

## ORIGINAL ARTICLE

# A Preliminary Assessment of the Caves and Bats in Kaligandaki Canyon, Western, Nepal

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## INTRODUCTION

Caves are large natural holes in rock faces, hillsides or underground voids (Culver & Pipan 2009). They provide habitat for a large variety of highly-specialized invertebrates as well as a number of vertebrates, including bats (Kunz 1982). Caves are characterized by the absence of light, nearly stable year-round temperatures and high relative humidity which provides favourable habitat conditions for a diverse array of fauna (Schilthuizen et al. 2005).

Natural caves and other man-made underground sites, such as tunnels and mines, are key roost sites essential for the survival of a large variety of bats (Mickleburgh et al. 2002, Furey & Racey 2016). The presence of bats inside a cave depends on the cave's physical and microclimatic conditions and colony size can vary from a few individuals to millions (Kłys & Wołoszyn 2010, Furey & Racey 2016). A large colony of bats can also remarkably alter the cave ecosystem by modifying microclimatic conditions and providing guano; an essential food source for many invertebrates and energy supply in resource-scarce cave environments (Romero 2009, Ladle et al. 2012). Caves provide bats with shelter, as protection from adverse weather conditions as well as from

### ABSTRACT

By virtue of geology, Nepal harbours hundreds of caves and provides potential habitat for a large variety of bats. However, limited studies have focused on cave dwelling bat species in Nepal. Our study along the Kaligandaki canyon - the deepest gorge in the world - aimed to explore its caves, examine cave inhabiting bat species, and to identify any major prevailing threats to the cave fauna. Roost count surveys, evening emergence counts, harp trap and mist nets were used to assess bats using caves. Out of 20 caves, bat populations were recorded in 13, with guano evident in two additional caves. This included records of a total of 12 species across all studied caves. Cave tourism was observed to be a major threat to bats and the cave environment. Therefore, we recommend the regulation of cave tourism and a halt to tourism-related development in and around these caves.

predators, and an important site for hibernation, mating, breeding and pup rearing (Ortega & Maldonado 2006, Furey & Racey 2016). Overall, cave dwelling bats spend over half of their lives inside the caves (Kunz & Fenton 2003). Considering their significance for bats and their relative scarcity in the landscape, it is critical to understand the bat species composition, population dynamics and possible threats for individual caves to develop an appropriate bat and cave friendly conservation plan (Graham 1988).

Of the 26 mammalian orders, "Chiroptera" consists of over 1400 species of bats worldwide (Simmons & Cirranello 2020), of which 142 species are known from South Asia (Srinivasulu et al. 2020). The latest checklists include 53 species of bats from highly diversified landscapes of Nepal (Acharya et al. 2010, Thapa 2010). However, due to lack of specific information on the only record of *Sphaeris blanfordi* Thomas, 1891, the erroneous location of *Myotis siligorensis* Horsfield, 1855 and a lack of taxonomic details on *Rhinolophus subbadius* Blyth, 1844, the occurrence of these three species are debated (Csorba et al. 2003, Pearch 2011, Thapa 2014). Further, *Scotozous dormeri* Dobson, 1875 and *Tylonycteris fulvida* Peters, 1872 were recorded for the first time in Nepal (Thapa et al. 2012, Sharma

et al. 2019). A recent revision of specimens of *Philetor brachyopterus* Temminck, 1840 from Nepal has reassigned these specimens to *Hypsugo joffrei* Thomas, 1915 (Saikia et al. 2017) but it was again revised to poorly known species *Mirostrellus joffrei* Thomas, 1915 (Görföl et al. 2020). All these findings add up a total of 52 confirmed bat species occurring in Nepal. Additionally, Thapa (2018) mentioned the first record of *Myotis frater* Allen, 1923, *Nyctalus aviator* Thomas, 1911 and *Cynopterus brachyotis* Muller, 1838 from Nepal however, due to the unpublished nature of the report, these species are not currently included in the Nepalese bat checklist. Of these 52 species, two species are categorized as critically endangered, one as endangered, two as vulnerable, four as near threatened, 24 as least concern and 17 as data deficient in the National Red List (Jnawali et al. 2011) excluding *S. dormeri* and *T. fulvida* which needs further assessments. Nepal also holds record of only endemic species *Myotis csorbai* Topal, 1997 and *Myotis sicarius* Thomas, 1915, which is endemic to South Asia (Molur & Srinivasulu 2008, Srinivasulu et al. 2010, Jnawali et al. 2011, Csorba & Thapa 2016).

Due to several geological processes; mainly deformation of naturally rich limestone, a major component of the caves (Culver & Pipan 2009, Toomey 2009, Furey & Racey 2016), in the Himalaya (Dhital 2015), Nepal harbors hundreds of caves and possibly provides suitable habitat for a large variety of bats; however, only a few studies were conducted on cave dwelling bats of the country. Several caves in Kathmandu valley (Chobhar cave, Godawari cave and Nagarjun cave), eastern Nepal (Haleshi cave, Basaha cave, Bhairav cave, Paame cave and Dungdela cave) (Thapa 2012, 2018), Pokhara valley (Bat cave, Mahendra cave, Gupteshore cave, Sita cave, Birendra cave, Putali cave, Crazy cave, Peace cave and Buddha cave), Sangya (Kailash cave) and Tanahu (Siddha cave) (Bates & Harrison 1997, Csorba et al. 1999, Acharya 2006, Adhikari 2008) were previously studied but most caves in other parts of the country, especially in the western regions of Nepal, are yet to be explored biospeliologically. These previous studies provided partial baseline distribution data on several of Nepal's cave dwelling bat species, e.g. *Hipposideros armiger* Hodgson, 1835, *Hipposideros cineraceus* Blyth, 1853, *Hipposideros pomona* Andersen, 1918, *Rhinolophus affinis* Horsfield, 1823, *Rhinolophus pearsonii* Horsfield, 1851, *Rhinolophus sinicus* Anderson, 1905, *Rhinolophus ferrumequinum* Schreber, 1774, *Rhinolophus macrotis* Blyth, 1844, *Rhinolophus pusillus* Temminck, 1834, *Miniopterus fuliginosus* Hodgson, 1835, *M. csorbai* Topal, 1997, *Lyroderma lyra* Geoffroy, 1810, *Rousettus leschenaultii* Desmarest, 1820 and *Eonycteris spelaea* Dobson, 1871 (Sharma et al. 2018a), however the country still lacks a complete checklist of caves and their relative bat species composition. Although a few conservation attempts have been made for the tree roosting bat, *Pteropus giganteus* Brunnich, 1782 (Acharya 2015, Neupane et al. 2016, Manandhar et al. 2018, Sharma et al. 2018b, Katuwal et al. 2019), only a handful of information is available on cave bat species and they are omitted from conservation efforts.

Not much is known for the bats and caves of the Kaligandaki canyon except for occasional reports from Hodgson (1835), Suwal & Verheugt (1995), Bates & Harrison (1997), Shrestha (1997) and Csorba et al. (1999). Even though

these studies documented the presence of a few bat species e.g. *H. armiger*, *R. affinis*, *R. leschenaultii*, *P. giganteus*, and *Plecotus* sp. E. Geoffroy, 1818 from the Kaligandaki canyon, there is little documentation of cave specific studies. This paper presents the first targeted assessment of the status of caves and their bat species composition in the Kaligandaki landscape.

## MATERIALS AND METHODS

### Study area

The Kaligandaki canyon (28°42'24"N, 83°38'43"E) separates the major peaks of Dhaulagiri on the West and Annapurna on the East of Himalayan range (Carosi et al. 2014). These two peaks are above 8000 m in elevation and standing in the opposite direction creates the deepest gorge in the world (Carosi et al. 2014). The Kaligandaki river (nearly 630 km in length) flows north to south through districts from upper Mustang to Myagdi, Baglung, and Parbat (Fig. 1) and terminates in Devghat, Chitwan district forming the Narayani river. The study was conducted along the Kaligandaki river elevating from 800-2800 m a.s.l. and covering approximately 90 km distance from Kushma, Parbat district (28° 14' 0"N, 83° 41'0"E) to Jomsom, Mustang district (28°47'0"N, 83°43'50"E). The upper region (2100 m and above) of the study site i.e. Ghasa to Jomsom lies within the Annapurna Conservation Area (ACA) in Mustang district whereas the lower region (2100 m and below) i.e. Ghasa to Kushma lie within Myagdi, Baglung and Parbat districts of Western Nepal (Fig. 1). The climate of the upper region is temperate and sub-alpine; desiccated by strong winds and high solar radiation, the maximum temperature reaches up to 23°C in June and a minimum of -2.5°C in January (MOAD 2018). The climate of the lower region is sub-tropical and temperate; the maximum temperature reaches up to 30°C in July and a minimum of 8°C in January (MOAD 2018). Vegetation is dominated by *Pinus wallichiana*, *Thuja* sp., and *Juglans regia* in the higher elevations while, in the lower areas, it is dominated by *Dalbergia sissoo*, *Diploknema butyraceae*, *Pinus roxburgii*, *Toona ciliata*, *Alnus nepalensis*, *Shorea robusta*, *Ficus bengalensis*, *Ficus cunia* and *Dendrocalamus* sp.

### Preliminary field visits

Preliminary field visits were made from September to October of 2017 at seven survey stations i.e. Kushma, Baglung, Galeshore, Tatopani, Ghasa, Khobang and Jomsom, separated by an approximate distance of 13 to 15 km. Two to three days were spent on each station, consulting with local people to identify potential cave roosts. Accessible caves were checked for direct evidence of bat presence (sightings, guano) whereas inaccessible caves were monitored via evening emergence counts. The geographical location of each cave was marked using Garmin E-Trex 10 GPS and plotted using QGIS 3.12.2 (QGIS Development Team 2020). Cave length was measured using 30m length measuring tape and for partially accessible caves, length was measured only to the access point for humans. Due to a lack of equipment for measuring height, the ocular method was used to estimate the maximum ceiling height of the caves.

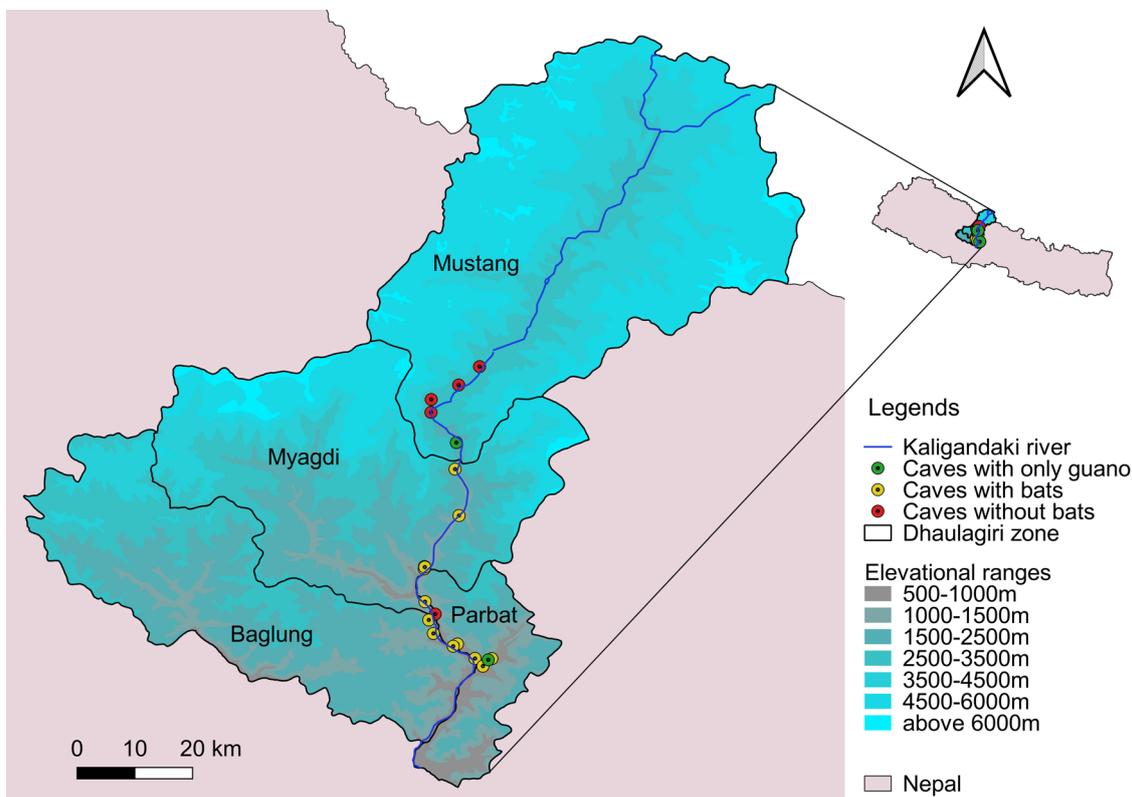


Fig. 1 - Distribution map of the caves of Kaligandaki canyon.

### Roost count survey

A roost count survey was conducted in all accessible caves. Colony size was estimated using a tally counter through the direct count method in small colonies whilst the photography counting method was employed to estimate colony size for dense colonies of bats (Kunz et al. 1996). Photographs of roosting chambers were taken using Canon EOS 750D with Tamron 18-400 mm zoom lens covering the whole area. The close up photographs of bats were also taken to identify the species.

### Evening emergence count

Evening emergence counts were conducted in both partially accessible and inaccessible bat roosting caves 30 minutes after the sunset during emergence time (6:20 PM) and ended after bat emergence ceased. The total number of bats exiting and re-entering the cave was counted using tally counters and the actual count was determined by subtracting re-entering bats over exiting (Kunz et al. 1996).

### Trapping surveys

Bat trapping surveys were conducted in October 2017 and April 2018. Trapping surveys were only conducted at eight caves during October 2017. Of these, capture effort was consistent across five of these caves; Alpeshore, Gupteshore, Laleshore, Parbati and Pauwa cave (Table 1), which were surveyed twice (again in April 2018) to record any change in bats diversity whereas, remaining three were only surveyed in October 2017. In both survey periods, a four bank of harp trap and two mist nets (height 2.6 m, length 4 m and 6 m, and 38 mm mesh) were used to capture the bats in front of the cave entrances. Depending on the

cave entrance, different traps were deployed. The harp trap was set on predominantly flat surfaces at the cave entrance whilst mist nets were set on uneven surfaces at about 0.5 m above the ground level. Both the harp trap and mist nets were left open for three hours between 6:00 PM to 9:00 PM. During peak emergence time, bats were released as soon as possible otherwise, checked in every 10 minutes to minimise distress.

The morphometric measurements of captured bats were taken using a dial caliper (0.01 mm accuracy) following Bates & Harrison (1997) and Acharya et al. (2010). The measurements included head and body length (HB), forearm length (FA), ear length (EL), hindfoot length (HF), tibia length (TIB), tail length (TL), etc. The key distinguishing feature of each species was noted. The body weight was measured using Pesola spring balance (0.1 gm accuracy). Bats were released after being photographed for reference. No voucher specimens were collected during this study. Bats species were identified by comparing close up photographs and morphometric measurements with reference literature (Bates & Harrison 1997, Acharya et al. 2010, Srinivasulu et al. 2010).

### Threats documentation

Threats to the caves were identified through direct observation during the cave visits. Anthropogenic activities in and around the caves such as, religious and construction activities, infrastructures development, pollution, etc. were noted.

### Data analysis

The captured effort was calculated by multiplying total

**Table 1** - Capture effort applied in eight caves of the Kaligandaki canyon. Night survey represents October 2017 (and April 2018).

Caves	Number mist net used	Number harp trap used	Trapping hour	Night survey	Capture effort (m <sup>2</sup> nh)
Lalleshore	2	1	3	1(1)	181.92
Gupteshore	2	1	3	1(1)	181.92
Alpeshore	2	1	3	1(1)	181.92
Parbati	2	1	3	1(1)	181.92
Pauwa	2	1	3	1(1)	181.92
Army Barek	2	0	3	1	78
Tara	2	0	3	1	78
Siddha	0	1	3	1	12.96

netted area (m<sup>2</sup>) by total netted hour (nh). Range, mean and standard deviation values of each morphometric measurements were calculated. Shannon-Weaver diversity index,  $H' = -\sum_{i=1}^k \left[ \frac{p_i}{N} \log \left( \frac{p_i}{N} \right) \right]$ , where,  $H'$  = the diversity index,  $p_i$  = the relative abundance (S/N), S=the number of individuals for each species, and N=total number of individuals (Shannon & Weaver 1949), was used to compare the diversity between the caves. To understand the relationship between bat species richness and cave's physical factors (number of entrances, length of the cave, number of chambers, and maximum ceiling height and elevation), a Pearson correlation coefficient was calculated. No microclimatic variables were considered.

## RESULTS

In total, 20 caves were identified of which Gupteshore cave of Parbat district is located in the lowest elevation (810 m) while the Mamti cave of Mustang district is at the highest elevation (2681 m; Table 2). Bat populations were recorded in 13 caves from sightings, and guano was detected in two additional caves whilst no evidence of bats was found in the remaining five caves (Table 2). Most of the caves with bat records (8/13) contained a single bat species with colony size <200, and were located at an elevational range of 831–2016 m (Table 2). Five caves contained multiple bat species with colony sizes >200, and were located from 810–1267 m (Table 2). Caves with no bat sighting were present from 814–2681 m elevational range (Table 2). Bats inhabiting caves were found to occur mostly in forest habitat (5/13) followed by agro-forest land (4/13) and pasture (2/13) whereas, only one such cave was found in agriculture and one in an urbanized area (Table 2). Most of the bat caves were partially accessible (6/13), followed by accessible (4/13), whereas three caves were found to be inaccessible (Table 2). The highest numbers of entrances were found in Parbati cave (four entrances) which was the most species-rich cave (seven species), followed by Alpeshore (six species) which was also the longest (750 m), most chambered (ten) and tallest (50 m) cave (Table 2) and reported the largest number of bats (3012 individuals), followed by Gupteshore cave (1560; Table 2). Water sources were present in only four caves of which Gupteshore and Alpeshore had permanent water flow throughout the year, Lalleshore and

Parbati had seasonal water flow (only in rainy season) whilst the remaining caves were devoid of water sources (Table 2).

During our repeat survey periods of 5 major cave systems, a total of 259 individuals of bats comprising 5 families, 7 genera and 12 species were captured (Table 3). Most species of bats were recorded from Family *Rhinolophidae* (4), followed by *Hipposideridae* (3) (Table 3, Fig. 2). The morphometric measurements and key feature of captured bats are provided in Table 4. *H. armiger* was the most captured bat (34.4%), which was also recorded in 9/13 of the bat inhabited caves, followed by *R. affinis* (18.53%), which was found in 5/13 of the bat inhabited caves (Table 3 & 4, Fig. 3). *H. pomona*, *R. luctus* and *R. macrotis* were only captured once (Table 3, Fig. 3). The majority of the species were insectivorous except for two fruit bats; *R. leschenaultii*, which was recorded in Alpeshore and Tara cave, and *C. sphinx*, which was recorded only in Parbati cave (Table 4, Fig. 3). *H. pomona*, *L. lyra*, and *R. macrotis* were restricted to only one cave, *H. cineraceus*, *R. luctus* and *R. pusillus* to two caves whereas *M. fuliginosus* to three caves (Table 4, Fig. 3). An unidentified cave *Myotis* sp. (FA=35.5 mm, TIB=15 mm, HF=6.5, TL=33.3 mm, HB=44.2 mm, and BW=4 gm) was recorded in Alpeshore and Parbati cave during both survey periods (Table 3 & 4, Fig. 3).

During the roost count survey in multi-species caves, *H. armiger*, *R. leschenaultii* and *C. sphinx* were observed to roost nearby the entrances (10–50 m away from the entrance point) and on high ceilings (10–30 m above from the cave surface). Other species, e.g. *H. cineraceus*, *R. affinis*, *R. pusillus* and *Myotis* sp., were observed to occupy the cave spaces distant from the entrances (70–300 m away from the entrance point), narrow tunnels and relatively low chambers (4–6 m above from the cave surface), although the height of which were inaccessible to humans. Colonies of *H. armiger* and *H. cineraceus* were scattered creating space between each individual whilst *R. affinis* and *R. pusillus* were observed as either solitary or forming several small clusters (5–15 individuals). Colonies of *R. leschenaultii* were dense and noisy whilst *C. sphinx* was silent and observed as either solitary or forming several small clusters (2–15 individuals). Although *M. fuliginosus* was third most captured bat (Table 3), their colonies were not recorded during the roost count surveys. The *Myotis* sp. was observed roosting solitary.

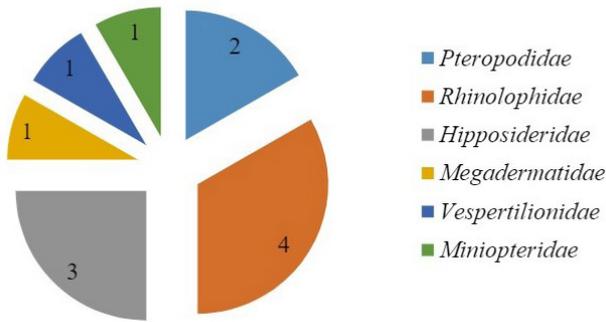
**Table 2** - Caves found along the Kaligandaki canyon from Kushma to Jomsom. For partially accessible caves, cave length is provided to the access point from their entrance. Colony size represents roost counts (and evening emergence count). Other cave feature information includes number of cave chambers, estimated height of the tallest point of the cave ceiling, and associated cave habitat. "na" means not available' information.

Caves name & district	GPS locations	Elevation (a.s.l) (m)	Cave length (m)	No. of entrances	Colony size	Species richness	Human accessibility	Other cave features
Laleshore cave 1, Chuwa-Parbat district	83.704N, 28.227E	824	90	2	224 (300)	2	Incomplete	Two chambered, ceiling ca. 20m tall, located at agro farms, water flow during rainy season
Laleshore cave 2, Chuwa-Parbat district	83.698N, 28.225E	814	90	1	na	Guano only	Incomplete	Single chambered, ceiling ca. 5m tall, located at roadside
Gupteshore cave, Kushma-Parbat district	83.674N, 28.227E	810	150	2	343 (1560)	5	Incomplete	Five chambered, ceiling ca. 40m, located at steep pastures, water flow throughout the year
Milanchowk cave, Milanchowk-Parbat district	83.586N, 28.328E	831	16	1	13	1	Complete	Single chambered, ceiling ca. 4m tall, located at urban area
Alpeshore cave, Kushma-Parbat district	83.688N, 28.214E	818	750	2	551 (3012)	6	Incomplete	Ten chambered, ceiling ca. 50m tall, located at agro-forest land, water flow throughout the year
Parbati cave, Pang-Parbat district	83.643N, 28.253E	846	210	4	87 (1210)	7	Incomplete	Single chambered, ceiling ca. 35m tall, located at pastureland, water flow during rainy season
Pipale odar, Pang-Parbat District	83.636N, 28.249E	826	22	1	3 (9)	1	Incomplete	Single chambered, ceiling ca. 8m tall, located at forest habitat
Chamere kuna, Lasti – Parbat district	83.604N, 28.306E	897	12	2	na	na	Complete	Single chambered, ceiling ca. 12m tall, located at forest habitat
Army barek cave, Baglung district	83.601N, 28.271E	846	na	1	116	1	Inaccessible	Inaccessible due to tough terrain, located in forest habitat
Aadheri cave, Kudule- Baglung district	83.593N, 28.295E	855	23	2	3 (18)	1	Incomplete	Single chambered, ceiling ca. 5m tall, located at forest habitat
Pauwa cave, Ranipauwa-Myagdi district	83.586N, 28.390E	1267	na	2	256	3	Inaccessible	Inaccessible due to small entrance opening, located at agro-forest land
Malluwa odar, Chamere-Myagdi district	83.586N, 28.389E	1211	18	2	88	1	Complete	Single chambered, ceiling ca. 12m tall, located at forest habitat
Tara cave, Ranipauwa-Myagdi district	83.585N, 28.386E	1189	46	2	80	1	Complete	Single chambered, ceiling ca. 25m tall, located at forest habitat

<b>Siddha cave</b> , Pokhara Bazar, Myagdi district	83.646N, 28.480E	1273	na	1	8	1	Inaccessible	Inaccessible due to small entrance opening, located at agro-forest land
<b>Kopchepani cave</b> – Myagdi district	83.640N, 28.563E	2016	15	1	9	1	Complete	Single chambered, ceiling ca. 8m tall, located at agro-forest land
<b>Ghasha odar</b> , Ghasha-Mustang district	83.642N, 28.610E	2125	16	2	na	na	Complete	Single chambered, ceiling ca. 3m tall, located at forest habitat
<b>Kokethani cave</b> –Kokethani-Mustang district	83.598N, 28.664E	2561	na	1	na	na	Inaccessible	Inaccessible due to tough terrain, located at forest habitat
<b>Boksikhola cave</b> , Mustang district	83.597N, 28.686E	2577	6	1	na	na	Complete	Single chambered, located at forest habitat
<b>Tukuche cave</b> , Tukuche-Mustang district	83.646N, 28.712E	2589	20	1	na	na	Complete	Single chambered, located at urbanized area
<b>Mamti cave</b> , Marpha-Mustang district	83.682N, 28.745E	2681	4	1	na	na	Complete	Single chambered, located at urbanized area

**Table 3** - Comparison of species abundances and Shannon diversity index in five cave system of the Kaligandaki canyon, numbers of individuals captured represents October 2017 (and April 2018), “na” means not available information or no capture in a particular cave.

Species/Caves	Gupteshore	Alpeshore	Parbati	Laleshore	Pauwa	Total	Relative abundance (%)
<i>R. leschenaultii</i>	na	6 (8)	na	na	na	14	5.4
<i>C. sphinx</i>	na	na	8 (3)	na	na	11	4.2
<i>H. armiger</i>	16 (12)	4 (3)	15 (14)	12 (13)	na	89	34.4
<i>H. cineraceus</i>	8 (5)	na	na	na	3 (6)	22	8.5
<i>H. pomona</i>	na	na	na	na	1 (0)	1	0.4
<i>L. lyra</i>	na	na	na	na	5 (8)	13	5.0
<i>M. fuliginosus</i>	6 (4)	4 (5)	6 (7)	na	na	32	12.4
<i>Myotis</i> sp.	na	3 (1)	2 (1)	na	na	7	2.7
<i>R. affinis</i>	10 (7)	5 (7)	8 (9)	4 (8)	na	58	22.4
<i>R. luctus</i>	na	na	1 (0)	na	na	1	0.4
<i>R. macrotis</i>	na	1 (0)	na	na	na	1	0.4
<i>R. pusillus</i>	3 (6)	na	1 (0)	na	na	10	3.8
<b>Total</b>	<b>43 (34)</b>	<b>23 (24)</b>	<b>41 (34)</b>	<b>16 (21)</b>	<b>9 (14)</b>	<b>259</b>	<b>100</b>
<b>Diversity (H')</b>	<b>1.48 (1.53)</b>	<b>1.69 (1.44)</b>	<b>1.61 (1.36)</b>	<b>0.56 (0.66)</b>	<b>0.93 (0.98)</b>		
<b>Average diversity</b>	<b>1.50</b>	<b>1.56</b>	<b>1.48</b>	<b>0.61</b>	<b>0.80</b>		



**Fig. 2** - Composition of cave bat species richness in respective families in the Kaligandaki canyon recorded during October 2017 to April 2018.



**Fig. 4** - Threats observed in caves of the Kaligandaki canyon during cave visit on October 2017, installed electrical system (red circle), cemented roadway (red arrow) and constructed temple (yellow arrow) inside Gupteshore cave.



**Fig. 3** - Bats of the Kaligandaki canyon, family Hipposideridae: 1. *H. armiger*, 2. *H. Pomona*, and 3. *H. cineraceus*, family Rhinolophidae: 4. *R. luctus*, 5. *R. macrotis*, 6. *R. pusillus*, and 7. *R. affinis*, family Pteropodidae: 8. *C. sphinx* and 9. *R. leschenaultii*, family Megadermatidae: 10. *L. lyra*, family Miniopteridae: 11. *M. fuliginosus*, and family Vespertilionidae: 12. *Myotis* sp., 13. *N. noctula*, 14. *T. fulvida*, and 15. *Pipistrellus* sp.

**Table 4** - Bat species recorded on the caves of Kaligandaki canyon with their general morphometric measurements; value of body weights (BW), head-body (HB) and forearm length (FA). N represents number of individuals of each species measured, "r" as range value, "m" as average value and "sd" as standard deviation value of each measurement. Remarks include the key taxonomic feature of the species.

Bat species	Family	Roost caves identified by trapping and roost survey	N	Morphometric measurements			Remarks
				BW (gm) r:m:sd	HB (mm) r:m:sd	FA (mm) r:m:sd	
<i>R. leschenaultii</i>	<i>Pteropodidae</i>	Alpeshore, Tara	5	14:56:3.5	14.1:122.5:3.5	5.9:77.3:1.5	Absence of claw on 2 <sup>nd</sup> digit
<i>C. sphinx</i>	<i>Pteropodidae</i>	Parbati	9	10:49:2.5	8.8:96.1:2.2	13:69.4:3.3	Presence of ear margin on both sides
<i>H. armiger</i>	<i>Hipposideridae</i>	Lalashore, Gupteshore, Alpeshore, Parbati, Milanchowk, Army barek, Maluwa, Siddha, Kopchepaani	5	11:54:2.3	8.2:94.6:2.1	7.3:90.4:1.8	Presence of 4 supplementary nose-leaflets.
<i>H. cineraceus</i>	<i>Hipposideridae</i>	Gupteshore, Pauwa	5	0:4:0	3.8:36.8:0.9	4.6:35.4:1.2	Size of noseleaf <5mm
<i>H. pomona</i>	<i>Hipposideridae</i>	Pauwa	1	0:8:0	0:48.2:0	0:38.6:0	Size of noseleaf >5mm
<i>L. lyra</i>	<i>Megadermatidae</i>	Pauwa	4	5:43:1.3	8.9:73.3:2.2	15.6:59.5:3.9	Noseleaf tall, >10mm
<i>M. fuliginosus</i>	<i>Miniopteridae</i>	Gupteshore, Alpeshore, Parbati	5	3:20:0.8	5.1:54.2:1.3	6.6:46.5:1.7	2 <sup>nd</sup> phalanx of 3 <sup>rd</sup> finger is 3 times longer than 1 <sup>st</sup> finger
<i>Myotis</i> sp.	<i>Vespertilionoidea</i>	Alpeshore, Parbati	2	0:4:0	0.9:44.2:0.2	0.9:35.5:0.2	Interfemoral membrane attached to toes, hindfoot=6.5mm
<i>R. affinis</i>	<i>Rhinolophidae</i>	Lalashore, Gupteshore, Alpeshore, Parbati, Aadheri	5	3:18:0.8	5.6:52.6:1.4	4.6:51.9:1.2	Short ear, Broad horseshoe
<i>R. luctus</i>	<i>Rhinolophidae</i>	Parbati, Pipale	1	0:56:0	0:73.4:0	0:74.5:0	Presence of basal lappets on either side of the sella.
<i>R. macrotis</i>	<i>Rhinolophidae</i>	Alpeshore	1	0:16:0	0:44.6:0	0:42.8:0	Large ear, ear length=22.5mm
<i>R. pusillus</i>	<i>Rhinolophidae</i>	Gupteshore, Parbati	3	1:6:0.3	3:37.8:0.8	2.6:36.8:0.7	Triangular shape sella

**Table 5** - Pearson correlation coefficient calculated between species richness and cave's physical characteristics among bats inhabited caves recorded along Kaligandaki canyon.

	Cave's physical characteristics	Sample size (n)	Correlation coefficient (r)
Species richness vs	Number of cave entrances	13	+0.76
	Elevation	13	-0.32
	Cave length	10	+0.70
	Number of cave chambers	10	+0.81
	Maximum ceiling height	10	+0.85

**Fig. 5** - Temple construction for religious purpose in Parbati cave observed during the cave visit on April 2018.**Fig. 6** - Colony of *C. sphinx* using cave as a roosting site in Parbati cave.

During October 2017 species diversity was high in Alpeshore (1.69), followed by Parbati cave (1.61) whereas, during April 2018, diversity was high in Gupteshore (1.53) followed by Alpeshore cave (1.44) (Table 3). Overall mean diversity was highest in Alpeshore followed by Gupteshore whilst diversity was lowest in Laleshore cave (Table 3). The number of cave entrances, cave length, the number of cave chambers and the maximum ceiling height of the caves were found to be positively correlated with species richness, whereas elevation was negatively correlated (Table 5).

Cave tourism was observed as the main threat to the caves in Kaligandaki canyon. Gupteshore cave has been used as a religious shrine for over 30 years and receives >10,000 visitors annually (as per cave management committee). Religious activities such as daily worship with the use of incense sticks and bells (particularly during bat emergence time), as well as the spreading of *Hordeum* sp. seeds inside the cave was observed. A more recent trend promoting caves as tourist sites was also observed. Alpeshore and Laleshore cave are cave visit sites recommended by the municipality. Parbati cave is also undergoing construction which aims to facilitate tourism in near future. Major threats observed at Gupteshore cave include road construction, temple construction, cementing of surfaces, the installation of electrical systems, unregulated cave visits and pollution (Fig. 4). Likewise, road construction, temple construction, pollution and fire ignition were observed in Parbati cave (Fig. 5). Laleshore cave was threatened by electrical systems and pollution. Although electrical systems have been installed in Alpeshore cave to promote cave visits, the system was not in working condition and this cave suffered the fewest disturbances from tourism compared to the previously listed study caves. The remaining caves in the Kaligandaki canyons were not found to be at risk from such anthropogenic pressures at the time of this study.

## DISCUSSION

The surveyed segment represented only 14.3% of the Kaligandaki river system. Twenty caves with 12 bat species richness were the firsthand reports from the Kaligandaki canyon. Four cave systems namely Alpeshore, Gupteshore, Parbati, and Laleshore represented the significant bat roosts owning multiple chambers and entrances, long with tall ceiling and presence either seasonal or permanent water drainage throughout the year. Cave bat species richness is dependent upon several factors, such as a cave's structural and microclimatic characteristics (Avila-Flores & Medellín 2004, López-González & Torres-Morales 2004, Furey & Racey 2016). Our study showed caves which were long, possessed high ceilings, with multiple chambers and entrances, and the presence of water sources possessed higher bat diversity and population sizes which supports previous findings (Brunet & Medellín 2001, Quibod et al. 2019). On the contrary, caves which lacked these properties only supported individual species with small colony sizes or no bats. Our study also showed elevation was an important environmental variable. Caves which supported the highest diversity of population sizes occurred below 1300 m, whereas no bats were found in caves above 2100 m. This finding corroborates with Piksa et al. (2013), which recorded higher species

**Table 6** - Number of bats captured from other sites; remaining caves (Army barek, Tara and Siddha), fruiting areas, bamboo patches, forest edges and agriculture lands of the Kaligandaki canyon.

Species	Captured habitat	Numbers
<i>R. leschenaultii</i>	Tara cave and fruiting areas	12
<i>C. sphinx</i>	Fruiting areas	6
<i>H. armiger</i>	Army barek, Siddha cave and forest edges	5
<i>R. affinis</i>	Forest edges and agriculture lands	2
<i>N. noctula</i>	Forest edges	1
<i>Pipistrellus</i> sp.	Bamboo patches and agriculture lands	7
<i>T. fulvida</i>	Bamboo patches	1
Total		34

richness in mid-elevations (1100-1400 m) which gradually decreased at both the higher and lower elevations. The higher elevational region of Kaligandaki canyon is covered with tall rocky mountains, tough terrain and deserted lands which narrowed our cave exploration effort to areas of the landscape that were accessible which could account for the low abundance of bat caves at high elevation. As bat species richness is known to gradually decreases with increased elevation (Graham 1990, Reardon & Schoeman 2017), it is unclear whether highly diversified bats caves in Kaligandaki landscape are also distributed between 800-1300 m or if wider survey efforts are required.

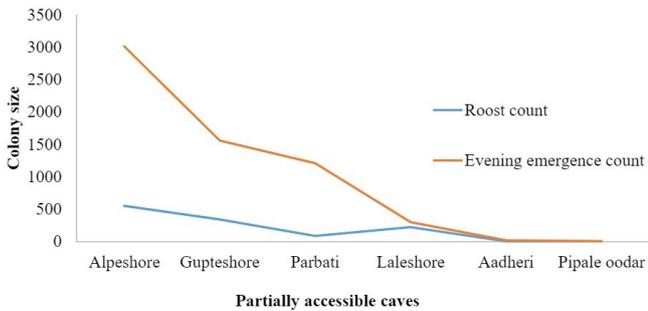
This study presents the first record of *C. sphinx*, *R. pusillus*, *R. macrotis*, *R. luctus*, *H. cineraceus*, *H. pomona*, *L. lyra*, *M. fuliginosus*, and *Myotis* sp. and re-record of *H. armiger*, *R. affinis* and *R. leschenaultii* from the Kaligandaki canyon. This study also presents the second record of *H. pomona* (previously recorded from Mahendra cave, Pokhara) from Nepal, and the first record of *R. luctus* from western Nepal (previously recorded from eastern to central Nepal; Baniya et al. 2019). *C. sphinx* is a tent-making bat species and is generally found roosting on the underside midrib of leaves of *Musa* sp., *Arecaceae* sp., *Areca catechu* and *Schima walichii* (Acharya et al. 2010). Interestingly, it was recorded roosting in Parbati cave (Fig. 6) which is the first report of the species using cave as a roosting site from Nepal.

*H. armiger* and *R. affinis* were the most captured bats and found to occur in most of the bat inhabited caves. Both are the most common and most widespread cave dwelling bat species throughout the country (Bates & Harrison 1997, Csorba et al. 1999, Acharya 2010, Acharya et al. 2010) which may account for their occurrence in most of the caves and high relative abundances during our study period. This also indicates that the habitat across Kaligandaki canyon is most probably more suitable to them. *R. luctus* is solitary and is known to roost in; old houses, tree cavities, tunnel, mines, holes and caves (Csorba et al. 2003). Perhaps due to its lone roosting behaviour and variety of preferred habitats, it was captured only once from the caves. The limited number of captures for *H. pomona* and *R. macrotis* could be due to our low trapping effort.

Although multiple bat species were recorded in some caves of the Kaligandaki canyon, each species were utilizing different parts of the cave. As their distribution inside the

caves varied with the cave's physical and microclimatic properties (Tuttle & Stevenson 1978, Rajasegaran et al. 2018, Barros et al. 2020), species-specific roost selection or preferences might have differentiated their cave utilization. The large-sized bat species of Kaligandaki canyon were observed to roost near to the cave entrances on high ceilings, whilst medium to small-sized bat species were seen to use deeper sections of the cave. This could be due to their flight mechanism; as small-sized cave bats have higher manoeuvre ability than larger species (Riskin et al. 2010, Hedenström & Johansson 2015), or it may be due to anthropogenic disturbances; as smaller sized bats, such as *H. cineraceus*, are highly sensitive to human disturbances which may compel them to use deeper parts of the cave which are more protected (Biswas et al. 2011) unlike, larger bats, such as *H. armiger* and *R. leschenaultii*, which are more adaptive to such disturbances (Kumar et al. 2015, Sharma 2019). For these species, roosting in higher ceilings may be beneficial for avoiding varieties of terrestrial predators (Vonhof & Barclay 1996) or mitigating anthropogenic disturbances from cave visits.

Bats from the family *Hipposideridae* maintain individual spaces whilst roosting (Ho & Lee 2003), whereas individuals from the *Rhinolophidae* family form small clusters or use solitary roosts (Lino et al. 2015). *R. leschenaultii* roosts are generally noisy, dense and their colony size varies from hundreds to thousands of individuals (Bates & Harrison 1997, Bates & Helgen 2008). Similarly, both *M. fuliginosus* and cave *Myotis* sp. usually have large colonies (Molur et al. 2002, Kruskop 2016, Benda & Paunović 2019). This reflected roosts found in our study caves, except numbers of *R. leschenaultii* were less than 100 individuals in Tara cave, no colony of *M. fuliginosus* was documented and *Myotis* sp. was observed to roost solitarily. As *M. fuliginosus* and *Myotis* sp. were only recorded from partially accessible caves, no colony record in such caves could be due to their limited accessibility; perhaps large colonies of *M. fuliginosus* and *Myotis* sp. are using deeper parts of the cave than were accessible. The partially accessible caves also showed a high variation in colony size estimates between roost count surveys and evening emergence counts (Fig. 7). This further supports our hypothesis that larger populations of bats are using inaccessible parts of the caves for roosting and to avoid anthropogenic pressures.



**Fig. 7** - Comparison of colony size in partially accessible caves of the kaligandaki canyon calculated through roost count method and evening emergence count on October 2017.

Some species encountered during the survey remained unidentified because of very similar morphological characteristics. The morphological characteristics of *Myotis* sp. is similar with *M. csorbai* and *M. longipes*. They are morphologically similar and requires for either cranio-dental characteristics or genetic analysis to separate to a species level which was not attempted in this study. *M. longipes* is distributed in Afghanistan, India and was thought to occur in Nepal till 1997 with only recorded location from Kailash cave of Sangya district (Bates & Harrison 1997, Kruskop 2016); however, Topal (1997) described new species *M. csorbai* and Csorba et al. (1999) collected numerous samples from the same cave which is approximately 30 km away from the study caves. Since then, species was considered as *M. csorbai* and enlisted as endemic to Nepal (Topal 1997, Csorba et al. 1999, Acharya et al. 2010, Jnawali et al. 2011). As this species is confined in the Himalayan landscape (Bates & Harrison 1997, Csorba & Thapa 2016) and it's distribution ranges overlap with our study caves, it is most likely that unidentified *Myotis* sp. to be *M. csorbai*, although needs genetic confirmation.

Species diversity of Gupteshore cave remained comparable both in October 2017 and April 2018 however, the diversity of Alpeshore and Parbati cave decreased in April 2018. This could be due to changes in anthropogenic disturbances as Alpeshore cave was less accessible due to large volume of rainwater inflow in October 2017, and Parbati cave underwent temple construction activities in April 2018. It may also be due to seasonal fluctuations or our limited capture effort as *R. luctus* and *R. pusillus* were not captured from Parbati cave in April 2018 and *R. macrotis* was only captured from Alpeshore cave in October 2017.

Cave tourism is growing in the Nepalese tourism sector. Caves of Pokhara valley (e.g. Bat cave, Mahendra cave and Gupteshore cave) and Siddha cave of Bandipur, Tanahu, caves of Kathmandu valley and Halesi cave of Khotang are widely promoted as attractive tourist destinations (Acharya et al. 2010, Thapa 2012, 2018). After the successful promotion of these caves, many other caves throughout the country are now being promoted for tourist activities. Over 30 species of bats recorded from Nepal are partly or wholly cave dwellers (Acharya et al. 2010) yet there is no obvious guidelines for cave tourism, and many caves are potentially threatened like those of Kaligandaki region. These caves may provide roosting sites to bats for hibernation in winter and breeding in summer and permanent shelter

to some species throughout the year. During hibernation and breeding periods, bats are highly sensitive and any human disturbances can be detrimental for their survival (McCracken 1989, Thomas 1995, Klys & Wołoszyn 2010, Furey & Racey 2016). Infrastructure development around the cave structure, cave modification for tourism and uncontrolled inflow of tourists can cause the rapid degradation of the cave environment. We therefore strongly recommend the management committees for these caves implement bat-friendly management actions to ensure the conservation of these fragile cave ecosystem.

This study was focused only along the Kaligandaki river, and there are many areas in Parbat, Baglung, Myagdi and Mustang districts which have the potential to harbour caves supporting bats. Therefore, an extensive survey covering all these areas and across different seasons is needed to understand diversity and seasonal variation in species composition across the caves of Kaligandaki region. As study was confined within the cave habitat, a detailed investigation of the species occurring in the region which includes different habitats should be a priority research area. Our trapping surveys in several habitats across adjacent caves also recorded additional three tree dwelling species including *T. fulvida* as a new record for the country, nationally data deficient *N. noctula* and *Pipistrellus* sp. (Table 6, Fig. 3) (Jnawali et al. 2011, Sharma et al. 2019). If explored entirely, who knows what this landscape holds further. We recommend future studies employ morphometrics, genetics and acoustic methods to fully understand bat diversity in the Kaligandaki landscape.

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