

# Intact forests of the Hkakabo Razi Landscape are a hotspot of bat diversity in South-east Asia

PAUL J. J. BATES, PIPAT SOISOOK, SAI SEIN LIN OO, MARCELA SUAREZ-RUBIO  
AWATSAYA PIMSAI, ARIYA DEJTARADOL and SWEN C. RENNER

**Abstract** The Hkakabo Razi Landscape, in northern Kachin, Myanmar, is one of the largest remaining tracts of intact forest in South-east Asia. In 2016, we undertook a survey in its southern margins to assess bat diversity, distribution and ecology and evaluate the importance of the area for global bat conservation. Two collecting trips had taken place in the area in 1931 and 1933, with four bat species reported. We recorded 35 species, 18 of which are new for Kachin. One species, *Murina hkakaboraziensis*, was new to science and three, *Megaerops niphanae*, *Phoniscus jagorii*, *Murina pluvialis*, were new records for Myanmar. Our findings indicate high bat diversity in Hkakabo Razi; although it comprises only 1.7% of Myanmar's land area, it is home to 33.6% of its known bat species. This emphasizes Hkakabo Razi's importance for conserving increasingly threatened, forest-interior bats, especially in the families Kerivoulinae and Murinae. There is also a high diversity of other mammals and birds within the Hkakabo Razi Landscape, which supports its nomination as a World Heritage Site.

**Keywords** Bats, biodiversity assessments, Chiroptera, Hkakabo Razi Landscape, Kachin, Myanmar, Northern Mountain Forest Complex

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## Introduction

Tropical forests in South-east Asia have high levels of species richness and endemism (Kingston, 2010), with four of the world's 25 biodiversity hotspots found in

the region (Myers et al., 2000). However, South-east Asia, including parts of Myanmar, also has one of the highest rates of deforestation, habitat destruction and degradation (Keenan et al., 2015; Curtis et al., 2018; Estoque et al., 2019). Approximately 80 million ha of forest were lost during 2005–2015, including nearly 4 million ha in Myanmar (Estoque et al., 2019). In the Philippines and parts of Indonesia, it is projected that 98% of forests will be lost by 2022 (Hughes, 2017). In Viet Nam, forests are becoming more fragmented and degraded, and closed-canopy forests constitute only 4.6% of the total forested area (WorldBank, 2005). Rapid land-use changes mean that much of the region's fauna is threatened (Kingston, 2010) and the density of threatened vertebrates is amongst the highest in the world (Hughes, 2017). It has been estimated that the region, which includes 20 hotspots of extinction risk (Cardillo et al., 2006), could lose up to 42% of its biodiversity by 2100 (Sodhi et al., 2004).

With an area of 11,280 km<sup>2</sup> (Suarez-Rubio et al., 2020), the Hkakabo Razi Landscape is one of the largest remaining tracts of mainly intact forest in South-east Asia (Bhagwat et al., 2017). It is located along the south-eastern slopes of the eastern sub-Himalayan mountain range and comprises Hkakabo Razi National Park, the Hponkan Razi Wildlife Sanctuary and the proposed southern extension of Hkakabo Razi National Park (Fig. 1; Suarez-Rubio et al., 2020).

The forests of Hkakabo Razi have high structural integrity and experienced low rates of deforestation during 1989–2016 (Suarez-Rubio et al., 2020). During 1991–1999, the annual deforestation rate was < 0.2%, concentrated on the plains of Putao and Naung Mung (Renner et al., 2007). The forests are situated at the meeting point of three biodiversity hotspots: Indo-Burma, Himalaya and Mountains of South-west China (Myers et al., 2000). Bird species richness is high (Renner & Rappole, 2011; Renner et al., 2015), with 40% of Myanmar's c. 1,100 bird species occurring in the area (Renner et al., 2015). In 2014, the Hkakabo Razi Landscape was proposed as a World Heritage Site under criteria (ix) and (x) for its high integrity and outstanding ecological values (World Heritage Centre, 2014).

Although the diversity of birds and larger mammals in the Hkakabo Razi Landscape is relatively well known (Rao et al., 2013; Renner et al., 2015), this is not the case for most other taxa. Only two previous surveys included bats: by the Earl of Cranbrook and Kingdon-Ward in 1931 and by Kaulback in 1933. Seventeen specimens of four species were collected during these surveys (Hill, 1962). Elsewhere in

PAUL J. J. BATES\* ([orcid.org/0000-0003-3630-739X](https://orcid.org/0000-0003-3630-739X)) Harrison Institute, Sevenoaks, UK

PIPAT SOISOOK ([orcid.org/0000-0002-1404-3568](https://orcid.org/0000-0002-1404-3568)) and AWATSAYA PIMSAI ([orcid.org/0000-0003-3974-7059](https://orcid.org/0000-0003-3974-7059)) Faculty of Science, Prince of Songkla University, Hat Yai, Thailand

SAI SEIN LIN OO ([orcid.org/0000-0001-9897-6164](https://orcid.org/0000-0001-9897-6164)) Department of Zoology, Mandalay University, Mandalay, Myanmar

MARCELA SUAREZ-RUBIO ([orcid.org/0000-0002-0596-2626](https://orcid.org/0000-0002-0596-2626)) Institute of Zoology, University of Natural Resources and Life Sciences, Vienna, Austria

SWEN C. RENNER (Corresponding author, [orcid.org/0000-0002-6893-4219](https://orcid.org/0000-0002-6893-4219)) and ARIYA DEJTARADOL ([orcid.org/0000-0002-3258-1618](https://orcid.org/0000-0002-3258-1618)) Ornithology, Natural History Museum Vienna, Vienna, Austria. E-mail [swen.renner@nhm-wien.ac.at](mailto:swen.renner@nhm-wien.ac.at)

\*Also at: University of Natural Resources and Life Sciences, Vienna, Austria

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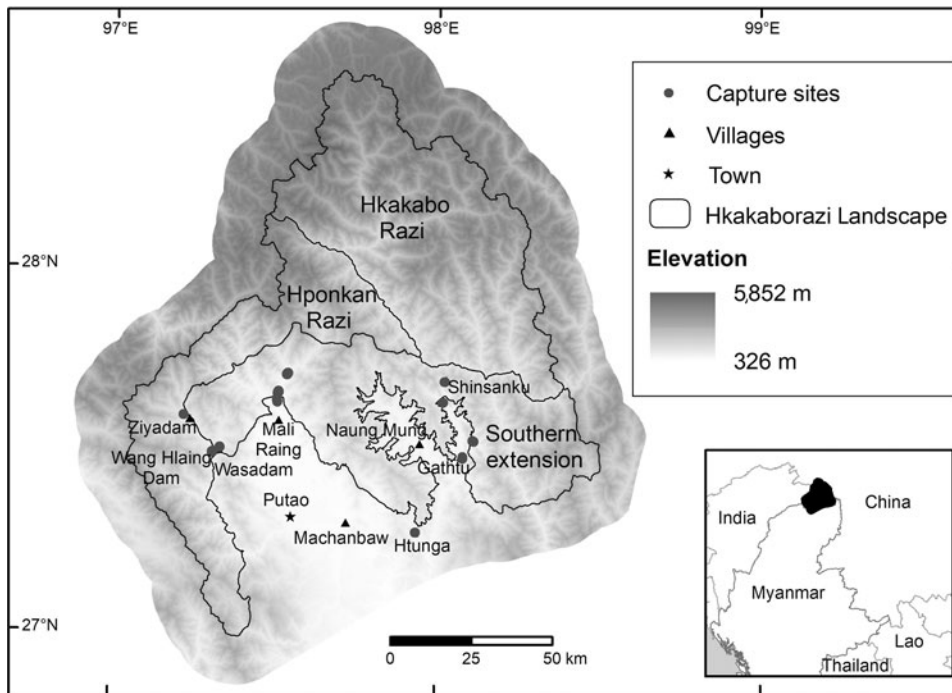


FIG. 1 The Hkakabo Razi Landscape in northern Myanmar, including the 11 capture sites of 2016.

Kachin State bat research was mostly conducted during 1931–1945 (Bates et al., 2000) and in the early 21st century (Bates et al., 2004; Struebig et al., 2005). None was extensive and only one involved harp-traps and mist-nets (Struebig et al., 2005).

Bats are recognized as a critical component of South-east Asia's fauna, comprising 30% of the region's mammal species and 50% of the mammal species within the tropical rainforest ecoregions (Kingston, 2010). South-east Asia is home to 27% of global bat diversity (385 of the currently recognized 1,411 bat species; Simmons & Cirranello, 2020). Nearly half of the region's bat species are predicted to be extinct by the end of the 21st century, and forest-dependent species are particularly vulnerable (Kingston, 2010, 2013; Frick et al., 2019). As Kingston (2010) noted, this is a catastrophic decline, including the loss of the many ecosystem services that bats provide.

### Study area

The mountain ranges of the Hkakabo Razi Landscape encircle the Putao Plains, except to the south, where lowlands give way to the headwaters of the Ayeyarwady River (Fig. 1). The altitude ranges from 450 m in the Putao Plains to 5,881 m at the summit of Mount Hkakabo Razi. Except for dry deserts, all major vegetation types are present. The area is predominantly covered by different forest types, tropical to subtropical (semi-deciduous) from lowlands to alpine zones. Above the alpine vegetation, rock/boulder and glaciers/snow fields occur (Renner et al., 2015). Settlements and agriculture are restricted mainly to the flood plains of Putao and Naung Mung (Renner et al., 2007). In some areas, swidden cultivation has

created a patchwork of secondary forest in various stages of regeneration. The Hkakabo Razi Landscape is home to >8,000 people, and except for Putao and Naung Mung townships, virtually no other settlement exceeds 100 inhabitants (Suarez-Rubio et al., 2020).

### Methods

We undertook fieldwork during 28 nights at 11 sites (Table 1), in the southern margins of the Hkakabo Razi Landscape at altitudes of 450–1,220 m (Fig. 1), using four-bank harp-traps and mist-nets, and conducting roost surveys and acoustic surveys (Supplementary Table 1). Wherever possible, we used a suite of three capturing methods to maximize success. Four-bank harp-traps were set in forests, across trails and over streams, and checked during 18.00–21.00 and again at dawn. This resulted in a total of 66 harp-trap nights, with one trap-night defined as one trap set per night. Mist-nets (70 denier nylon, 30 × 30 mm mesh size; Ecotone, Gdynia, Poland) were also set along and across forest trails and across streams. They were opened during 18.00–21.00 and checked regularly. In addition, we employed some canopy nets; in Tana cave we used mist-nets and hand nets. Mist-net hours, including canopy nets, totalled 718. We conducted transect and point acoustic surveys with a Pettersson D1000x bat detector (Pettersson Elektronik, Uppsala, Sweden) and analysed echolocation calls with BatSoundPro4.1 (Pettersson Elektronik, Uppsala, Sweden). We identified bat calls to species level using the call database of the Princess Maha Chakri Sirindhorn Natural History Museum (P. Soisook,

TABLE 1 Sampling effort by method at 11 capture sites in the Hkakabo Razi Landscape in 2016.

Site	Elevation (m)	House-holds <sup>1</sup>	Dates	Harp-trap nights	% of total trap nights	Mist-net hours	% of total mist-net hours	Transect recording (hours)	Stationary recording (hours)
Wan Hlaing Dam	850–1,200		5–7 Feb.	6	9.1	162	22.6	2	12
Ziyadam	850–1,200	54	9, 11 Feb.	12	18.2	108	15.0	2	12
Wasadam	850–1,200		12 Feb.	0	0.0	0	0.0	1	0
Mali Raing 1	470–690		16–19 Feb.	8	12.1	105	14.6	1	12
Mali Raing 2	470–690	0	20–24 Feb.	8	12.1	88	12.3	1	12
Mali Raing 3	470–690		25–28 Feb.	8	12.1	99	13.8	1	12
Shinsanku	590–1,220		5–7 Mar.	8	12.1	69	9.6	1	4
Gawlai	590–1,220	81	10–11 Mar.	4	6.1	0	0.0	1	0
Gathu	590–1,220		12–13 Mar.	6	9.1	81	11.3	1	12
Tana cave	590–1,220		14 Mar.	0	0.0	6	0.8	0	0
Htunga	660	30	17 Mar.	6	9.1	0	0.0	1	0

<sup>1</sup>Number of households within community borders of capture sites.

unpubl. data; Hughes et al., 2010; Hughes et al., 2011; Francis, 2019).

We took 62 non-lethal tissue samples from 27 species for molecular analysis, and 19 voucher specimens of 13 taxonomically ambiguous, small vespertilionid species. We estimated the expected species numbers  $S$  based on the spatial effort (capture sites) for the three detection methods, treated separately and combined. We included one unidentified *Murina* species and one unidentified *Myotis* species in the analysis. In addition to estimating the expected species numbers for 10 capture sites (Tana cave was excluded from this particular analysis), we extrapolated the expected species numbers for a hypothetical 30 capture sites (for all combined methods and for acoustic/sight sampling) in *EstimateS 9.1.0* (Colwell, 2013), and for 28 harp-traps and mist-netting capture sites, to examine the difference between observed diversity and theoretically expected diversity. To assess the effort per method, we established a matrix for all detected species with frequency indications per method employed and per sites where they were encountered. The estimator  $S$  indicates that our effort would have been maximized with 28 capture sites for harp-trapping and 30 capture sites for all other methods.

## Results

We recorded a total of 203 bats of 35 species in six families in the Hkakabo Razi Landscape (Supplementary Table 1), of which two have been described as new species (*Murina hkakaboraziensis* and *Kerivoula furva*) and five are new species records for Kachin State, including two that are also new for Myanmar (Kuo et al., 2017; Soisook et al., 2017). The Vespertilionidae with eight genera and 19 species were the most diverse, with 54.3% of all species recorded (Supplementary Table 1). However, with 64 individuals (31.5% of captures) their abundance was relatively low. Fruit bats (Pteropodidae) accounted for only 11.4% of total diversity but 28.6% of

captures. With 38 captures, *Cynopterus sphinx* was the most commonly captured species. The rank-abundance curves indicate a typical pattern of a few species with many individuals and many species with few individuals (Fig. 2).

The rarefaction curve suggests that if we had tripled our effort and increased the number of capture sites from 11 to a hypothetical 30, we could have expected  $48.8 \pm 7.8$  species, an increase of c. one-third. This is based on the three detection methods combined (audio recording, harp-traps and mist-nets; Fig. 3).

Of the 27 species captured in harp-traps and mist-nets, nine were only captured in harp-traps and eight were only captured in mist-nets (Supplementary Table 1). Of the 13 species detected by acoustic/sight surveys, eight were not captured in mist-nets or harp-traps. We recorded six species in Tana cave, the only limestone cave encountered; four of these were captured in mist-nets; two species (*Taphozous theobaldi* and *Hipposideros armiger*) were found nowhere else (Supplementary Table 1).

Our surveys up to 645 m (the median elevation) resulted in 22 species and 111 records; at altitudes of 645–1,220 m, we recorded 92 individuals of 31 species (Supplementary Table 1). Of the 203 individual bat records, 130 (64.0%), representing 25 species, were captured within or near the edge of intact forest. All other species were from secondary forest, settlements or shrub.

## Discussion

Our survey of bats in the Hkakabo Razi Landscape provides a baseline species list for an area nominated as a World Heritage Site. It increases the number of species known from this area from four (Hill, 1962) to 36, the number known from Myanmar from 100 to 104 species (Bates et al., 2015; Dar et al., 2019; Francis, 2019; Simmons & Cirranello, 2020), and the number known from Kachin State (89,041 km<sup>2</sup>) from 38 to 56 (Fig. 4), which is 14.5% of South-east

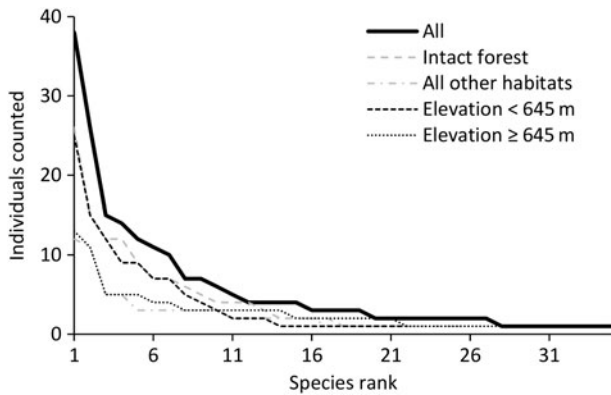


FIG. 2 Species rank-abundance curve based on all capture methods combined, for different habitat types and elevation (median elevation) for bats surveyed in the Hkakabo Razi Landscape in 2016.

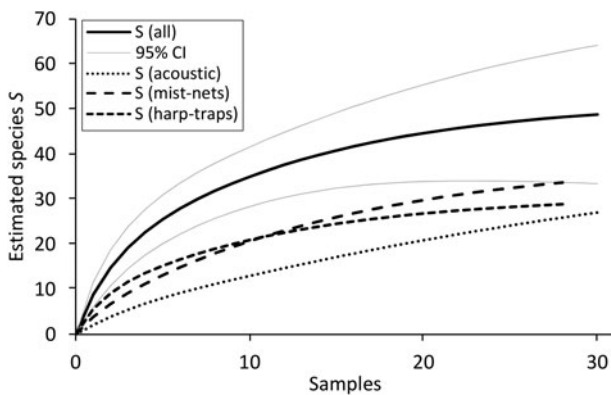


FIG. 3 Species rarefaction curve for all capture methods with 95% confidence intervals and for 30 hypothetical capture sites, additionally separated for the three capture methods (base: ten capture sites used for all methods and acoustic survey; eight sites for all mist-nets and harp-traps).

Asia's 385 bat species. In a global context, this exceeds the 47 species recorded from North America (Simmons & Cirranello, 2020), with an area of 24.71 million km<sup>2</sup>.

However, it is not only the number of species recorded in the Hkakabo Razi Landscape that is remarkable but also the species composition, which indicates that the area is an important refuge for forest-interior specialist bats. We recorded 12 species, belonging to two subfamilies, the Kerivoulinae (*Kerivoula*, *Phoniscus*) and Murininae (*Murina*). Many of these taxa are little-known and have been discovered and described only recently. Two are categorized on the IUCN Red List (IUCN, 2020) as Data Deficient, five as Least Concern, four have yet to be assessed, and one is only identified to genus (Supplementary Table 1). Forest-interior specialist bats are a priority for chiropteran conservation, being most at risk from habitat change. They have strong site fidelity, are less geographically mobile than nomadic generalist bats such as *Cynopterus sphinx*, and have smaller home ranges that do

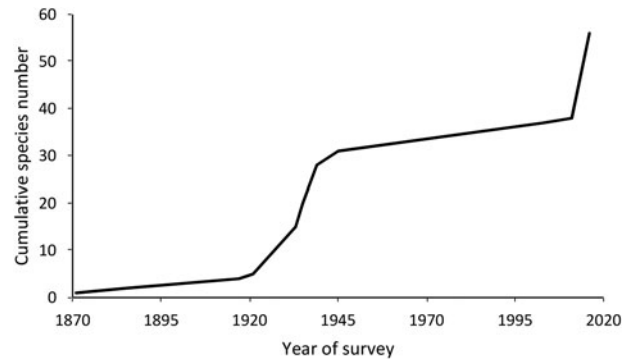


FIG. 4 Cumulative number of bat species recorded from Kachin State, Myanmar (1871–2016), including the number of new species for Kachin from each survey period.

not extend beyond forest boundaries (Struebig et al., 2008; Huang et al., 2019). Compared to cave-roosting bats, they are more susceptible to microclimate and habitat changes and more vulnerable to loss of roosting sites, which include hollows and cavities of standing and fallen trees (Struebig et al., 2008). Furthermore, they have eco-morphological adaptations, which constrain their ecological flexibility (Furey et al., 2010). These include specialized wing morphology (low wing loading, low aspect ratios), which restricts them to hunting in environments with dense vegetation (Schnitzler & Kalko, 2001), and specialized acoustic characteristics (short duration, low intensity but very high frequency calls), which allow them to glean their arthropod prey in narrow spaces but is ill-suited for prey detection in more open habitats (Kingston et al., 2003).

Baseline data for the Hkakabo Razi Landscape contribute to our understanding of the ecology, diversity, composition, assemblages, and the natural spatio-temporal changes of the bat fauna in an intact eastern Himalayan forest. This will help to devise effective conservation strategies. With further, more temporally and spatially widespread research within Hkakabo Razi, these data will complement those obtained elsewhere in the Indo-Chinese subregion and from South-east Asia's Sundaic lowland forest bats, such as from Krau Wildlife Reserve in peninsular Malaysia. Krau is considered home to 'the highest diversity of bats recorded anywhere in the Old World tropics' (Kingston et al., 2009, p. 11), with > 70 bat species, including 14 species of Kerivoulinae and Murininae, recorded during 1980–2008 (Struebig et al., 2008).

Apart from Krau, the Hkakabo Razi forests have one of the highest recorded diversities of forest-interior specialist bat species in the Murininae and Kerivoulinae. In Bukit Barisan Selatan National Park, one of the last refuges of intact forest in Sumatra, of a total of 60 bat species, 11 were forest-interior specialists in these subfamilies (Huang et al., 2014). In the disturbed forests of Kim Hy Nature Reserve, Viet Nam, which includes extensive limestone

karst, 42 species were recorded, but the diversity of forest-interior bats is considerably lower, with five Murininae and two Kerivoulinae (Furey et al., 2010). In the watershed protection forest in the south-eastern Truong Son (Annamite Mountains), 20 species were recorded, including six forest-interior bats, one Kerivoulinae and five Murininae (Son et al., 2016). Although other areas in Viet Nam have a bat diversity comparable to that of the Hkakabo Razi Landscape (Put Mat with 39 species, Cuc Phuong with 38 species and Phong Nha with 32 species), the number of forest specialists is lower. However, most of the surveys there were undertaken prior to the use of harp-traps (Hendrichsen et al., 2001). Our findings from Hkakabo Razi reinforce the view that large forest tracts should be conservation priorities in landscape-level planning because they support rare, forest specialist species (Struebig et al., 2010).

Although our survey was short and geographically restricted, it indicates that the Hkakabo Razi Landscape has a highly diverse bat fauna and is a conservation priority for bats in South-east Asia. As one of the last remaining extensive tracts of mainly intact forest in Asia, it fully deserves the protection that could be provided through a listing as a World Heritage Site.

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**Author contributions** Study design: SCR, PJJ; fieldwork: PS, SSLO, AP; data analysis: MSR, AD, PS, SSLO, AP; writing: PJJ; revisions: all authors.

**Conflicts of interest** None.

**Ethical standards** This work abided by the *Oryx* guidelines on ethical standards. The Nature and Wildlife Conservation Division of the Forestry Department (NWCD) endorsed the study and granted permission to capture bats and access the protected areas under a contract with UNESCO (Phase II 504MYA4001). All voucher specimens were taken in accordance with national Myanmar law and the animal protection laws of the EU. All procedures were approved by the Nagoya Protocol process, represented by MoNREC NR-2/2-2017.

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