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A recent survey of bats with descriptions of echolocation calls and new records from the western Himalayan region of Uttarakhand, India

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The Himalayan region is a global biodiversity hotspot that faces severe pressures from a growing human population, rapid urbanization and climate change. While taxa like birds, plants and butterflies have been effectively surveyed along vast elevational gradients, there is immense paucity in such data for nocturnal and secretive animals like bats. We surveyed 22 sites in Uttarakhand in the western Himalayas spread across 600 m to 3,000 m a.s.l. A total of 35 species from 15 genera and five families were observed. We report the echolocation calls for 32 species, of which nine species have been recorded for the first time in the world. Additionally, we sequenced the cytochrome oxidase-I (COI) gene from 26 individuals belonging to 13 species. Eight species: *Tadarida teniotis*, *Murina leucogaster*, *Murina aurata*, *Murina cyclotis*, *Myotis* cf. *frater*, *Myotis* cf. *annectans*, *Mirostrellus joffrei*, *Arielulus circumdatus* and *Eptesicus tatei* are new records for the western Himalayan region. *Myotis* cf. *frater* is a new record for the entire Indian Subcontinent. In addition, we present an updated checklist of 49 species of bats for Uttarakhand state by reviewing previous literature. Our study will serve as a crucial baseline for future research by researchers and forest management authorities as the echolocation calls will be used to collect more occurrence data to elucidate the patterns of species richness across elevational gradients and to initiate the monitoring of bat populations.

Key words: DNA barcoding, India, bioacoustics, inventory, checklist, Himalaya

INTRODUCTION

The Himalayas — the tallest and largest mountain range in the world — are a global biodiversity hotspot (Myers *et al*., 2000). The Himalayas straddle 2,400 km from west to east, accompanied by a decline in latitude (Dahal and Hasegawa, 2008). As a result, there are vast differences in climate and vegetation as one goes from west to east in the Himalayas. Compared to the Andes, the Himalayas have received little attention in studies related to elevational gradients. Patterns of species richness have been explored in birds (Joshi and Bhatt, 2015; Dixit *et al*., 2016, Katuwal *et al*., 2016; Santhakumar *et al*., 2018), plants (Bhattarai *et al*., 2004; Acharya *et al*., 2011; Sharma *et al*., 2019) and butterflies (Acharya and Vijayan, 2015) that are relatively more conspicuous and easier to survey or well represented in secondary data. These patterns have further been explored in the aforementioned taxa in the light of macroecological theories to improve the understanding of the drivers of species distributions in birds (e.g., Price *et al*., 2011; Ghosh-Harihar and Price, 2014; Ishtiaq and Barve, 2018) and plants (Oommen and Shanker, 2005; Manish *et al*., 2017; Manish and Pandit, 2018; Rana *et al*., 2019 among others). However, we severely lack baseline data for taxa that are difficult to survey like moths (Dey *et al*. 2017), reptiles (Chettri *et al*., 2010) and non-volant small mammals (Hu *et al*., 2017).

With over 1,400 species globally, bats form the second largest order of mammals (Burgin *et al*., 2018). In India, bats constitute the most diverse mammalian order with 127 species (Saikia, 2018), followed by rodents with 102 species (Chakravarty and Ramachandran, 2020). Bats play an important

role in a variety of ecosystem services like pollination, seed dispersal and insect pest control. In addition, bats are important biological indicators on account of their high species diversity, sensitivity to environmental changes, higher trophic position (of insectivorous bats), long life span, and slow reproductive rate (Jones *et al*., 2009). Moreover, despite being nocturnal animals, bat populations — with due consideration — can be monitored acoustically in a cost-effective manner using ultrasonic recorders (Stahlschmidt and Brühl, 2012) and such an exercise is important in the context of anthropogenic disturbance, climate change and disease surveillance. However, information on diversity, distribution, ecology, behaviour and echolocation calls is quite fragmented for most tropical and subtropical regions, and particularly in the Himalayan region.

The earliest accounts on bat diversity in the Himalaya come from the western and central Himalaya (Dobson, 1872; Hutton, 1872; Scully, 1887). These studies established the preliminary inventory of Chiropteran diversity in the Himalaya which included species shared with Europe such as, *Rhinolophus ferrumequinum*, *Barbastella communis* (revised to *B. darjelingensis*), *Plecotus auritus* (revised to *P. homochrous*), *Vespertilio blythii* (now, *Myotis blythii*). Around the same time, Peters (1872) discovered a rare, endemic species *Harpiola grisea* in the Mussoorie region. Some regions in Uttarakhand were re-surveyed in the 1960s and 1970s (Bhat, 1974) and again in the 1990s (Bates and Harrison, 1997) in which *Eonycteris spelaea* and *Sphaerias blanfordi* were recorded for the first time from western Himalaya (Bhat, 1974). In 2004− 2006, comprehensive bat surveys were conducted in Himachal Pradesh (Saikia *et al.*, 2011) and Nepal (reviewed in Thapa, 2014). Thanks to several integrative taxonomic surveys conducted in South Asia, the systematics of many bats also changed considerably and a need for more complete studies was evidenced (Saikia, 2018). However, in the last three decades, most parts of the Himalayas have seen rapid urbanisation, increased tourism and developmental projects like dams and highway construction. It is therefore timely to intensively resurvey a broad region of the state to gather information on current bat diversity and occurrence. Until now, no study has documented the echolocation calls of bats in the Himalayas, which prevents the scope of using acoustic sampling in understanding natural history and in monitoring bat populations. It has been shown that re-surveying indicator taxa that were surveyed historically, one can detect perturbations in plant and animal communities that may be linked to urbanization, habitat destruction or climate change (Alberch, 1993; Pereira and Cooper, 2006; Magurran *et al*., 2010).

With this background, we conducted a survey of bats in the state of Uttarakhand in the western Himalayan region of India. For the first time, an effort to create an echolocation call library and produce reference DNA barcodes of bats in this region was undertaken.

Materials and Methods

Study Area

We surveyed 22 sites distributed at the following broad locations in the Garhwal division: Dehradun, Mussoorie, Devalsari, Dhanaulti, Chamba, Kedarnath Wildlife Sanctuary, Lansdowne, and Pangot in Nainital district in the Kumaon region of Uttarakhand state. The sampling locations spanned elevations from 600 to 3,000 m a.s.l. (Fig. 1 and Appendix I). Corresponding to elevation, changes are seen in the dominant vegetation and forest types across an elevational gradient (Gairola *et al*., 2008). For example, at elevations below 1,000 m, the vegetation is dominated by *Shorea robusta* and the hill slopes are covered with shrubs like *Woodfordia* spp. whereas in the hills from 1,500 to 2,500 m a.s.l. *Pinus roxburghii*, *Cedrus deodara*, *Quercus leucotrichophora*, *Rhododendron arboreum* dominate. Above 2,500 m, *Abies pindrow*, *Picea smithiana* and other species of *Quercus* and *Rhododendron* are replaced by stunted *Betula* spp. and *Juniperus* spp. in alpine meadows (Gairola *et al*., 2008).

Bat Sampling, Sound Recording and Acoustic Analysis

Sampling was conducted from February to June 2016. Kedarnath Wildlife Sanctuary was resampled in April 2017 and 2018. We have added only one individual record of *Myotis muricola* (which was not caught in that location in 2016–17) from the 2018 data in this study. A reconnaissance survey was undertaken in November 2015 during which time only one bat was caught. Bats were captured using mist nets typically set for four to five hours after dusk (18.30 or 19.00 to 22.30 or 23.00 h). In order to assess species richness of bats, sampling was conducted in open and shaded streams, gorges, oak, cedar and rhododendron forests, and forest clearings and trails, including near human habitation. Usually, two to three ground mistnets of 6 and 9 m length, 2.5 m width (30 or 36 mm mesh size, three or four shelves) were set up on lightweight, telescopic aluminium poles across streams and forest trails. To avoid resampling the same individuals and to have independent call samples, each site was visited only once (except for six sites). In two occasions, when we found roosts of bats, a hand net was used to capture them.

Bat capture methods followed standard procedures as described in Kunz and Parsons (2009) and handling was done as per recommendations of the American Society of Mammalogists (Sikes *et al*., 2016). Age (classified as juvenile or adult), sex and reproductive condition (pregnant versus non-pregnant) were recorded before taking body mass and standard

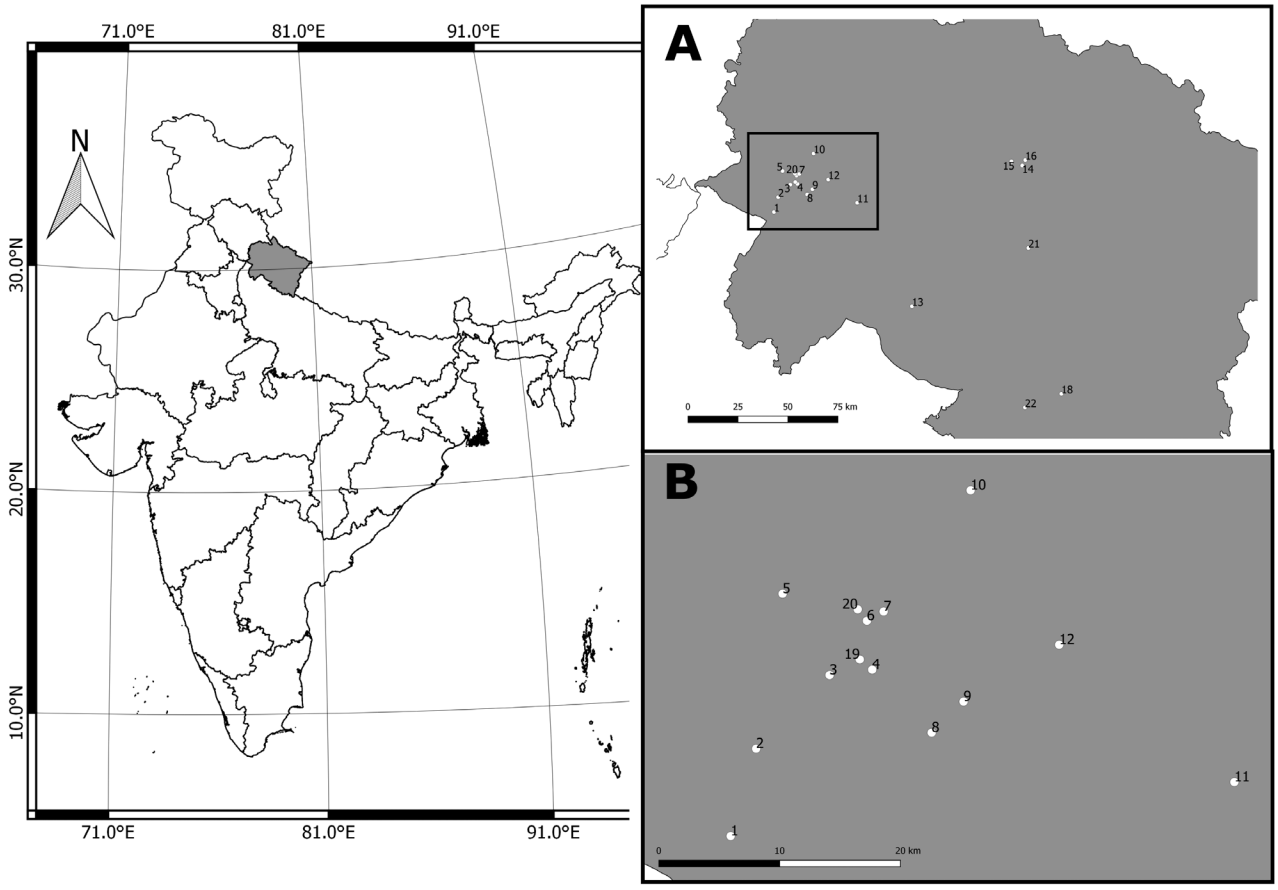

FIG. 1. Map of India showing the location of Uttarakhand (shaded). A: Locations of all the 22 sampling sites in Uttarakhand: 1 — Wildlife Institute of India Campus, 2 — Bajawala, 3 — Guniyal Gaon, 4 — Rajpur, 5 — Benog WLS, 6 — Woodstock dorms, 7 — Hanifl Centre, 8 — Maldevta, 9 — Taapu Sera, 10 — Devalsari, 11 — Ranichauri, 12 — Dhanaulti, 13 — Lansdowne, 14 — Mandal, 15 — Bulkhan, 16 — Ansuya Devi, 17 — Shokharakh, 18 — Pangot, 19 — Jharipani, 20 — Landour Bazaar, 21 — Gairsain, 22 — Pawalgarh. B: Map zoomed in to show the locations in Dehradun, Tehri-Garhwal and Chamba districts where most of the sampling was concentrated. See Appendix I for more details

measurements. Morphometric measurements were taken to the nearest 0.1 mm with dial calipers. Body mass (BM) was measured using a spring balance (0.5 g accuracy). Species were identified to the best possible match based on measurements and qualitative characters following Bates and Harrison (1997), Srinivasulu *et al*. (2010) and Borissenko and Kruskop (2003). To confirm our morphological identification, we also produced barcode sequences for part of the captured bats (see below). However, as the taxonomy of bats in India is not properly resolved, some identities must be considered as tentative and are likely to see revisions in the future. No specimens were collected as voucher but blood samples were taken on FTA cards (Whatman, GE Healthcare, Buckinghamshire, England) for subsequent molecular analysis.

Echolocation calls were recorded from hand-held individuals in the case of rhinolophids and hipposiderids, and on release from individuals of other families. The calls of *Murina leucogaster, M. cyclotis* and *M. aurata* were recorded in rooms with brick walls. Consequently, the calls presented in this paper must be interpreted as calls produced in dense and cluttered environments, where typically pulses are of shorter duration. The calls were recorded full spectrum (.wav format) using an Anabat Walkabout bat detector (Titley Scientific, Brendale, Australia) with a sampling rate of 500 kHz and a range of 10–250 kHz onto its inbuilt recorder. The recordings were analysed using BatSound Pro 3.31 (Pettersson Elektronik AB, Uppsala, Sweden). Up to 10 clear calls with highest signal to noise ratio were selected from each recording and the means for each call parameter were used for further analysis. Start frequency, end frequency and duration were measured from a spectrogram with FFT size = 1024, BatSound default FFT overlap and a Hanning window; the frequency of maximum energy (FMaxE, also known as peak frequency) was measured from power spectrum (Fig. 2). We refrained from measuring inter-pulse interval as this parameter is known to be highly dependent on the amount of clutter in the habitat (Pedro and Simonetti, 2014).

DNA Barcoding and Molecular Identification

As most DNA barcodes of Asian bats available so far are from north of the Himalayas (e.g., Kruskop *et al.*, 2012) or from Indochina (e.g., Francis *et al.*, 2010), we generated new barcode sequences from the blood samples taken from some bats that we captured in Uttarakhand. Total genomic DNA was extracted from blood using phenol-chloroform method. The cytochrome c oxydase subunit 1 (COI) gene, a 658 bp fragment,

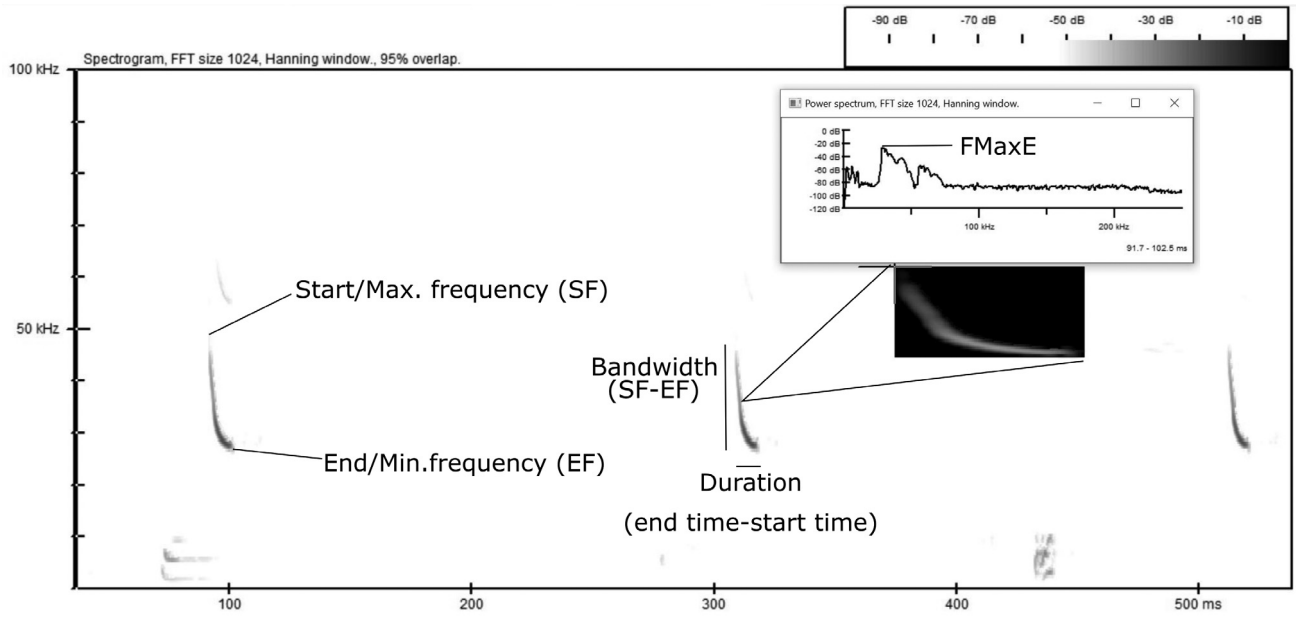

FIG. 2. Pictorial depiction of call parameters that were measured to characterise echolocation calls. FMaxE was measured using a power spectrum whereas the other parameters were measured using a spectrogram

was amplified following the protocol and standard primer cocktail used for DNA barcoding of mammals (Ivanova *et al*., 2012). PCR was performed in 10.5 µL master mix comprising 6.25 µL 10% Trehalose, 2 µl ddH_2O, 1.25 µl 10X PCR buffer, 0.625 µl 50mM $MgCl_2$, 0.125 µl each of 10 µM forward and reverse primer cocktails (VF-1 and VR-1; Ivanova *et al*., 2012), 0.0625 µl 10mM dNTPs and 0.06 µl Platinum Taq (5 U/ µl). The PCR cycle used was 94°C for 2 min; 5 cycles (94°C for 30 s, 50°C for 40 s, and 72°C for 1 min); 35 additional cycles (94°C for 30 s, 55°C for 40 s, and 72°C for 1 min); final extension at 72°C for 10 min (Ivanova *et al.*, 2012). Cleaned PCR fragments were sequenced in both directions using the same amplification primers. Chromato-grams were visualized, aligned and assembled with Sequencher 4.1 (Gene Codes Corp., Ann Arbor, Michigan).

New sequences were submitted to a BLAST search in GenBank database (Boratyn *et al*., 2013) and to the Barcode of Life Database (BOLD) identification engine (Ratnasingham and Hebert, 2013) to determine the closest taxa sequenced so far (as of 31.10.2018). BOLD includes several thousand barcoded and carefully identified Asian bats and thus provides an efficient taxonomic database to identify COI sequences (see e.g. Francis *et al.*, 2010; Kruskop *et al.*, 2012). To understand phylogenetic similarities with closely-related species, we constructed neighbour-joining (NJ) trees based on Kimura 2 Parameter model of DNA divergence using MEGA (Kumar *et al.*, 2016). All new COI sequences from this study were deposited in GenBank under the accession numbers MN339178–MN339197 and MN714904–MN714905 (Appendix II).

RESULTS

In total we captured and examined 35 species (plus *Pteropus giganteus* which was only seen) of bats during our survey (Table 1) and recorded the echolocation calls of 32 of them (Fig. 3 and Table 2). The calls of the following nine species are described here for the first time: *Arielulus circumdatus*, *Eptesicus tatei*, *Murina aurata*, *M. leucogaster*, *Myotis longipes*, *M. nipalensis*, *Plecotus homochrous*, *P. wardi* and *Submyotodon caliginosus*. We also characterised genetically 26 individuals of 13 species using 555−657 bp of the COI gene (Fig. 4). The total sampling effort across all sites was 463.5 trap hours (one trap hour = one 6 or 9m net open for one hour). One species, *M. nipalensis* is a new record for the state of Uttarakhand. Nine species: *Tadarida teniotis*, *Murina aurata*, *M. cyclotis*, *M. leucogaster*, *M.* cf. *frater*, *M.* cf. *annectans*, *M. joffrei*, *A. circumdatus* and *E. tatei* are new records for Uttarakhand as well as the entire western Himalayan region (Jammu and Kashmir, Himachal Pradesh and Uttarakhand) (Fig. 5). *Myotis* cf. *frater* constituted a new record for the Indian Subcontinent as well. Furthermore, due to taxonomic uncertainties, we also report the occurrence of several unidentified species which may prove new to the region (one *Pipistrellus* sp.) or even new to science (one *Myotis* sp.). Whilst our comparisons of diversity across sites and elevations were constrained by unequal sampling effort, we recorded the highest number of bat species in Devalsari (10 species) and in the 1,000–2,000 m elevational range (20 species — Table 1 and Appendix I). A brief review of the species detected during this study is provided below.

TABLE 1. List of 49 species from seven families reported from Uttarakhand from this and previous studies with their elevation range and threat status. Species reported from this study are highlighted in bold. * Indicates new record for Indian Subcontinent. [1] Indicates new record for Uttarakhand. [2] Indicates new record for the western Himalayan region (Uttarakhand, Himachal Pradesh and Jammu & Kashmir). IUCN status: LC – Least concern, DD – Data deficient, '–' shows species that are pending assessment

No.	Family/Species	Sites	Elevation range (m)	IUCN status	References
	Pteropididae				
1	***Pteropus giganteus***	Dehradun, Haridwar, Rajaji National Park, Corbett Tiger Reserve, Rishikesh	300–600	LC	This study; Joshi, 2016; Sharma and Nafees, 2018; S. Prasad pers. comm.
2	*Rousettus leschenaultii*	Tanakpur, Dehradun, Pauri, Almora and Nainital districts	200–1800	LC	Bates and Harrison, 1997
3	*Cynopterus sphinx*	Dehradun, Chamoli, Nainital, Almora and Pithoragarh districts	500–1900	LC	Bates and Harrison, 1997
4	*Sphaerias blanfordi*	Chamoli, Almora and Pithoragarh districts	1400–1900	LC	Bates and Harrison, 1997
5	*Eonycteris spelaea*	Nainital and Pithoragarh districts	1900	LC	Bates and Harrison, 1997
	Megadermatidae				
6	*Megaderma lyra*	Khamaria, Ranibagh	200–500	LC	Bates and Harrison, 1997
	Molossidae				
7	***Tadarida teniotis*** [1, 2]	Taapu Sera	1007	LC	Chakravarty, 2017
	Rhinolophidae				
8	*Rhinolophus ferrumequinum*	Almora, Mussoorie, Katarmal	1400–2000	LC	Bates and Harrison, 1997
9	***R. affinis***	Maldevta, Woodstock dorms, Benog WLS, Devalsari, Dhanaulti, Landour Bazaar, Bilaspur, Kaladhungi	140–2022	LC	This study; Bates and Harrison, 1997
10	***R. sinicus***	Mandal, Mussoorie, Dhakuri	1530–2600	LC	This study; Bates and Harrison, 1997
11	***R. lepidus***	Mandal, Benog WLS, Ansuya Devi, Khati, Almora, Ranibagh	1530–2582	LC	This study; Bates and Harrison, 1997
12	***R. pusillus***	Bajawala; Mussoorie, Almora	638–2000	LC	This study; Bates and Harrison, 1997
13	***R. luctus***	Maldevta, Jharipani, Pangot, Mussoorie	969–2000	LC	This study; Bates and Harrison, 1997
14	***R. macrotis***	Jharipani, Mussoorie	1410–2000	LC	This study; Bates and Harrison, 1997
15	***R. pearsonii***	Mandal, Benog WLS, Ansuya Devi, Mussoorie, Narkota, Loharkhet	670–2582	LC	This study; Bates and Harrison, 1997
	Hipposidaeridae				
16	*Hipposideros cineraceus*	Dehradun, Mussoorie	500–2000	LC	Bates and Harrison, 1997
17	*H. speoris*	Dehradun	500	LC	Bates and Harrison, 1997
18	***H. armiger***	Maldevta, Woodstock dorms, Gairsain, Bageshwar, Almora	969–2000	LC	This study; Bates and Harrison, 1997
	Vespertilionidae				
19	***Plecotus homochrous***	Devalsari, Dhanaulti, Ansuya Devi, Shokharakh, Phurkia (?)	1698–3065	–	This study; Bates and Harrison, 1997
20	***P. wardi***	Shokharakh, Milam, Martoli	3065–3500	–	This study; Bates and Harrison, 1997
21	***Barbastella darjelingensis***	Benog WLS, Hanifl Centre, Kapkot	1070–2179	LC	This study; Bates and Harrison, 1997
22	***Nyctalus leisleri***	Bajawala, Maldevta, Devalsari, Dhanaulti, Pangot, Dugalbitta, Katarmal	638–2560	LC	This study; Bates and Harrison, 1997

TABLE 1. Continued.

No.	Family/Species	Sites	Elevation range (m)	IUCN status	References
23	***Nyctalus montanus***	Mussoorie	2000	LC	Bates and Harrison, 1997
24	***Murina leucogaster*** [1, 2]	Devalsari	1698	LC	This study
25	***M. cyclotis*** [1, 2]	Devalsari	1698	LC	This study
26	***M. huttoni***	Lansdowne, Dhanaulti, Dehradun, Khati	500–2200	LC	This study; Bates and Harrison, 1997
27	***M. aurata*** [1, 2]	Ansuya Devi	2582	LC	This study
28	*Harpiola grisea*	Jharipani	1600	DD	Bates and Harrison, 1997
29	*Myotis formosus*	Dehradun, Mussoorie, Katarmal	500–2000	LC	Bates and Harrison, 1997
30	***M. longipes*** [1]	Mandal, Benog WLS, Woodstock dorms, Gairsain, Ansuya Devi	1490–2582	DD	This study
31	***M. nipalensis*** [1]	Pawalgarh	495	LC	This study
32	*M. siligorensis*	Dwali, Mussoorie Dugalbitta	950–2580	LC	Bates and Harrison, 1997
33	***M.* cf. *frater*** [*, 1, 2]	Mandal, Devalsari	1490–1698	LC	This study
34	***M. muricola***	Mandal, Ansuya Devi, Dehradun, Phurkia, Deori	500–2582	LC	This study; Bates and Harrison, 1997
35	***M.* cf. *annectans*** [1, 2]	Devalsari	1698	LC	This study
36	***M. blythii***	Devalsari, Mussoorie	1698–2000	LC	This study; Bates and Harrison, 1997
37	***Submyotodon caliginosus***	Shokharakh	3065	–	This study
38	***Mirostrellus joffrei*** [1, 2]	Mandal	1490	DD	This study
39	***Pipistrellus tenuis***	Bajawala, Rajpur, Sitabani, Ramnagar, Haldwani, Kaladhungi	300–1025	LC	This study; Bates and Harrison, 1997
–	*Pipistrellus* sp.	WII Campus	593	–	This study
40	*P. javanicus*	Ramnagar, Dhakuri, Mussoorie	300–2600	LC	Bates and Harrison, 1997
41	*P. coromandra*	Mussoorie, Dhakuri, Loharkhet, Ramnagar	300–2600	LC	Bates and Harrison, 1997
42	***P.* cf. *ceylonicus*** [1]	Maldevta, Mandal, Lansdowne, Devalsari, Dhanaulti	846–2114	LC	This study
43	*Falsistrellus affinis*	Location not available	–	LC	Bates and Harrison, 1997
44	***Arielulus circumdatus*** [1, 2]	Shokharakh	3065	LC	This study
45	***Eptesicus tatei*** [1, 2]	Shokharakh	3065	LC	This study
46	***E. serotinus***	Mandal, Devalsari, Mussoorie	1490–2000	LC	This study; Bates and Harrison, 1997
47	***Scotophilus heathii***	Bajawala, Haldwani, Kaladhungi, Ramnagar	300–638	LC	This study; Bates and Harrison, 1997
48	***S. kuhlii***	Ramnagar	300	LC	Bates and Harrison, 1997
Miniopteridae					
49	***Miniopterus fuliginosus***	Bajawala, Maldevta, Woodstock dorms, Benog WLS, Dhanaulti, Ramnagar	300–2114,	LC	This study; Bates and Harrison, 1997

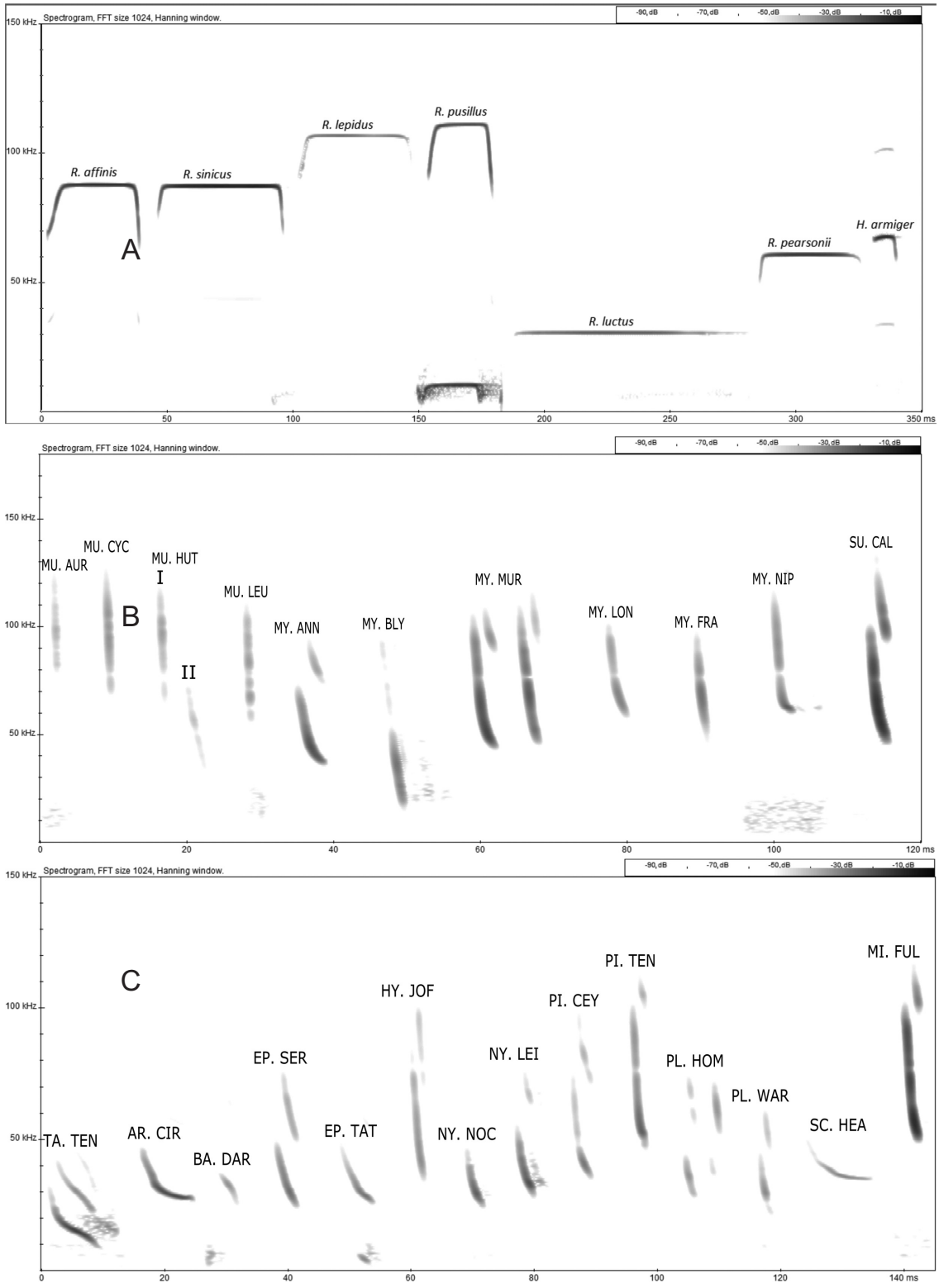

FIG. 3. Echolocation calls of bats with A) constant frequency (CF) calls, B) steep frequency modulated (FM) calls, and C) frequency-modulated with quasi constant frequency (FM-QCF) calls. Key to species abbreviations in B: MU. AUR — *M. aurata*, MU. CYC — *M. cyclotis*, MU. HUT — *M. huttoni*, MU. LEU — *M. leucogaster*, MY. ANN — *M.* cf. *annectans*, MY. BLY — M. *blythii*, MY. MUR — *M. muricola*, MY. LON — *M. longipes*, MY. FRA — *M.* cf. *frater*, MY. NIP — *M. nipalensis*, SU. CAL — *S. caliginosus*. Key to species abbreviations in C: TA. TEN — *T. teniotis*, AR. CIR — *A. circumdatus*, BA. DAR — *B. darjelingensis*, EP. SER — *E. serotinus*, EP. TAT — *E. tatei*, HY. JOF — *H. joffrei* (now *Mirostrellus joffrei*), NY. NOC — *N. noctula*, NY. LEI — *N. leisleri*, PI. CEY — *P.* cf. *ceylonicus*, PI. TEN — *P. tenuis*, PL. HOM — *P. homochrous*, PL. WAR — *P. wardi*, SC. HEA — *S. heathii*, MI. FUL — *M. fuliginosus*

TABLE 2. Echolocation call parameters of bats with constant frequency (CF), quasi constant frequency (QCF), frequency modulated (FM) and FM-QCF calls. * — first echolocation call descriptions for the species

Species	Start/Max. frequency (kHz)	End/Min frequency (kHz)	FMaxE (kHz)	Duration (ms)	Bandwidth (kHz)	No. of calls recorded
Hipposideros armiger	–	–	68.2 ± 1.9	7.8 ± 0.3	–	5
Rhinolophus affinis	–	–	88.0 ± 0.3	24.3 ± 7.2	–	7
R. lepidus	–	–	106.3 ± 4.3	30.2 ± 11.8	–	3
R. luctus	–	–	31.3	82.2	–	1
R. pearsonii	–	–	61.25 ± 0.3	42.5 ± 5.1	–	4
R. pusillus	–	–	111.5	28.6	–	1
R. sinicus	–	–	87.9	42.1	–	1
*Arielulus circumdatus**	44.8	26.8	28.9	9.1	17.9	1
Barbastella darjelingensis	37.3 ± 1.0	26.2 ± 1.8	33.4 ± 0.3	2.1 ± 0.6	11.0 ± 2.5	3
Eptesicus serotinus	50.0 ± 4.45	22.9 ± 0.89	29.7 ± 1.5	3.7 ± 0.73	27.1 ± 3.6	2
*E. tatei**	46.5	25.3	29.5	5.2	21.3	1
Mirostrellus joffrei	70.5	33.9	43.8	2.1	36.6	1
Miniopterus fuliginosus	88.9 ± 10.0	47.0 ± 2.2	53.1 ± 1.3	3.8 ± 0.8	42.0 ± 10.4	11
*Murina aurata**	111.7	80.6	97.2	0.8	31.1	1
M. cyclotis	120.1	68.8	95.4	1.8	51.3	1
M. huttoni						
Call type I	107.5 ± 10.45	63.8 ± 10.28	83.0 ± 17.13	1.2 ± 0.09	43.6 ± 0.16	2
Call type II	74.4	43.4	58.4	1.9	31.0	1
*Murina leucogaster**	98.9	59.3	69.3	0.9	39.6	1
Myotis cf. *annectans*	61.3 ± 10.09	36.22 ± 0.96	41.91 ± 0.55	3.33 ± 0.91	25.06 ± 9.66	3
M. blythii	51.4	18.5	35.4	2.1	32.9	1
M. muricola						
Call type I	104.7 ± 2.09	47.8 ± 3.66	51.9 ± 2.51	52.94 ± 5.74	4.0 ±0.5	2
Call type II	108.3	47.4	69.3	60.9	3.7	1
*Myotis longipes**	98.4 ± 11.79	60.6 ± 3.60	70.0 ± 2.46	2.9 ± 0.37	37.8 ± 12.69	10
M. cf. *frater*	96.8 ± 3.15	47.9 ± 3.13	68.0 ± 3.86	2.52 ± 0.17	48.91 ± 1.36	4
*M. nipalensis**	112.1	59.9	67.3	2.4	52.2	1
*Submyotodon caliginosus**	96.3	46.8	60.3	3.0	49.5	1
Nyctalus noctula	47.5 ± 7.93	21.9 ± 2.69	28.4 ± 1.15	3.0 ± 1	28.7 ± 9.39	5
N. leisleri	58.7 ± 9.09	27.4 ± 2.24	34.2 ± 1.72	3.4 ± 0.84	31.3 ± 8.81	9
Pipistrellus cf. *ceylonicus*	67.0 ± 10.05	36.9 ± 0.90	41.4 ± 1.51	4.3 ± 1.93	30.0 ± 9.92	21
P. tenuis	95.0 ± 5.94	49.6 ± 0.41	54.6 ± 1.75	3.4 ± 0.91	45.4 ± 6.36	2
*Plecotus homochrous**						
Call type I	37.0 ± 7.45	27.0 ± 9.89	31.3 ± 7.12	1.9 ± 1.39	10.0 ± 3.04	4
Call type II	67.5	54.1	61.1	1.4	13.4	1
*Plecotus wardi**	40.0 ± 2.69	26.9 ± 1.79	31.3 ± 1.72	1.8 ± 0.39	13.2 ± 3.99	4
Scotophilus heathii	52.5 ± 15.28	34.1 ± 2.22	37.9 ± 4.74	6.7 ± 3.77	18.4 ± 13.15	3
Tadarida teniotis	31.6 ± 2.27	9.9 ± 1.01	15.6 ± 0.58	8.4 ± 1.24	20.7 ± 4.28	6

Species Account and Review

Family Pteropodidae

Pteropus giganteus Brunnich, 1782
Indian Flying Fox

New locality records

Dehradun district: Dehradun; Haridwar district: Haridwar.

Previous records

Haridwar district: Rajaji National Park (Joshi, 2016); Nainital district: Corbett Tiger Reserve (Sharma and Nafees, 2018); Pauri-Garhwal district: Rishikesh (S. Prasad personal communication).

Remarks

It is the only *Pteropus* found in the study area and in mainland India (Bates and Harrison, 1997). *Pteropus giganteus* was not sampled but seen roosting in Haridwar and Dehradun. Both roosts had ca. 100 individuals. This species is common in the plains and none were seen in the hills above 1,000 m a.s.l. In other hill states of India, roosts of this species have also been recorded from low-lying areas only (Bates and Harrison, 1997; Saikia *et al*., 2011).

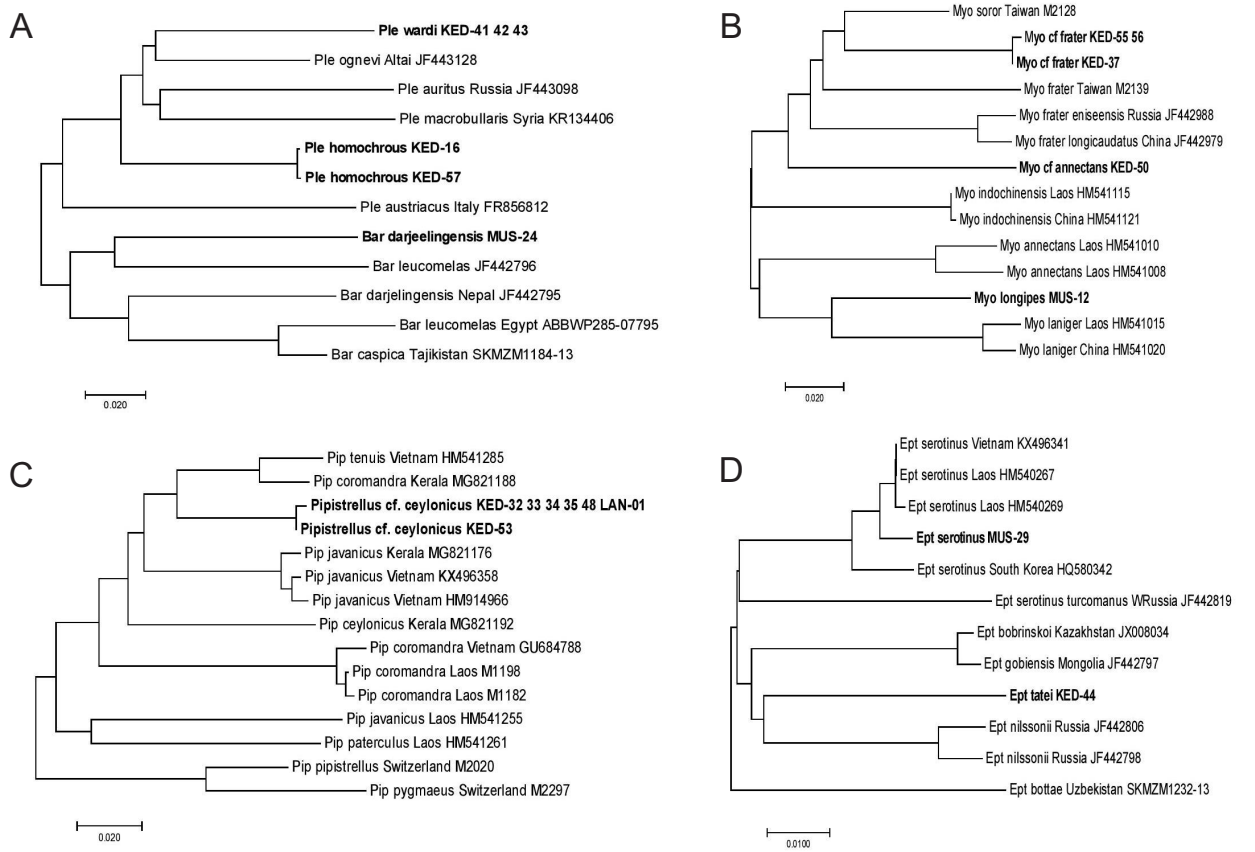

FIG. 4. Neighbour-joining trees of 12 Uttarakhand bat haplotypes (highlighted in bold face) compared to sequences available in the GenBank or BOLD databases. These reconstructions are based on K2P pairwise distances computed from alignments of 555 to 657 bp of the COI mitochondrial gene. A — Plecotine bats, B — *Myotis* bats, C — *Pipistrellus* bats and D — *Eptesicus* bats. For each publicly accessed sequence, we report the original species identification, country of origin and reference number of the GenBank or BOLD repositories

Family Molossidae

Tadarida teniotis Rafinesque, 1814
European Free-tailed Bat

New locality records

Dehradun district: Dehradun city; Tehri-Garhwal district: Taapu Sera. First record for Uttarakhand and western Himalaya. This record has been detailed in Chakravarty (2017).

Remarks

A total of 30 individuals were captured in March 2016 at Taapu Sera. All the captured individuals were males. Measurements were recorded from six individuals. All individuals were identifiable by their large size (forearm length, FA = 60.1–63.2 mm) and ears not joined over forehead (Chakravarty, 2017). Around 15 individuals were roosting behind three vertical water pipelines in the main building of the Forest Research Institute, Dehradun. In India, this species was known from a single historical record from Kurseong in the Eastern Himalayas (see Bates and Harrison, 1997) and until recent reports from acoustic surveys in Bihar and Kerala (Deshpande and Kelkar, 2015).

Family Rhinolophidae

Rhinolophus affinis Horsfield, 1823
Intermediate Horseshoe Bat

New locality records

Tehri-Garhwal district: Devalsari.

Previous records

Dehradun district: Mussoorie, Nainital district: Bilaspur and Kaladhungi (Bates and Harrison, 1997).

Remarks

Eight individuals were caught at six sites. They were identified by their size (FA = 52.7–55.5 mm,

FIG. 5. Portraits of some new records for the western Himalayan region from our survey: A — *E. tatei*, B — *A. circumdatus*, C — *M.* cf. *frater*, D — *P.* cf. *ceylonicus*, E — *M. leucogaster* and F — *M. aurata*

BM = 17.7 g — Appendix III) and the shape of the noseleaf with low and rounded connecting process and triangular lancet. The species was typically caught along streams and trails in *Quercus* and *Cedrus* forests above 1,500 m. At Maldevta, it was caught over a stream running through shrub-covered hills slopes. At Landour Bazaar, in the middle of Mussoorie town we observed five individuals gliding and picking moths that were resting on the window of a cafe. One of these was caught with a hand net. Peak echolocation frequency was 88.0 kHz (n = 7). In India, it is found throughout the Himalayas, Northeast India and the Andaman Islands (Molur *et al.*, 2002; Saikia *et al.*, 2011).

One individual from Mussoorie sequenced for 540 bp of the COI was genetically very close to (<1% sequence divergence) specimens of *R. affinis* from Myanmar (e.g., GenBank sequence KP192682) and Thailand (e.g., sequence KP192692) which confirms our initial morphological identification.

Rhinolophus sinicus Andersen, 1905
Chinese Horseshoe Bat

New locality records

Chamoli district: Mandal village.

Previous records

Dehradun district: Mussoorie; Bageshwar district: Dhakuri (Bates and Harrison, 1997).

Remarks

One individual was caught at Mandal at a clearing in a secondary forest. It was identified by its smaller size compared to the previous species (FA = 45.68 mm and BM = 10.5 g — Appendix III). The sella was similar to that of *R. affinis* but its lancet had concave lateral margins. Although morphologically distinct, it was acoustically similar to *R. affinis* with a peak echolocation frequency of 88 kHz. Such acoustic similarities between the two abovementioned species have also been observed in China (Zhang *et al.*, 2009). In India, this species is found in the Himalayas and parts of Northeast India (Molur *et al.*, 2002; Saikia *et al.*, 2011).

Rhinolophus lepidus monticolus Blyth, 1844
Blyth's Horseshoe Bat

New records

Chamoli district: Ansuya Devi.

Previous records

Dehradun district: Mussoorie; Bageshwar district: Khati; Almora district: Almora, Nainital district: Ranibagh (Bates and Harrison, 1997).

Remarks

Four individuals were caught at Mandal, Ansuya Devi and Benog WLS in brooks and streams running through mixed oak forests. The individual caught at Benog WLS in May 2016 was pregnant. They were identified by their larger FA (38.3–41.3 mm) and broader connecting process than *R. pusillus*. The FMaxE measured at Mandal and Ansuya Devi was 101 and 109 kHz, respectively. The observed difference was not attributed to body size as the individual caught at Mandal was smaller than those from Ansuya Devi. *R. lepidus* is widely distributed in India.

Rhinolophus pusillus blythii Temminck, 1834
Least Horseshoe Bat

New locality records

Dehradun district: Dehradun.

Previous records

Dehradun district: Mussoorie; Almora district: Almora (Bates and Harrison, 1997).

Remarks

One individual was caught at Bajawala while flying low over an open stream. It was identified by its smaller size (FA = 35.1 mm) in comparison to *R. lepidus* and narrower tips of the connecting process. Its FMaxE was recorded at 112 kHz. *Rhinolophus pusillus* has been recorded in the Himalayas east of Uttarakhand. There are also scattered records from peninsular India (Molur *et al.*, 2002) but it has not been reported from Himachal Pradesh (Saikia *et al.*, 2011).

Rhinolophus luctus Temmick, 1835
Woolly Horseshoe Bat

New locality records

Tehri-Garhwal district: Maldevta; Dehradun district: Jharipani; Nainital district: Pangot.

Previous records

Dehradun district: Mussoorie (Bates and Harrison, 1997).

Remarks

Three solitary individuals were found roosting in caves in Maldevta, Jharipani and Pangot. In March, they were observed in a torpid state in Maldevta and Jharipani. In Pangot, a mother was seen with two pups in June. None of the bats were captured for ethical reasons. We recorded the calls of the individual at Pangot. The FMaxE was 31 kHz. All three individuals were identified based on their large size (FA > 70 mm; no precise measurement was taken to avoid arousing these torpid individuals), dark pelage and large noseleaf with prominent basal lappets. *Rhinolophus luctus* has been reported from Himalayas and Northeast India and an isolated record from Central India (Molur *et al.*, 2002).

Rhinolophus macrotis Blyth, 1844
Big-eared Horseshoe Bat

New locality records

Dehradun district: Jharipani.

Previous records

Dehradun district: Mussoorie (Bates and Harrison, 1997).

Remarks

Only one individual was caught at a cave in Jharipani in November 2015 during the reconnaissance survey. It was identified by its small size (FA = 41 mm — Appendix III), proportionately large ears (ear length, EL = 25 mm) and the shape of its noseleaf comprising a long, wide and wavy

sella. These morphological characters match with *R. macrotis* following Bates and Harrison (1997) and Srinivasulu *et al*. (2010). The call could not be recorded properly as we did not have a recording device during that period. However, the FMaxE was identified to be around 60 kHz using an Elekon BatScanner heterodyne detector (Elekon AG, Luzern, Switzerland). *Rhinolophus macrotis* has been recorded from scattered locations in Himalayas and Northeast India (Molur *et al.*, 2002). No recent published records exist from western Himalaya (Saikia, 2018). It is not a common bat and little is known about its habits (Bates and Harrison, 1997). Furthermore, a recent review of Tu *et al*. (2017) suggest that this taxon represents a complex of several species, thus genetic (which we lack from the single individual caught) and more precise bioacoustic data are still needed to resolve the taxonomic uncertainty surrounding this species complex in India.

Rhinolophus pearsonii Horsfield, 1851
Pearson's Horseshoe Bat

New locality records

Chamoli district: Mandal.

Previous records

Dehradun district: Mussoorie; Rudraprayag district: Narkota; Bageshwar district: Loharkhet (Bates and Harrison, 1997).

Remarks

Four individuals were caught in forest clearings and trails in oak forests and temperate evergreen forest at Mandal, Benog WLS and Ansuya Devi. They were identified by their intermediate size (FA = 51.2–54.2 mm — Appendix III) with respect to other rhinolophids found in the study area and by a differently-shaped noseleaf and lower lip. The sella had a broad base. Their calls had an FMaxE of 61 kHz. These characteristics are similar to those measured in *R. pearsonii* elsewhere (e.g. Zhang *et al.*, 2009). In India, *R. pearsonii* occurs in the Himalayas east of Uttarakhand and Northeast India (Molur *et al.*, 2002). It has not been reported from Himachal Pradesh (Saikia *et al.*, 2011).

Family Hipposideridae

Hipposideros armiger Hodgson, 1835
Great Himalayan Leaf-nosed Bat

New locality records

Chamoli district: Gairsain.

Previous records

Dehradun district: Mussoorie; Bageshwar district: Bageshwar; Almora district: Almora (Bates and Harrison, 1997).

Remarks

Five individuals were sampled. Four of these were caught from roosts in Maldevta and Gairsain. One individual was caught in a mistnet in an oak forest in Mussoorie. This is the largest insectivorous bat in India and its identity was unmistakable due to its size (FA 85.1–95.2 mm — Appendix III) and distinct noseleaf. The FMaxE had a range of 64–70 kHz. This species occurs in the Himalayas and Northeast India (Molur *et al.*, 2002; Saikia *et al.*, 2011).

One individual from Mussoorie had a COI sequence (602 bp) very similar (<1%) to homologous sequences of *H. armiger* from China (e.g. sequence HM540313) and Indochina (e.g., sequence HM540313).

Family Vespertilionidae

Plecotus homochrous Hodgson, 1847
Himalayan Long-eared Bat

New locality records

Tehri-Garhwal district: Devalsari, Dhanaulti; Chamoli district: Ansuya Devi, Shokharakh.

Previous records

Bageshwar district: Phurkia (?) (as *P. auritus* in Bates and Harrison (1997) but revised as *P. homochrous* in Spitzenberger *et al*. (2006).

Remarks

Ten individuals were captured at four locations: Devalsari, Dhanaulti, Ansuya Devi and Shokharakh. All individuals were males and were caught in dense primary forests of oak, cedar or sub-alpine rhododendron. The species was primarily identified by their smaller size (FA = 36.3–40.7 mm — Appendix III) relative to *P. wardi*. Their pelage was dense and largely brown dorsally and ventrally, but not woolly as described by Spitzenberger *et al*. (2006). However, the pelage characteristics are subjective and require a larger sample to find unifying patterns. *Plecotus homochrous* has been recorded in the southern slopes of the Himalayas from Jammu and Kashmir to northern West Bengal, generally at lower altitudes than *P. wardi* (Spitzenberger *et al.*, 2006) — but as shown here — may occur in syntopy.

Two individuals from Ansuya (KED-16 and KED-57) sequenced for 598 bp of the COI differed from each other by a single mutation. As *P. homochrous* had never been barcoded before, we report its sequence here for the first time. These haplotypes differ by at least 11.5% sequence divergence from any reference *Plecotus* and appear relatively basal with no special taxonomic affinities in the NJ tree (Fig. 4A).

Plecotus wardi Thomas, 1911
Kashmir Long-eared Bat

New locality records

Chamoli district: Shokharakh.

Previous records

Pithoragarh district: Milam, Martoli (under *P. austriacus* in Bates and Harrison (1997) but revised as *P. wardi* in Spitzenberger *et al*. 2006)).

Remarks

Two individuals, a male and a pregnant female, flew together into the mist net at Shokharakh in April 2016. They were identified by their relatively larger size (FA = 42.8 and 41.2 mm, respectively — Appendix III) and robust build compared to the two *P. homochrous* that were also caught at the same net before and after these bats. *Plecotus wardi* has been reported from the southern slopes of the Himalayas in Jammu and Kashmir, Uttarakhand (previously 'Uttaranchal' and 'Uttar Pradesh' prior to the year 2000) and Nepal. It typically occurs at higher elevations than *P. homochrous* (Spitzenberger *et al.*, 2006).

We obtained the COI sequences (633 bp) from three individuals from Shokharakh (KED-41, KED-42 and KED-43), all of which were identical. Again, this haplotype is the first available for *P. wardi* and the closest relative in BOLD are sequences of *P. ognevi* from Central Asia (e.g., JF443128), which are at least 11.5% divergent. Haplotypes from both species appear as sister taxa in the NJ tree (Fig. 4A).

Barbastella darjelingensis Cretzschmar, 1826
Eastern Barbastelle

New locality records

None.

Previous records

Dehradun district: Mussoorie; Bageshwar district: Kapkote [as *B. leucomelas* in Bates and Harrison (1997), revised as *B. darjelingensis* in Benda and Mlikovsky (2008) and Kruskop (2015)].

Remarks

Four individuals were caught at Benog WLS and Landour. The habitat at Benog WLS was a primary oak forest and at Landour, one individual was caught at a clearing on the top of a ridge. Three pregnant females were caught at Benog WLS in May 2016. *Barbastella darjelingensis* occurs in the Himalayas and Northeast India (Molur *et al.*, 2002; Kruskop, 2015) but a recent record by Wordley *et al*. (2014) from southern India suggests that it may be more widespread.

One individual from Mussoorie was sequenced for 556 bp of the COI gene. Compared to all available reference sequence of *Barbastella*, this haplotype was quite divergent (> 15% sequence divergence), including from those of Asian *B. leucomelas* (e.g., sequence JF442796), *B. caspica* (e.g., SKMZM1184-13) or one Nepalese *B. darjelingensis* (JF442795), as illustrated in Fig. 4A. Such high genetic distances are well above usual intra-specific divergences for bats (Baker and Bradley, 2006) meaning that the taxonomy of Himalayan barbastelles is still unsettled, as suggested by Kruskop (2015) and Kruskop *et al*. (2019).

Nyctalus leisleri Kuhl, 1817
Leisler's Bat

New locality records

Dehradun district: Bajawala; Tehri-Garhwal district: Maldevta, Devalsari, Dhanaulti; Nainital district: Pangot.

Previous records

Rudraprayag district: Dugalbitta; Almora district: Katarmal (Bates and Harrison, 1997).

Remarks

Eleven individuals were caught at four locations: Bajawala, Maldevta, Dhanaulti and Pangot. They were caught flying over open streams and in broad streams in oak forests. This is a smaller species of *Nyctalus*. The sampled individuals had an average FA = 44.28 mm — Appendix III). We could not conclusively separate *N. leisleri* from the endemic and range-restricted *N. montanus* based on the only known difference i.e. bicoloured versus uniform brown hairs for the latter. This character is, however, known to vary with season in European *N. leisleri* and is thus unlikely to be taxonomically relevant.

Two individuals from Devalsari and Pangot were sequenced and differed from each other by seven mutations (1.1%) over a stretch of 610 bp of COI. This is approximately the same divergence as that measured with other sequences of Eurasian *N. leisleri* available in BOLD, confirming the conspecificity of these geographically distinct populations. According to Saikia (2018) these are the first published records of this species in India since 1997.

Nyctalus noctula (Schreber, 1774)
Common Noctule

New locality records

Dehradun district: Benog WLS and Hanifl Centre (Mussoorie); Tehri-Garhwal district: Maldevta, Taapu Sera.

Previous records

Chamoli district: Gwaldam (in Bates and Harrison, 1997).

Remarks

Eight individuals were caught at five locations: Maldevta, Taapu Sera, Devalsari, Benog WLS and Landour at open streams in relatively undisturbed areas, primary oak forests and a forest clearing near human habitation. They were told apart from *N. leisleri* by their larger size (average FA = 53.71 mm, Fig. 4A). Two pregnant females were captured at Benog WLS in May 2016. *Nyctalus noctula* occurs across the Himalayas and Northeast India (Molur *et al.*, 2002). According to Saikia (2018) these are the first published records of this species in India since 1997.

Murina leucogaster Milne-Edwards, 1872
Greater Tube-nosed Bat

New locality records

Tehri-Garhwal district: Devalsari; Pauri-Garhwal district: Lansdowne. New record for the state and the western Himalayan region.

Previous records

None.

Remarks

One individual was caught at Devalsari in a primary deodar forest. It is larger than other *Murina* in the study area; the sampled individual had FA = 37.8 mm — Appendix III. The pelage had long and soft fawn-coloured hairs (paler ventrally, Fig. 5E) which sparsely covered the dorsal part of the interfemoral membrane. The posterior border of the ears had conspicuous emargination which separates it from other *Murina* spp. reported from the study area. A pregnant female was caught in Devalsari in May 2016. Echolocation call was recorded indoors. There are only two records of *M. leucogaster* from the Indian Subcontinent, one from Nepal and the other from northern West Bengal (Bates and Harrison, 1997; Molur *et al.*, 2002). The latest IUCN update has classified the population from the Subcontinent as extinct (Stubbe *et al.*, 2016). Hence, the record mentioned herein is the first sighting of *M. leucogaster* from the western Himalayas. It is, however, still unclear whether this slightly larger Himalayan form usually assigned to the subspecies *M. l. rubex*, is conspecific with *M. leucogaster* that is otherwise patchily found in Central and East Asia (Stubbe *et al*., 2016). Comparative DNA data would have provided valuable insight in this context, but unfortunately no blood sample could be obtained from this individual. According to Saikia (2018) these are the first published records of this species in India since 1997.

Murina cyclotis Dobson, 1872
Round-eared Tube-nosed Bat

New locality records

Tehri-Garhwal district: Devalsari. New record for the state and the western Himalayan region.

Previous records

None.

Remarks

One individual was caught at Devalsari in the intersection of deodar forest and scrub-covered hills. It was identified by its size (FA = 32.73 mm — Appendix III) and absence of emargination on ears (which separates it from *M. leucogaster* and *M. tubinaris*). Its pelage was composed of long and soft, bright orange hairs (in which it differed from known specimens of *M. huttoni* of Indian Subcontinent) which moderately covered the dorsal part of the interfemoral membrane. The ventral pelage was largely white. The hind legs were densely covered with hairs. The ears were broadly rounded. The first upper premolar was shorter than the second which ruled out the rare and endemic, *Harpiola grisea* (Bhattacharya, 2002). Echolocation call

was recorded indoors. *Murina cyclotis* is the most widely distributed *Murina* in India. It has been reported from scattered locations in Northeast India, Andhra Pradesh, the Himalayas east of Nepal (Molur *et al.*, 2002; Ruedi *et al*., 2012), Western Ghats (Menon, 2014; Raghuram *et al*., 2014) and Andaman and Nicobar Islands (Aul *et al*., 2014). This is the first record of this species from the Western Himalayas.

Murina huttoni Scully, 1881
Hutton's Tube-nosed Bat

New locality records

Pauri-Garhwal district: Lansdowne; Tehri-Garhwal district: Dhanaulti.

Previous records

Dehradun district: Dehradun; Bageshwar district: Khati.

Remarks

Two individuals were caught together in an undisturbed oak forest in Dhanaulti and one in a pine forest in Lansdowne. They were identified by their size (average FA = 35.2 mm — Appendix III) and presence of indistinct emargination on the posterior border of the ears. The pelage had long and soft hairs of dull brown or buff colour, which is unique among Indian *Murina*. The dorsal interfemoral membrane and feet had short hairs. Echolocation calls were recorded outdoors. *Murina huttoni* is considered as a widespread species that is distributed throughout the Himalaya and disjunctly in China, Laos PDR, Vietnam and peninsular Malaysia (Csorba *et al*., 2019). In the Indian Subcontinent it is known from Pakistan, Jammu and Kashmir, Uttarakhand, Nepal, West Bengal, Assam and Arunachal Pradesh (Molur *et al.*, 2002).

Two individuals from Dhanaulti and Lansdowne sequenced for 597 bp of COI differed by a single mutation. Interestingly, both haplotypes diverged extensively (> 6.5%) from those of bats assigned to *M. huttoni* from China (e.g. sequence HM540979), Laos (e.g., HM540976) or Vietnam (KX098592) (Francis *et al*., 2010; Tu *et al.*, 2015). Because the Uttarakhand samples are the first ones collected near the type locality (Dehradun) of *M. huttoni*, they can be considered as topotypes, whereas genetically divergent bats from other countries deposited in GenBank or BOLD might represent another taxon of *Murina*.

Murina aurata Milne-Edwards, 1872
Little Tube-nosed Bat

New locality records

Chamoli district: Ansuya Devi. New record for the western Himalayan region.

Previous records

None.

Remarks

One individual was captured at Ansuya Devi in a clearing in secondary montane forest. It was identified by its smaller size (FA = 29.4 mm — Appendix III) than other *Murina* spp. of the study area and its striking pelage. It was densely covered with long hairs banded golden at the tips and black near the base all over its body and on its forearm, hind legs and interfemoral membrane. These characters are similar to those of *Harpiola grisea*, however the first upper premolar was smaller than the second as against *Harpiola* where it is larger (Bates and Harrison, 1997; Bhattacharya, 2002). *Murina aurata* has been recorded four times in the Indian Subcontinent; twice in Nepal and once each in Eastern Himalayas and Northeast India (Bates and Harrison, 1997). This is the first record from Western Himalayas which represents the westernmost occurrence of this poorly known species. According to Saikia (2018) these are the first published records of this species in India since 1997.

Myotis longipes (Dobson, 1873)
Kashmir Cave Bat

New locality records

Dehradun district: Benog WLS and Woodstock School; Chamoli district: Mandal. New record for Uttarakhand.

Previous records

None.

Remarks

Ten individuals (FA = 33.1–36.5 mm — Appendix III) were caught trawling over an open stream in Mandal and over brooks in oak forests in Benog WLS, Woodstock dorms, Gairsain and Ansuya Devi. The individuals had hind feet, greater than or about half of the length of the tibiae. The wing attachment was to the base of metatarsus near the ankle and these bats had relatively long ears with narrow, tall and straight tragus and small canines. According to

Topál (1997), *M. longipes* is likely endemic to Afghanistan and India and records from elsewhere require revision as its distinction from the related *M. laniger* is unclear (Ruedi *et al*., 2013). In India it has been reported from Jammu and Kashmir (Topál, 1997) and Meghalaya (Kruskop, 2016). These are the first records from Uttarakhand.

One individual from Mussoorie was sequenced for 614 bp of the COI. This haplotype differed by at least 9.9% from any other *Myotis* sequence found in GenBank or in BOLD, including those assigned to *longipes* or *laniger* (e.g., HM541025). It appears therefore in a quite distant position from putative congeners in the NJ tree, suggesting that the whole species complex needs taxonomic revision (Fig. 4B). This sequence of *Myotis longipes* from Uttarakhand is the closest available to the type locality (Kashmir). Besides those reported by Topál (1997), no other recent records exist from western Himalaya (Saikia, 2018).

Myotis nipalensis Dobson, 1871
Nepalese Myotis

New locality records

Nainital district: Pawalgarh. New record for Uttarakhand.

Previous records

None.

Remarks

One individual was caught with a handheld net out of a colony of *c.* 20 individuals from a tunnel in Pawalgarh in June 2016. It was identified by its size (FA = 34.75 mm — Appendix III), small hind foot length (6.64 mm) in relation to tibia, relatively well-developed canines and the attachment of wings to the base of the toe. Fur was creamy-white ventrally and brownish with lighter tips dorsally. Although the type locality of *M. nipalensis* lies in the Himalayas (Kathmandu, Nepal) most modern faunal records from India do not mention this taxon because it was often included as a junior synonym of *M. mystacinus* (e.g., Bates and Harrison, 1997 or Saikia, 2018). Hence the actual distribution of this species in the Himalaya is not known as yet. These are the first explicit records of this species in India since 1997.

Myotis muricola (Gray, 1864)
Nepalese Whiskered Bat

New locality records

Chamoli district: Mandal, Ansuya Devi.

Previous records

Dehradun district: Dehradun, Mussoorie; Bageshwar district: Phurkia; Almora district: Deori (Bates and Harrison, 1997). However, as most authors did not make the difference between *M. muricola* and *S. caliginosus* (see below), part or all these records may not represent genuine *M. muricola*.

Remarks

One individual was caught over a stream at an oak forest edge in Mandal and another in a primary broadleaved forest in Ansuya. They were identified by their size (FA: 35.9, 37.9 mm — Appendix III), small hind foot length (5.1, 6.6 mm) with respect to tibiae, relatively well-developed canines and wing attachment (to the base of the toe). The ventral fur was dark grey, not whitish, and it lacked any forward-projecting emargination to the rear edge of the ear. *M. muricola* is distributed across the Himalayas and in parts of Northeast Asia (Bates and Harrison, 1997).

Myotis cf. *frater* Aellen, 1923
Long-tailed Whiskered Bat

New locality records

Tehri-Garhwal district: Devalsari; Chamoli district: Mandal. New record for the country.

Previous records

None.

Remarks

Five individuals were caught at the intersection of scrub-covered hills and cedar forest, primary oak forest and forest edge. They were of intermediate size (average FA = 41.1 mm — Appendix III) compared to other Myotinae of the study area, had a long tail, very small feet (about 30% of tibiae) with wing membranes attached to the basis of toe, and relatively short ears (Fig. 5C). These characters are typical of members of the long-tailed whiskered bat *Myotis frater* species group (Tsytsulina and Strelkov, 2001). However, none of the taxa contained in this group have been mentioned so far from the Indian Subcontinent (e.g., Bates and Harrison, 1997; Benda and Gaisler, 2015). A recent molecular survey (Ruedi *et al.*, 2015) confirmed that the nominal species (*M. f. frater*) is found exclusively in China and Taiwan, together with the sister species *Myotis soror*, whereas *M. f. kaguyae* occurs in Japan, *M. f. longicaudatus* in the Russian Far East and *M. f. eniseensis* in Siberia. The only taxon in this group

that occurs close to the Indian ubcontinent is *Myotis bucharensis*, a very rare bat living in desert regions of Turkestan, Tajikistan and Uzbekistan (Benda and Gaisler, 2015). The bats that we captured lived in more forested habitats and had a much darker pelage than that reported for the latter species. Thus, although they clearly belong to the distinctive *M. frater* species group defined by Tsytsulina and Strelkov (2001), the Uttarakhand specimens might represent a new taxon. Unfortunately, no representative specimen was conserved as a voucher hindering any further description of this interesting species.

Three specimens from Mandal were sequenced for 597 bp of the COI and differed by a single mutation. No matching sequence was found in the GenBank or BOLD reference databases, as all diverged by at least 12% from these Indian haplotypes, including those of *M. frater* reported from Russia (e.g., sequence JF442988) and China (e.g., sequence JF442979) (Kruskop *et al.*, 2012). The closest relative is apparently the Taiwanese endemic *M. soror* (Fig. 4B), whose COI sequence diverges by 9% from the Uttarakhand haplotypes. Given such high genetic distances between those taxa, the taxonomic position of the Indian samples is unsettled.

Myotis cf. *annectans* Dobson, 1871
Hairy-faced Bat

New locality records

Tehri-Garhwal district: Devalsari.

Previous records

None.

Remarks

Two individuals were caught in Devalsari at an intersection of cedar forest and scrub-covered hills and one in Mandal at the edge of an oak forest. They were distinctive by their larger size (average FA = 46.3 mm — Appendix III) compared to *M.* cf. *frater*. Dorsal pelage was short, soft and dark brown in colour. Ventral pelage had dark bases and pale grey tips. All individuals showed a distinct fawn-coloured patch near the abdomen. The ears were small with bluntly-rounded tips and the tragii were broad and curved. The muzzle was hairless. Upper canines were short and robust. Feet were relatively short with a wing insertion to the ankle. According to the keys used, this bat species would key out as *Myotis annectans* or *M.* (*montivagus*) *peytoni.* However, we could not verify the craniodental characters which differentiate species in this difficult taxonomic group (Görföl *et al.*, 2013), and hence preferred to leave this *Myotis* as cf. *annectans*, with some reservation.

One individual from Mandal was sequenced for 597 bp of the COI. None of the homologous sequence of *Myotis* available in GenBank or BOLD matched this haplotype. In particular, the Uttarakhand haplotype differed considerably (> 13%) from any reference sequences assigned to *M. annectans* or to *M. indochinensis/montivagus* from South-East Asia (Francis *et al.*, 2010; Kruskop *et al.*, 2012), which again suggests further taxonomic complications (Fig. 4B). As the type locality of *M. annectans* (and other related taxa in this group, see Görföl *et al.*, 2013) lies in north-eastern India, i.e. far away from Indochinese samples available so far in public repositories, it is possible that the later represent other species while the Uttarakhand specimen is a real *annectans*.

Myotis blythii Tomes, 1857
Lesser Mouse-eared Bat

New locality records

Tehri-Garhwal district: Devalsari.

Previous records

Dehradun district: Mussoorie (Bates and Harrison, 1997).

Remarks

One individual was caught in Devalsari at an intersection of deodar forest and scrub. This species is unambiguously identified in the studyarea as it is the largest *Myotis* in India with robust build and long and slender tragii. It has been reported from Western Himalayas and arid scrublands of Rajasthan (Molur *et al.*, 2002; Saikia *et al.*, 2011).

Submyotodon caliginosus (Tomes, 1859)
Blanford's Bat

New locality records

Chamoli district: Shokharakh.

Previous records

Some records of *M. mystacinus* or *M. muricola* may be referable to this species (Benda and Gaisler, 2015); at least the type specimens of *Vespertilio caliginosus* and *V. blanfordi*, both from Himachal Pradesh, are earlier records of its occurrence in the Western Himalayas.

Remarks

One individual was caught over a brook at a sub-alpine forest in Shokharakh. It was identified by its size (FA = 36.3 mm — Appendix III), shorter ears (EL = 11.5 mm) than other Myotinae, with strong forward-projecting emargination to the rear edge; broad, short, curved and forwardly-directed tragus, and slightly bulging forehead. Its fur was shaggy. The hind feet were very small; less than half the size of the tibiae. Wing attachment was to the base of the toe. The teeth were small; upper canines and molars were well-developed while the pre-molars were reduced. *Submyotodon caliginosus* is often considered synonymous with *M. muricola,* hence, the actual distribution of this species is still understudied. Benda and Gaisler (2015) suggested that this poorly known species might be restricted to the mountain regions of western Himalaya, including northern India, Pakistan and marginally eastern Afghanistan. The generic name associated to this species, *Submyotodon*, was proposed by Ruedi *et al.*, (2015) based on the distinctive genetic and morphological characters that differentiate them from any other Myotinae.

Mirostrellus joffrei Thomas, 1915
Joffre's Pipistrelle

New locality records

Chamoli district: Mandal. New record for the western Himalayan region.

Previous records

None.

Remarks

One individual was caught flying over an open stream at the edge of an oak forest in Mandal village. It differed markedly from any *Pipistrellus*-like species on account of its tragus shape and pelage characters. The tragus was more like that of *Nyctalus* spp. than *Pipistrellus* spp. The dorsal pelage consisted of long and silky hair of a rich, chocolate brown colour, whereas it was a contrasting yellow on the ventral side, as in the specimen illustrated in Saikia *et al*. (2017). This is a very rare species known from very few specimens from a few locations in northern Myanmar, India, Nepal and Vietnam (Görföl *et al*. 2020). Within the political boundaries of India, *M. joffrei* has been caught in Meghalaya and Sikkim (these specimens were wrongly assigned to *Philetor brachypterus*) (Saikia *et al*., 2017). This is the first record from Western Himalayas.

Pipistrellus tenuis Temminck, 1840
Indian Pygmy Bat

New locality records

Dehradun district: Bajawala, Shikhar Falls.

Previous records

Nainital district: Sitabani, Ramnagar, Haldwani, Kaladhungi.

Remarks

Four individuals were caught at Bajawala and Shikhar Falls at streams in scrub-covered hills. They were identified by their smaller size (FA = 26.9–29.5 mm — Appendix III) in comparison to other *Pipistrellus* spp. and by the absence of hair on interfemoral membrane. Their small size and other pelage characters led some authors (e.g. Sinha, 1999) to consider the Indian form as a distinct species *P. mimus* Wroughton, 1899. It is a widespread species that has been reported from nearly all states in India but it appears to be restricted to areas below 1,500 m a.s.l. (Bates and Harrison, 1997).

Pipistrellus sp. (Gray, 1838)
Unknown Pipistrelle

New locality records

Dehradun district: Wildlife Institute of India Campus.

Remarks

One individual was caught at Wildlife Institute of India (WII) Campus at a stream at the edge of a sal forest near human habitation. It appeared slightly larger than *P. tenuis* (FA = 31.5 mm — Appendix III) and its interfemoral membrane had short hairs near the body. However, as similar-sized species in this group in the Indian Subcontinent (e.g. *P. javanicus*, *P. coromandra* or *P. paterculus*) are particularly difficult to identify with external or even craniodental characters (Bates *et al*., 2005), we refrained from assigning this animal to any specific species.

Pipistrellus cf. *ceylonicus* Kelaart, 1852
Kelaart's Pipistrelle

New locality records

Tehri-Garhwal district: Maldevta, Devalsari, Dhanaulti; Chamoli district: Mandal; Pauri-Garhwal district: Lansdowne. New record for Uttarakhand.

Previous records

None.

Remarks

Thirty individuals were caught at five sites: Maldevta, Mandal, Devalsari, Dhanaulti and Lansdowne. It is a common bat at altitudes above 1,500 m and was always caught in rather open forests or near human habitation. They were identified by their larger size relative to other pipistrelles (average FA = 34.5 mm — Appendix III).

Seven individuals from Mandal and Lansdowne were sequenced and produced 635 bp. KED-32, KED-33, KED-34, KED-35, KED-48 and LAN-01 all had identical COI haplotypes, while KED-53 differed by only two mutations from the latter (0.3% seq. div.). These haplotypes from Uttarakhand had no matching sequences published in either GenBank or BOLD. The closest available sequences of *Pipistrellus* are those of *P. tenuis* from Indochina (at least 7.6% sequence divergence; HM541285) but appear well apart from the Uttarakhand haplotype (Fig. 4C). An unpublished sequence from Kerala assigned by Srinivasulu and colleagues to *P. coromandra* (sequence MG521188) is slightly more similar (at 7.1%), but still unlikely represents the same taxon as the north Indian ones (Fig. 4C). Another unpublished sequence from Kerala (sequence MG521192) and assigned by the same authors to *P. ceylonicus* is even more divergent (10%). Hence, although we are confident that our common species from Uttarakhand is morphologically close to *P. ceylonicus*, the considerable taxonomic uncertainty which exists in the available reference sequences and the absence of voucher to check in more details diagnostic morphological characters hinders a firm identification of our sampled bats. *P. ceylonicus* has been reported from peninsular India, Northeast India and Himachal Pradesh (Bates *et al.*, 2008*b*; Saikia *et al.*, 2011; Boro *et al.*, 2018).

Arielulus circumdatus (Temminck, 1840)
Black-gilded Pipistrelle

New locality records

Chamoli district: Shokharakh. New record for Uttarakhand and Western Himalaya.

Previous records

None.

Remarks

One male was caught at the edge of sub-alpine rhododendron forest at Shokharakh. It was identified by its size (42.86 mm — Appendix III) and distinctive pelage in which the hairs were soft and long, dark brown at the base with cuprous red tips. The ear margin was broad white and the tragus was pipistrelle-like and creamish in colour (Fig. 5B). *Arielulus circumdatus* is a rare species that has been reported only thrice in the Indian Subcontinent from Nepal, Meghalaya and Mizoram (Bates and Harrison, 1997; Mandal *et al*., 2000).

Eptesicus tatei Ellerman and Morrison-Scott, 1951
Sombre Bat

New locality records

Chamoli district: Shokharakh. New record for Uttarakhand and Western Himalaya.

Previous records

None.

Remarks

One female was caught at the edge of sub-alpine rhododendron forest at Shokharakh. It was smaller than *E. serotinus* (FA = 42.8 mm — Appendix III). Overall, it superficially resembled *Eptesicus nilssonii* from Europe. The dorsal pelage was dark sooty black with golden-brown hair-tips, giving a frosted appearance to the long and dense fur. The ventral pelage was lighter, yellowish brown near the tips, but much darker along the bases of hairs, which were comparatively shorter than in the dorsal parts. The ears were oval with rounded tips, without fleshy bases (Fig. 5A); the tragus was relatively short and rounded, but straight (not curved inwards, like in *Eptesicus pachyotis* or *Nyctalus*). Six dermal ridges could be counted on the posterior border of the ears. Naked parts were dark, nearly black (especially ears and tragus). The inner (first) upper incisor was bifid, the outer (second) one being considerably smaller and with a single cusp. Our specimen from Uttarakhand thus corresponded very closely to the description of the type series of *E. tatei* made by Dobson (1878) under the name "*Vesperugo atratus*". *Eptesicus tatei* is a very rare bat, possibly endemic to India, and known from just three specimens from Darjeeling in the Himalaya of West Bengal (Bates and Harrison, 1997). It has not been recorded recently (Saikia, 2018). Nothing is known of its ecology.

This individual was sequenced for 586 bp of the COI gene. None of the existing reference sequences matched closely this haplotype (Fig. 4D), confirming the singularity of this extremely rare species.

The closest taxa were Oriental samples of *E. serotinus*, *E. bottae* and *E. nilssonii* (Fig. 4D), but they diverged by at least 7.3 % from *E. tatei*.

Eptesicus serotinus Schreber, 1774
Common Serotine

New locality records

Tehri-Garhwal district: Devalsari.

Previous records

Dehradun district: near Mussoorie (Bates and Harrison, 1997).

Remarks

Two individuals were caught at Devalsari and Mandal at the intersection of deodar forest and dry scrub, and at the edge of an oak forest, respectively. The species was identified by its small and blunt tragus, large size (average FA = 52.0 mm — Appendix III)) and soft dorsal pelage of greyish-black hair. The ears had transverse ridges. *Eptesicus serotinus* has been recorded across the Himalayas and parts of Northeast India (Molur *et al.*, 2002).

One individual from Mussorie (MUS-29) was sequenced for 657 bp of the COI. Comparisons in BOLD identified this haplotype as a member of a cluster of sequences (Fig. 4D) including *E. serotinus* sampled in Vietnam (e.g., sequence KX496341), Laos (e.g. sequence HM540267) and China (Francis *et al.*, 2010) and differed by less than 1% from those haplotypes. All other sequences currently assigned to *E. serotinus* and coming from the West Palearctic are much more divergent. These relationships thus confirm recent genetic investigations (Juste *et al.*, 2013) suggesting that the South and East Asian forms represent a species distinct from *E. serotinus*.

Scotophilus heathii Horsfield, 1831
Asiatic Greater Yellow House Bat

New locality records

Dehradun district: Bajawala.

Previous records

Nainital district: Haldwani, Kaladhungi, Ramnagar (Bates and Harrison, 1997).

Remarks

Three individuals were captured over an open stream at Bajawala. They were easily identified by their size (FA = 60.91–61.92 mm — Appendix) and acutely curved, sickle-shaped tragus. The ventral pelage was characteristically bright yellow. *Scotophilus heathii* is a common and widespread bat in India. It is found throughout the country but has not been reported from elevations above 1,000 m in the Himalayas (Molur *et al.*, 2002). It was not reported from Himachal Pradesh by Saikia *et al.* (2011) and even in this study we did not encounter this species in the hills.

Family Miniopteridae

Miniopterus fuliginosus Hodgson, 1835
Eastern Bent-winged Bat

New locality records

Dehradun district: Bajawala; Tehri-Garhwal district: Dhanaulti.

Previous records

Dehradun district: Mussoorie; Nainital district: Ramnagar (as *Miniopterus schreibersii* in Bates and Harrison, 1997).

Remarks

Thirteen individuals were caught at five sites: Bajawala, Maldevta, Landour, Benog WLS and Dhanaulti at a variety of habitats: open streams, shrub-covered hills to oak forests. Pregnant females were caught in May in Benog WLS. The species was identified by its domed forehead, rhomboidal ears and an extra-long third phalange of the second finger; and from other *Miniopterus* by its size (FA = 47.5–49.3 mm — Appendix III).The latter values in particular are smaller than those of *Miniopterus magnater* measured in NE India (FA = 50.6 ± 0.9 mm; Saikia *et al.*, 2018). Although published records of *M. fuliginosus* (usually reported as *Miniopterus schreibersii* in previous publications) mainly come from the Himalayas, Northeast India and a single area of the Western Ghats of Maharashtra (Molur *et al.*, 2002; Wordley *et al.*, 2014), it is likely more widespread.

Discussion

Comments on Noteworthy Distribution Records

We have reported the presence of 35 species and calls of 32 species. Twelve species are reported for the first time from western Himalaya or from Uttarakhand which takes the consolidated checklist

up to 49 species in Uttarakhand. The most widespread and frequently caught species were: *Pipistrellus* cf. *ceylonicus*, *M. longipes*, *R. affinis*, *N. leisleri*, *N. noctula* and *M. fuliginosus*. All of these species except for *M. longipes* were captured from 600 to 2,100 m a.s.l. *Myotis longipes* was only caught above 1,400 m a.s.l. *Pipistrellus tenuis*, *S. heathii*, *M. nipalensis*, *R. pusillus* and *T. teniotis* were only caught at the foothills (close to or below 1,000 m a.s.l.). *Pipistrellus tenuis* and *S. heathii* have only been reported from the foothills in the Subcontinent (Bates and Harrison, 1997) and may likely be restricted to lower elevations. *Rhinolophus pusillus* and *T. teniotis*, though, have been recorded from elevations above 1,500 m a.s.l. (Bates and Harrison, 1997). The distribution of *M. nipalensis* is not properly known. Notable records from our survey include rare species such as *A. circumdatus*, *E. tatei*, *M. joffrei*, *M. aurata* and *M. leucogaster*. All of these are Indomalayan species that are known from sporadic records in eastern India, Nepal and Southeast Asia (Bates *et al.*, 2008*a*; Francis *et al*., 2008; Görföl *et al*., 2016; Molur *et al*., 2016; Stubbe *et al*., 2016). Therefore, our records extend the known distribution ranges of these species by 800 to 1,000 km. In the case of *A. circumdatus* and *E. tatei* the elevational distributions are also extended by ca. 1,000 m. However, we did not catch any of the four species of pteropodids reported previously from Uttarakhand. Pteropodids can also be identified by their distinctive flight pattern, but none were seen in flight. Most published records of this family are from the Kumaon division from the 1960s and 1970s. The plant species composition of mid and high altitude forests in Uttarakhand is similar to temperate regions (Körner, 2000; Gairola *et al*., 2008), so tropical fruiting trees are limited. It is probable that pteropodids occur in low densities, at least above 1,500 m a.s.l., and more sampling will be needed to document them.

We caught the highest diversity of bats at mid-elevation sites (1,000−2,000 m a.s.l.) and specifically in Devalsari. While most sites in the mid-elevation were dominated by oak (*Quercus* spp., mostly *Q. leucotrichophora*) forests, Devalsari was the only site that had predominantly deodar (*Cedrus deodara*) forest surrounded by dry scrub-covered hills. This difference in habitat might have resulted in the capture of species that were not caught elsewhere in the study area. However, we cannot conclude a mid-domain effect or that Devalsari has the highest alpha diversity (relative to area) because our trapping effort is not uniform across sites and elevation zones. In low elevations we could not sample in protected areas with relatively undisturbed habitats as they are tiger reserves where working at night is prohibited. Therefore, we might have missed some important forest-dwelling species. Sampling at elevations above 3,000 m a.s.l. was also a challenge as the main habitat is open, sloping meadow with windy conditions that do not favour mistnetting.

Comments on the Echolocation Call Library

We have described the echolocation calls of 32 species of which, nine species were recorded for the first time. To our knowledge, this is the largest published echolocation call library by species, after Hughes *et al*. (2010, 2011) and the largest among the few published from India (Raghuram *et al*., 2014; Wordley *et al*., 2014; Srinivasulu *et al*., 2017). Our low sample sizes per species do not allow us to significantly differentiate across/classify species using multivariate statistics. The echolocation calls of *Rhinolophus* spp. and *Hipposideros* spp. can be identified reasonably, except for *R. affinis* and *R. sinicus*. The similarity in peak frequency of these two species has also been reported from China (Zhang *et al*., 2009) and Nepal (SMCRF bat call library (not peer-reviewed), available online at http://smcrf.org/resource/nepalbatcall/). Both *R. sinicus* and *R. affinis* have been collected from Mussoorie in the past (Bates and Harrison, 1997; Thomas, 2000). However, we only caught *R. affinis* in Mussoorie, Devalsari and Dhanaulti, despite our reasonable sampling effort. Similarly, we only caught *R. sinicus* in Kedarnath Wildlife Sanctuary.

We found overlap in the echolocation calls of several pairs or groups of species emitting frequency-modulated (FM), quasi constant frequency (QCF) and FM-QCF calls. Among FM-QCF species, *A. circumdatus* and *E. tatei*, *M. joffrei* and *P.* cf. *ceylonicus*, *M. fuliginosus* and *P. tenuis* have similar spectral features. All these pairs of species were captured at the same locations and habitats during our survey and are definitely syntopic. *Pipistrellus* cf. *ceylonicus* and *S. heathii* are also acoustically similar (also see Wordley *et al*., 2014) but the latter is possibly absent from elevations above 1,500 m a.s.l. We advise caution in identifying the above species pairs solely based on acoustics, at least, in Uttarakhand.

Among open-space foraging QCF species, *N. leisleri*, *N. noctula* and *E. serotinus* have overlapping frequencies. The similarities in our measurements

are partly an artefact of recording with a hand-release; however, the problems with classifying the calls of free-flying individuals of these species are well-known in Europe (Russo and Jones, 2002). When comparing calls recorded in open space, Russo and Jones (2002) suggest looking for alternating call structures that are characteristic of *Nyctalus* spp. As expected, there was a high degree of overlap among the *Murina* spp., and *Myotis* spp. and *S. caliginosus*. With the exception of *M. blythii* that is easily identifiable in this region, our data from both these genera show overlaps in peak frequencies but the end frequencies seem segregated and may be useful in acoustic identification. However, we discourage the identification of the following species pairs from recordings: *M. longipes* and *M. nipalensis* and, *S. caliginosus* and *M. muricola*.

Our study sets up a crucial baseline on diversity, local and elevational distribution and echolocation calls of the bats of Uttarakhand. As a signatory to the Convention on Biodiversity, all states in India are mandated to document their diversity. In this regard, we have filled a crucial gap in Uttarakhand and the checklist presented here will find usefulness in species management and conservation. We envision our echolocation call library to be of importance not only to ecologists but also to taxonomists and biogeographers as Uttarakhand lies in the junction of the Palaearctic and Indomalayan zones. Since our results show that acoustic identification of FM bats may be ambiguous, we recommend the use of acoustic surveys and monitoring only at smaller geographical scales in better-surveyed sites like Kedarnath WLS.

Comments on Species Identification

It was our initial choice not to keep any voucher from the captured bats, and to try to identify species based on photographs, external measurements, echolocation calls, and for some individuals, on non-lethal genetic data, as recommended by Russo *et al.* (2017). However, we experienced that for poorly studied areas such as Uttarakhand, reliable identification of several taxa, including some extremely rare or potential new species, was not feasible without additional craniodental investigations. This was not only due to the presence of very similar species that are nearly impossible to differentiate with external characters (e.g. pipistrelles), but also because several taxa are still poorly known or totally absent from the available identification keys for India (e.g., *S. caliginosus* or *M. frater*). The nearly complete lack of carefully identified, voucher-based reference sequences from the Indian Subcontinent available in genetic repositories also contribute to our inability to apply otherwise efficient DNA barcoding methods to identify new samples (Francis *et al.*, 2010). Even when referenced DNA barcodes existed in public repositories (e.g., in BOLD) new taxonomic challenges emerged, either because the previously identified specimens likely represented distinct species than the one assigned to the sequence (e.g., *M. huttoni* from outside India), or because the global systematics of difficult groups are still largely unsettled (e.g. for *Pipistrellus* or small Myotinae of the Himalayas). Unfortunately, if these presumably rare or unknown species remain taxonomically unidentified, they have no scientific or legal existence and therefore escape protection. We therefore strongly recommend that bat surveys conducted in such species-rich, but poorly documented areas as the Himalaya should include a reasonable collection of voucher specimens. These specimens must be deposited in public repositories such as those of the Zoological Surveys of India, in order to be accessed and properly identified by specialized taxonomists. In saying this we, of course, do not advocate indiscriminate collection of specimens (Russo *et al*., 2017), but highlight the need for better reference sequences in poorly sampled areas. There must be a strong justification in the need for collecting specimens and when possible, should be limited to few male specimens. The ultimate goal of taking vouchers must be to create unequivocal non-invasive identification of the species so that future researchers do not have to kill individuals of the same species for the purpose of their research.

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Appendix I

Details of the locations that were sampled during this survey with sampling effort. Locations 19–22 were sampled opportunistically using handheld nets

No.	Site	District	Dominant habitat	Mean elevation (m a.s.l.)	No. of	
					trap hours	species detected
1	Wildlife Institute of India (WII) Campus	Dehradun	Forest edge	593	23	1
2	Bajawala	Dehradun	Open stream	638	16	7
3	Guniyal Gaon	Dehradun	Open stream	860	7	1
4	Rajpur	Dehradun	Shrub-covered hills	1025	6	1
5	Benog WLS	Dehradun	Oak and deodar forest	1755	23.5	8
6	Woodstock dorms	Dehradun	Oak forest	1787	16.5	4
7	Hanifl Centre	Dehradun	Ridge top (oak forest clearing)	2179	7	2
8	Maldevta	Tehri-Garhwal	Shrub-covered hills	846	8	8
9	Taapu Sera	Tehri-Garhwal	Open stream	1007	9	2
10	Devalsari	Tehri-Garhwal	Deodar forest and scrub	1698	54	10
11	Ranichauri	Tehri-Garhwal	Secondary oak forest	1827	9	0
12	Dhanaulti	Tehri-Garhwal	Oak forest	2114	25.5	6
13	Lansdowne	Pauri-Garhwal	Pine forest	1615	22.5	2
14	Mandal	Chamoli	Village, forest edge and streams	1530	90.5	9
15	Bulkhan	Chamoli	Sub-alpine forest	2800	7	0
16	Ansuya Devi	Chamoli	Primary and secondary forest	2582	62.5	7
17	Shokharakh	Chamoli	Sub-alpine forest	3065	48	5
18	Pangot	Nainital (Kumaon)	Oak forest	1976	28.5	2
19	Jharipani*	Dehradun	Shrub-covered hills	1410	–	2
20	Landour Bazaar*	Dehradun	City	2022	–	1
21	Gairsain*	Chamoli	Pine forest	1993	–	1
22	Pawalgarh*	Nainital (Kumaon)	Sal forest	495	–	1

Appendix II

Species name, origin, field number and GenBank reference corresponding to the barcode (COI) sequences generated in this study. All sequences from Indian bats are based on blood samples taken from released bats, whereas sequences of other bats were issued from the frozen tissue collection of the Muséum d'Histoire Naturelle de Genève (MHNG)

Taxon	District, Country	Field number	GenBank number
Barbastella darjelingensis	Dehradun district, India	MUS-24	MN339178
Eptesicus serotinus	Dehradun district, India	MUS-29	MN339179
E. tatei	Chamoli district, India	KED-44	MN339180
Hipposideros armiger	Dehradun district, India	MUS-11	MN339181
Murina huttoni	Pauri-Garhwal district, India	LAN-05	MN339182
M. huttoni	Tehri-Garhwal district, India	MUS-40	MN339183
Myotis cf. *frater*	Chamoli district, India	KED-37	MN714904
M. cf. *frater*	Chamoli district, India	KED-55 and KED-56	MN339184
M. frater	Miaoli province, Taiwan	MHNG 1998.053	MN339185
M. longipes	Dehradun district, India	MUS-12	MN339186
M. cf. *annectans*	Tehri-Garhwal district, India	KED-50	MN339187
M. soror	Hualien province, Taiwan	M2128	MN339188
Nyctalus leisleri	Nainital district, India	NTL-01	MN714905
N. leisleri	Dehradun district, India	MUS-51	MN339189
Pipistrellus pipistrellus	Rhodos, Greece	MHNG 1992.004	MN339190
P. pygmaeus	Thurgau province, Switzerland	MHNG 3003.068	MN339191
P. cf. *ceylonicus*	Chamoli and Pauri-Garhwal districts, India	KED-32 to 35, 48 and LAN-01	MN339192
P. cf. *ceylonicus*	Chamoli district, India	KED-53	MN339193
Plecotus homochrous	Chamoli district, India	KED-16	MN339194
P. homochrous	Chamoli district, India	KED-57	MN339195
P. wardi	Chamoli district, India	KED-41-43	MN339196
Rhinolophus affinis	Dehradun district, India	MUS-13	MN339197

Appendix III

Measurements of eight external morphological traits of 33 bat species. FA — forearm length, BM — body mass, Tail — tail length, EL — ear length, HF — hind foot length, TIB — tibia length, T — thumb + claw length, W — wingspan. *n* indicates the number of individuals caught (including juveniles and pregnant females). Numbers in each column denote mean values followed by minimum to maximum values. Number in parentheses after mean values of each measurement indicates sample sizes only for adult and non-pregnant individuals. Where no number in parentheses is specified, all the individuals sampled were non-pregnant adults (except *M. leucogaster* where only one pregnant female was caught). All measurements were taken from live animals in the field. Wingspan was measured from wing tracings. Measurements are in mm and BM is in g

Family/Species	*n*	FA	BM	Tail	EL	HF	TIB	T	W
				Molossidae					
Tadarida teniotis	6	62.2							
		60.1–63.2	–	–	–	–	–	–	–
				Rhinolophidae					
Rhinolophus affinis	8	53.8	17.1 (6)	18.7 (4)	17.2 (4)	9.2 (4)	22.6 (4)	5.5 (4)	310.2 (4)
		52.7–55.6	16–18.5	14.3–22.1	14.6–19.3	8.2–9.7	21.6–23.5	5.0–6.4	282.9–318
R. sinicus	1	45.7	10.5	21.6	13.8	6.5	19.4	4.4	250.1
R. lepidus	4	39.6	5.8 (3)	16.5	15.2	5.7	15.6	3.4	240.8
		38.3–41.3	5.5–6	11.6–20.0	14.8–16.0	4.8–6.6	13.3–18.1	2.5–4.7	224.6–247.6
R. pusillus	1	35.1	6	16.7	16.1	5.2	14.8	4.6	–
R. cf. *macrotis*	1	41	–	–	25	–	18	–	–
R. pearsonii	4	52.8	16.4	18.1 (2)	24.2 (2)	10.0 (2)	26.6 (2)	5.0 (1)	320.4
		51.2–54.2	15.5–17	16.7–19.6	23.3–25.1	10.0–10.1	25.3–27.8		290.0–378
				Hipposideridae					
Hipposideros armiger	5	90.5	54.5	–	–	–	–	–	504.4 (4)
		85.1–95.3	49–58						475.1–532.7
				Vespertilionidae					
Plecotus homochrous	10	38.4	6.2	42.2 (6)	30.5 (6)	7.3 (6)	15.3 (6)	5.9 (6)	252.1
		36.3–40.7	4.5–8	38.02–49.6	27.0–35.2	5.1–8.4	12.6–19.0	4.7–7.6	237.7–261.2

Appendix III. Continued

Family/Species	*n*	FA	BM	Tail	EL	HF	TIB	T	W
P. wardi	5	42.3	9.25 (4)	40.1 (1)	32.6 (1)	8.3 (1)	21.0 (1)	5.1 (1)	288.1 (4)
		41.8–43.1	7.5–10						270.4–316
Barbastella darjelingensis	4	42.2 (4)	9 (1)	–	–	–	–	–	271.4 (3)
		41.2–43.4							263.7–283.5
Nyctalus leisleri	11	44.4 (8)	15 (5)	34.3 (3)	11.6 (3)	8.2 (3)	18.1 (3)	6.0 (3)	31.0 (2)
		40.1–49.7	13–17	31.4–38.7	10.2–13.3	6.8–9.9	15.1–23.9	5.1–6.6	308.3–312.7
N. noctula	7	54.3	26 (1)	45.9 (1)	17.9 (1)	9.6 (1)	19.9 (1)	–	316.2 (1)
		51.5–56.1							
Murina leucogaster	1	38.00	–	29.8	14.7	7.9	16.3	7.1	286.8
M. cyclotis	1	32.7	8.5	25.00	12.8	6.5	14.6	7.9	227.0
M. huttonii	3	35.2	9.2	34.0	17.4	8.7	15.9	8.5	262.5
		34.4–36.5	8–11	31.0–37.9	14.9–20.9	8.0–10.0	13.0–17.93	7.1–10.0	255.5–271.0
M. aurata	1	29.4	5.5	20.2	13.0	6.6	13.05	4.7	203.7
Myotis longipes	11	35.0	5.5	29.6 (8)	12.8	7.3	14.2	5.3 (10)	233.1 (10)
		33.1–36.5	4–6	25.1–34.6	10.4–15.0	5.2–9.3	11.0–16.5	4.3–6.5	219.9–252
M. nipalensis	1	34.7	8	35.9	12.2	6.6	14.7	7.5	227.7
M. muricola	2	36.9	4.5	32.0 (1)	11.5	5.8	15.3	4.6	266 (1)
		35.9–37.9	3.5–5.5		10.1–12.8	5.1–6.6	15.3–15.3	4.5–4.7	
M. cf. *frater*	5	41.1	8.5	41.4 (1)	13.2	7.2	20	5.9 (2)	288.7
		39.5–43.0	7–11		11.5–16.3	6.5–8.2	18.5–21.6	5.3–6.5	274.1–304
M. cf. *annectans*	3	46.3	11	37.04	15.4	8.3	20.3	5.08 (1)	288.5
		46.1–46.4	9–14	35.96–38.12	13.3–16.7	7.1–9.95	19.58–21.63		283.7–293.2
M. blythii	1	56.0	20.5	46.4	23.4	13.4	25.1	10.0	346.6
Submyotodon caliginosus	1	36.3	6	29.6	11.4	4.8	14.6	3.3	254.7
Mirostrellus joffrei	1	37.9	11	29.6	13.0	6.6	15.0	4.9	229.9
Pipistrellus tenuis	4	27.9	3.5 (2)	23.3	7.8	4.2	10.7	3.5 (2)	–
		26.7–29.5	3–4	21.4–26.5	6.5–8.2	3.3–5.2	10.1–11.6	3.4–3.6	
Pipistrellus sp.	1	31.5	5	22.8	10.0	–	11.6	–	182
P. cf. *ceylonicus*	30	34.5	6.9 (22)	30.7 (10)	10.8 (13)	5.4 (12)	12.9 (12)	4.8 (10)	236.1 (19)
		31.4–36.4	4–9	21.5–41.3	9.6–12.8	3.9–7.7	10.3–14.8	4.4–5.3	220.6–252
Arielulus circumdatus	1	42.9	10	–	–	–	–	–	306
Eptesicus tatei	1	42.8	13	40.8	13.3	6.6	18.5	5.4	294
E. serotinus	2	52.0	21.5	39.4 (1)	16.7 (1)	10.1 (1)	20.1 (1)	8.2 (1)	344.1 (2)
		51.2–52.9	20–23						334.3–354
Scotophilus heathii	3	61.3 (3)	40.5 (2)	53.9 (2)	15.7 (2)	11.5 (2)	25.1 (2)	7.5 (2)	–
		60.9–61.9	35–36	50.0–57.7	15.1–16.3	9.9–13.0	25–25.2	7.1–7.8	
				Miniopteridae					
Miniopterus fuliginosus	13	48.5 (13)	14.7 (8)	43.8 (5)	10.2 (5)	9.2 (5)	20.4 (5)	6.2 (5)	300.6 (5)
		47.5–49.3	13–15.5	40.0–50.9	9.7–11.9	9.4–9.7	19.6–21.3	5.2–6.5	285.7–309.9