4 ± 0.6	11.8 ± 0.1	23.2 ± 2.5	(Uhrin et al 2009)
	15.4 ± 3.3	13.2 ± 1.2	11.1 ± 1.3	18.4 ± 4.7	(Papadatou et al 2008)
	12.8 ± 0.4	11.2 ± 0.2	10.3 ± 0.1	13.9 ± 1.2	(Pandourski and Karaivanov 2007)
	16.5 ± 2.5	12.2 ± 1.4	10.2 ± 1.2	20.1 ± 2.3	(Benda et al 2006)
	15.3 ± 2.5	11.4 ± 0.8	8.0 ± 0.7	16.8 ± 2.4	(Obrist et al 2004)
	17.0 ± 4.6	13.0 ± 1.5	12.1 ± 1.2	16.6 ± 3.5	(Russo and Jones 2002)
T. aegyptiaca	24.4 ± 4.7	19.4 ± 2.3	16.7 ± 2.7	15.5 ± 4.9	(Deshpande and Kelkar 2015), n = 120
	27.1 ± 0.4	20.9 ± 0.5	18.8 ± 0.4	12.1 ± 1.0	(Fenton et al 2004)
C. plicatus	35.9 ± 6.4	23.7 ± 3.1	19.8 ± 2.9	12.3 ± 4.0	(Deshpande and Kelkar 2015), n = 54
	36.8 ± 8.1	27.4 ± 5.7	26 ± 6.8	7.2 ± 2.1	(Utthammachai 2009)
O. wroughtoni	24.9 ± 2.3	16.2 ± 0.9	13.0 ± 0.9	11.9 ± 4.3	(Deshpande and Kelkar 2015), n = 310

Mean ± standard deviation values of each echolocation parameter are provided,^{n} represents the sample size.

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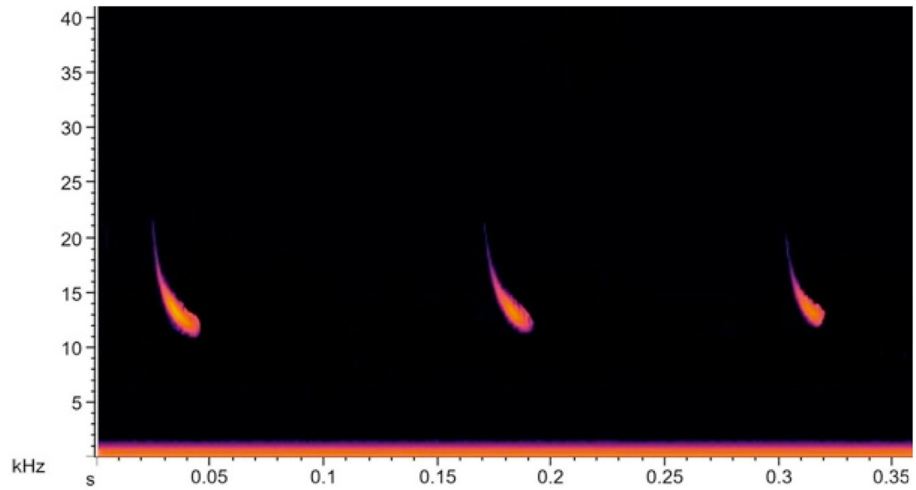

Figure 2. Representative spectrograms of *T. teniotis* recorded in the Kali Gandaki canyon, Nepal.

Table 2. Descriptive summary of seasonal, elevational, and habitat-wise activity of *T. teniotis* in Kali Gandaki canyon, Nepal.

Seasons/Elevational ranges	*T. teniotis* activity		Total activity
	Autumn	Winter	
800–1200 m	0	51	51: 2.7 ± 3.21, n = 18
2100–2500 m	105	43	148: 8.1 ± 3.9, n = 18
Total activity	105: 5.7 ± 6.3, n = 18	94: 5.1 ± 2.1, n = 18	199
Habitat types			Total activity
Forest			5.56 ± 3.27, n = 9
Agriculture land			8.44 ± 3.42, n = 9
Human settlement			8.11 ± 3.93, n = 9

^{0}represents no activity, mean ± standard deviation values of *T. teniotis* activity are provided, and ^{n} represents the sample size.

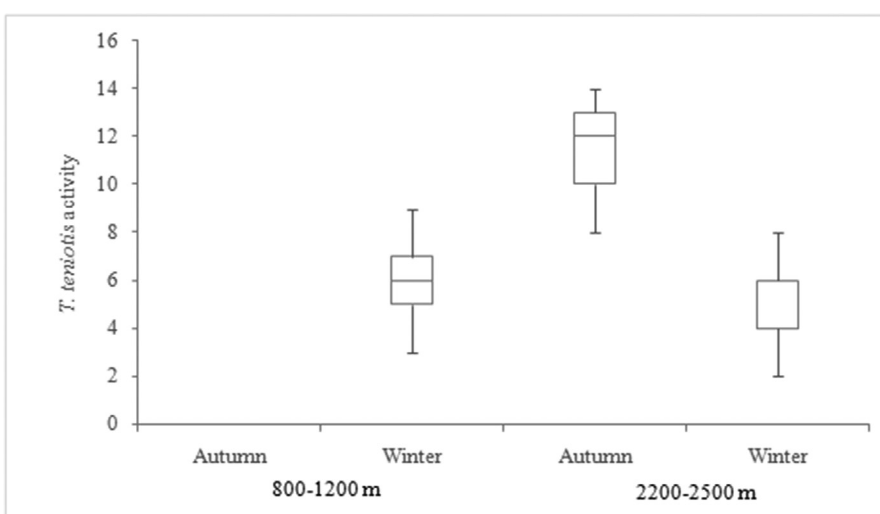

Figure 3. Box-plot comparison of *T. teniotis* activity in two different elevational ranges during autumn and winter season in the Kali Gandaki canyon, Nepal. No plot in autumn at 800–1200 m indicates absence of *T. teniotis*. Cap of lower whisker indicates the minimum number of passes and upper whisker the maximum passes. Likewise, the horizontal line separating the rectangle is the median value; upper and lower lines parallel to the median are 3rd and 1st quartile values, respectively, except at 2200–2500 m in winter where the value of median and 1st quartile is equivalent. The rectangular box denotes the interquartile range.

higher elevational regions did not vary significantly. This indicates some proportion of the population only exhibited elevational movement while the rest preferred to stay. A similar pattern has been previously recorded in closely related *T. brasiliensis*, where males and females of different ages do not migrate (Geluso 2008). As in most temperate bat species, migration is sexually driven (Altringham 2011; Fleming and Eby 2003; McGuire and Boyle 2013; Moussy et al 2012); perhaps only mature females of *T. teniotis* moved to the lower regions during winter while males and juvenile females remained at the higher elevation which resulted in a non-significant difference in activity between lower and higher regions (McGuire and Boyle 2013). Migration of females to the lower

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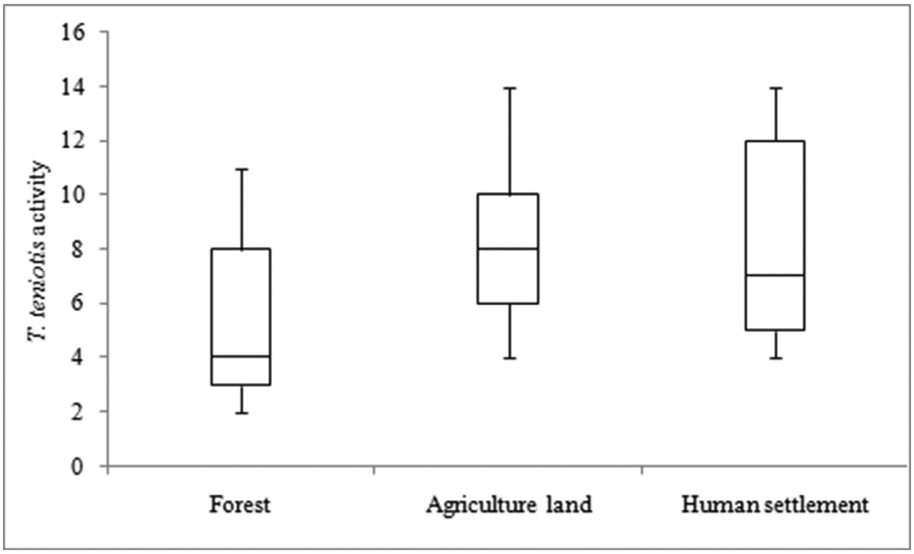

Figure 4. Box-plot comparison of *T. teniotis* activity in three different habitat types in the Kali Gandaki canyon, Nepal. The end of lower whisker indicates the minimum number of passes and upper whisker the maximum passes. Likewise, the horizontal line separating a rectangle is the median value; upper and lower lines parallel to the median line are 3rd and 1st quartile values respectively. Therefore, the entire box represents the interquartile range.

Table 3. Summary of statistical tests.

Tests	Shapiro-Wilk test values	Tests values
Paired t test: *T. teniotis* activity between seasons at 2100–2500 m	Autumn: 11.67 ± 2.07, n = 9, s = 0.93, df = 9, ***p* = 0.45** Winter: 4.77 ± 1.92, n = 9, s = 0.96, df = 9, ***p* = 0.76**	t = 16.98, df = 8, ***p* = 0.00**
Independent t test: *T. teniotis* activity between altitude in winter season	800–1200 m: 5.67 ± 2.01, n = 9, s = 0.95, df = 9, ***p* = 0.71** 2100–2500 m: 4.77 ± 1.92, n = 9, s = 0.96, df = 9, ***p* = 0.76**	t = 1.15, df = 8, *p* = 0.28

Mean ± standard deviation values of *T.teniotis* activity are provided, ^{n} represents the sample size, ^{s}as calculated Shapiro-Wilk value, ^{df} as degree of freedom, ^{p} as significant value, ^{t} as calculated t test value. Normally distributed and statistically significant values are in bold.

elevation could be due to rich resources that might meet their high energy demands during embryonic development, pregnancy, and lactation or for finding suitable nursery roosts during winter (McGuire and Boyle 2013).

The overall activity of *T. teniotis* was higher at 2100–2500 m than at 800–1200 m. The activity at 800–1200 m was only during the winter season and possibly due to migratory female populations. The high activity at 2100–2500 m could be due to both migratory and resident population during autumn and only resident population during the winter season. Many temperate insectivorous bat species gather to mate before the start of the winter (a phenomenon known as “swarming”), and this could have resulted in high activity during autumn (Angell et al 2013; McGuire and Boyle 2013; Paul et al 2000; Rivers et al 2006; Senior et al 2005). Although overall activity varied elevationally, the difference was negligible across seasons, as the low activity at 2100–2500 m during winter was balanced by the activity of probable migratory populations at 800–1200 m.

The overall activity of *T. teniotis* was found to be negligibly lower in forest than in agricultural land and human settlements. Usually, *T. teniotis* is a generalist in using foraging habitats and feeds across a large variety of habitat types (Russo and Jones 2003). It is also an aerial hawking species which flies above the tree canopy (Marques et al 2004; Voigt and Holderied 2012) and may exploit all kinds of habitats.

This study was only limited to acoustic identification, but it demonstrates the effectiveness of acoustics in collecting occurrence and ecological data on aerial hawking species of bats without the use of invasive methods. In considering several benefits of invasive methods, it could also be an effective tool to review taxonomic status of enigmatic species like *T. teniotis* that has always been unclear due to its superiority over *T. insignis* Blyth, 1862; *T. latouchei* Thomas, 1920; and *T. coecata* Thomas, 1922, which were formerly considered to be its subspecies (Wang 2003). However, recent studies recognized *T. insignis* and *T. latouchei* as a full species, while *T. coecata* was only considered as a synonym of *T. insignis* (Kock 1999; Simmons 2005; Smith et al 2008). *T. insignis* is distributed from central and south-eastern China, Japan, Taiwan, and the Korean Peninsula, whereas *T. latouchei* from the north-east of China, Japan, Lao People’s Democratic Republic, Thailand, and Viet Nam (Fukui and Sano 2019; Thong and Loi 2020). Although these subspecies were given full consideration to species level, the taxonomic status of *T. teniotis* from Indian Subcontinent is still controversial although it has been recorded from numerous places in the Himalayan landscape.

Conclusions

This paper presents the first record of *T. teniotis* from Nepal and the first evidence of differential seasonal activity at different elevations from the Himalayan landscape of South Asian countries. Our results indicate that *T. teniotis* may undertake seasonal migration in this landscape and in the entire Himalayas. We hypothesize that these elevational movements may be driven by cold temperature and low food availability, resource limitation, or suitability of nursery roosts for gestating females during the winter season. Hence, we recommend multi-season surveys to understand their seasonal demographics and spatial-temporal movement in the Kali Gandaki canyon. As the study was conducted only in the Kali Gandaki canyon, other regions of the Himalayan landscape, especially 800–2500 m, are high potential sites for the occurrence of this species. We recommend using acoustic monitoring, which

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has already been proven suitable to study these species to locate new distribution locations and understand their habitat use and seasonal migration in the Himalaya.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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