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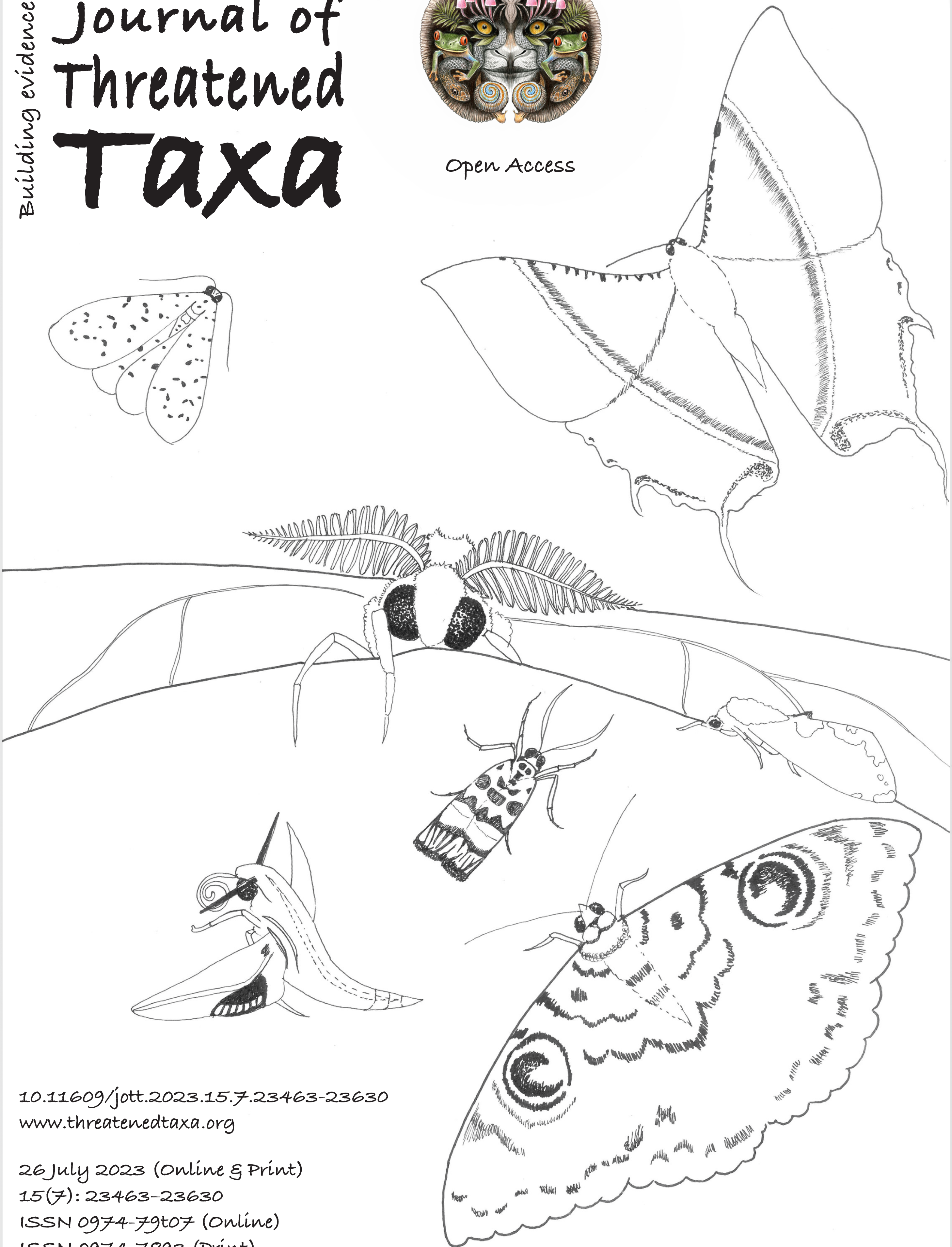

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Cover: Celebrating the unsung heroes—moths, our nocturnal pollinators. © Priyanka Iyer.

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COMMUNICATION

Does small mammal species richness have a bimodal elevation gradient in Sikkim Himalaya?

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Abstract: The most reported elevation gradients in species richness are a unimodal peak and linear decline. However, the overlap of different biogeographic realms in a region can influence such gradients. We used live-capture data on small mammals (voles, rats, mice, shrews, and pikas) to describe elevation gradients in species richness in Sikkim, where Afrotropical, Indo-Malayan, and Palearctic fauna occur in the lower, middle, and higher elevations, respectively. We sampled 38 trap lines in an elevation range of 300 m to 4,200 m, which we binned into nine elevation zones. Each trap line had 50 Sherman traps run for 3–5 nights during 2003–05 and 2012–13. We had a total of 9,069 trap nights with 430 captures, including 13 species of murid rodents, five ground shrews, two voles, and one each of pika and tree shrews. The capture rate in a trap line ranged from 0 to 19.7 per 100 trap night (mean = 5.30±0.767 SEM) with a peak at 2,501–3,001 m (3.29±0.644), coinciding with temperate broad leaf and conifer forests. Species richness seemed to have a minor peak at 501–1,000 m (2.50±0.645 species per trapline) and a clear peak at 3,001–3,500 m (3.29±0.644), coinciding with tropical forests and temperate mixed conifer forests, respectively. The apparent bimodal elevation gradient is due to the overlap of western Asian and Indo-Malayan fauna in the lower elevation and of the latter and Palearctic fauna in the higher elevation. More intensive sampling is needed to test this hypothesis that the overlap of biogeographic regions can influence elevation gradient in species richness.

Keywords: Altitude, capture rate, rodents, shrews, species composition.

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Author contributions: All authors participated in project design, JT and SK collected and analyzed data, AK administered the project, all authors participated in writing this manuscript.

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INTRODUCTION

The pattern of species richness along elevation gradient is among the most widely studied macroecology topics (Gaston 2000; McCain 2005; McCain & Grytnes 2010; Guo et al. 2013; Stevens et al. 2019). The most reported pattern is a unimodal mid-elevation peak followed by a monotonic decline in species richness with increasing elevation (Rahbek 1995; McCain & Grytnes 2010; Amori et al. 2019; Stevens et al. 2019). In Himalaya, mid-elevation peak has been reported in trees (Oommen & Shanker 2005; Acharya et al. 2011a), birds (Acharya et al. 2011b), amphibians (Chettri & Acharya 2020) and snakes (Chettri et al. 2010), although the elevation at which species richness peaks varies with the taxa. Species richness in lizards (Chettri et al. 2010) and butterflies decline linearly with elevation (Acharya & Vijayan 2015; Dewan et al. 2021). Nonvolant small mammals (primarily rodents and shrews) are perhaps the taxon in which elevation gradient in species richness has been most studied globally since this group is species-rich and locally abundant (Stevens et al. 2019). A mid-elevation peak is the most widely reported species richness pattern in non-volant small mammals (McCain 2005; McCain & Grytnes 2010; Stevens et al. 2019). However, the elevation gradient in species richness in small mammals has been little studied in the Himalayan region, in contrast with several studies in other parts of the world (see McCain 2005; Stevens et al. 2019 for reviews). Perhaps, the only study is Hu et al. (2017) who sampled small mammals in an elevation range of 1,800 m to 5,400 m on the southern slope of central Himalaya and reported a mid-elevation peak at 2,700–3,300 m, possibly a transition zone between Oriental and Palearctic regions.

The factors that influence elevation gradient patterns include climate (e.g., precipitation and temperature), space (e.g., species area richness and mid-domain effect), evolutionary history (e.g., speciation and extinction rates), and biological processes (e.g., competition, predation and habitat heterogeneity) (McCain & Grytnes 2010; Stevens et al. 2019). Although climatic factors have a major influence, climatic variables such as temperature and precipitation affect different taxa differently (Stevens et al. 2019). Most cold-blooded taxa show a decline in species richness with increasing elevation, since temperature declines with elevation. The factors that cause unimodal mid-elevation peak, widely reported in birds and mammals, are less known although water-energy balance (Hu et al. 2017) and productivity are possible factors (Stevens et al. 2019). Other factors such as species-area, evolutionary history and habitat heterogeneity have been studied even less (Stevens et al. 2019).

This paper examines elevation gradients in species richness in small mammals in Sikkim. Although the state of Sikkim in the eastern Himalaya is only 7,096 km^2 in area, it covers an elevation range of 200 m to >8,000 m. Sikkim also is uniquely located where the Indo-Malayan and Palearctic realms meet, and western Asian elements found in dry parts of India occur in the lower elevations. Among the small mammals reported from Sikkim (Naulak & Pradhan 2020), crocidurines (Dubey et al. 2008) and other Soricidae such as *Sorex* spp. and *Soriculus* spp. (Ohdachi et al. 2006), *Microtus* (Barbosa et al. 2018) are of Holarctic/Palearctic affiliation; *Rattus* (Robins et al. 2008) and the *Niviventer* (Ge et al. 2021) are of India-Malayan affiliation. Although taxa of Afrotropical affiliation are absent from those reported from Sikkim some are of West Asian origin, e.g., *Mus* (Suzuki et al. 2013) and *Tatera* (Khalid et al. 2022).

In this study, we examined the species richness patterns and composition of small mammal communities (murid rodents, pikas, ground, and tree shrews) along the elevation gradient from 230 m to 4,200 m. Our goal is to describe elevation gradients in species richness rather than to examine its relationship with several other factors reported in the literature (McCain 2005; Stevens et al. 2019).

Study area

Sikkim is a mountainous Indian state in the Himalayan biodiversity hotspot (Image 1), covering 7,096 km^2 and an elevation range from 200 m to ~8,000 m with an average slope of ~45˚ (Haribal 1992). Due to rugged terrain and rapid changes in elevation over short distances, temperature and precipitation vary considerably across the state. In southern Sikkim, the temperature varies from 6°C in winter to 35°C in summer, while winter temperature in the north falls much below freezing and the summer temperature is <20°C. Annual rainfall and precipitation days for 1995–96 was 1,310.44 mm and 91 at 300 m, 4,327 mm and 190 at 2,000 m, and 4,553.09 mm and 198 at 3,200 m (Krishna 2005). Almost the entire state of Sikkim comes in the catchment area of river Teesta.

The vegetation changes rapidly along the elevation gradient from the tropical semi-deciduous forest (<900 m) to tropical broadleaf (900–1,800 m), temperate broadleaf (1,800–2,800 m), temperate coniferous forest (2,800–3,800 m), sub-alpine (3,800–4,500 m), and alpine scrub to meadows (>4,500 m) (Haribal 1992).

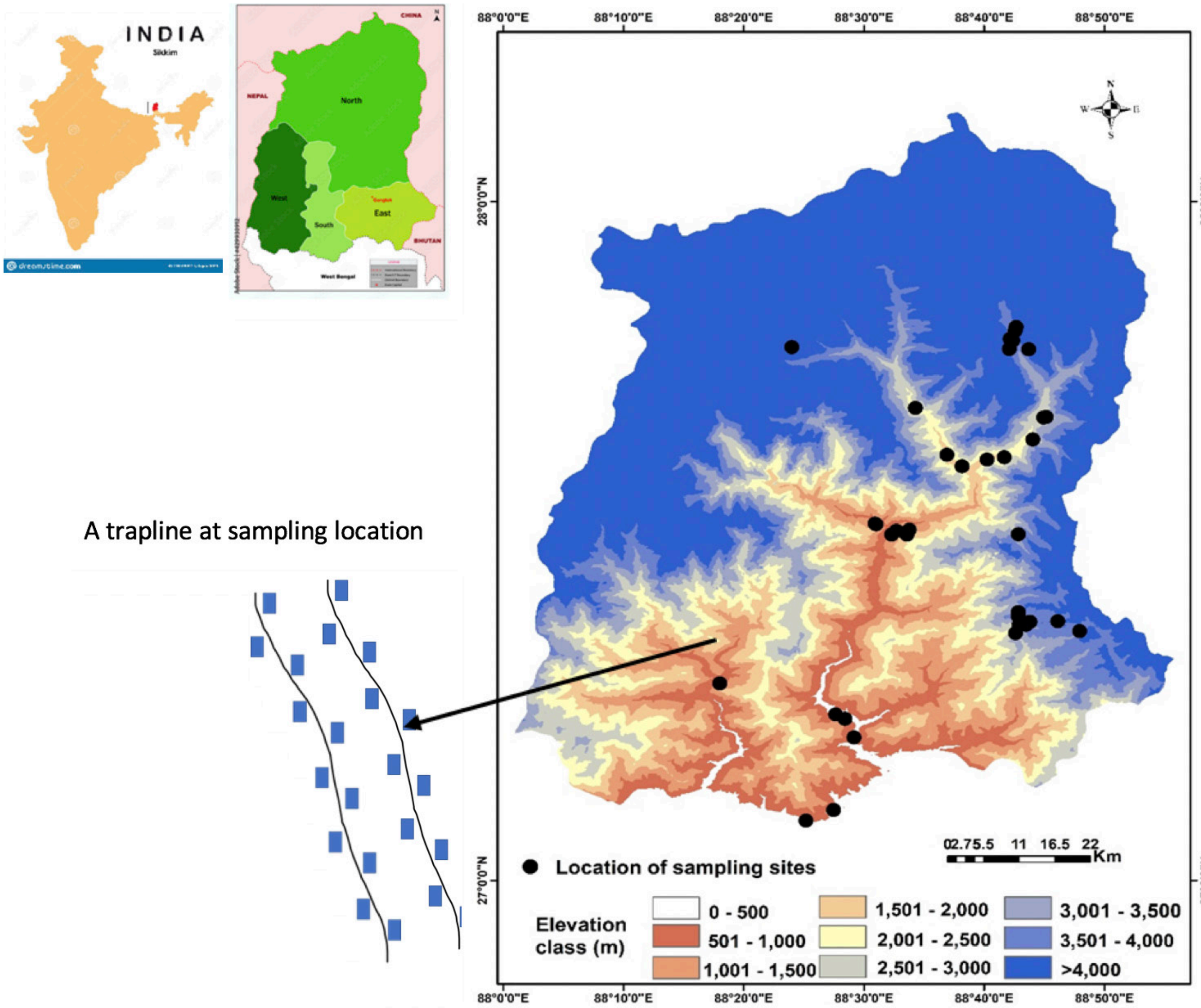

Image 1. State of Sikkim, showing administrative districts, 38 sampling locations, and a layout of traps along trail at each location.

The vegetation in the lower elevation mostly consists of *Shorea robusta, Terminalia myriocarpa, Pinus roxburgi*, and *Bombax ceiba* in the tropical semi-deciduous forest; *Engelhardtia spicata, Schima wallichii*, and *Castanopsis indica* in tropical broadleaf forest; *Quercus* sp., *Symplocos* sp., and *Rhododendron* sp. in the temperate broadleaf forest; *Abies densa*, *Juniperus recurva, Rhododendron* sp. in the coniferous forest; and dwarf *Juniperus* sp. and *Rhododendron* sp. mostly dominate the subalpine and alpine pastures of higher elevation areas in Sikkim. A more exhaustive vegetation classification identifies 12 forest types (Tambe et al. 2011). Some of the major forest types are the same as Haribal (1992) with similar elevation ranges, whiles others in Tambe et al. (2011) are subcategories within the major forest types in Haribal (1992).

METHODS

We sampled small mammals using Sherman live traps (7.5 × 9 × 23 cm) placed at 10 m intervals on alternate sides of existing natural trails in different elevation zones of the Sikkim Himalaya. We laid 38 traplines in an elevational range of 300 m to 4,200 m at an interval of ~500 m. We categorized this elevation range into nine elevation zones of 500 m, and sampled zones by laying three to seven traplines in each zone. Each such trap line had 50 traps which were run for three to five days, depending on the weather conditions. Since murid rodents, ground shrews and voles are mostly nocturnal, we kept the traps open only at night to prevent the capture of diurnal animals such as ground squirrels and birds. We checked and closed the traps every morning and baited them in the evening with a mixture of peanut butter, pulses, and crushed biscuits. The captured individuals were measured, weighed, photographed, ear punched (to detect recaptures) and released about 25 to 50 m away from the trap to minimize recaptures while also releasing the animals in the same vegetation type as they were captured. Species identification, in some cases up to the subspecies level, was done following on Agrawal (2000).

We located the sampling trails in forests that were least affected by human activities. Six trails (<800 m) in the south district, where agriculture (including fallow) covered about 30% of the land area, were in reserved forests as far away as possible from agricultural fields. Ten trails (>3,000 m) were in Kyongnosla Alpine Sanctuary, which had no human settlements and livestock grazing was prohibited. The remaining 22 trails (>1,000 m) were in protected areas and reserved forest in North Sikkim District where agriculture covered only 3% of the land area (http://slbcsikkim.co.in/General/Agriculture.aspx, accessed on 04 July 2023).

The uncertain and fluctuating temperature and precipitation profile of the study area allowed sampling only during certain months of the year. Thus, we did not sample the higher elevations (>2,000 m) in the winter months (November–April). The sampling in the north and south districts of Sikkim (Trapline No. 1–28) was from June 2003 to April 2004 and May 2005 to December 2005 (Thapa 2008) and that in East Sikkim District was done between May 2012 to June 2013.

Data Analysis

The capture rate for each trapline was calculated as (n/t_n) x100, where n is the animals trapped, and t_n is the number of trap nights. The number of species caught in each elevation zone was the observed species richness. Although this is always an underestimate of real species richness (Gwinn et al. 2015), we did not attempt to estimate the latter because both the number of trap lines and individuals caught were too few to meet the recommendations for the use of species richness estimators (Gotelli & Colwell 2010). Moreover, much of the underlying information needed for estimating species richness, such as species abundance distribution and detection probabilities (Gwinn et al. 2015) was unavailable. Therefore, we have used the number of species caught per trap line (of 50 traps) which can be considered the alpha diversity (McCain 2005) for examining the elevation gradient.

RESULTS

Elevational pattern of species

From over 9,069 trap nights of sampling effort, we live-trapped 430 individuals belonging to 22 taxa and 21 species (Table 1). The number of animals caught in a trapline varied from 0 (in four traplines in zone 1,001–1,500 m) to 46 (zone 2,501–3,000 m) with a mean of 11.32 (±1.742 SEM). We sampled only one elevation zone (3,501–4,000 m) in 2003–05 (n = 5 traplines) and 2012–13 (n = 2 traplines), which had similar capture rates per 100 trap nights (8.77 and 7.5, respectively). The capture rate in a trap line ranged from 0 to 19.7 (mean = 5.30±0.767). The capture rate was the highest at 2,501–3000 m, before declining, although still greater than at lower zones (Figure 1).

Muridae was the most species-rich family (13, including subspecies) in the region followed by Soricidae (ground shrews- including five species), Cricetidae (voles- including two species), Ochotonidae (pika), and Tupaiidae (tree shrew), the latter two families including one species each. The number of species captured in a zone was not significantly correlated either with the number of traplines (Spearman's rho = 0.527, p = .09), trap-nights (rho = 0.368, p = .330) or trapped animals (rho = 0.479, p = .192). However, zone 3,001–3,500 m accounted for the highest number of trapped animals (114) and species richness corresponding to the maximum effort in the zone with 1,661 trap-nights in seven traplines (Table 1).

Species richness per trapline had a minor peak at 500–1,000 m and a major peak at 3,000-3,500 m (Figure 1). The differences in capture rate and species richness among the five vegetation types was similar to the elevation gradient (Figure 2). The capture rates were highest in the subalpine and conifer forests and lowest in the tropical forests at the lower elevations. Species richness per trapline appeared to show two peaks: a small peak in the tropical deciduous forest and a larger peak in the subalpine forest.

Species composition

The species richness (including subspecies) in an elevation zone ranged from three to eight, the composition of which changed from lower to higher elevation (Figure 3). Three species of *Mus* occurred primarily in the lower elevations (<2,000 m), while five species (*Microtus sikimensis, Ochotona* sp., *Pitymys* sp., and *Sorex* sp.) occurred primarily at >3,000 m, while *Soriculus nigrescens* occurred >1,000 m. The remaining 12 species had narrow elevation ranges (e.g.,

Table 1. Details of trapping effort and captures of small mammals in nine elevation zones in Sikkim.

Elevation Zone (in m)	N of trap-lines	N trap nights	N of animals	N of taxa in zone	Taxa trapped (see below for taxa identities)
<500	3	794	9	3	4, 14, 17
501–1000	4	1171	36	6	1, 4, 5, 8, 17, 22
1001–1500	7	1449	44	4	2, 4, 17, 20
1501–2000	3	568	13	5	6, 8, 15, 16, 18, 20
2001–2500	3	741	29	4	8, 10, 15, 20
2501–3000	3	460	57	4	2, 7, 8, 20
3001–3500	7	1661	114	8	2, 3, 7, 11, 12, 13, 19, 20
3501–4000	5	1475	93	5	1, 3, 9, 11, 19
4001–4500	3	750	35	3	1, 3, 11

1. *Crocidura* sp.
2. *Episoriculus caudatus*
3. *Microtus sikimensis*
4. *Mus mus castaneus*
5. *Mus mus homurus*
6. *Mus pahari*
7. *Niviventer eha*
8. *N. fulvescens*
9. *Niviventer* sp.
10. *N. niviventer*
11. *Ochotona* sp.
12. *Pitymys* sp.
13. *Rattus blandfordi*
14. *R. nitidus*
15. *R. r. brunne*
16. *R. r. tistae*
17. *R. sikkimnesis*
18. *R. turkestanicus*
19. *Sorex* sp.
20. *Soriculus nigrescense*
21. *Suncus murinus*
22. *Tupia* sp.

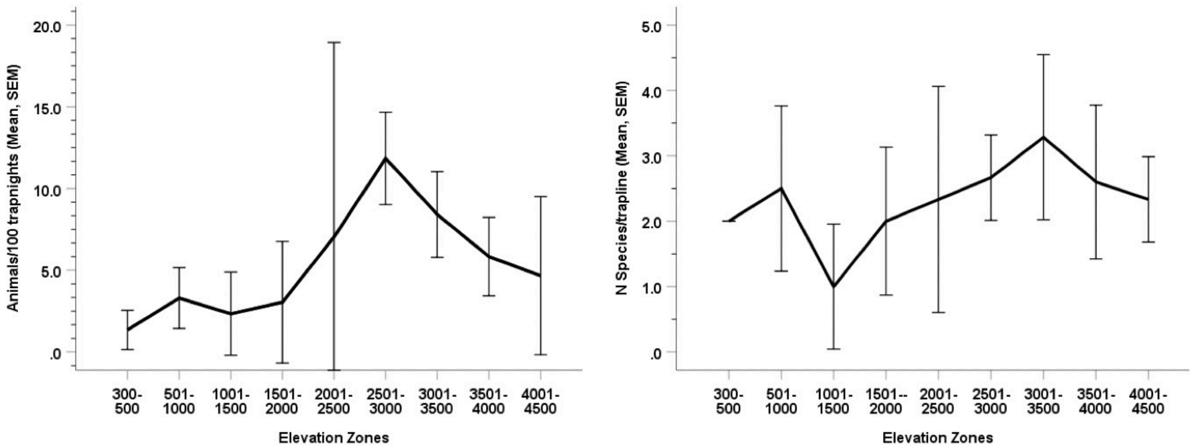

Figure 1. Changes in total capture rates (left) and number of species of small mammals caught per trap line in nine elevation zones (right).

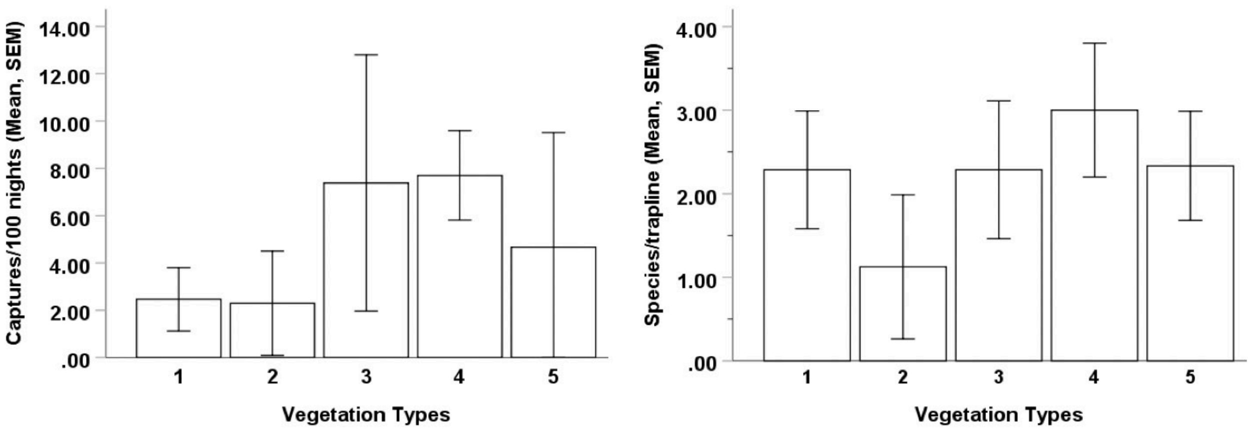

Figure 2. Capture rates (left) and number of species of small mammals caught per trapline (right) in five vegetation types in Sikkim: 1—Tropical dry deciduous | 2—Tropical broadleaf | 3—Temperate broadleaf | 4—Temperate mixed coniferous | 5—Subalpine.

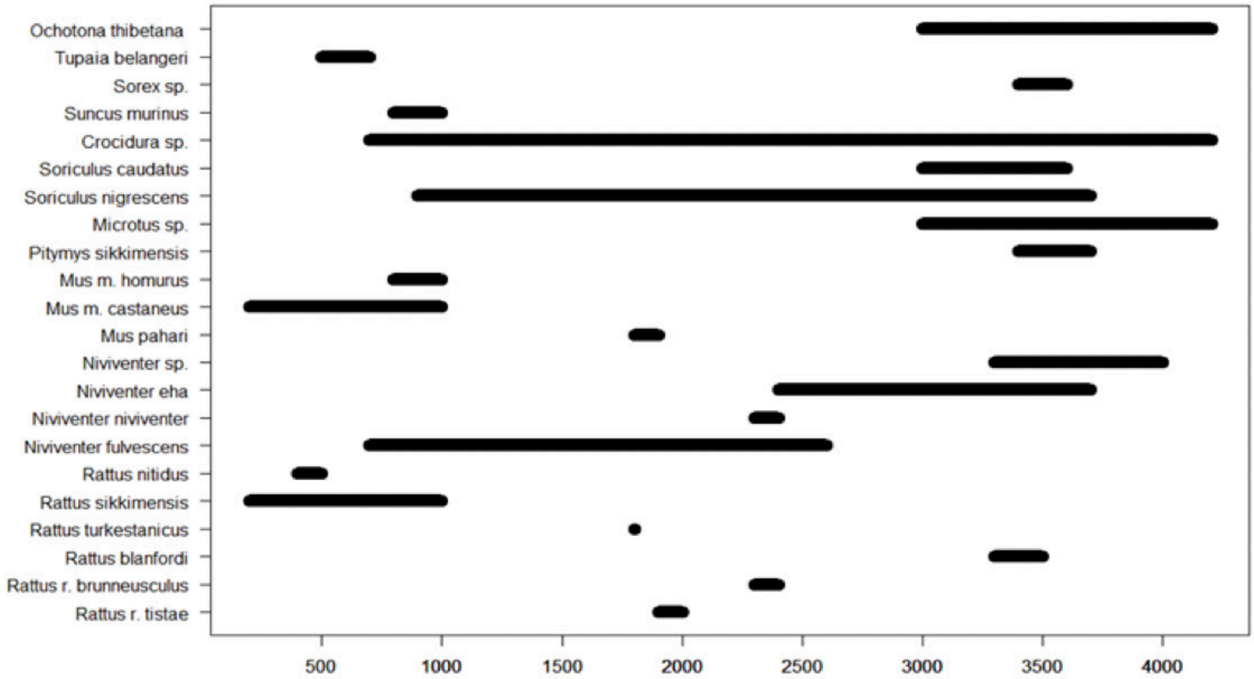

Figure 3. Elevation ranges of 22 species of small mammals caught during 2003–05 and 2012–13.

Tupaia sp.). Only *Crocidura* sp. and *Soriculus caudatus* had wide elevational ranges (Figure 3). This pattern indicates a type of substitution of rats and mice in the low and mid elevations by voles and ground shrews at the higher elevations. At the family level, Muridae and Soricidae were captured from all elevation zones except >4,000 m for the former and <500 m for the latter. Ochotonidae and Cricetidae were captured only above 3,000 m.

DISCUSSION

We used data from live trapping of small mammals in an elevation range from 230 m to 4,200 m in Sikkim to describe the elevation gradient in species richness and compositional changes. The capture rates were greater in the higher elevations, although there was considerable variation within each elevation zone. While some studies have reported higher capture rates in higher elevations (e.g., Rickart et al. 1991; Heaney 2001), others have reported lower capture rates (e.g., Li et al. 2003). An important factor influencing capture rates is the sampling season since small mammals show drastic seasonal fluctuations in abundance, especially in higher elevations. However, we sampled lower elevations (<2,000 m) after summer showers in March up to September, and the higher elevations during June to early November, when small mammal abundances were expected to peak. Therefore, at their respective peaks, abundances are greater in the higher elevations. Similarly, abundances in subalpine forests are far greater than in the tropical forests in the lower elevation. The capture rates of <4% in the tropical forests in this study is comparable to that reported from undisturbed rainforests in the Western Ghats – 2.12% (Kumar et al. 2002) and 4.38% (Kumar et al. 1997) although less than reported from sites in tropical Africa (6.88%, Hounmavo et al. 2023). Capture rates in temperate forests are often much greater and sometimes very high depending on fruit masts (Grendelmeier et al. 2018).

Species richness showed a clear peak at 3,001–3,500 m, coinciding with mixed conifer forest, and a smaller peak at 501–1,000 m, coinciding with tropical forests (deciduous and broadleaf). In unimodal richness gradients, the peak occurs at higher elevations in taller mountains (McCain 2005) like the larger peak in this case. However, we believe that on biogeographical considerations, two peaks are likely. In the lower elevations, taxa of West Asian and Indo-Malayan affiliations overlap at the edge of their respective elevation ranges and at the sub-alpine forests where taxa of Indo-Malayan and Palearctic affiliations overlap. Out of the 56 studies that McCain (2005) reviewed, only two had peaks in alpha diversity at lower and higher elevations, perhaps due to a lack of sampling of the entire gradient or in mid-elevations. This was probably not the case in our study since we had among the highest number of traplines (seven) in 1,001–1,500 m, which had the lowest species richness. Human alteration of habitat was not a factor since these seven trails were in protected forests in North Sikkim District, where agricultural land is only 3%, and human population density was 10 per km^2 (www.indiacensus.net/states/sikkim accessed on 04 July 2023).

In the same landscape, trees show a unimodal peak at ~1500 m, coinciding with tropical broadleaf forests (Acharya et al. 2011a). Total species richness in amphibians also peak at the same elevation (Chettri & Acharya 2020), whereas reptile species richness peak at 500–1,000 m, coinciding with tropical deciduous forests, although lizards decline linearly with elevation and snakes show a unimodal peak (Chettri et al. 2010). Peak in the bird species richness at 1,800–2,000 m (Acharya et al. 2011b), overlapped with temperate broad leaf forests. Overall species richness in butterflies declines linearly with elevation (Dewan et al. 2021). Our data show a clear peak in small mammal species richness at a higher elevation (3,001–3,500 m) compared to the above taxa in Sikkim. This is due to the presence of species of Palearctic/Holarctic affiliation in Cricetidae (Dubey et al. 2008; Barbosa et al. 2018), Soricidae (Ohdachi et al. 2006) and Ochotonidae (Melo-Ferreira et al. 2015), along with species of Indo-Malayan affinity, e.g., *Niviventer* spp. (Ge et al. 2021). In Gyirong Valley in Central Himalaya, Hu et al. (2017) reported 22 species (from 21,600 trap nights) with similar species composition (13 Muridae, 3 Cricetidae, 3 Soricidae, and 3 Ochotonidae). The species richness peaked at 2,700–3,300 m, covered by mixed conifer and subalpine forests (Liang et al. 2020). In our study, the species richness peaked at 3,001–3500 m, where the same forest types occur. Hu et al. (2017) suggested that the peak species richness was probably due to the overlap of Indo-Malayan and Palaearctic regions, although they did not examine species composition in this context. Our data also suggests a smaller peak at 501–1,000 m, due to the presence of species rich Indo-Malayan taxa such as *Rattus* (Robins et al. 2008) and *Niviventer* (Ge et al. 2021), along with species of West Asian affinity such as *Mus* (Suzuki et al. 2013). Hu et al. (2017) did not include forests at <1,800 m with tropical deciduous and broadleaf forests, where western Asian and Indo-Malayan fauna overlap. This overlap can result in another peak in species richness, as our study shows. Thus, Himalaya in Sikkim probably has a bimodal peak in alpha species richness of small mammals. Only a study with more intensive trapping effort can test this hypothesis.

CONCLUSIONS

We examined the elevation gradient in species richness of small mammals using data from live traps covering an elevation range of 230–4,200 m. There is a clear peak in species richness at 3,001–3,500 m and probably another minor peak in the lower elevation (501–1,000 m). These peaks are likely because of the overlap of West Asian and Indo-Malayan fauna in the lower elevation and of the latter and Palaearctic fauna in the higher elevation. This bimodal peak contrasts with unimodal peaks reported from the area in plants, amphibians, snakes, and birds and linear decline reported in lizards and butterflies. Most of the reports of unimodal peaks in small mammals come from areas where biogeographic realms do not overlap, or this issue has not been addressed. The Himalaya in Sikkim is an ideal site to examine the influence of overlaps of biogeographic realms on elevation gradients.

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