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**Cover: A male Scarlet Skimmer perching on vegetation by the banks of a waterbody. Ink and watercolour illustration by Ananditha Pascal.**

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ARTICLE

# Morpho-taxonomic studies on the genus *Fissidens* Hedw. (Bryophyta: Fissidentaceae) in Senapati District, Manipur, India

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**Abstract:** The present study on the moss flora of Senapati District, Manipur, revealed 11 species of the genus *Fissidens*: *F. anomalus* Mont., *F. bryoides* Hedw., *F. crenulatus* Mitt., *F. ceylonensis* Dozy & Molk., *F. crispilus* var.*robinsonii* (Broth.) Z.Iwats. & Z.H.Li, *F. diversifolius* Mitt., *F. elongatus* Mitt., *F. ganguleei* Nork., *F. nobilis* Griff., *F. pulchellus* Mitt., and *F. viridulus* (Sw.) Wahlenb., belonging to the family Fissidentaceae (Bryophyta). Of these, six species—*F. crenulatus*, *F. crispulus* var. *robinsonii, F. diversifolius*, *F. elongatus*, *F. pulchellus*, and *F. viridulus*—were reported for the first time from the state of Manipur, northeastern India. Detailed morpho–taxonomic description, colour photomicrographs, and an artificial key were provided for easy identification.

**Keywords:** Costa, dentation, diversity, leaf border, limbidium, morphology, moss flora, new addition, northeastern India, peristome.

**Maola:** Senapati District, Manipur leino ezhovu shiipa hrii vano modo ye kopho lino *Fissidens* otta chiirokalio (11) phahiko neloe, siikhrumai ozhu khrusii, *F. anomalus* Mont., *F. bryoides* Hedw., *F. crenulatus* Mitt., *F. ceylonensis* Dozy & Molk., *F. diversifolius* Mitt., *F. elongatus* Mitt., *F. ganguleei* Nork., *F. nobilis* Griff., *F. pulchellus* Mitt., *F. crispilus* var. *robinsonii* (Broth.) Z.Iwats & Z.H.Li, ye *F. viridulus* (Sw.) Wahlenb. khruhi koe. Hi thopfiihi Fissidentaceae tikocho family lihi bue. *Fissidens* chiirokalio (11) hilino otta choro (6) phahi India arii chiipra, Manipur state jiiha li-a kariso mosiiprawe. Siikhrumei ozhu sii *F. crenulatus*, *F. diversifolius*, *F. elongatus*, *F. pulchellus*, *F. crispulus* var. *robinson* ye *F. viridulus* hikhru hie. Shiipa khrumeihi siimakriilo koru duno kohrii okhrezhie khru, ozho kalar photomicrographs ea otta kozhiipra kahi, hivano molowo siimakriilo koru moshu mozii khruhia akhrupie riitho hithoe.

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**Author contributions:** KK: Carried out the field surveys, specimen collection, photography, preservation, visualisation, deposition of herbarium specimens and drafted the manuscript. KE: Conceptualised the study design, helps in the identification of specimens, photo plate preparation, supervises the research work and revision of the manuscript. Both authors read and agreed to the final manuscript.

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## INTRODUCTION

The taxonomic classification of the family Fissidentaceae has experienced multiple paradigmatic shifts over the years and its infrageneric classification has been attempted by many bryologists like Brotherus (1901, 1924), Norkett (1969), Bruggeman-Nannenga (1978), Pursell (1988), Pursell & Bruggeman-Nannenga (2004), Suzuki & Iwatsuki (2007), and Suzuki et al. (2018). The most accepted classification given by Pursell & Bruggeman–Nannenga (2004) recognized four subgenera—*Aloma* Kindb., *Fissidens* Hedw., *Octodiceras* (Brid.) Broth., and *Pachyfissidens* (Müll.Hal.) Kindb.—based on taxonomically important characters like peristome type, costa type, and number of files of exothecial cells. The most recent classification given by Suzuki et al. (2018) was based on combined molecular and morphological evidence, and they recognized three subgenera—*Fissidens*, *Neoamblyothallia* (Broth.) Tad.Suzuki & Z.Iwats., and *Pachyfissidens*. This refined taxonomical classification was supported by an intricate analysis of gametophyte morphology, the detailed structural composition of peristome dentition, and cytotaxonomic evidence with a focus on reproductive traits.

Manipur, known for its stunning landscapes and vibrant cultural heritage, is situated in the northeastern part of India and lies between 23.830°–25.681° N and 93.051°–94.780° E, having a geographical area of 22,327 km$^2$. The state epitomizes ecological diversity and biological richness, marked by the juxtaposition of its rugged peripheral hill ranges and expansive inner plains. Despite being known for its ecological wealth, there still remains a notable paucity of research dedicated to bryophytes of the state. Earlier research on bryophytes of Manipur was done by Biswas & Calder (1936), Deb (1954), Lal (1979), Singh & Kishor (2009), Singh et al. (2010, Govindapyari et al. (2012), Govindapyari (2014), Devi et al. (2019), and Asthana et al. (2021). Senapati District is situated in the northern side of Manipur and is characterized by its striking topographical contrasts, featuring rugged hills that tower over narrow, low valleys. This dynamic landscape fosters a diverse ecosystem, where the intertwining terrains create habitats teeming with ecological richness and natural beauty. The exploration of lower plant flora remains in its nascent stage, largely hindered by the challenging, rugged terrain of most areas, rendering them inaccessible to researchers and significantly limiting comprehensive studies.

The present morpho-taxonomic investigation on the genus *Fissidens* Hedw. (Fissidentaceae) of Senapati District, Manipur revealed the occurrence of 11 species—*F. anomalus* Mont., *F. bryoides* Hedw., *F. crenulatus* Mitt., *F. ceylonensis* Dozy & Molk., *F. crispulus* var. *robinsonii* (Broth.) Z.Iwats. & Z.H.Li, *F. diversifolius* Mitt., *F. elongatus* Mitt., *F. ganguleei* Nork., *F. nobilis* Griff., *F. pulchellus* Mitt., and *F. viridulus* (Sw.) Wahlenb. Review of available literature like Gangulee (1971), Nath et al. (2011), Asthana & Srivastava (2015), Manjula & Manju (2020), Sreenath & Rao (2020), revealed that six species—*F. crenulatus*, *F. crispulus* var. *robinsonii, F. diversifolius*, *F. elongatus*, *F. pulchellus*, and *F. viridulus,* were found to be new additions to the moss flora of Manipur. Detailed taxonomic description, colour photomicrographs, and an artificial key are provided for easy identification.

## MATERIALS AND METHODS

The plant specimens were collected from various localities in Senapati District. The collected specimens were kept temporarily in zip-locked polythene bags for morphological and anatomical studies. Dried specimens were soaked in water for 2–5 min to stretch out the plant body fully, and morphological characters were observed under Hoverlabs Stereozoom microscope (HV-ZOOM-IV TR); macro-photographs and micro-photographs were taken from Hoverlabs trinocular microscope along with image viewing and processing software called 'Image View' to measure object sizes. The air-dried moss specimens were preserved in a standard herbarium packet (6×4 in) of brown paper. The specimens were deposited in the cryptogamic herbarium of Dhanamanjuri University (DMH), Manipur, for future reference.

**1. *Fissidens anomalus*** Mont., Ann. Sci. Nat. Bot. Ser. 2, 17: 252. 1842; Gangulee, Mosses E. India Fasc. 2: 555. 1971. (Image 1a–f)

Plant small, light green in fresh and brownish-green when dry, branched, up to 3.5 cm long and 0.5 cm wide. Leaves in 17–20 pairs, 3.0–3.5 mm long, 0.5–0.7 mm wide, broader at base; upper leaves larger than the lower, ligulate, apex acute, dorsal lamina short decurrent; sheathing lamina unequal or open sheathing covering 1/2 of the leaf, margin crenulate-dentate at the apical area with differentiated border. Leaf cells, quadrate hexagonal, at apical area, 6–10 × 2–8 µm, median cell, 3–9 × 4–9 µm and basal cell 10–28 × 5–12 µm. Costa is gradually diminishing below the tip.

**Taxonomic treatment**

**Key to the species of *Fissidens* of Senapati District, Manipur**

1a. Limbidium present .......... 2
1b. Limbidium absent .......... 6

2a. Limbidium entirely present on all lamina .......... 3
2b. Limbidium limited to specific lamina .......... 4

3a. Nerve ending below apex .......... *F. viridulus*
3b. Nerve percurrent or excurrent .......... *F. bryoides*

4a. Semi-limbidium on sheathing lamini; lamina cells smooth .......... *F. diversifolius*
4b. Semi-limbidium on leaf lamini; lamina cells papillate .......... 5

5a. Leaf cells with single mamillose or coarse papillae .......... *F. crenulatus*
5b. Leaf cells multi papillate .......... *F. ceylonensis*

6a. Leaf margin crenulate or denticulate .......... 7
6b. Leaf margin having differentiated border .......... 9

7a. Leaf cells round and smooth .......... *F. ganguleei*
7b. Leaf cells papillose .......... 8

8a. Leaf cells rounded hexagonal with one conical papilla on each cell .......... *F. crispulus* var. *robinsonii*
8b. Leaf cells quadrate hexagonal with one or two conical papilla on each cell .......... *F. pulchellus*

9a. Leaf lanceolate, margin regularly toothed.......... *F. elongatus*
9b. Leaf ligulate, margin irregularly toothed.......... 10

10a. Leaves 17-20 pairs, sheathing lamini 1/2 and unequal, leaf curled towards stem when dried … *F. anomalous*
10b. Leaves 15 pairs, sheathing lamini 1/3 and unequal, leaf not much curled when dried .......... *F. nobilis*

**Habitat:** Plants found growing as corticolous or epiphyllous together with other mosses.

**Range:** China, India, Indonesia, Myanmar, Philippines, Thailand, and Vietnam.

**Distribution in India**: Kerala, Madhya Pradesh, Manipur (present report), Meghalaya, Sikkim, Tamil Nadu, Uttarakhand, and West Bengal.

**Specimen examined**: India: Manipur, Senapati District, Liyai Khullen Village, 1800 m, 17.ix.2024, K.K00329.

**2. *Fissidens bryoides*** Hedw., Sp. Musc. Frond. 153. 1801; Gangulee, Mosses E. India Fasc. 2: 469. 1971. (Image 1g–k)

Plant small, dark green to brownish-green, not much curled up when dry, branched in some older parts, up to 4.0–4.5 mm long, 2.1–2.5 mm broad with leaves. Rhizoids present on the base of the stems. Leaves in 7–8 pairs, 1.0–1.5 mm long, 0.3–0.4 mm wide, acute to cuspidate, sometimes acuminate, oblong ligulate; uniformly wide from its base to the apex, narrows into a tapering point at the apex; costa strong, mostly percurrent to shortly excurrent, light yellowish-brown, diminishing below the tip, margin limbate, serrulate to denticulate at leaf apices, lamini rather equal or closed sheathing covering 1/2 of the leaf length. Limbidium present entirely, one to two cell-layered on the dorsal lamina; two to four cell-layered on the sheathing lamina; leaf cells smooth, cells around the costa are slightly larger.

**Habitat**: Plants found growing on rocks (saxicolous), in shaded and moist places in close association with liverworts like *Cephalozia* sp.

**Range**: Africa, Brazil, Canada, Chile, China, Costa Rica, Greenland, Hawaii Island, India, Indonesia, Iraq, Japan, Libya, Mexico, Mongolia, Philippines, Sri Lanka, and United States.

**Distribution in India**: Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Maharashtra, Manipur, Meghalaya, Odisha, Rajasthan, Tamil Nadu, Uttarakhand, and West Bengal.

**Specimen examined**: India: Manipur, Senapati District, Pudunamai Village, 1600–1800 m, 16.ix.2024, K.K00285.

**3. *Fissidens crenulatus*** Mitt., J. Proc. Linn. Soc., Bot., Suppl. 1(2): 140. 1859; Gangulee, Mosses E. India Fasc. 2:504. 1971. (Images 1l–p)

Plant small, monoicous, stems reddish-brown, curled up when dry, fertile shoots 4.5–5.0 mm long and 0.6–0.8 mm wide with leaves. Leaves 8–9 pairs, 0.9–1 mm long, 0.3–0.4 mm wide, oblong-lingulate to oblong lanceolate, wider near base, apex acute, margins serrulate; sheathing lamina 3/4 of the leaf length, equal

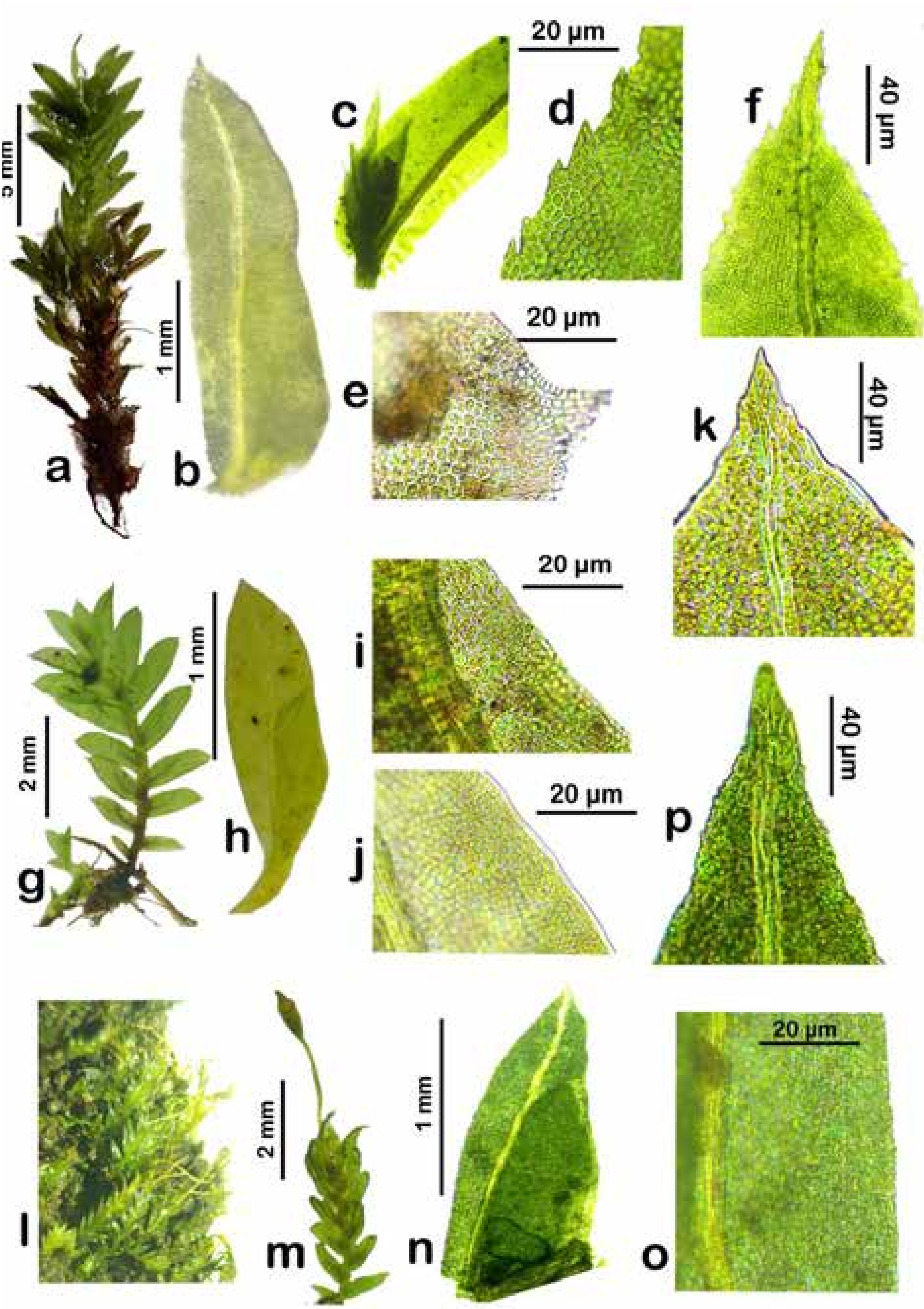


**Image 1.** ***Fissidens anomalus*** **Mont. (a–f): a—plant body | b—leaf | c—leaf base | d—leaf marginal cells | e—leaf basal cells | f—leaf apex.** ***Fissidens bryoides*** **Hedw. (g–k): g—plant body | h—Leaf | i—leaf basal cells | j—leaf marginal cells | k—leaf apex.** ***Fissidens crenulatus*** **Mitt. (l–p).: l—habitat photo | m—plant body | n—leaf | o—leaf marginal cells | p—leaf apex. © Kholi Kaini.**

in mature leaves; leaf cells mamillose. Costa excurrent, light brown, wider at the base. Semi-limbidium ends below the apex in some leaves, smooth, simple, in two rows, sheathing lamini completely bordered, cells cartilaginous, in a single row in the apical part, in three rows at the basal area.

**Habitat**: The plants found growing on moist soil in shaded trails in association with other mosses.

**Range:** China, India, Indonesia, Japan, Malaysia, Myanmar, Nepal, New Guinea, Philippines, and Vietnam.

**Distribution in India**: Andhra Pradesh, Assam, Karnataka, Kerala, Manipur – present report, Meghalaya, Odisha**,** Tamil Nadu, Uttar Pradesh, and West Bengal.

**Specimen examined**: India: Manipur, Senapati District, Ekhra (Tadubi), 1625–1650 m, 16.ix.2024, K.K00281.

**4.** ***Fissidens ceylonensis*** Dozy & Molk., Musc. Frond. Archip. Ind. 7. 1844; Gangulee, Mosses E. India Fasc. 2:511. 1971. (Image 2a–f)

Plants are small, terrestrial, yellowish-green, leaves folded and curled, pressed to the stem when dry, stems rust-like, fertile shoots 2.5–4.0 mm long, 0.6–0.9 mm wide with leaves. Leaves in 6–8 pairs, oblong–lingulate, 0.8–0.9 mm long, 0.2–0.3 mm wide, broadest at base, apiculate from a broad base, apex acute to widely acute; sheathing lamina mostly equal. Semi-limbidium is poorly developed, in 1–3 rows, absent, or reduced in sterile plants. Costa percurrent, ending just below the leaf tip. Seta, bent abruptly or erect, brown, 3–5 mm long. Capsule, erect, ovoid, brown, 0.6 mm long and 0.3 mm wide. Spores, green to translucent, 7.2–11.3 µm in diameter.

**Habitat**: The plants are found growing on soil in shaded, steep banks in association with liverworts.

**Range**: India, Indonesia, Malaysia, Nepal, New Zealand, Philippines, Thailand, and Vietnam

**Distribution in India**: Andhra Pradesh, Assam, Bihar, Kerala, Madhya Pradesh, Manipur (present report), Odisha, Sikkim, Tamil Nadu, Uttarakhand, Uttar Pradesh, and West Bengal

**Specimen examined**: India: Manipur, Senapati District, Ekhra (Tadubi Village), 1625–1650 m, 16.ix.2024, K.K00281.

**5.** ***Fissidens diversifolius*** Mitt., J. Proc. Linn. Soc., Bot., Suppl. 1(2): 140. 1859; Gangulee, Mosses E. India Fasc. 2: 492. 1971. (Image 2g–k)

Plant small, dioicous, unbranched, bright green when fresh and dark green on dry specimens, stem orange-brown, 4–5 mm long and 1.2–1.4 mm broad with leaves. Leaves in 6–8 pairs, lanceolate, slightly twisted when dry, 0.8–1 mm long, 0.3 mm broad, broader at base, acute at apex; sheathing lamina 1/3 of the leaf length, usually equal, dorsal lamina narrow down and ends at nerve base semi-limbidium, simple, smooth, in 1–5 rows of elongated pellucid, smooth cells completely bordering the sheathing lamini. Costa terminating below the leaf tip.

**Habitat**: The plants found growing in a moist, red laterite rocky soil in association with some liverworts like *Solenostoma* sp. and moss like *Pogonatum* sp.

**Range**: Bhutan, India, Japan, Myanmar, and Nepal.

**Distribution in India**: Assam, Arunachal Pradesh, Bihar, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Manipur (present report), Odisha, Tamil Nadu, and West Bengal.

**Specimen examined**: India: Manipur, Senapati District, Elai waterfall, 1600–1900 m, 28.ix.2024, K.K00367.

**6.** ***Fissidens elongatus*** Mitt., J. Proc. Linn. Soc. Bot., Suppl. 1(2): 139. 1859; Gangulee, Mosses E. India Fasc. 2: 561. 1971. (Image 2l–q)

Plants are large, sturdy, dark green in both fresh and dry conditions, stems are branched, 6.0–6.5 cm long, 2.5–2.7 mm wide, with leaves. Leaves in 53–102 pairs, lanceolate, acuminate at apex, 2.7–3.0 mm long, 0.4–0.5 mm wide; sheathing lamina 1/2 the leaf length, unequal, dorsal lamina, wedge shaped to round at the base, meeting the stem at the leaf attachment; leaf cells at the apical area irregular, slightly mamillose, marginal cells slightly crenulate, regularly arranged. Costa percurrent, slightly lighter in shade than the leaf.

**Habitat**: The plants found thriving on rocky substrates under persistent dripping water.

**Range of Distribution**: Japan and India.

**Distribution in India**: Andhra Pradesh, Assam, Arunachal Pradesh, Bihar, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Manipur (present report), Meghalaya, Odisha, Tamil Nadu, and West Bengal.

**Specimen examined**: India: Manipur, Senapati District, Willong Village, 1258–1682 m, 16.xii.2023, K.K00175.

**7.** ***Fissidens ganguleei*** Nork. in Gangulee, Mosses E. India Fasc. 2: 527. 1971. (Image 3a–f)

Plants are small, bright green to pale yellowish-green, 7.0–7.5 mm long, 1.5–2.0 mm wide, with leaves, branched or unbranched. Leaves in 14–16 pairs, oblong–lanceolate, slightly curled or crumpled when dry, 1.5–2.0 mm long, 0.2–0.3 mm wide, acute at apex, slightly

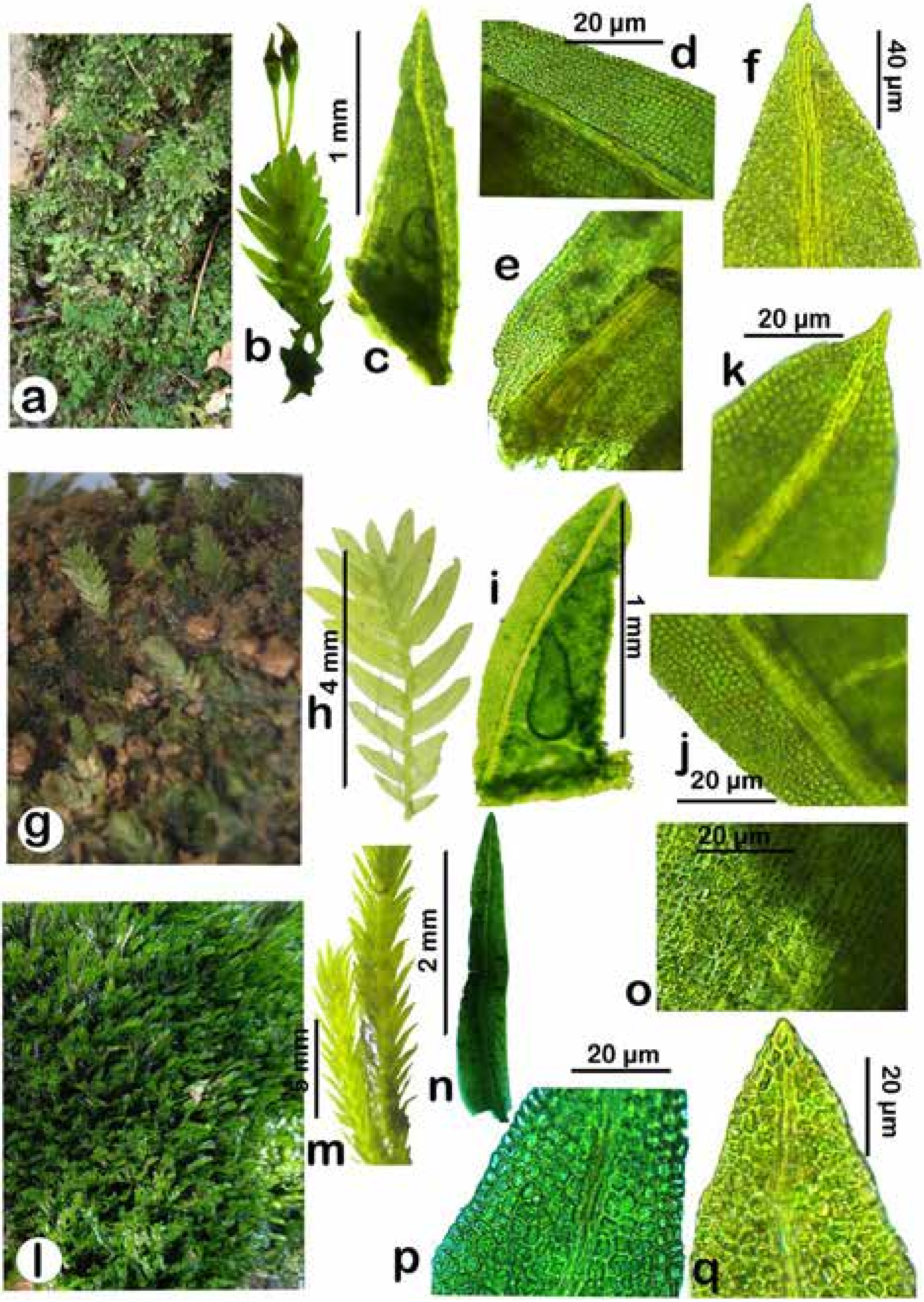


**Image 2. *Fissidens ceylonensis* Dozy & Molk. (a–f): a—habitat photo | b—plant body | c—leaf | d—leaf marginal cells | e—Leaf basal cells | f—leaf apex. *Fissidens diversifolius* Mitt. (g–k): g—habitat photo | h—plant body | i—leaf | j—leaf marginal cells | k—leaf apex. *Fissidens elongatus* Mitt. (l–q): l—habitat photo | m—plant body | n—leaf |o—leaf basal cells | p—leaf marginal cells | q—leaf apex. © Kholi Kaini.**

broader at the basal part; leaf margin slightly crenulate or serrate; sheathing lamina, unequal, 1/3 of the leaf, dorsal lamina base slightly decurrent; leaf cells quadrate to rounded hexagonal; cells in sheathing lamini similar to those of apical and dorsal lamini.

**Habitat**: The plants grow on moist soil and rocks, in shaded areas associated with mosses and liverworts.

**Range**: Bangladesh, China, India, Indonesia, Japan, Korea, Nepal, and Vietnam.

**Distribution in India**: Andhra Pradesh, Karnataka, Kerala, Manipur (present report), Tamil Nadu, Telangana, and West Bengal.

**Specimen examined**: India: Manipur, Senapati District, Khonem Thana Village, 1000–1173 m, 30.ix.2024, K.K00377.

**8.** ***Fissidens nobilis*** Griff., Calcutta. J. Nat. Hist. 2: 505. 1842; Gangulee, Mosses E. India Fasc. 2: 550. 1971. (Image 3g–l)

Plants are large, brownish-green in both fresh and dry conditions, leaves not much curled when dry; the shoot is 3.8–5.0 cm long and 10–11 mm wide with leaves. Leaves in 15 pairs, ligulate, 6–7mm long, 1.4–1.5 mm wide, 2 cell-layered, 3–4 layers at margin; border well-defined, double serrated, without limbidium, apex symmetrical, margin toothed; sheathing lamina 1/3, unequal, detachable, broader at base. Perichaetal leaf is shorter and narrower.

**Habitat**: The plants found growing on rocks in dark-shaded areas in association with thallose liverworts.

**Range**: China, India, Japan, Korea, Nepal, Philippines, Thailand, Vietnam.

**Distribution in India**: Andhra Pradesh, Assam, Karnataka, Kerala, Madhya Pradesh, Manipur, Meghalaya, Odisha, Sikkim, Tamil Nadu, and West Bengal.

**Specimen examined**: India: Manipur, Senapati District, Koziirii (Maopundung Village), 1437–1921 m, 01.x.2024, K.K00409.

**9.** ***Fissidens pulchellus*** Mitt., J. Proc. Linn. Soc., Bot., Suppl. 1(2): 140. 1859; Gangulee, Mosses E. India Fasc. 2: 524. 1971. (Image 3m–r)

Plant medium to large, bright green when fresh, dull brownish-green in herbarium, stem orange-grey, shoots 1.0–1.5 cm long, 2.0–2.3 mm wide with leaves. Leaves in 25–27 pairs, oblong–lanceolate, curled when dry, 1.0–1.5 mm long, 0.25–0.29 mm wide, borders sharp, distinctly denticulate margins; cells quadrate-hexagonal, with one or two conical papillae on each cell. Sheathing lamina 2/3 of the leaf, unequal or rarely equal, dorsal lamina base slightly decurrent. Costa excurrent or sometimes percurrent ending into a short apiculus, diminishing below the apex.

**Habitat**: The plants found thriving on a thin layer of soil overlaying rocky substratum, nestled within the shade of other rocks.

**Range**: India, Nepal.

**Distribution in India:** Andhra Pradesh, Arunachal Pradesh, Bihar, Karnataka, Kerala, Madhya Pradesh, Manipur (present report), Meghalaya, Odisha, Tamil Nadu, Uttarakhand, and West Bengal.

**Specimen examined**: India, Manipur, Senapati District, Koziirii (Maopundung Village), 1437–1921 m, 01.x.2024, K.K00405.

**10.** ***Fissidens crispulus* var. *robinsonii*** (Broth.) Z. Iwats. & Z.H.Li, Moss Fl. China 2:26. 2001. Gangulee, Mosses E. India Fasc. 2: 534. 1971. (Image 4a–e).

Plants are small, yellowish-green, unbranched, twisted when dry, shoots 6.5–7.0 mm long and 2.1–2.3 mm wide with leaves. Leaves in 10–12 pairs, ligulate–lanceolate, narrow, acuminate with spiny tip, 2.5–2.7mm long, 0.4–0.5 mm wide, apical margin, crenulated, cells rounded hexagonal, thin-walled, each with mamillose to conical papillae but not obscure, irregular; sheathing lamina more than 1/2 of the leaf length, unequal, crispate with incurved hook-like tips when dry; dorsal lamina base rounded, decurrent to base in single layer cells. Costa prominent, excurrent with spiny aristate apiculus. Limbidium and border, absent. Perichaetal leaves are longer than other leaves.

**Habitat**: The plants thrive on damp, living tree trunks, situated near water sources in association with other mosses. The place of collection is predominantly shaded throughout the year, profiting from minimal human disturbance.

**Range**: China, India, and Philippines.

**Distribution in India**: Andaman & Nicobar Islands, Andhra Pradesh, Goa, Karnataka, Kerala, Maharashtra, and Manipur (present report).

**Specimen examined**: India: Manipur, Senapati District, Koziirii (Maopundung Village), 1437–1921 m, 01.x.2024, K.K00389.

**11.** ***Fissidens viridulus*** (Sw.) Wahlenb., Fl. Lapp: 334. 1812; Gangulee, Mosses E. India Fasc. 2: 464. 1971. (Image 4f–j)

Plant small, pale green, stems unbranched, usually single, shoots 4–5 mm long, 1.5 mm wide, with leaves. Leaves in 5–7 pairs, ovate-lanceolate to elliptical

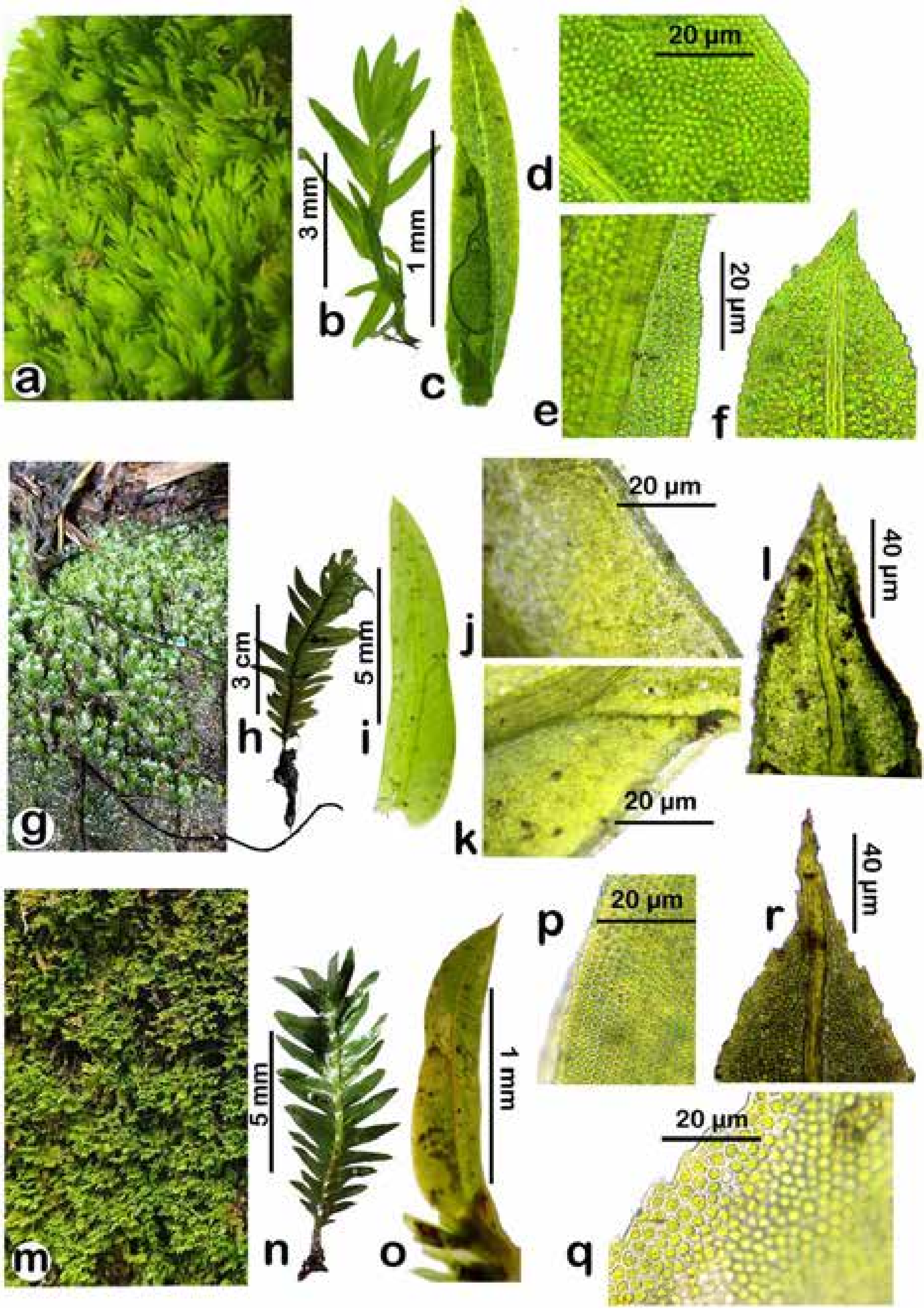


**Image 3.** ***Fissidens ganguleei*** **Norkett ex Gangulee. (a–f): a—habitat photo | b—plant body | c—leaf | d—leaf marginal cells | e—leaf basal cells | f—leaf apex.** ***Fissidens nobilis*** **Griff. (g–l): g—habitat photo | h—plant body |I—leaf | j–k leaf marginal cells | l—leaf apex.** ***Fissidens pulchellus*** **Mitt. (m–s): m—habitat photo | n—plant body | o—leaf | p–q—Leaf marginal cells | s—leaf apex. © Kholi Kaini.**

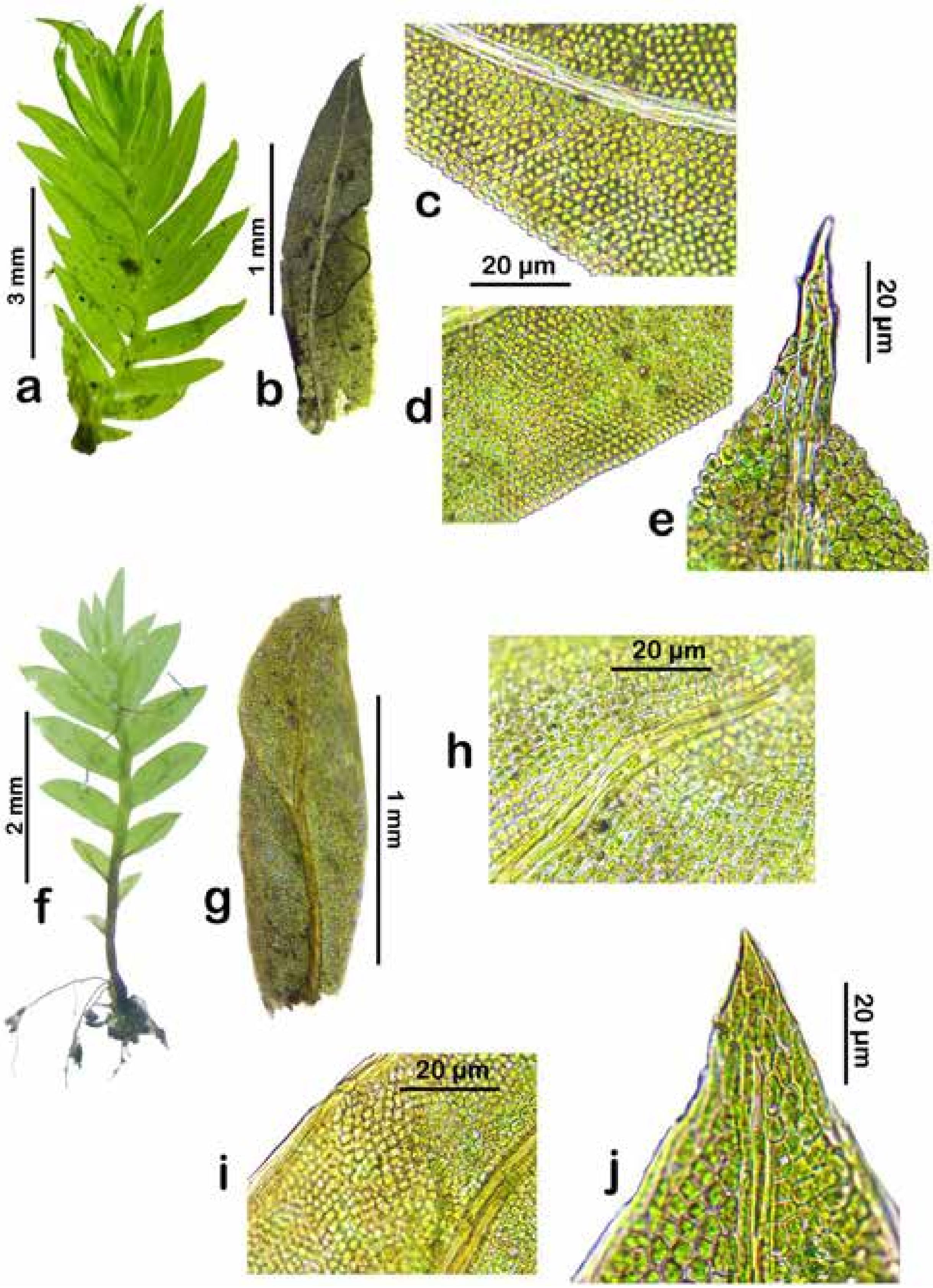


**Image 4.** ***Fissidens crispilus*** **var.** ***robinsonii*** **(Broth.) Z.Iwats. & Z.H.Li (a–e): a—plant body | b—leaf | c–d—Leaf marginal cells | e—leaf apex.** ***Fissidens viridulus*** **(Sw.) Wahlenb. (f–j): f—plant body | g—leaf | h—leaf cells | i—leaf marginal cells | j—leaf apex. ©Kholi Kaini.**

lanceolate, apex apiculate to acute, widest at the middle, 0.7–1.2 mm long, 0.3–0.5 mm wide, margin smooth, entire with clearly defined border except at the apex, lamina cells unistratose, smooth; sheathing lamina 2/3 of the leaves, equal; cells similar to those of the apical and dorsal lamini. Costa ending below the apex, apical cells single-layered. Limbidium narrow, elongated, unistratose, all-around leaf except below the apex.

**Habitat**: The plants are found growing on the soil together with mosses, *Pogonatum* sp.

**Range**: Australia, China, India, Nepal, Russia, Africa, Europe, and North America.

**Distribution in India**: Assam, Manipur (present report), Karnataka, Sikkim, Uttarakhand.

**Specimen examined**: India: Manipur, Senapati District, Ekhra (Kalinamai Village), 1625–1650 m, 16.ix.2024, K.K00326.

## CONCLUSIONS

The present investigation on the genus *Fissidens* of Senapati District of Manipur revealed the occurrence of 11 species, chiefly found in three habitats: terricolous, saxicolous, and corticolous. The species were identified based on the presence or absence of limbidium, costa length, leaf margin cells, and marginal dentation, papillae of leaf cells, and differentiation of leaf border. Five species—*F. viridulus*, *F. bryoides*, *F. diversifolius, F. crenulatus,* and *F. ceylonensis* exhibit the presence of limbidium, which were further categorized based on the extent of its presence, i.e. present throughout or limited to a specific area. Six species—*F. ganguleei, F. crispulus* var. *robinsoni, F. pulchelus, F. elongatus, F. anomalous,* and *F. nobilis* are characterized by the absence of limbidium, which are further differentiated based on the dentation of leaf margin, distinctive leaf border, and presence or absence of leaf cell papillae. These species fall under six sections of the genus *Fissidens*—sect. *Fissidens* (*F. bryoides*, *F. viridulus*), sect. *Semilimbidium* Müll.Hal. (*F. diversifolius*, *F. crenulatus*, *F. ceylonensis*), sect. *Crenularia* Müll.Hal. (*F. pulchellus*), sect. *Aloma* (Kindb.) Müll.Hal. (*F. ganguleei*), sect. *Crispidium* Müll. Hal. (*F. crispulus* var. *robinsonii*), and sect. *Serridium* Müll.Hal. (*F. nobilis, F. anomalous, F. elongatus*) (Gangulee 1971).

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ARTICLE

# Ecology and conservation concerns of *Indianthus virgatus* (Marantaceae): an endemic species of the Western Ghats–Sri Lanka Biodiversity Hotspot

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**Abstract:** *Indianthus virgatus* (Roxb.) Suksathan & Borchs., a monotypic species of Marantaceae endemic to the Western Ghats–Sri Lanka biodiversity hotspot, holds important ecological, ethnobotanical, and conservation value. The present study aimed to understand the ecology of *I. virgatus* and to assess its current distribution, threats, and conservation needs. We compiled species' distribution data from herbarium records, online repositories, taxonomic literature, supplemented with field surveys (2023–2025), and ground validation across its range in the Western Ghats. Results indicate that *Indianthus* populations are generally small (10–50 m²) and fragmented, occurring in wet forest ecosystems and along plantation boundaries at elevations of 100–1,200 m. Phenological observations show that the species flowers year-round, with peak flowering during the monsoon. Major threats include habitat loss from agricultural expansion, plantation development, and road construction, compounded by competition from invasive species. While *Indianthus* is classified as Critically Endangered in Sri Lanka, its global conservation status remains unassessed by the IUCN Red List. This study provides baseline ecological, taxonomic, and distributional information, highlighting the species' vulnerability and underscoring the urgent need for conservation measures, including habitat protection, community engagement, and a formal global IUCN Red List assessment.

**Keywords:** Diversity, ethnobotanical value, habitat, invasive species monotypic, IUCN Red List, threatened flora.

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**Author details:** See end of this article.

**Author contributions:** SBV—research design, conceptualization, field data collection, data compilation, data analysis, writing, and editing the manuscript. VP—research design, conceptualization, methodological guidance, data analysis, writing and editing the manuscript, and supervision. BG—field data collection, herbarium verification, taxonomic assessment. RG—field data collection, data curation. BM—field data collection, data curation. DY—taxonomic support, species verification, and manuscript review. AM—methodological guidance, and manuscript review

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## INTRODUCTION

The Western Ghats (WGs)-Sri Lanka biodiversity hotspot is home to a wide range of endemic plant species, many of which have developed unique adaptations to their specific habitats (Blicharska et al. 2013; Vignesh et al. 2024). *Indianthus virgatus* (Roxb.) Suksathan & Borchs., a monotypic species in the Marantaceae family, is one such plant. Endemic to this hotspot, it holds significant ecological, ethnobotanical, and conservation significance (Suksathan et al. 2009; Sangeetha & Rajamani 2019; Arumugam 2021; Vishnu et al. 2024). The Marantaceae family, known for its diversity in tropical ecosystems, includes several relict species such as *Donax canniformis* K.Schum. and *Stachyphrynium spicatum* (Roxb.) K.Schum., which are confined to specific, often isolated regions (Niissalo et al. 2016; Veldkamp & Turner 2016). *I. virgatus* primarily grows in fragmented, humid habitats across the WGs–Sri Lanka biodiversity hotspot (Suksathan et al. 2009). However, it is increasingly threatened by habitat degradation and human activities.

Despite being classified as Critically Endangered in Sri Lanka (The National Red List 2020), the IUCN Red List status of this species in the WGs–Sri Lanka biodiversity hotspot remains unassessed, highlighting a critical gap in its conservation strategy. Globally, 32 species of Marantaceae have been assessed under the IUCN Red List of Threatened Species, most of which are categorized as Vulnerable or Endangered (Table 1).

The disjunct distributions of wet-zone species in the Indian subcontinent (Karanth 2003), such as *I. virgatus*, reflect evolutionary processes where relict species, once part of widespread distributions, have become restricted to isolated patches due to historical climatic and ecological shifts (Hardie & Hutchings 2010; Tagliari et al. 2021). These species are often vulnerable to extinction because of their narrow ecological niches and limited adaptability to environmental fluctuations (Sax et al. 2013). In the case of *I. virgatus*, ongoing habitat loss due to agricultural expansion, urbanization, overexploitation, and climate change exacerbates the risk of extinction, particularly as its distributions are confined to small, fragmented areas (Vishnu et al. 2024). Despite these challenges, little is known about the population dynamics, distribution patterns, and ecological requirements of this species, limiting the ability to accurately assess its conservation status.

This study provides preliminary ecological insights into *I. virgatus* and the threats it faces within its native range in the WGs. Given the scarcity of prior ecological data for this species, we document its diversity, range delimitation, and taxonomic characteristics. These observations do not constitute a formal assessment but establish a baseline that highlights the species' distinctiveness and potential conservation concerns. With additional data on population size, threats, regeneration dynamics, and ecological requirements, this baseline could inform a more comprehensive evaluation and contribute to a future IUCN Red List assessment.

## MATERIALS AND METHODS

Species distribution data of *I. virgatus* were compiled through herbarium consultations and opportunistic field surveys. Herbarium records were examined at the Kerala Forest Research Institute (KFRI), Herbarium of the French Institute of Pondicherry (HIFP), Central National Herbarium, Howrah (CAL), Calicut University Herbarium (CALI), Tropical Botanic Garden and Research Institute (TBGT), and the Botanical Survey of India herbaria at Coimbatore (MH) and Pune (BSI), following standard herbarium acronyms listed in the Index Herbarium. Online repositories (e.g., GBIF, Plants of the World Online) were also referred to for specimen citations and occurrence data (Supplementary Table 1).

Field visits were carried out across ~35–40 sites spanning Goa, Karnataka, Kerala, and Tamil Nadu between August 2023 and February 2025. These were opportunistic surveys, guided by herbarium records, literature, and local reports. At each location, GPS coordinates were recorded using a Garmin ETREX 32x. Opportunistic observations were made on habitat type, associated vegetation, and land-use pressures. Select sites were revisited multiple times to assess habitat stability and persistence of subpopulations.

Population size and patch structure were documented qualitatively, with estimates of patch extent ($m^2$) and approximate abundance categories (scattered individuals, small clumps, dense patches). Information on co-occurring species was obtained through opportunistic field observations, as systematic plot-based inventories were not conducted. Species threats, including invasive species, proximity to plantations, and ongoing road expansion near *I. virgatus* populations, were directly assessed in the field. Ethnobotanical knowledge was compiled from qualitative information shared by local communities and supplemented with data from published sources.

A few representative sites were repeatedly

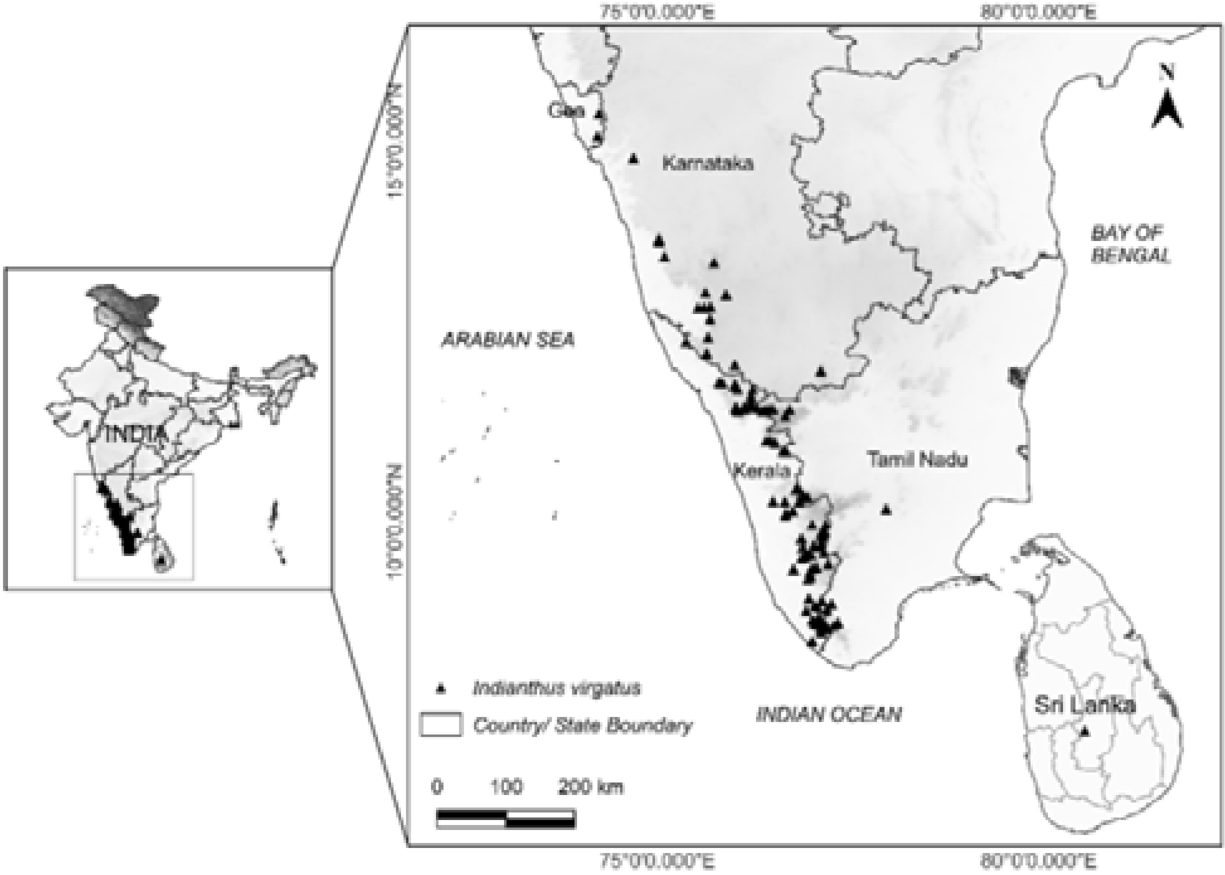


**Figure 1. Map showing the distribution of *Indianthus virgatus* in India and Sri Lanka.**

monitored through continuous field visits between August 2024 and February 2025 to assess population stability, habitat conditions, and land-use dynamics. In addition to distributional surveys, detailed taxonomic observations were carried out using both field collections and herbarium specimens. Photographs were taken with a Canon EOS 3000D camera, while flowers were dissected and imaged under a stereo microscope (Lawrence and Mayo; Model: LYNX LM-52-3621). The identification key was developed following Suksathan et al. (2009), with modifications based on a comparative study of herbarium collections and direct examination of live specimens (Supplementary Table 1). Taxonomic characters were described from field observations and comparative analyses with reference literature (Keshavamurthy & Yoganarasimhan 1990; Mohanan & Sivadasan 2002; Bhat 2014; Nayar et al. 2014).

## RESULTS

Field surveys confirmed the presence of *I. virgatus* across numerous fragmented locations in the WGs, specifically in Goa, Karnataka, Kerala, and Tamil Nadu (Figure 1). Subpopulations were generally small, with patch sizes ranging from approximately 10–50 $m^2$ and an average of about 20 $m^2$. Historical herbarium records, spanning from 1857–2023, corroborated these observations, showing that the species has maintained a scattered and discontinuous distribution over time. In Sri Lanka, populations were largely restricted to the Central and Sabaragamuwa provinces, consistent with earlier reports of their critical endangerment in the wild.

*Indianthus* is a monotypic endemic genus confined to the wet zones of the WGs and Sri Lanka. The species is also reported from a few Myristica swamps in Kulathupuzha, Anchal, and Shendurney (Image 1). It thrives largely in moist and humid environments, favouring evergreen and semi-evergreen forest patches. The species is commonly found in swampy areas, particularly along the banks of perennial and temporary streams, which provide consistent moisture essential for its growth and survival. It also occurs on rocky, sloping hills of tea, coffee, and cardamom plantations, often in proximity to forest boundaries. These habitats are typically located at mid and higher elevations, ranging 300–1,200 m, though populations can occasionally be found at lower elevations between 100 and 300 m. Many of its populations are located adjacent to plantations of tea, coffee, and cardamom, which share a similar ecological niche (Image 2). This overlap with human-modified environments emphasizes the need for conservation measures, as habitat disturbances can threaten its survival.

**Phenology and Taxonomic History**

*Indianthus* is a tall, perennial herb exhibiting flowering and fruiting throughout the year, with peak reproductive activity during the monsoon and post-monsoon seasons. This phenological pattern is strongly influenced by seasonal rainfall, as the species responds to the availability of moisture and favourable climatic conditions. Flowering and fruiting are rarely observed during summer (April–May), highlighting the species' reliance on monsoonal cycles for optimal reproductive performance. The holotype species, *Phrynium virgatum,* was first validated by Roxburgh in 1810. He observed that "it was found in the late Dr. Anderson's garden at Madras and subsequently introduced to the Botanic Garden at Calcutta". The specimen was initially reported to have been collected from Tinnevelly–Travancore. However, after several revisions concerning morphological and taxonomic distinctions, the species was reclassified into the distinct genus *Indianthus* by Suksathan et al. (2009), based on phylogenetic evidence.

**Taxonomic Treatment**

Perennial rhizomatous herb, forming dense tufts; stems erect, slender, simple, green, glabrous, three to six m tall (c. 10–18 ft), thickened at nodes; rhizome short, creeping, fibrous. Leaves distichous; sheath tubular, green; petiole slender, up to three cm long; lamina lanceolate, 15–45 × 4–20 cm, coriaceous, bright green, margin entire, apex cuspidate, base cuneate, surfaces glabrous; young leaves light green, becoming uniformly green at maturity. Inflorescence terminal, panicle, up to 70 cm long, dichotomously branched, many-flowered; pedicels slender, up to one cm long, with hairy prophyll two to three cm long. Flowers white, odourless, paired, bracts green, lanceolate, c. 3 × 0.2 cm, persistent; sepals three, lanceolate; corolla with five distinct petals, of which the two outer are petaloid, and the three inner are differentiated into two lateral obovate staminodes (0.6–0.8 cm long) and a third united with the single fertile stamen to form a petaloid structure bearing the anther. Inner staminodes smaller, inconspicuous. fertile stamen one, anther basifixed; ovary inferior, trilocular; style slender, curved, stigma curved, three-lobed. Fruit is a green, dehiscent capsule with a persistent perianth; seeds one to three, ellipsoidal, glossy (Image 1).

Vernacular name: Malabar Arrowroot (English), Kattu Kuva, Kuva (Malayalam), Koovai, Malakkuvai (Tamil), Geta-oluwa (Sinhala), Koove (Kannada).

Specimens examined: West Bengal, Calcutta Botanic Garden, Royle, PH00017033 (CAL!); Travancore/Tinnevelly (Holotype), s. coll. #6616A–D, K001124308–K001124310 (CAL!); India, Wallich N. #6616, K000357867 (CAL!). India, Kerala, Thrissur, Kollathirumedu, Vazhachal, 06.vii.1988, N. Sasidharan.; MH 7451 (MH!); Tamil Nadu, Courtallam, K. Subramanyam, 100865 (CALI!); Kerala, 8 km from Athirumala, Thomas V.P. & Prasanth A.V. 02.iii.2008, 103044 (CALI!); Kerala, Pambla Dam, Dani Francis & Prof. Santhosh Nampy. 08.iii.2017, 152012 (CALI!); Kerala, Calvary Mount, Dani Francis & Santhosh Nampy. 06.ix.2017, 154367 (CALI!); Kerala, near Valara Waterfalls, Dani Francis & Santhosh Nampy. 27.xii.2017, 156530 (CALI!); Tamil Nadu, Nadugani, 26.ii.1970, J.L. Ellis. 33599 (MH!); Tamil Nadu, Kulivayal, 25.vii.1972, E. Vajravelu. 41791 (MH!); Tamil Nadu, Gudalur, 11.iii.1969, D.B. Deb. 31666 (MH!); Tamil Nadu, Devala, Ooty, 12.i.1927, J.S. Gamble. 15602 (MH!); Kerala, KFRI 4940; Sri Lanka, Peradeniya, Thwaites G. 1855, *Clinogyne virgata* (Roxb.) Benth. PDA!

**Distribution Delimitation**

*Indianthus virgatus* has frequently been listed in several botanical databases, including in Plants of the World Online (POWO), to occur in India, Sri Lanka, and the Andaman Islands. In Florae Indicae Enumeratio: Monocotyledonae (Karthikeyan et al. 2009), the species was treated under the synonym *Donax virgata* (Roxb.) K.Schum. in Bot. Jahrb. Syst. 15: 440 (1892) and cited as distributed in the Andaman & Nicobar Islands, India, and Sri Lanka. This treatment has subsequently been adopted in later compilations and online platforms, which may have reinforced a distributional ambiguity. Field surveys, critical examination of herbarium collections, and a review of floristic literature indicate that there are currently no verifiable specimens or authentic records confirming the species' distribution in the Andaman Islands. All confirmed records are restricted to the WGs of India and Sri Lanka. The geological history of the Andaman Islands, which are

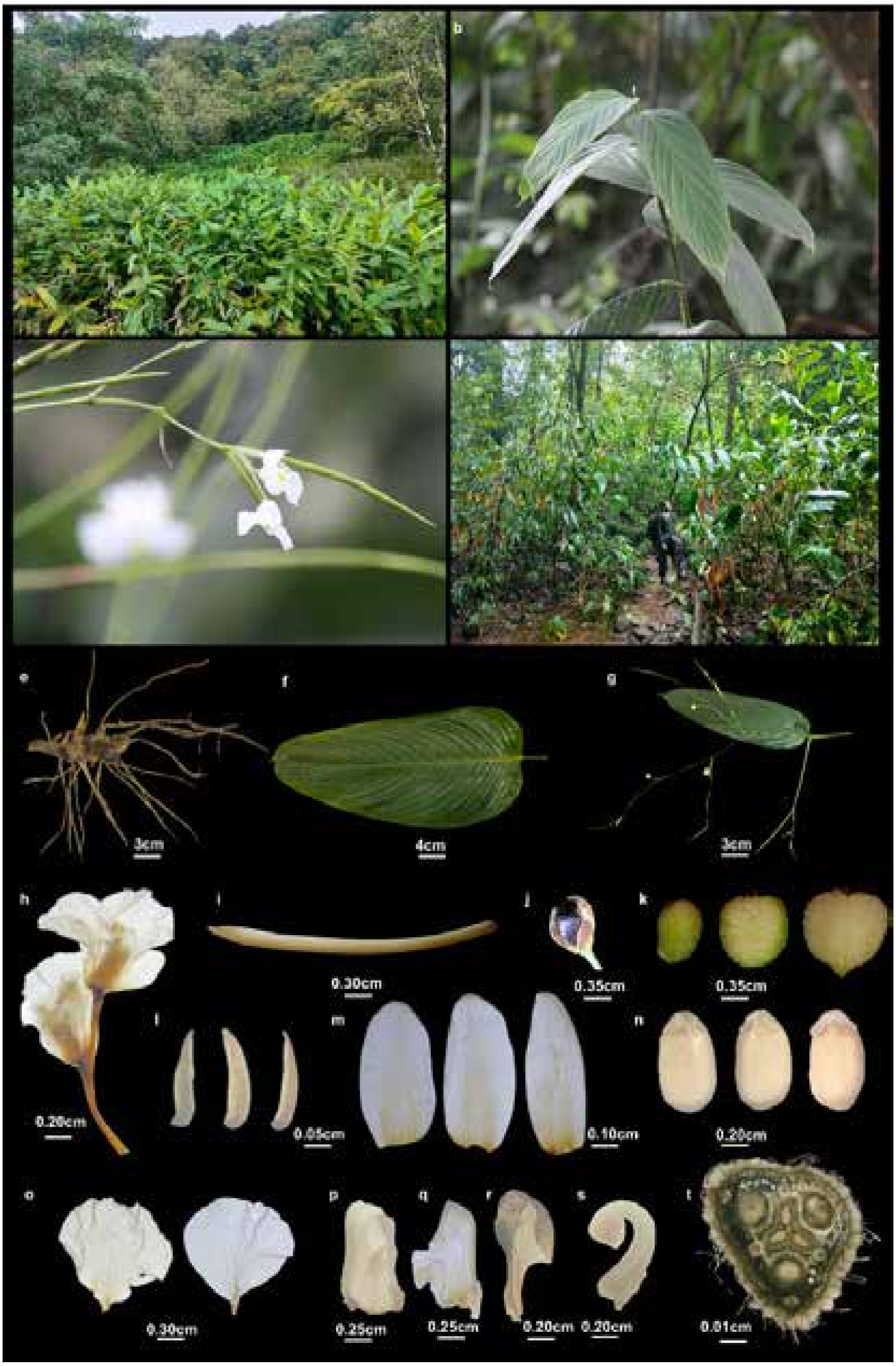


**Image 1.** ***Indianthus virgatus*** **(Roxb.) Suksathan & Borchs.: a—Dense understory population in Ranipuram, Kerala (CWGs) | b—Young and mature distichous leaves showing lanceolate lamina and glabrous surfaces | c—Paired white flowers | d—Individuals in a shaded forest understorey | e—Short fibrous rhizome | f—Single leaf showing coriaceous texture, entire margin, and cuspidate apex | g—Leaf with inflorescence branches, Panicle | h—Paired white flowers | i—Hairy prophyll | j—Dehiscent capsule | k—one, two, three seeded fruit | l—bracts - three | m—calyx - three | n—Seeds - three glossy | o—Outer petals - two | p & q—Petaloid staminode | r—Epipetalous stamen, basifixed | s—Stigma curved | t—Transverse section of the ovary showing trilocular structure. © Shreekara Bhat Vishnu.**

**Image 2. The habitat degradation and population decline of *Indianthus virgatus* in the Western Ghats. In Wayanad. a—The species is observed growing alongside the invasive *Mikania micrantha*, while in other areas | b—Encroachment by *Tithonia diversifolia* has led to noticeable reductions in population. In Kallar, Thiruvananthapuram | c—*Indianthus* individuals were found within dense *Mucuna bracteata* cover, indicating altered habitat conditions | d—Patch size was drastically reduced due to clearing of vegetation surrounding the roads, Gaalibeedu, Madikeri | e—Few individuals of *Indianthus* surviving on the edge of plantations, Idukki | f—Landslides, proximity to cardamom plantations where *Indianthus* has been washed out, Idukki | g–h—Highway expansion in Sakleshpura (KA) resulted in the destruction of more than 50–60 % of the *Indianthus* habitat and subpopulations. Remaining fragments of *I. virgatus* in Thiruvananthapuram (Kallar) | i—*I. virgatus* adjacent to streams and rubber plantations. © Shreekara Bhat Vishnu.**

**Table 1. IUCN Global and Sri Lanka National Red List status of Indian Marantaceae species.**

| Species | IUCN Status (Global) | National Red List (Sri Lanka) |
|---|---|---|
| *Donax canniformis* (G.Forst.) K.Schum. | - | - |
| *Indianthus virgatus* (Roxb.) Suksathan & Borchs. (*Schumannianthus virgatus* (Roxb.) Rolfe) | - | CR B2ab(i,ii,iii) (PE) |
| *Maranta arundinacea* L. | Not Applicable (cultivated) | - |
| *Phrynium imbricatum* Roxb. | - | - |
| *Phrynium nicobaricum* Didr. | - | - |
| *Phrynium pubinerve* Blume (*Phrynium rheedei* Suresh & Nicolson) | - | EN B1ab(i,ii,iii) +2ab(i,ii,iii) |
| *Schumannianthus dichotomus* (Roxb.) Gagnep. | - | - |
| *Stachyphrynium placentarium* (Lour.) Clausager & Borchs. | - | - |
| *Stachyphrynium repens* (Retz.) K.Schum. | - | - |
| *Stachyphrynium spicatum* (Roxb.) K.Schum. (*Stachyphrynium zeylanicum* (Benth.) K.Schum.) | LC | CR(PE) |
| *Thalia geniculata* L. | Not Applicable (cultivated) | - |

part of the Burma–Java subduction arc and have never been connected to mainland India–Sri Lanka (Pal et al. 2003), does not support a vicariance explanation for the species' distribution. Furthermore, dispersal seems improbable, since *I. virgatus* produces capsular fruits with arillate seeds dispersed primarily by ants (Horvitz & Beattie 1980), a mechanism poorly suited for transoceanic transport. Overall, these observations suggest that reports of *I. virgatus* from the Andaman Islands should be regarded as unsubstantiated until supported by verifiable collections.

### Habitat Destruction and Threats

The species in the southern WGs is distributed in Myristica swamps, which are a Critically Endangered ecosystem in itself. Further north, across the central WGs, the species' distribution is found adjacent to tea- coffee plantations and highways. As per our field observations, these areas are highly uncertain and dynamic due to changing landscapes, ongoing road construction, and plantation expansions. Invasive species such as *Chromolaena odorata* (L.) R.M.King & H.Rob., *Mikania micrantha* Kunth, *Tithonia diversifolia* (Hemsl.) A.Gray, *Miconia crenata* (Desr.) DC., *Lantana camara* L., and *Mucuna bracteata* DC. ex-Kurz were also found co-occurring with *I. virgatus* (Image 2), which may inhibit the growth and expansion of its subpopulations as these invasive species are shown to have negative allelopathic effects (Del Fabbro & Prati 2015; Thiébaut et al. 2019). In the CWGs, Goa represents the northernmost distribution record of *Indianthus,* which occurs in less than five fragmented sites (Datar et al. 2005; Datar & Lakshminarasimhan 2013). These distributions are largely confined to areas adjacent to plantations and lie outside protected regions, highlighting their extreme vulnerability.

### Use and Trade

*Indianthus virgatus* is widely utilized by tribal communities in Kerala and Tamil Nadu, including the Mulla Kurumba, Kuruchiya, and Kani tribes. Its leaves and rhizomes are traditionally used to treat ailments such as dysentery and skin diseases (Silja et al. 2008; Rajith & Ramachandran 2010; Sangeetha & Rajamani 2018, 2019). Interactions with local communities further revealed ethno-veterinary applications, such as employing the leaves to alleviate joint pain in livestock. Beyond medicinal applications, *I. virgatus* plays an important ecological role. For example, the field observations indicate that *I. virgatus* is among the preferred feed for elephants and wild boars, while also serving as a nectar source for butterflies and other faunal assemblages. The species also holds significant cultural and culinary value. In parts of Kerala and Karnataka, its leaves are used as an alternative to banana leaves for preparing traditional dishes and are used in hotels across the southern WGs for daily meal service. In a prominent Kerala temple, the leaves are used to serve prasadam. During the rainy season, leaves are used to make protective coverings against rain, locally referred to as '*Gorabalu*' in Kannada. Near Kulathupuzha, leaves are harvested daily for similar purposes.

These diverse ethnobotanical practices underline the cultural, medicinal, ecological, and commercial significance of *I. virgatus*, emphasizing the importance of further research on its applications, sustainable use, and conservation.

### Conservation Status of Indian Marantaceae

Although *I. virgatus* is listed as Critically Endangered in Sri Lanka (CR B2ab (i,ii,iii); The National Red List 2020), it has not yet been evaluated for the global IUCN Red List. A review of other Indian Marantaceae indicates that most species remain unassessed globally, despite several being regionally rare or threatened. Table 1 summarizes the IUCN Global and Sri Lanka National Red List status of selected Indian Marantaceae, highlighting significant gaps in conservation evaluation. These findings emphasize the need for formal global assessments and conservation prioritization of endemic and relict taxa, given their restricted distributions and susceptibility to habitat disturbance.

## CONCLUSION

The present study represents the first comprehensive attempt to document the taxonomy, distribution, and threats to *I. virgatus*, a monotypic taxon of high conservation value. By combining field observations, herbarium and live specimen studies, and opportunistic records of co-occurring species, we were able to delineate its ecological niche and highlight the fragility of its remaining populations. Our findings indicate that *I. virgatus* exists in fragmented patches, confined to habitats that are under pressure from plantations, road construction, and invasive species. Since the species is habitat-specific and sensitive, these conditions not only threaten the survival of existing populations but also limit the species' potential for natural regeneration and population expansion. Given its restricted range, observed population decline, and vulnerability to

**Key to selected Asian Marantaceae genera**

1a. Plants without real above-ground stems, forming ground-level rosettes of leaves ............ **2**
1b. Plants with distinct above-ground stems (caulescent) ............ **3**
2a. Flower groups strongly compact (brachyblastic); bracteoles absent; sepals short (≤⅓ length of corolla tube); fruit dehiscent, one to two seeded ............ ***Stachyphrynium***
2b. Flower groups brachyblastic or sub-brachyblastic (slightly elongated); bracteoles absent or one per flower; sepals ≥½ as long as corolla tube; fruit dehiscent, one to three seeded ............ ***Phrynium***
3a. Inflorescence a terminal panicle up to 70 cm; flower groups dolichoblastic; bracteoles absent; stamen with large petaloid appendage; fruit three-seeded, dehiscent ............ ***Indianthus***
3b. Inflorescence not a large terminal panicle; flower groups dolichoblastic, two-flowered ............ **4**
4a. Bracteoles absent; corolla tube shorter than lobes; fruit three-seeded, dehiscent ............ ***Schumannianthus***
4b. Bracteoles present, small and glandular; stems tall, branched; fruit one- to two-seeded, indehiscent ............ ***Donax***
4c. Bracteoles absent, fruit one-seeded, indehiscent, caryopsis-like ............ ***Halopegia***

ongoing habitat disturbances, *I. virgatus* requires urgent conservation action. A formal assessment by the IUCN Red List is crucial to provide global recognition of its threatened status and facilitate policy-level interventions. Additionally, community engagement and habitat protection strategies will be essential to protect the species and its unique microhabitat.

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ARTICLE

# An updated floral diversity of Tal Chhapar Wildlife Sanctuary, Rajasthan, India

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**Abstract:** Tal Chhapar Wildlife Sanctuary, located on the eastern edge of the Thar Desert, supports higher floristic diversity and structural complexity compared to other arid zone ecosystems. A comprehensive floristic survey conducted from 2022 to 2024 recorded 211 angiosperm species belonging to 146 genera and 49 families, including one species from the magnoliids, 44 eudicots, and four monocots. Poaceae emerges as the dominant family with 49 species, followed by Asteraceae and Amaranthaceae, each contributing 17 species. Herbaceous plants were predominant, accounting for 40% of the flora, followed by grasses 23%, trees 12%, and shrubs 12%. Therophytes were the most common life form (105 species), followed by phanerophytes (55), hemicryptophytes (38), chamaephytes (11), and geophytes (2). The number of perennial plants (106 species) was almost equal to that of annuals (105 species), suggesting increased resilience to climate variability. Additionally, the survey identified one 'Endangered' species, *Tecomella undulata*, and one 'Critically Endangered' species, *Commiphora wightii*. Overall, this study provides a comprehensive floristic inventory of Tal Chhapar Wildlife Sanctuary, revealing its rich floral diversity and highlighting key species of conservation concern.

**Keywords:** Angiosperms, checklist, climatic variability, conservation, flora, floristic survey, inventory, life forms, plants, vegetation.

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**Author contributions:** Concept and design: SS and OI; Data collection: SS; Analysis: SS and OI; Manuscript writing: SS; Supervision: OI. Manuscript review and comments: SS and OI

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## INTRODUCTION

Biodiversity refers to the variety and variability of biological organisms. It is a fundamental indicator of ecosystem health, directly reflecting its vitality, resilience, and stability (Byrnes et al. 2015; Wagg et al. 2022). The richness of plant diversity within an ecosystem not only enhances the aesthetic value of the landscape but also significantly contributes to the overall productivity of the ecosystem by providing essential resources such as food, medicine, fuel, and shelter that are crucial for the survival and well-being of both wildlife and humans (Singh et al. 2005). In arid and semi-arid regions, plant diversity is essential for regulating the water cycle, stabilizing soil, and combating desertification, thereby maintaining ecological balance (Ayangbenro & Babalola 2021). The loss of biodiversity in such fragile environments could lead to severe environmental degradation and disrupt ecosystem services that sustain local communities. Therefore, preserving plant diversity is essential for maintaining ecological balance and ensuring the long-term sustainability of human life in these regions. In recent years, increased anthropogenic activities, including mining, agricultural expansion, habitat fragmentation, and changes in land use, have been observed in these regions, underscoring the urgent need for conservation efforts (Islam & Rahmani 2011; Ram 2021).

Arid and semi-arid ecosystems exhibit pronounced spatiotemporal variability in vegetation composition due to changes in rainfall, temperature, and grazing pressure, making them highly vulnerable to climatic variability (Chapungu et al. 2020; Wu et al. 2023; Sur et al. 2024; Al-Mutairi 2025). These environmental factors strongly influence net primary productivity and ecosystem $CO_2$ exchange, affecting vegetation dynamics across temporal scales (Knapp & Smith 2001; Huxman et al. 2004a,b). Continuous, systematic plant monitoring in such landscapes provides essential time-series data to track changes in community composition and species resilience (Bagchi et al. 2017; Reddy et al. 2020; Tiruvaimozhi 2024). Such periodic assessments also effectively capture ephemeral species limited to short favourable conditions and enable early detection of invasive species like *Prosopis juliflora,* facilitating timely management interventions in these ecosystems (Kumar et al. 2021; Burke 2023).

To date, numerous studies across western Rajasthan have significantly contributed towards understanding regional plant diversity, including notable works by Gupta & Sharma (1977), Singh et al. (1997), Sharma & Aggarwal (2008), Sharma & Purohit (2013), Parihar & Choudhary (2017), Meena & Khan (2023), and Sanadya et al. (2023). Moreover, in the past five years, three floristic surveys have been conducted in the Tal Chhapar Wildlife Sanctuary representing a significant shift in shrub and herbaceous plant diversity within the sanctuary from 2015 to 2023. These are Kaur et al. (2020) reporting 78 species, Bagoriya et al. (2021) 139 species, and Karel & Gena (2023) 132 species. These changes are likely driven by environmental factors (Wu et al. 2021, 2023) and adaptive management practices. Despite this evidence of ecological dynamism, long-term and repeated monitoring remains limited, constraining our understanding of species turnover, vegetation resilience, and ecosystem stability. The present study therefore aims to bridge this gap through a biennial floristic reassessment of Tal Chhapar, focusing on documenting current plant diversity, detecting species additions or losses relative to prior records, and revalidating taxonomic designations under the APG IV classification. This study aims to provide a comprehensive checklist of angiosperm diversity within the sanctuary, offering valuable insights to inform conservation efforts and management strategies that preserve biodiversity and promote the well-being of local communities.

## MATERIALS AND METHODS

### Study area

Tal Chhapar Wildlife Sanctuary (TWS) (27.840° N, 74.484° E), situated in Sujangarh Tehsil of Churu District in northwestern Rajasthan, covers an area of 719 ha, as shown in Figure 1. It is divided into two unequal halves by the Chhapar-Sujangarh state highway. Located within the 3-A Thar Desert (Rodger et al. 2002), the sanctuary experiences extreme temperatures, ranging from -1 °C in December–January to 50 °C in May–June, with 95% of its annual rainfall occurring during the monsoon season, July–September. According to Champion & Seth (1968), the vegetation of the study area is classified as "the desert thorn forest (6B/C1)." The sanctuary landscape features grass species such as *Cenchrus setigerus*, *Cynodon dactylon*, *Desmostachya bipinnata*, *Dichanthium annulatum*, *Lasiurus scindicus*, and *Sporobolus marginatus*, interspersed with tree species like *Acacia nilotica*, *Azadirachta indica*, *Capparis decidua*, *Prosopis cineraria*, *Neltuma juliflora*, *Salvadora persica*, and *Ziziphus mauritiana* creating a savannah-like ecosystem (Kaur et al. 2020).

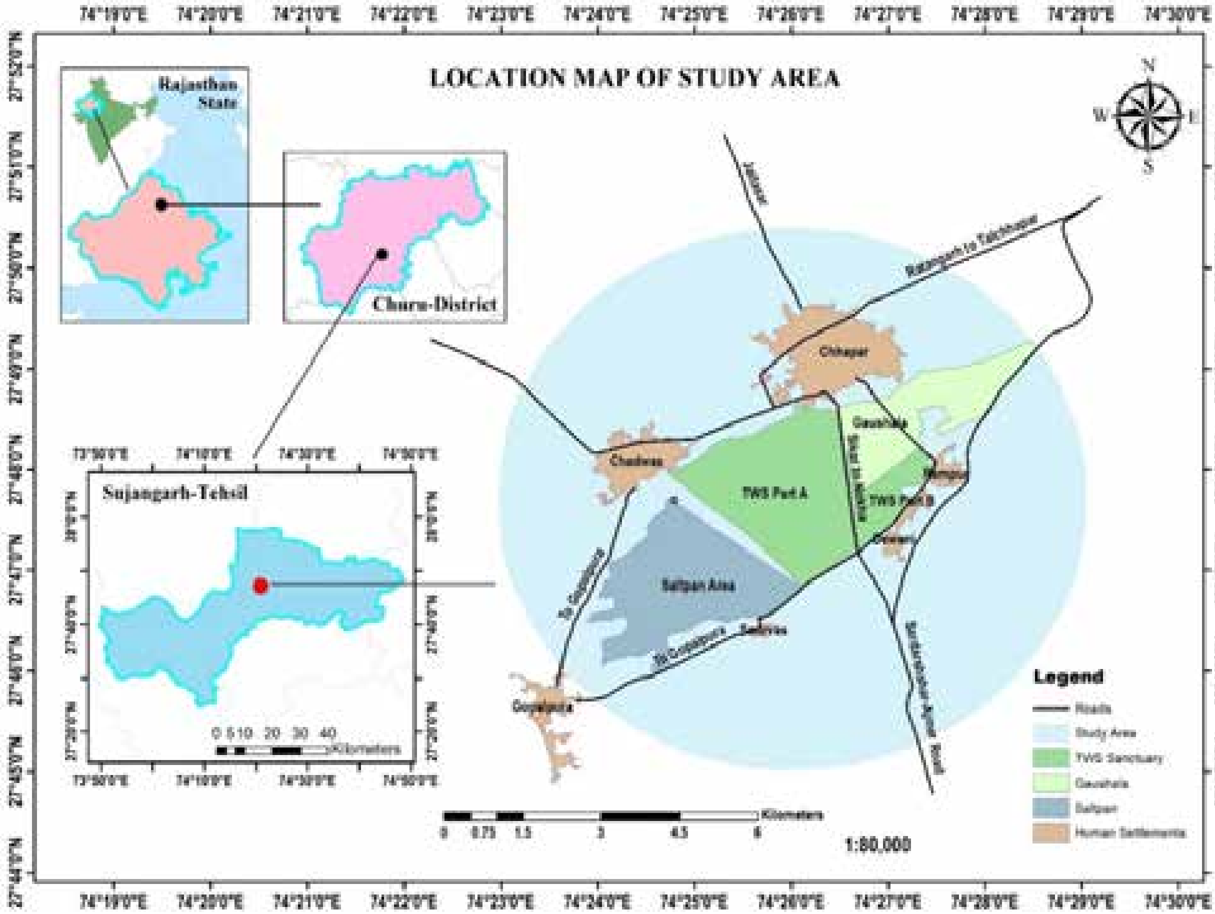


Figure 1. Location map of the study area: Tal Chhapar Wildlife Sanctuary, Churu, Rajasthan.

## Methods

The present study was conducted from August 2022–March 2024, spanning the post-monsoon, winter, and spring seasons, which are known for peak plant diversity in this region. This time frame was strategically chosen to capture maximum diversity, as species diversity is typically lowest during the summer, while evenness remains relatively stable throughout the year (Kaur et al. 2020). The sanctuary was surveyed every 15 days using a random search approach to collect plant samples. The researcher moved systematically through the study area without following predetermined routes or fixed sampling points, ensuring unbiased sampling across diverse microhabitats. The voucher specimens were tagged, prepared as herbarium specimens following the standard procedure (Rao & Sharma 1990), and deposited at the Herbarium of the Department of Wildlife Science, Aligarh Muslim University, Uttar Pradesh. Plant specimens were identified in the field using the existing Flora of Rajasthan and relevant published literature (Shetty & Singh 1987, 1991, 1993; Bhandari 1995; Peddi et al. 2014; Charan & Sharma 2016; Sanadya et al. 2023). The species nomenclature was updated according to the latest standards of the International Plant Name Index (IPNI), with binomial names and author citations sourced from trusted databases such as Plants of the World Online (POWO 2025) and World Flora Online (WFO 2025). Angiosperm classification followed the Angiosperm Phylogeny Group IV (2016) system, with plants categorized into magnoliids, monocots, and eudicots. To ensure clarity and ease of reference, families, their respective genera, and the species within each genus have been organized in alphabetical order in each angiosperm group. A comprehensive checklist of the flora in TWS Sanctuary was compiled, detailing species' vernacular names, angiosperm types, growth habits, plant life forms as classified by Raunkiaer's system (Raunkiaer 1934), and their distribution.

## RESULTS

### Floristic diversity of TWS

Table 1 summarizes the findings from the floristic survey carried out in TWS, revealing a total of 211 identified species belonging to 49 families and 146 genera. Eudicots dominated the flora, with 44 families, 116 genera, and 154 species. Asteraceae emerges as the most diverse eudicot family, with 16 genera and 17 species, followed by Amaranthaceae (10 genera, 17 species), and Fabaceae (13 genera, 16 species). Monocots were represented by only four families, contributing significantly to the flora, with 29 genera and 56 species. Within monocots, Poaceae stands out as the dominant family, with 26 genera and 49 species, thereby enriching the sanctuary's floristic diversity, as illustrated in Figure 2. In the present survey, the family Annonaceae was the sole representative of the magnoliids, comprising a single species.

Furthermore, *Eragrostis* was identified as the most diverse genus, comprising eight species, followed by *Amaranthus,* with six species, and *Cyperus* and *Sporobolus,* each with five species. These four genera together accounted for 11.37% of the total flora, highlighting the sanctuary's ecological complexity and plant diversity across various genera, as shown in Table 1.

### Classification of plants based on their growth habits and Raunkiaer's Life forms

The composition and adaptation strategies of the sanctuary's flora were analyzed using growth habits and Raunkiaer's life form classification. Growth habit analysis revealed that herbaceous plants were the most dominant, accounting for 40% of the total flora (84 species), followed by grasses at 23% (49 species), trees 12% (26 species), and shrubs 12% (26 species) also contributed significantly, while climbers 5% (10 species), succulents 5% (11 species), and sedges 3% (two species) represented smaller proportions, as illustrated in Figure 3.

Similarly, Raunkiaer's classification, based on the position of perennating organs, identified therophytes (annuals surviving as seed) as the most prevalent category, constituting 49.8% (105 species) of the flora. Phanerophytes (perennial trees and shrubs with buds located over 25 cm above ground) accounted for 18% (38 species), while hemicryptophytes (buds at or just above the soil surface) represented 16.59% (35 species). Chamaephytes (buds up to 25 cm above ground) and geophytes (plants with underground storage organs) collectively formed 16% of the flora, with 11 and two species, respectively, as shown in Figure 4.

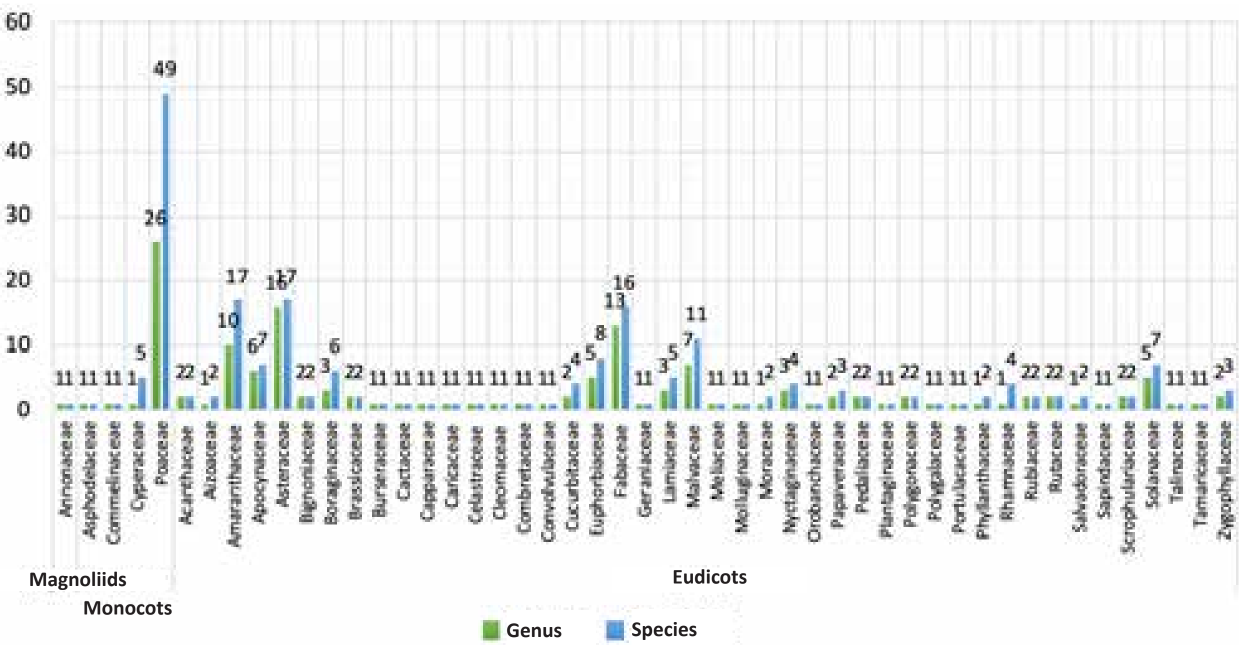


**Figure 2. Angiosperm diversity of Tal Chhapar Wildlife Sanctuary, Rajasthan.**

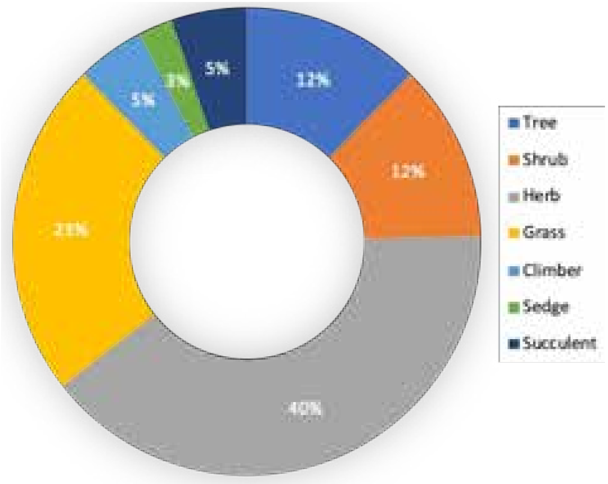


Figure 3. Vegetation composition of Tal Chhapar Wildlife Sanctuary, Rajasthan.

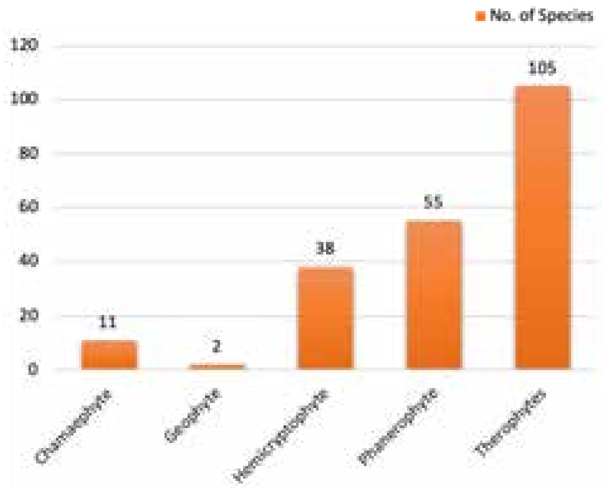


Figure 4. Classification of plants based on their Raunkiaer's Life forms.

Image 1. Plant species of conservation importance: a—*Commiphora wightii* | b—*Tecomella undulata*.

### Ecological importance and conservation priorities of the sanctuary

As outlined in Table 1, the sanctuary is home to 211 identified species, of which 72.51% (153 species) are native and 27.49% (58 species) are introduced. The species are nearly evenly distributed, with 49.76% (105 species) being annuals and 50.24% (106 species) perennials, as shown in Figure 5. Additionally, the sanctuary hosts two IUCN Red Listed species: *Commiphora wightii*, classified as 'Critically Endangered' (Ved et al. 2015), and *Tecomella undulata*, classified as 'Endangered' (Plummer 2021), also depicted in Images 1a&b.

## DISCUSSION AND CONCLUSION

This study recorded 211 angiosperm species within the sanctuary, showing a significant increase compared to previous reports of 78 species (Kaur et. al. 2020), 139 species (Bagoriya et al. 2020), and 102 species (Karel & Gena 2023). Among these, 108 species were recorded for the first time in the sanctuary. This increase in the species' number may be attributed to habitat changes influenced by management practices such as removing invasive species like *Neltuma juliflora,* maintaining waterholes during dry periods, implementing controlled burns, and

**Table 1. Updated floristic diversity of Tal Chhapar Wildlife Sanctuary, Churu in Rajasthan.**

| Name of species with its first publication year | Vernacular names | Angiosperm types | Nature | Growth habits | Life forms | Distribution |
|---|---|---|---|---|---|---|
| **1. Annonaceae** | | | | | | |
| *Monoon longifolium* (Sonn.) B.Xue & R.M.K.Saunders (2012) * | Ashok | Ma | P | T | Ph | N |
| **2. Asphodelaceae** | | | | | | |
| *Aloe vera* (L.) Burm.f. (1768) | Guarpatta | M | P | Su | Ch | I |
| **3. Commelinaceae** | | | | | | |
| *Commelina benghalensis* L. (1753) | Moriyabati, Bakhana | M | A | H | Th | N |
| **4. Cyperaceae** | | | | | | |
| *Cyperus bulbosus* Vahl (1805) | Mothh | M | P | Se | Ge | N |
| *Cyperus compressus* L. (1753) | Mothio | M | A | Se | Th | N |
| *Cyperus flavidus* Retz. (1788) | Peeli-mutha | M | A | Se | Th | N |
| *Cyperus iria* L. (1753) | Moth | M | A | Se | Th | N |
| *Cyperus rotundus* L. (1753) | Motha | M | P | Se | Ge | N |
| **5. Poaceae** | | | | | | |
| *Acrachne racemosa* (B.Heyne ex Roth) Ohwi (1947) | Jaran, Chinki | M | A | G | Th | N |
| *Aristida adscensionis* L. (1753) | Lampro | M | A | G | Th | N |
| *Aristida funiculata* Trin. &Rupr. (1842) | Lamp | M | A | G | Th | N |
| *Aristida mutabilis* Trin. & Rupr. (1842) | - | M | A | G | Th | N |
| *Aristida setacea* Retz. (1786) | Danta | M | A | G | Th | N |
| *Bothriochloa pertusa* (L.) A.Camus (1931) | Chhoti-jergi | M | P | G | He | N |
| *Cenchrus biflorus* Roxb. (1820) | Bhurut | M | A | G | Th | N |
| *Cenchrus ciliaris* L. (1771) | Dhaman, Anjan | M | P | G | He | N |
| *Cenchrus prieurii* (Kunth) Maire (1931) | Lambio-bhurut | M | P | G | He | N |
| *Cenchrus setigerus* Vahl (1806) | Kala Dhaman | M | P | G | He | N |
| *Chloris barbata* Sw. (1797) | Boj-patra | M | A | G | Th | N |
| *Chloris flagellifera* (Nees) P.M.Peterson (2015) | Ganthil Ghas | M | P | G | He | N |
| *Chloris virgata* Sw. (1797) | Gharniaghas | M | P | G | He | I |
| *Cynodon dactylon* (L.) Pers. (1805) | Doob | M | P | G | He | N |
| *Dactyloctenium aegyptium* (L.) Willd. *(*1809) | Makaro | M | A | G | Th | N |
| *Dactyloctenium scindicum* Boiss. (1859) | Mansa | M | P | G | He | N |
| *Desmostachya bipinnata* (L.) Stapf (1900) | Dab | M | P | G | He | N |
| *Dichanthium annulatum* (Forssk.) Stapf (1917) | Karad | M | P | G | He | N |
| *Dichanthium aristatum* (Poir.) C.E.Hubb. (1940) | - | M | P | G | He | N |
| *Digitaria bicornis* (Lam.) Roem. & Schult. (1817) | Jheranio | M | A | G | Th | N |
| *Digitaria sanguinalis* (L.) Scop. (1771) | Baans Ghas | M | A | G | Th | N |
| *Echinochloa colonum* (L.) Link (1833) | Soma, Phunkia | M | A | G | Th | N |
| *Eleusine indica* (L.) Gaertn. (1788) | Ghoda-doob | M | A | G | Th | N |
| *Eleusine tristachya* (Lam.) Lam. (1792) | - | M | A | G | Th | I |
| *Enteropogon monostachyos* (Vahl) K.Schum. (1894) | - | M | P | G | He | N |
| *Eragrostis cilianensis* (All.) Vignolo ex Janch. (1907) | - | M | A | G | Th | N |
| *Eragrostis ciliaris* (L.) R.Br.(1818) | Burbudi | M | A | G | Th | N |
| *Eragrostis japonica* (Thunb.) Trin. (1830) | - | M | A | G | Th | N |
| *Eragrostis minor* Host (1827) | Poongyo | M | A | G | Th | N |
| *Eragrostis multiflora* Trin. (1830) | Chuvalio | M | A | G | Th | N |

| | Name of species with its first publication year | Vernacular names | Angiosperm types | Nature | Growth habits | Life forms | Distribution |
|---|---|---|---|---|---|---|---|
| | *Eragrostis pilosa* (L.) P.Beauv. (1812) | Chidi-pinkhia | M | A | G | Th | N |
| | *Eragrostis tenella* (L.) P.Beauv. ex Roem. & Schult. (1817) | Bharburo | M | A | G | Th | N |
| | *Eragrostis unioloides* (Retz.) Nees ex Steud. (1854) | - | M | A | G | Th | N |
| | *Lasiurus scindicus* Henrard (1941) | Sevan | M | P | G | He | N |
| | *Melanocenchris jacquemontii* Jaub. & Spach (1851) | - | M | A | G | Th | N |
| | *Panicum turgidum* Forssk. (1775) | Murantio Ghas | M | P | G | He | N |
| | *Perotis indica* (L.) Kuntze (1891) | Lonki-puncho | M | A | G | Th | N |
| | *Polypogon viridis* (Gouan) Breistr. (1966) | - | M | A | G | Th | N |
| | *Saccharum spontaneum* L. (1771) | Kans | M | P | G | He | N |
| | *Schoenefeldia gracilis* Kunth (1830) | Tarwaria | M | A | G | Th | N |
| | *Sporobolus airoides* (Torr.) Torr. (1853) | - | M | P | G | He | I |
| | *Sporobolus coromandelianus* (Retz.) Kunth (1829) | - | M | P | G | He | N |
| | *Sporobolus diandrus* (Retz.) P.Beauv. (1812) | Chiria ka Dana | M | P | G | He | N |
| | *Sporobolus indicus* (L.) R.Br. (1810) | - | M | P | G | He | I |
| | *Sporobolus ioclados* (Nees ex Trin.) Nees (1841) | Poolongi | M | P | G | He | N |
| | *Tetrapogon tenellus* (J.Koenig ex Roxb.) Chiov. (1907) | Lampada | M | A | G | Th | N |
| | *Tragus berteronianus* Schult. (1824) | - | M | A | G | Th | I |
| | *Tripidium bengalense* (Retz.) H.Scholz (2006) | Munja | M | P | G | He | N |
| | *Urochloa ramosa* (L.) T.Q.Nguyen (1966) | Muret | M | A | G | Th | N |
| **6. Acanthaceae** | | | | | | | |
| | *Andrographis paniculata* (Burm.f.) Wall. ex Nees (1832) | Kalpnath | E | A | H | Th | N |
| | *Dicliptera paniculata* (Forssk.) I.Darbysh. (2007) | Kagjangha | E | A | H | Th | N |
| **7. Aizoaceae** | | | | | | | |
| | *Trianthema portulacastrum* L. (1753) | Sato | E | A | Su | Th | N |
| | *Trianthema triquetrum* Willd. ex-Spreng. (1825) | Dhedosanto | E | A | Su | Th | N |
| **8. Amaranthaceae** | | | | | | | |
| | *Achyranthes aspera* L. (1753) | Chirchita | E | P | H | He | N |
| | *Aerva javanica* (Burm.f.) Juss. ex-Schult. (1819) | Safed Bui | E | P | H | Ch | N |
| | *Aerva tomentosa* Forssk. (1775) | Buari | E | P | H | Ch | N |
| | *Amaranthus blitum* L. (1753) ** | Lal Bhaji | E | A | H | Th | I |
| | *Amaranthus blitoides* S.Watson (1877) | Chaulai | E | A | H | Th | I |
| | *Amaranthus hybridus* L. (1753) ** | Chaulai | E | A | H | Th | I |
| | *Amaranthus polygonoides* L. (1759) | Kairee, Sevari | E | A | H | Th | I |
| | *Amaranthus spinosus* L. (1753) | Chandelo | E | A | H | Th | I |
| | *Amaranthus viridis* L. (1763) | Jangali Chaulai | E | A | H | Th | I |
| | *Atriplex halimus* L. (1753) | - | E | P | Su | He | I |
| | *Chenopodiastrum murale* (L.) S.Fuentes, Uotila & Borsch (2012) | Khartua | E | A | H | Th | N |
| | *Chenopodium album* L. (1753) | Bathua | E | A | H | Th | N |
| | *Dysphania pumilio* (R.Br.) Mosyakin & Clemants (2002) | - | E | A | H | Th | I |
| | *Haloxylon salicornicum* (Moq.) Bunge ex Boiss. (1879) | Lana | E | P | S | Ph | N |
| | *Soda stocksii* (Boiss.) Akhani (2020) | - | E | A | H | Th | N |
| | *Suaeda fruticosa* Forssk. ex J.F.Gmel. (1776) | Lani | E | P | H | Ch | N |
| | *Suaeda monoica* Forssk. ex J.F.Gmel. (1776) | - | E | P | S | Ch | N |

| | Name of species with its first publication year | Vernacular names | Angiosperm types | Nature | Growth habits | Life forms | Distribution |
|---|---|---|---|---|---|---|---|
| **9. Apocynaceae** | | | | | | | |
| | *Calotropis gigantea* (L.) W.T.Aiton (1811) | Safed Aak | E | P | S | Ph | N |
| | *Calotropis procera* (Aiton) W.T.Aiton (1811) | Aakado | E | P | Su | Ph | N |
| | *Carissa carandas* L. (1767) * | Karonda | E | P | S | Ph | N |
| | *Cascabela thevetia* (L.) Lippold (1980) * | Peeli Kaner | E | P | T | Ph | I |
| | *Leptadenia pyrotechnica* (Forssk.) Decne. (1838) | Khimp | E | P | S | Ph | N |
| | *Nerium oleander* L. (1753) * | Kaner | E | P | T | Ph | N |
| | *Tabernaemontana divaricata* (L.) R.Br. ex Roem. & Schult. (1819) * | Chandini | E | P | S | Ph | N |
| **10. Asteraceae** | | | | | | | |
| | *Blumea lacera* (Burm.f.) DC. (1834) | Kukrondha | E | A | H | Th | N |
| | *Cyanthillium cinereum* (L.) H.Rob. (1990) | Sahadevi | E | A | H | Th | N |
| | *Echinops echinatus* Roxb. (1832) | Unt-kantalo | E | P | H | He | N |
| | *Eclipta prostrata* (L.) L. (1771) | Jal Bhangro | E | A | H | Th | I |
| | *Erigeron bonariensis* L. (1753) | - | E | A | H | Th | I |
| | *Helianthus annuus* L. (1753) | Surajmukhi | E | A | H | Th | I |
| | *Lactuca serriola* L. (1756) | - | E | A | H | Th | I |
| | *Launaea procumbens* (Roxb.) Ramayya & Rajagopal (1969) | Janlee Gobi | E | P | H | He | N |
| | *Parthenium hysterophorus* L. (1753) | Gajar Ghas | E | A | H | Th | I |
| | *Pluchea lanceolata* (DC.) C.B.Clarke (1876) | Rasna | E | P | H | He | N |
| | *Pseudoconyza viscosa* (Mill.) D'Arcy (1973) | Gandhana | E | A | H | Th | N |
| | *Pulicaria undulata* (L.) C.A.Mey. (1831) | Sohanfali | E | A | H | Th | N |
| | *Pulicaria wightiana* (DC.) C.B.Clarke (1876) | - | E | P | H | He | N |
| | *Tridax procumbens* L. (1753) | Jayanti | E | A | H | Th | I |
| | *Sonchus oleraceus* L. (1753) | Aakadio | E | A | H | Th | I |
| | *Verbesina encelioides* (Cav.) Benth. & Hook.f. ex A.Gray (1876) | Jangali pSurajmukhi | E | A | H | Th | I |
| | *Xanthium strumarium* L. (1753) | Aandheeda | E | A | H | Th | N |
| **11. Bignoniaceae** | | | | | | | |
| | *Tecoma fulva* (Cav.) G.Don (1837) * | - | E | P | S | Ph | I |
| | *Tecomella undulata* (Sm.) Seem. (1862) | Rohida | E | P | T | Ph | N |
| **12. Boraginaceae** | | | | | | | |
| | *Cordia dichotoma* G.Forst. (1786) * | Goonda | E | P | T | Ph | N |
| | *Euploca marifolia* (J.Koenig ex Retz.) Ancy &P.Javad (2020) | Choti Santari | E | P | H | He | N |
| | *Euploca ovalifolia* (Forssk.) Diane & Hilger (2003) | Kunden | E | P | H | He | N |
| | *Euploca strigosa* (Willd.) Diane & Hilger (2003) | Kamediya | E | A | H | Th | N |
| | *Heliotropium europaeum* L. (1753) | - | E | A | H | Th | N |
| | *Heliotropium zeylanicum* (Burm.f.) Lam. (1789) | - | E | A | H | Th | N |
| **13. Brassicaceae** | | | | | | | |
| | *Brassica juncea* (L.) Czern. (1859) ** | Rai | E | A | H | Th | I |
| | *Farsetia stylosa* R.Br. (1826) | Hiran-chabo | E | A | H | Th | N |
| **14. Burseraceae** | | | | | | | |
| | *Commiphora wightii* (Arn.) Bhandari (1965) | Guggal | E | P | S | Ph | N |
| **15. Cactaceae** | | | | | | | |
| | *Opuntia elatior* Mill. (1768) | Nag-phani | E | P | Su | Ph | I |

| Name of species with its first publication year | Vernacular names | Angiosperm types | Nature | Growth habits | Life forms | Distribution |
|---|---|---|---|---|---|---|
| **16. Capparaceae** | | | | | | |
| *Capparis decidua* (Forssk.) Edgew. (1862) | Kair | E | P | S | Ph | N |
| **17. Caricaceae** | | | | | | |
| *Carica papaya* L. (1753) * | Papito | E | P | T | Ph | I |
| **18. Celastraceae** | | | | | | |
| *Gymnosporia senegalensis* (Lam.) Loes. (1893) * | Kakero | E | P | T | Ph | N |
| **19. Cleomaceae** | | | | | | |
| *Cleome viscosa* L. (1753) | Bagro | E | A | H | Th | N |
| **20. Combretaceae** | | | | | | |
| *Combretum indicum* (L.) DeFilipps (1998) | Madhumati | E | P | C | Ph | N |
| **21. Convolvulaceae** | | | | | | |
| *Cressa cretica* L. (1753) | Rudravanti | E | P | H | He | N |
| **22. Cucurbitaceae** | | | | | | |
| *Citrullus colocynthis* (L.) Schrad. (1838) ** | Tumba | E | A | C | Th | N |
| *Citrullus lanatus* (Thunb.) Matsum. & Nakai (1910) ** | Matiro | E | A | C | Th | I |
| *Cucumis melo* L. (1753) ** | Kaachri | E | A | C | Th | N |
| *Cucumis prophetarum* L. (1755) | Khat-khachro | E | P | C | Ch | N |
| **23. Euphorbiaceae** | | | | | | |
| *Acalypha indica* L. (1753) | Khokali | E | A | H | Th | N |
| *Croton bonplandianus* Baill. (1864) | Kapur-kur | E | A | H | Th | I |
| *Euphorbia caducifolia* Haines (1914) * | Danda-thor | E | P | Su | Ph | N |
| *Euphorbia hirta* L. (1753) | Bara-dudhi | E | A | H | Th | I |
| *Euphorbia prostrata* Aiton (1789) | Dudhi | E | A | Su | Th | I |
| *Euphorbia thymifolia* L. (1753) | Choti-dudhi | E | A | H | Th | I |
| *Jatropha gossypiifolia* L. (1753) | Ratanjoti | E | P | S | Ph | I |
| *Ricinus communis* L. (1753) | Arandio | E | P | S | Ph | I |
| **24. Fabaceae** | | | | | | |
| *Clitoria ternatea* L. (1753) | Koyalri | E | A | C | Th | I |
| *Dalbergia sissoo* Roxb. ex-DC. (1825) * | Sheesham | E | P | T | Ph | N |
| *Medicago polymorpha* L. (1753) | Ghasar | E | P | H | He | I |
| *Neltuma juliflora* (Sw.) Raf. (1838) * | VilaytiKikar | E | P | T | Ph | I |
| *Parkinsonia aculeata* L. (1753) | Rambaval | E | P | T | Ph | I |
| *Pongamia pinnata* (L.) Pierre (1898) * | Karanj | E | P | T | Ph | N |
| *Prosopis cineraria* (L.) Druce (1914) | Khejri | E | P | T | Ph | N |
| *Tephrosia purpurea* (L.) Pers. (1807) | Dhamasa | E | A | H | Th | N |
| *Trifolium repens* L. (1753) | Barseem | E | P | H | He | N |
| *Senegalia senegal* (L.) Britton (1930) | Kumta | E | P | T | Ph | N |
| *Senna tora* (L.) Roxb. (1832) | Phunwad | E | A | H | Th | I |
| *Vachellia jacquemontii* (Benth.) Ali (2014) | Bu-banwali | E | P | T | Ph | N |
| *Vachellia leucophloea* (Roxb.) Maslin, Seigler & Ebinger (2013) | Roonjh, Urajio | E | P | T | Ph | N |
| *Vachellia nilotica* (L.) P.J.H.Hurter & Mabb. (2008) | Banwal | E | P | T | Ph | N |
| *Vachellia tortilis* (Forssk.) Galasso & Banfi (2008) | Israeli Babool | E | P | T | Ph | I |
| *Vigna trilobata* (L.) Verdc. (1968) | Jangali Moth | E | A | C | Th | N |

| | Name of species with its first publication year | Vernacular names | Angiosperm types | Nature | Growth habits | Life forms | Distribution |
|---|---|---|---|---|---|---|---|
| **25. Geraniaceae** | | | | | | | |
| | *Geranium rotundifolium* L. (1753) | - | E | A | H | Th | N |
| **26. Lamiaceae** | | | | | | | |
| | *Leucas aspera* (Willd.) Link (1822) | Thumbai | E | A | H | Th | N |
| | *Leucas martinicensis* (Jacq.) R.Br. *(*1811) | Dargal | E | A | H | Th | N |
| | *Ocimum americanum* L. (1755) | Bapchi | E | A | H | Th | N |
| | *Ocimum tenuiflorum* L. (1753) | Ram Tulsi | E | P | H | Ph | N |
| | *Premna resinosa* (Hochst.) Schauer (1847) | Ghitti | E | P | S | Ph | N |
| **27. Malvaceae** | | | | | | | |
| | *Abutilon indicum* (L.) Sweet (1826) | Kanghi | E | P | S | Ch | N |
| | *Abutilon pannosum* (G.Forst.) Schltdl. (1851) | Khareti | E | P | H | Ch | N |
| | *Abutilon ramosum* (Cav.) Guill. & Perr. (1831) | Ramo-saag | E | P | H | Ph | N |
| | *Corchorus depressus* (L.) Peterm. (1845) | Chamghas | E | A | H | Th | N |
| | *Corchorus tridens* L. (1771) | Kagnasha | E | A | H | Th | N |
| | *Corchorus trilocularis* L. (1767) | Kagaroti | E | A | H | Th | N |
| | *Gossypium arboreum* L. (1753) * | Dharira | E | P | S | Ph | N |
| | *Grewia tenax* (Forssk.) Fiori (1912) | Gangeran | E | P | S | Ph | N |
| | *Hibiscus* × *rosa-sinensis* L. (1753) * | Gudhal | E | P | S | Ph | I |
| | *Malvastrum coromandelianum* (L.) Garcke (1857) | Khariniti | E | A | H | Th | I |
| | *Sida cordifolia* L. (1753) | Bal, Khariniti | E | P | H | Ch | N |
| **28. Meliaceae** | | | | | | | |
| | *Azadirachta indica* A.Juss. (1831) | Neem | E | P | T | Ph | I |
| **29. Molluginaceae** | | | | | | | |
| | *Hypertelis cerviana* L. (2016) | Chirmori | E | A | H | Th | N |
| **30. Moraceae** | | | | | | | |
| | *Ficus benghalensis* L. (1753) * | Bar | E | P | T | Ph | N |
| | *Ficus religiosa* L. (1753) | Pipal | E | P | T | Ph | N |
| **31. Nyctaginaceae** | | | | | | | |
| | *Boerhavia diffusa* L. (1753) | Chinawari, Santhi | E | P | H | He | N |
| | *Boerhavia erecta* L. (1753) | Saanth | E | P | H | He | I |
| | *Bougainvillea glabra* Choisy (1849) * | Bogan Bel | E | P | C | Ph | I |
| | *Commicarpus plumbagineus* (Cav.) Standl. (1916) | Lal Sakhari | E | P | C | He | N |
| **32. Orobanchaceae** | | | | | | | |
| | *Lindenbergia indica* (L.) Vatke (1875) | - | E | P | H | Ph | N |
| **33. Papaveraceae** | | | | | | | |
| | *Argemone mexicana* L. (1753) | Satyanashi | E | A | H | Th | I |
| | *Argemone ochroleuca* Sweet (1828) | - | E | A | H | Th | I |
| | *Fumaria indica* (Hausskn.) Pugsley (1919*)* | Pitpapro | E | A | H | Th | N |
| **34. Pedaliaceae** | | | | | | | |
| | *Sesamum indicum* L. (1753) ** | Jagali Til | E | A | H | Th | N |
| | *Pedalium murex* L. (1759) | DakhaniGokhr | E | A | H | Th | N |
| **35. Plantaginaceae** | | | | | | | |
| | *Bacopa monnieri* (L.) Wettst. (1891) | Brahmi | E | P | H | He | N |

| | Name of species with its first publication year | Vernacular names | Angiosperm types | Nature | Growth habits | Life forms | Distribution |
|---|---|---|---|---|---|---|---|
| **36. Polygonaceae** | | | | | | | |
| | *Calligonum polygonoides* L. (1753) | Phog | E | P | S | Ph | N |
| | *Polygonum plebeium* R.Br. (1810) | Rakht-shankh Pushp | E | A | H | Th | N |
| **37. Polygalaceae** | | | | | | | |
| | *Polygala erioptera* DC. (1824) | Johjhru, Boyasan | E | A | H | Th | N |
| **38. Portulacaceae** | | | | | | | |
| | *Portulaca pilosa* L. (1753) | Lunkia | E | A | Su | Th | I |
| **39. Phyllanthaceae** | | | | | | | |
| | *Phyllanthus amarus* Schumach. & Thonn. (1827) | - | E | A | H | Th | I |
| | *Phyllanthus urinaria* L. (1753) | - | E | A | H | Th | N |
| **40. Rhamnaceae** | | | | | | | |
| | *Ziziphus glabrata* (B.Heyne ex Schult.) B.Heyne ex Wight & Arn (1834) | - | E | P | T | Ph | N |
| | *Ziziphus mauritiana* Lam. (1789) | Ber | E | P | T | Ph | N |
| | *Ziziphus nummularia* (Burm.f.) Wight & Arn. (1833*)* | JhadBor | E | P | S | Ph | N |
| | *Ziziphus oenopolia* (L.) Mill. (1768) | Eramdi | E | P | S | Ph | N |
| **41. Rubiaceae** | | | | | | | |
| | *Hamelia patens* Jacq. (1760) | - | E | P | S | Ph | I |
| | *Spermacoce articularis* L.f. (1782) | Agio | E | A | H | Th | N |
| **42. Rutaceae** | | | | | | | |
| | *Bergera koenigii* L. (1767) * | Kadhi Patta | E | P | T | Ph | N |
| | *Citrus × aurantiifolia* (Christm.) Swingle (1913) * | Nimboo | E | P | S | Ph | I |
| **43. Salvadoraceae** | | | | | | | |
| | *Salvadora oleoides* Decne. (1844) | Kharo-jhaal | E | P | T | Ph | N |
| | *Salvadora persica* L. (1753) | Peelu | E | P | T | Ph | N |
| **44. Sapindaceae** | | | | | | | |
| | *Cardiospermum halicacabum* L. (1753) | Kanphuti | E | A | C | Th | N |
| **45. Scrophulariaceae** | | | | | | | |
| | *Anticharis senegalensis* (Walp.) Bhandari (1965) | Dharno Ghas | E | A | H | Th | N |
| | *Verbascum coromandelianum* (Vahl) HubMor. (1973) | - | E | A | H | Th | N |
| **46. Solanaceae** | | | | | | | |
| | *Datura innoxia* Mill. (1768) | Daturo | E | A | S | Th | I |
| | *Datura stramonium* L. (1753) | Bada Dhaturo | E | A | H | Th | I |
| | *Lycium barbarum* L. (1753) | Morali | E | A | S | Th | I |
| | *Physalis angulata* L. (1753) | Chipoti | E | A | H | Th | I |
| | *Solanum nigrum* L. (1753) | Makoi | E | A | H | Th | N |
| | *Solanum virginianum* L. (1753) | Adhkuntali | E | P | H | He | N |
| | *Withania somnifera* (L.) Dunal (1852) | Asgandha | E | P | S | Ch | N |
| **47. Talinaceae** | | | | | | | |
| | *Talinum fruticosum* (L.) Juss. (1789) | - | E | P | Su | He | I |
| **48. Tamaricaceae** | | | | | | | |
| | *Tamarix dioica* Roxb. ex. Roth (1820) | Lai | E | P | S | Ph | N |
| **49. Zygophyllaceae** | | | | | | | |
| | *Balanites aegyptiaca* (L.) Delile (1813) | Hingota | E | P | S | Ph | I |
| | *Balanites roxburghii* Planch. (1854) | Ingoriyo | E | P | T | Ph | N |

| Name of species with its first publication year | | Vernacular names | Angiosperm types | Nature | Growth habits | Life forms | Distribution |
|---|---|---|---|---|---|---|---|
| | *Zygophyllum creticum* (L.) Christenh. & Byng (2018) | Dhamaso | E | P | Su | Ch | I |
| Angiosperm Type: M—monocot \| E—eudicot \| Ma—magnoliids | | | | | | | |
| Nature of Plant : A—annual \| P—perennial | | | | | | | |
| Growth Habit : T—tree \| S—shrub \| H—herb \| G—grass \| C—climber \| Su—succulent \| Se—Sedge | | | | | | | |
| Life forms : Th—therophyte \| Ph—phanerophyte \| He—hemicryptophyte \| Ch—chamaetophyte \| Ge—Geophyte | | | | | | | |
| Distribution : N—native \| I—introduced or non-native | | | | | | | |
| Note: (*)—Planted by Forest Department near Forest Rest House and along the sanctuary's boundaries. | | | | | | | |
| Note: (**)—Cultivated crops | | | | | | | |

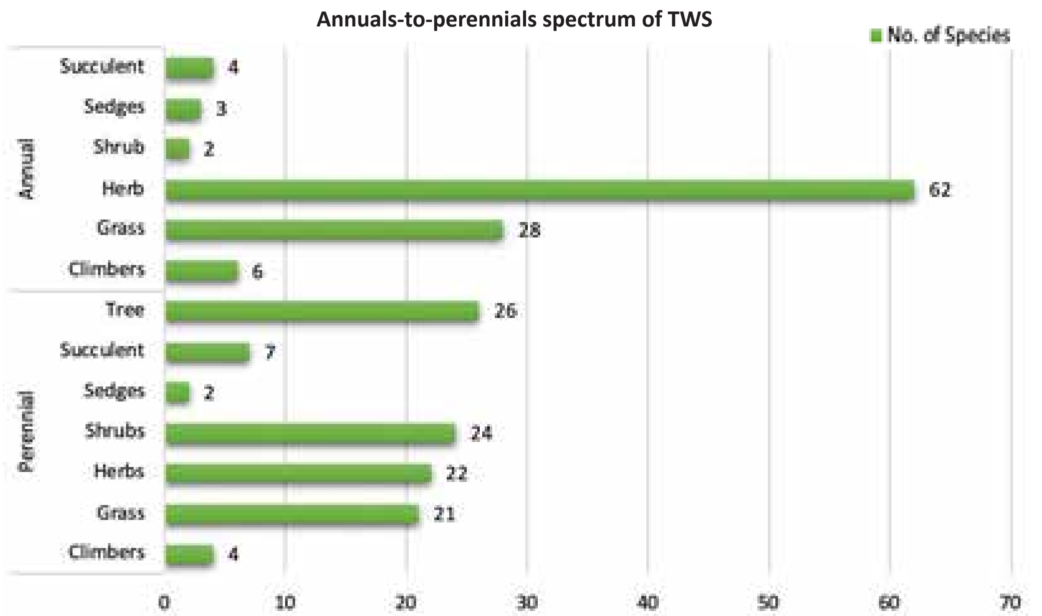


**Figure 5. Habit and Nature of the plant species at Tal Chhapar Wildlife Sanctuary, Rajasthan.**

regulating grazing. This warrants further investigation. This study also documented the absence of 51 species across 41 genera (Appendix I), comprising two aquatic plants, two ornamental plants, eight cultivated crops, and 40 wild species, which raises significant concern. This absence cannot be attributed to the exclusion of the summer season, as flowering and fruiting periods of these species overlapped with the study timeframe. If these species (particularly wild species) had been present in the sanctuary, they would have been observed during the study. Moreover, such patterns of species absence are not unprecedented in the sanctuary. Previous studies have also reported similar findings. For instance, Kaur et al. (2020) failed to document two previously recorded species, while Bagoriya et al. (2020), despite reporting 139 species, missed 27 species listed in earlier records. More alarmingly, Karel & Gena (2023) noted an increase in missing species, reporting the absence of 59 species. We hypothesized that environmental factors, such as fluctuations in rainfall and temperature, which are key drivers of grassland ecosystems (Wu et al. 2023), along with the inherent climatic instability of the Thar Desert, a critical factor in the region's ecology, have contributed to these variations in species compositions.

In this study, Poaceae with 26 genera and 49 species emerged as the most dominant family, followed by Asteraceae (16 genera, 17 species) and Amaranthaceae (10 genera, 17 species). These findings were consistent with those of Kaur et al. (2020), who identified these families as the most diverse and highlighted their functional role in shaping the sanctuary's ecological structure. It was observed that perennial species were equal to annuals in the sanctuary, with herbaceous plants dominating and grass species thriving in the semi-arid climate. This highlights the sanctuary's ability to support both short-term resilience and long-term ecosystem stability, which are fundamental to the sustained growth and health of the ecosystem (Gou et al. 2023). This may also account for the sanctuary's high proportion of native species, over 70%. Additionally, the sanctuary's high ecological resilience is evident from the presence of 49.76% therophytes—plants that endure unfavourable conditions, such as droughts and extreme temperatures, by surviving in seed form. The occurrence of introduced species, including cultivated crops and ornamental plants, merits attention. These species are mainly the result of anthropogenic influences, driven by the proximity of agricultural fields and human settlements to the sanctuary. In addition, forest management practices have contributed to their presence, with ornamental plants being deliberately introduced along boundaries and near rest houses to enhance the aesthetic appeal for visitors. Given their potential influence on native flora, these species have also been included in the sanctuary's plant checklist.

In conclusion, the sanctuary's floral diversity, featuring both native and non-native species, is thriving, providing support to wildlife and local communities, while reflecting the sanctuary's strong ecological resilience. The absence of certain species suggests the need for further investigation. To sustain this growth and ensure the long-term stability of the ecosystem, ongoing conservation efforts by the forest department are essential.

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**Appendix I. List of previously recorded plant species not encountered in surveys.**

| | Kaur et al. 2020 | Bagoriya et al. 2020 | Kare & Gena 2023 | Present survey |
|---|---|---|---|---|
| 1 | *Portulaca oleracea* | *Balanites roxburghii* | *Ailanthus excelsa* | *Ailanthus excelsa* (W) |
| 2 | *Portulaca quadrifida* | *Blumea* spp. | *Albizia lebbeck* | *Albizia lebbeck* (W) |
| 3 | | *Boerhavia elegans* | *Amaranthus spinosus* | *Arnebia hispidissima* (W) |
| 4 | | *Celosia argentea* | *Anticharis senegalensis* | *Bergia odorata* (W) |
| 5 | | *Cleome gracilis* | *Aristsida funiculata* | *Boerhavia elegans* (W) |
| 6 | | *Cleome gynandra* | *Arnebia hispidissima* | *Celosia argentea* (O) |
| 7 | | *Cleome viscosa* | *Bergia odorata* | *Cicer arietinum* (C) |
| 8 | | *Commicapus verticillatus* | *Urochloa ramosa* | *Cistanche tubulosa* (W) |
| 9 | | *Cressa cretica* | *Cassia tora* | *Citrullus fistulosus* (C) |
| 10 | | *Crotalaria medicaginea* | *Cenchrus prieurii* | *Cleome gracilis* (W) |
| 11 | | *Croton bonplandianus* | *Chenopodium album* | *Cleome gynandra* (W) |
| 12 | | *Dactyloctenium scindicum* | *Chenopodiastrum murale* | *Commicarpus verticillatus* (W) |
| 13 | | *Euphorbia prostrata* | *Cicer arietinum* | *Convolvulus arvensis* (W) |
| 14 | | *Gnaphalium* spp. | *Cistanche tubulosa* | *Crotalaria burhia*(W) |
| 15 | | *Heliotropium marifolium* | *Citrullus fistulosus* | *Crotalaria medicaginea* (W) |
| 16 | | *Indigofera linnaei* | *Citrullus lanatus* | *Cuscuta hyaline* (W) |
| 17 | | *Opuntia elatior* | *Clerodendrum phlomidis* | *Cuscuta reflexa* (W) |
| 18 | | *Parthenium hysterophorus* | *Commicapus verticillatus* | *Cyamopsis tetragonoloba* (C) |
| 19 | | *Portulaca pilosa* | *Convolvulus arvensis* | *Cyperus arenarius* (W) |
| 20 | | *Pulicaria wightiana* | *Cucumis melo* | *Cyperus niveus* (W) |
| 21 | | *Sporobolus marginatus* | *Cuscusta hyalina* | *Cyperus triceps* (W) |
| 22 | | *Suaeda nudiflora* | *Cyamopsis tetragonoloba* | *Digera muricata* (W) |
| 23 | | *Tamarix* spp. | *Cynodon dactylon* | *Gisekia pharnaceoides* (W) |
| 24 | | *Trianthema triquetra* | *Cyperus iria* | *Gnaphalium* sp. (W) |
| 25 | | *Tribulus terrestris* | *Dactyloctenium aegyptium* | *Grangea* sp. (W) |
| 26 | | *Verbesina enceioloides* | *Dalbergia sissoo* | *Heliotropium curassavicum* (W) |
| 27 | | *Zaleya govindia* | *Digera muricata* | *Heteropogon contortus* (W) |
| 28 | | | *Eleusine compressa* | *Hydrilla verticillata* (A) |
| 29 | | | *Eragrostis ciliaris* | *Imperata cylindrica* (W) |
| 30 | | | *Eragrostis tremula* | *Indigofera cordifolia* (W) |
| 31 | | | *Euphorbia hirta* | *Indigofera linnaei* (W) |
| 32 | | | *Euphorbia microphylla* | *Ipomoea purpurea* (O) |
| 33 | | | *Heliotropium curassavicum* | *Momordica balsamina* (W) |
| 34 | | | *Heliotropium ellipticum* | *Nymphaea nouchali* (A) |
| 35 | | | *Heteropogon contortus* | *Orobanche cernua* (W) |
| 36 | | | *Imperata cylindrica* | *Panicum antidotale* (W) |
| 37 | | | *Indigofera cordifolia* | *Pennisetum typhoideum* (C) |
| 38 | | | *Ipomoea purpurea* | *Phyllanthus niruri* (W) |
| 39 | | | *Maytenus emarginata* | *Polycarpaea corymbosa* (W) |
| 40 | | | *Nerium indicum* | *Salsola baryosma* (W) |
| 41 | | | *Nymphaea nouchali* | *Sonchus asper* (W) |
| 42 | | | *Orobanche cernua* | *Sorghum halepense* (C) |
| 43 | | | *Panicum antidotale* | *Striga angustifolia* (W) |
| 44 | | | *Panicum turgidum* | *Striga gesnerioides* (W) |

| | Kaur et al. 2020 | Bagoriya et al. 2020 | Kare & Gena 2023 | Present survey |
|---|---|---|---|---|
| 45 | | | *Parkinsonia aculeata* | *Tribulus pentandrus* (W) |
| 46 | | | *Parthenium hysterophorus* | *Tribulus terrestris* (W) |
| 47 | | | *Pennisetum typhoideum* | *Urginea indica* (W) |
| 48 | | | *Phyllanthus niruri* | *Vigna aconitifolia* (C) |
| 49 | | | *Polycarpaea corymbosa* | *Vigna radiata* (C) |
| 50 | | | *Portulca oleracea* | *Vigna unguiculata* (C) |
| 51 | | | *Saccharum spontaneum* | *Zaleya govindia* (W) |
| 52 | | | *Sesamum indicum* | |
| 53 | | | *Sonchus asper* | |
| 54 | | | *Sorghum halepense* | |
| 55 | | | *Tridax procumbens* | |
| 56 | | | *Vigna aconitifolia* | |
| 57 | | | *Vigna radiata* | |
| 58 | | | *Vigna unquiculata* | |
| 59 | | | *Zaleya govindia* | |

A—aquatic plants | C—cultivated crops | O—ornamental plants | W—wild plants.

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ARTICLE



# An updated checklist of the family Rosaceae in Arunachal Pradesh, India

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**Abstract:** An updated checklist of the Rosaceae family occurring in the state of Arunachal Pradesh, northeastern India, is presented here. Arunachal Pradesh, located in eastern Himalaya in the northeastern part of India, is rich in biodiversity and endemism. To understand the taxonomic diversity of Rosaceae in the state, a comprehensive taxonomic study was conducted based on field collections, scrutiny of herbarium specimens and published literature. The field surveys were carried out from 2019–2024 in various localities of Arunachal Pradesh. A total 164 taxa (158 species, 8 varieties, and 1 subspecies) of Rosaceae have been recorded under 27 genera where the *Rubus* is found as the most dominant one with 49 species. Four species are found as endemic to the state. *Rubus niveus* var. *micranthus* (D.Don) H. Hara, *Rubus alpestris* Blume, and *Potentilla fulgens* Wall. ex Sims have been reported as new distributional records for the state of Arunachal Pradesh. The findings of this study may provide the essential baseline data for understanding the species richness, biogeographic patterns, and conservation status of Rosaceae within the state.

**Keywords:** Conservation, diversity, endemic, IUCN status, new distribution record, northeastern India, occurrence, synonyms.

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**Author contributions:** The first author undertook the field survey, data collection and preparation of the manuscript. The second author conceptualise the concept, helped in preparation and finalization of the manuscript.

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## INTRODUCTION

The family Rosaceae is one of the most diverse and economically significant plant groups in the order Rosales of core eudicotyledons. It is represented by around 104 genera and 5,250 accepted species (POWO 2025). The family has a worldwide distribution, with the highest abundance in the Northern Hemisphere, particularly in western North America and eastern Asia (Robertson 1974). The family is characterized by deciduous or evergreen trees, shrubs, climbers, and mostly perennial herbs (Kalkman 2004). Molecular phylogenetic studies have strongly supported the monophyly of Rosaceae and its sister relationship to a clade formed by the other eight families of the order Rosales (Zhang et al. 2011; Angiosperm Phylogeny Group 2016). However, considerable progress has been made in the evolutionary studies of Rosaceae due to the availability of DNA sequence data (Wissemann & Campbell 2007). Potter et al. (2007) analysed six nuclear and four chloroplast genes, identifying three major clades within Rosaceae, viz., Rosoideae, Dryadoideae, and Spiraeoideae. The family is ecologically diverse and economically valuable, with species used for ornamentals, timber, fruits, and medicine. Many are recognized in traditional medicine, some for their antibiotic properties (Ansari 2014), and widely used by ethnic groups to treat various ailments (Khan & Shinwari 2016).

Arunachal Pradesh, located in the northeastern part of India, is renowned for its rich floristic diversity. The state encompasses a wide range of ecosystems, from tropical and subtropical forests at lower altitudes to temperate and alpine forests in the higher elevations. It is estimated that approximately 76.93% of India's plant families are found in Arunachal Pradesh (Halder et al. 2024). Numerous floristic studies have been conducted in the state, significantly contributing to the documentation of its plant diversity (Panigrahi & Naik 1961; Rao & Joseph 1965; Panigrahi & Joseph 1966; Chauhan et al. 1996; Chowdhery et al. 1996; Ambrish 2013; Pal 2013; Bhuyan et al. 2015–16; Dash & Singh 2017; Lidén & Adhikari 2019; Bhuyan & Pangu 2020; Taram et al. 2020; Lidén & Bharali 2020). In addition to these floristic works, several taxonomic studies have also been carried out by various researchers (Gajurel et al. 2008; Srivastava & Choudhury 2008; Buragohain et al. 2014; Bhaumik 2017; Ranibala et al. 2018; Taram & Tag 2022). Many new additions have been made to the flora of the state through these studies. However, a comprehensive account of the plant families and genera, indicating the current status of plant diversity, is still lacking. As the comprehensive accounts of most of the plant families of the states are lacking, it is difficult to estimate accurately the present status of occurrence of taxa in any group.

The Rosaceae family, one of the dominant and economically significant plant groups in the state, is particularly underexplored. Although over 100 species have been reported across various studies, a thorough examination of species diversity within each genus is still needed. Such an assessment is essential for a deeper understanding of the family's diversity, which is crucial for the conservation and management of these valuable taxa. In this context, the present study is attempted to prepare a comprehensive checklist of the family Rosaceae with respect to the state.

## MATERIALS & METHODS

The comprehensive inventory was compiled by reviewing the information available in the taxonomic literature, herbarium specimens, and field surveys conducted by the authors from 2019 to 2024 in various localities of Arunachal Pradesh. Voucher specimens housed at the Arunachal Pradesh Regional Centre of the Botanical Survey of India (ARUN), Eastern Regional Centre of the Botanical Survey of India (ASSAM), Central National Herbarium of the Botanical Survey of India (CAL), and the State Forest Research Institute, Itanagar (acronym: APFH), were carefully examined. The databases 'Plants of the World Online'(http://www.plantsoftheworldonline.org/)` and 'International Plant Name Index' (http://www.ipni.org) was cross checked for up-to-date nomenclature of the reviewed taxa. To comprehend the conservation status of each taxon, IUCN red-list database of threatened species (https://www.iucnredlist.org) was consulted. The species and infraspecific taxa are arranged alphabetically along with synonyms, distribution, area of occurrence in Arunachal Pradesh (AP), taxonomic notes and IUCN status. Cultivated varieties and hybrids are not included in the present study for taxonomic ambiguity.

## RESULTS

We recorded the occurrence of 164 taxa (158 species, 8 varieties, and 1 subspecies) of Rosaceae from Arunachal Pradesh (Images 1–2). The genus *Rubus* L. is represented by the maximum number of species (49 spp.), followed by *Prunus* L. (15 spp.), *Cotoneaster* Medik. and *Potentilla* L. (11 spp. each), and *Spiraea* L. (10 spp.), among others (Figure 1). Four species *Rubus ghanakantae*, *R.*

*hapoliensis*, *R. ramachandrae*, and *Spiraea subdioica* were found to be endemic in the state. *Rubus niveus* var. *micranthus*, *R. alpestris*, and *Potentilla fulgens* have been reported as new distributional records for the state of Arunachal Pradesh. In the IUCN Red List of Threatened Species, *Prunus ceylanica* is categorized as 'Endangered' (EN) while majority of the plant taxa were found as not evaluated (Figure 2).

**Taxonomic enumeration**

(based on field survey, herbarium records and literature review)

1. ***Agrimonia pilosa*** Ledeb., Index Seminum (TU, Dorpatensis) 1823 (Suppl.): 1. 1823; Pal, Fl. Arunachal Pradesh (India) 1: 277. 2013.

2. ***Agrimonia pilosa*** var. ***pilosa***

Occurrence: Lower Dibang Valley, Lower Subansiri, Siang, Tirap, Upper Subansiri, West Kameng

Status: Least Concern (IUCN).

3. ***Agrimonia pilosa*** var. ***nepalensis*** (D.Don) Nakai, Bot. Mag. (Tokyo) 47: 247. 1933. *Agrimonia nepalensis* D. Don, Prodr. Fl. Nepal.: 229. 1825; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 415. 1996.

Occurrence: West Kameng, Subansiri.

4. ***Argentina contigua*** (Sojak) Y.H.Tong & N.H.Xia in J. Trop. Subtrop. Bot. 24: 426. 2016. *Potentilla contigua* Sojak in Candollea 43: 160. 1988; Lidén & Bharali, Symbolae Botanicae Upsalienses 40: 103. 2020.

Occurrence: West Kameng.

5. ***Argentina leuconota*** (D.Don) Soják, Thaiszia 20: 94. 2010. *Potentilla leuconota* D. Don, Prodr. Fl. Nepal. 230. 1825; Dikshit & Panigrahi, The Family Rosaceae in India 4: 106. 1998; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 424. 1996; Lidén & Bharali, Symbolae Botanicae Upsalienses 40: 103. 2020.

Occurrence: West Kameng.

6. ***Argentina lineata*** (Trevir.) Soják, Thaiszia 20: 94. 2010. *Potentilla lineata* Trevir., Ind. Sem. Vratislav. 1822; Dikshit & Panigrahi, The Family Rosaceae in India 4: 93. 1998; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh 498. 2017; Lidén & Bharali, Symbolae Botanicae Upsalienses 40: 103. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons*)* 1: 465. 2020.

Occurrence: Kameng, Kurung Kumey, Shi Yomi, Tawang.

7. ***Argentina micropetala*** (D.Don) Sojak, in Thaiszia 20: 95. 2010. *Potentilla micropetala* D.Don in Prodr. Fl. Nepal.: 231. 1825; Lidén & Bharali, Symbolae Botanicae Upsalienses 40: 105. 2020.

Occurrence: West Kameng.

8. ***Argentina microphylla*** (D.Don) Soják, Thaiszia 20: 95. 2010. *Potentilla microphylla* D.Don, Prodr. Fl. Nepal. 231. 1825; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 426. 1996; Lidén & Bharali, Symbolae Botanicae Upsalienses 40: 104. 2020.

Occurrence: West Kameng, Tawang.

9. ***Argentina peduncularis*** (D.Don) Soják, Thaiszia 20: 95. 2010. *Potentilla peduncularis* D.Don, Prodr. Fl. Nepal. 230. 1825; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 427. 1996.

Occurrence: Lohit, Shi Yomi, Tawang, West Kameng.

10. ***Argentina polyphylla*** **(**Wall. ex Lehm.) Soják, Thaiszia 20: 95. 2010. *Potentilla polyphylla* Wall. [Cat. no. 1026. 1829, nom. nud.] ex Lehm., Nov. Stirp. Pug. 3: 13. 1831; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 427. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 467. 2020.

Occurrence: Shi Yomi, Tawang, West Kameng.

11. ***Aruncus gombalanus*** (Hand.-Mazz.) Hand.-Mazz., Akad. Wiss. Wien, Math.-Naturwiss. Kl. 60: 152. 1923; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 449. 2020.

12. ***Aruncus sylvester*** Kostel. ex Maxim., Trudy Imp. S.-Peterburgsk. Bot. Sada 6: 169. 1879; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 449. 2020.

13. ***Chamaecallis perpusilloides*** (W.W.Sm.) Smedmark in Pl. Syst. Evol. 301: 180. 2014; Lidén & Bharali, Symbolae Botanicae Upsalienses 40: 101. 2020.

Occurrence: West Kameng.

14. ***Cotoneaster acuminatus*** Lindl., Trans. Linn. Soc. London 13(1): 101. 1821 as '*acuminata*'; Kumar & Panigrahi, The Family Rosaceae in India 3: 36. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 415. 1996; Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 73.2015-16; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons*)* 1: 450. 2020.

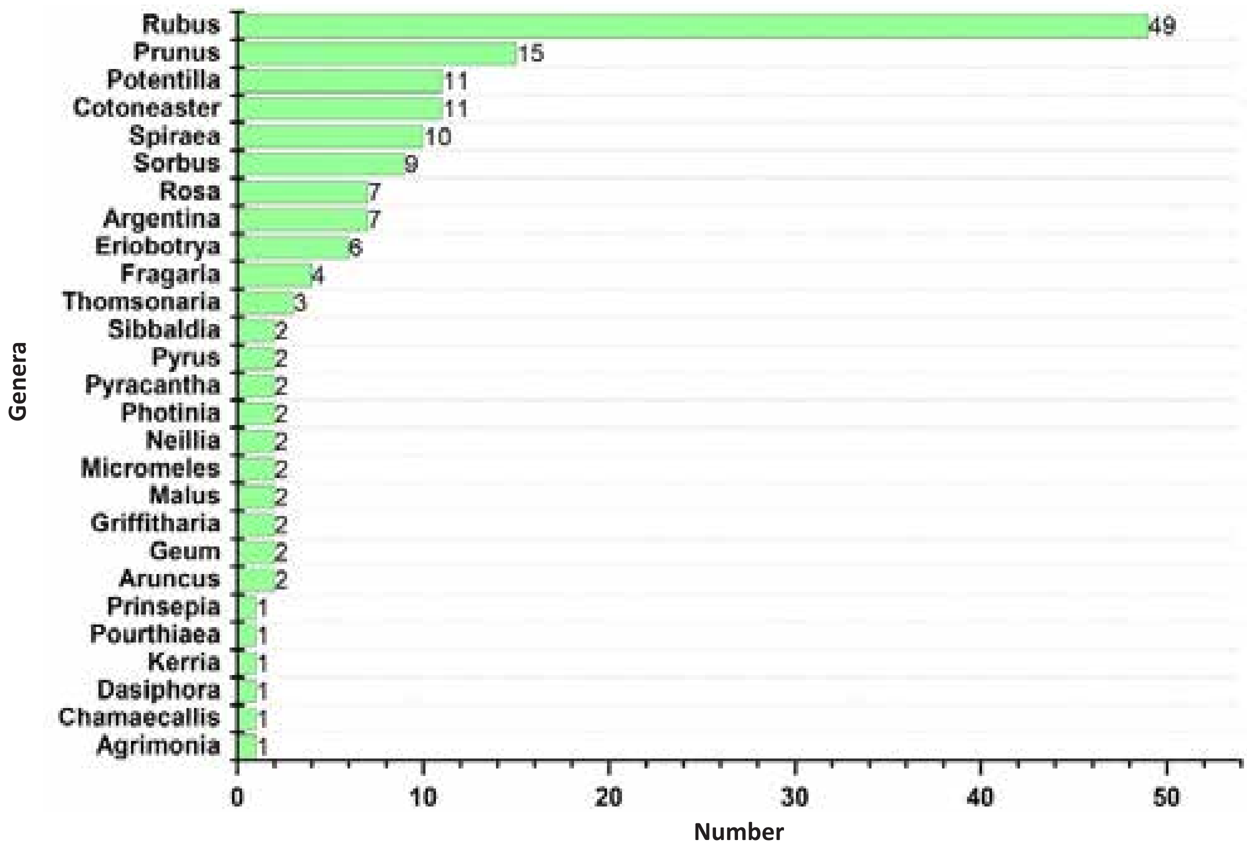


Figure 1. The genera of Rosaceae with number of species in Arunachal Pradesh.

Occurrence: Kameng, Shi Yomi.

15. ***Cotoneaster affinis*** Lindl., Trans. Linn. Soc. London 13 (1): 101. 1821; Kumar & Panigrahi, The Family Rosaceae in India 3: 43. 1995. *Cotoneaster bacillaris* Wall. (Cat. no. 660. 1829, nom. nud.) ex Lindl., Edwards's Bot. Reg. 15: sub t. 1229. 1829; Kumar & Panigrahi, The Family Rosaceae in India 3: 54. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 416. 1996; Pal, Fl. Arunachal Pradesh (India) 1: 278. 2013.

Occurrence: Kameng, Lohit, Lower Subansiri, Siang.

16. ***Cotoneaster cordifolius*** G.Klotz, Bull. Bot. Surv. India 5 (3&4): 212. 1963. *Cotoneaster cavei* G. Klotz, Bull. Bot. Surv. India 5: 213. 1964; Kumar & Panigrahi, The Family Rosaceae in India 3: 68. 1995; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 451. 2020.

17. ***Cotoneaster frigidus*** Wall. [Cat. no. 657. 1829, nom. nud.] ex Lindl., Edwards's Bot. Reg. 15: t. 1229. 1829 as '*frigida*'; Kumar & Panigrahi, The Family Rosaceae in India 3: 85. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 416. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 451. 2020.

Occurrence: West Kameng.

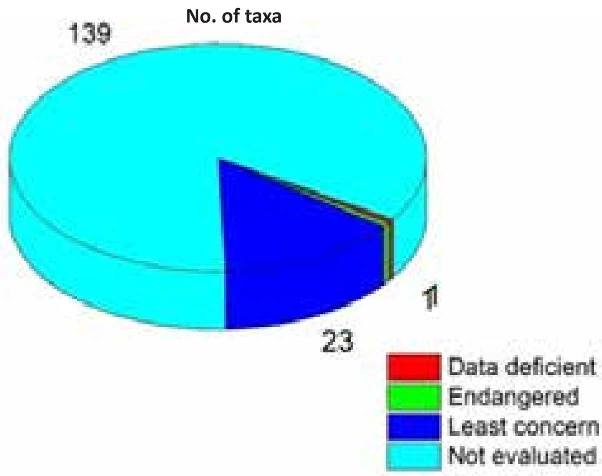


Figure 2. Taxa of Rosaceae under different IUCN Red List categories.

18. ***Cotoneaster integrifolius*** (Roxb.) G.Klotz in Wiss. Z. Martin-Luther-Univ. Halle- Wittenberg, Math.-Naturwiss. Reihe 12: 779. 1963. *Cotoneaster microphyllus* var. *thymifolius* (Wall. ex Lindl.) Koehne in Deut. Dendrol.: 227. 1893; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 453. 2020.

19. ***Cotoneaster microphyllus*** Wall. [Cat. no. 662. 1829, *nom. nud.*] ex Lindl., Edwards's Bot. Reg. 13: t. 1114. 1828 as '*microphylla*'; Kumar & Panigrahi, The Family Rosaceae in India 3: 121. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 416.1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 453. 2020.

Occurrence: Lohit, West Kameng.

20. ***Cotoneaster nitidus*** Jacques, J. Soc. Imp. Centr. Hort. 5: 516 (1859); Kumar & Panigrahi, The Family Rosaceae in India 3: 129. 1995; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 453. 2020.

21. ***Cotoneaster rotundifolius*** Wall. [Cat. no. 663. 1829, nom. nud.] ex Lindl., Edwards's Bot. Reg. 15: sub1229. 1829 as '*rotundifolia*'; Kumar & Panigrahi, The Family Rosaceae in India 3: 165. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 417. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 454. 2020.

Occurrence: Tawang, West Kameng.

22. ***Cotoneaster sandakphuensis*** G.Klotz in Bull. Bot. Surv. India 5: 213. 1963; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 454. 2020.

23. ***Cotoneaster sanguineus*** T.T.Yu in Bull. Brit. Mus. (Nat. Hist.) Bot. 1: 130. 1954; Kumar & Panigrahi, The Family Rosaceae in India 3: 171. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 417. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 454. 2020.

Occurrence: Tawang.

24. ***Cotoneaster simonsii*** Baker, Refug. Bot. 1: t. 55. 1869*. Cotoneaster assamensis* G.Klotz, Wiss. Zeitschr. Friedrich-Schiller-Univ. Jena, Math. -Naturwiss.Reihe 21(5-6): 996. 1972; Kumar & Panigrahi, The Family Rosaceae in India 3: 51. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 416. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 451. 2020.

Occurrence: West Kameng.

25. ***Dasiphora fruticosa*** (L.) Rydb., Monogr. N. Amer. Potent. 2: 188. 1898 var. ***fruticosa*** *Potentilla fruticosa* var. *rigida* (Wall. ex Lehm.) Th. Wolf in Biblioth. Bot. 16 (71): 57. 1908; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 423. 1996. *Potentilla rigida* Wall. ex Lehm. in Nov. Stirp. Pug. 3: 3. 1831; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons*)* 1: 468. 2020.

Occurrence: Kameng.

26. ***Eriobotrya bengalensis*** (Roxb.) Kurz, Prelim. Rep. Forest Pegu, App. A: lvii. 1875; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 419. 1996.

Occurrence: Changlang, Kameng, Tawang.

Status: Least Concern (IUCN).

27. ***Eriobotrya dubia*** (Lindl.) Decne., Nouv. Arch. Mus. Hist. Nat. 10: 145. 1874; Hook.f., Fl. Brit. India 2: 371. 1878; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 419. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 456. 2020.

Occurrence: Kameng.

28. ***Eriobotrya elliptica*** Lindl., Trans. Linn. Soc. London 13: 102. 1821; Hook.f., Fl. Brit. India 2: 372. 1878; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 456. 2020.

29. ***Eriobotrya longifolia*** (Decne.) Hook.f., Fl. Brit. India 2: 370. 1878. Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 456. 20.

30. ***Eriobotrya petiolata*** Hook.f., Fl. Brit. India 2: 370. 1878; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 419. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 456. 2020.

Occurrence: Kameng.

31. ***Eriobotrya salwinensis*** Hand.-Mazz., Symb.Sin. 7: 475. 1933; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 456. 2020.

32. ***Fragaria daltoniana*** J.Gay, Ann. Sci. Nat., Bot. sér. 4, 8: 204. 1857; Chowdhery et al. in Hajra et al., Mat.

Fl. Arunachal Pradesh 1: 420. 1996; Lidén & Bharali, Symbolae Botanicae Upsalienses 40: 101. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 456. 2020.

Occurrence: Lower Dibang Valley, Shi Yomi, Tawang, West Kameng.

33. ***Fragaria nilgerensis*** Schltdl. ex J.Gay, Ann. Sci. Nat., Bot. sér. 4, 8: 206. 1857; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 420. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 457. 2020.

Occurrence: Shi Yomi, West Kameng.

34. ***Fragaria nubicola*** **(**Lindl. ex Hook.f.) Lacaita, J. Linn. Soc. Bot. 43: 467. 1916; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 420. 1996; Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 68.2015-16; Dash & Singh, Fl. KurungKumey District, Arunachal Pradesh: 496. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 457. 2020.

Occurrence: Shi Yomi, Tawang, West Kameng.

35. ***Fragaria vesca*** L., Sp. Pl. 494. 1753; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 420. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 173. 2013; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 457. 2020.

Occurrence: West Kameng.

36. ***Geum elatum*** Wall. ex G.Don in Gen. Hist. 2: 526. 1832; Lidén & Bharali, Symbolae Botanicae Upsalienses 40: 102. 2020.

Occurrence: West Kameng.

37. ***Geum macrosepalum*** Ludlow, Bull. Brit. Mus. (Nat. Hist.), Bot. 5: 271. 1976; Purohit & Panigrahi, The Family Rosaceae in India 1: 167. 1991; Lidén & Bharali, Symbolae Botanicae Upsalienses 40: 102. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons) 1: 457. 2020.

Occurrence: Tawang, West Kameng.

38. ***Griffitharia lanata*** (Wall. ex G.Don) Rushforth, Phytologia 100: 236. 2018. *Sorbus lanata* (D.Don) Schauer, Ubers. Arbeiten Vera. Schles. Ges. Vaterl. Cult. 1847: 292. 1848; Bhuyan & Pangu, Bull. Arunachal Pradesh Forest Research 35 (1&2): 35. 2020.

Occurrence: East Kameng.

39. ***Griffitharia vestita*** (D.Don) Rushforth, Phytologia 100: 233. 2018; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons) 1: 458. 2020. *Sorbus cuspidata* (Spach) Hedl., Kongl. Svenska Vetensk. Acad. Handl., n. f., 35(1): 89. 1901; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 443. 1996; Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 77.2015-16; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 488. 2020.

Occurrence: Shi Yomi, Tawang, West Kameng.

40. ***Kerria japonica*** (L.) DC. in Trans. Linn. Soc. London 12: 157. 1818; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 458. 2020.

41. ***Malus indica*** (Wall.) B.B.Liu, Phytokeys 229: 52. 2023. *Docynia indica* (Colebr. ex Wall.) Decne., Nouv. Arch. Mus. Hist. Nat. 10: 131. 1874; Panigrahi & Naik, Bull. Bot. Surv. India 3 (3&4): 369. 1961; Chauhan et al. in Hajra, Fl. of Namdapha, Arunachal Pradesh: 159. 1996; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 417. 1996. Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 173. 2013; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 455. 2020.

Occurrence*:* Changlang, Lower Subansiri, Upper Subansiri, West Kameng.

42. ***Malus sikkimensis*** (Wenz.) Koehne. Gatt. Pomac.: 27. 1890; Ghora & Panigrahi, The Family Rosaceae in India 2: 384. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 421. 1996; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 496. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 459. 2020.

Occurrence: Kurung Kumey, West Kameng.

Status*:* Data Deficient (IUCN).

43. ***Micromeles cuspidata*** (Bertol.) C.K.Schneid., III. Handb. Laubholzk. 1: 700. 1906. *Micromeles polycarpa* (Hook. f.) Panigrahi in Bull. Bot. Surv. India 24: 238. 1982; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 459. 2020. *Photinia cuspidata* (Bertol.) Balakr., Fl. Jowai 1: 192. 1981; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 422. 1996. *Pyrus polycarpa* Hook. f. in Fl. Brit. India 2: 378. 1878; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 433. 1996.

Occurrence: Kameng, Lohit, Lower Subansiri, Siang, Subansiri, Tirap.

Status: Data Deficient (IUCN).

44. ***Micromeles griffithii*** Decne., Nouv. Arch. Mus. Hist. Nat. 10: 170. 1874. *Pyrus griffithii* (Decne.) Hook.f., in Fl. Brit. India 2: 377. 1878. *Sorbus griffithii* (Decne.) Rehder, C. S. Sargent, Pl. Wilson. 2: 277. 1915; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 508. 2017.

Occurrence: Kameng, Kurung Kumey.

45. ***Neillia rubiflora*** D.Don, Prodr. Fl. Nepal 229.: 1825; Purohit & Panigrahi, The Family Rosaceae in India 1: 28. 1991; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 421. 1996; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 497. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 459. 2020.

Occurrence: Kameng, Kurung Kumey, Shi Yomi.

46. ***Neillia thyrsiflora*** D.Don, Prodr. Fl. Nep.: 228. 1825; Panigrahi & Naik, Bull. Bot. Surv. India 3 (3&4): 370. 1961; Panigrahi & Joseph, Bull. Bot. Surv. India 8 (2): 146. 1966; Purohit & Panigrahi, The Family Rosaceae in India 1: 30. 1991; Chauhan et al. in Hajra, Fl. of Namdapha, Arunachal Pradesh: 160. 1996; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 421. 1996; Pal, Fl. Arunachal Pradesh (India) 1: 279. 2013; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 174. 2013; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 497. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 459. 2020.

Occurrence: Anjaw, Changlang, Kurung Kumey, Lower Subansiri, Shi Yomi, Tawang, Tirap, Upper Subansiri.

Status*:* Least Concern (IUCN).

47. ***Photinia griffithii*** Decne., Nouv. Arch. Mus. Hist. Nat. 10: 142. 1874; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 422. 1996; *Photinia glomerata* Rehder & E. H. Wison in C. S. Sargent, Pl. Wilson 1: 190. 1912; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 460. 2020.

Occurrence: West Kameng.

48. ***Photinia integrifolia*** Lindl. in Trans. Linn. Soc. London 13: 103 (1822); Chauhan et al. in Hajra, Fl. of Namdapha, Arunachal Pradesh: 160. 1996. *Photinia integrifolia* var.*sublanceolata* Miq., in Fl. Ned. Ind. 1(1): 387. 1855; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 423. 1996. *Photinia wardii* C. E. C. Fisch., Bull. Misc. Inform. Kew 1936: 28. 1936; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 423. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 461. 2020.

Occurrence: Changlang, KurungKumey, Lohit, Lower Subansiri, Siang, Shi Yomi, Upper Subansiri, West Kameng.

Status: Least Concern (IUCN).

49. ***Potentilla bryoides*** Sojak., Preslia 41: 350. 1969; Lidén & Bharali, Symbolae Botanicae Upsalienses 40: 103. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 463. 2020.

Occurrence: West Kameng.

Status: Least Concern (IUCN).

50. ***Potentilla caliginosa*** Sojak, Folia Geobot. Phytotax. 1: 346. 1966; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 463. 2020.

51. ***Potentilla coriandrifolia*** D.Don, Prodr. Fl. Nepal. 232. 1825; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 423. 1996; Dikshit & Panigrahi, The Family Rosaceae in India 4: 117. 1998; Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 70. 2015-16; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 498. 2017.

Occurrence: Shi Yomi, Kameng, Kurung Kumey.

52. ***Potentilla coriandrifolia*** var. ***dumosa*** Franch. in Pl. Delavay.: 214. 1890; Lidén & Adhikari, Pleione 13(1): 182. 2019.

Occurrence: West Kameng.

53. ***Potentilla fulgens*** Wall. ex Sims in Bot. Mag. 53: t. 2700. 1826.

Occurrence: West Kameng.

Note: The specimen had been collected by R. S. Rao (ASSAM, collection no. 7779) from West Kameng District of Arunachal Pradesh.

54. ***Potentilla griffithii*** Hook.f., Fl. Brit. India 2: 351. 1878 var. ***griffithii***

*Potentilla griffithii var. decurrens* Sojak in Candollea 43: 452. 1988; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 424. 1996.

55. ***Potentilla indica*** (Andrews) Th.Wolf, P. F. A. Ascherson & K. O. R. Graebner, Syn. Mitteleur. Fl. 6(1): 661. 1904; Dikshit & Panigrahi, The Family Rosaceae in

India 4: 133. 1998; Taram et al., in Journal of Threatened Taxa, 12 (17): 17319. 2020. *Fragaria indica* Andrews in Bot. Repos. 7: t. 479. 1807; Rao & Joseph, Bull. Bot. Surv. India, 7 (1-4): 144. 1965. *Potentilla khasiana* C. B. Clarke ex Dikshit & Panigrahi, Bull. Bot. Surv. India 21: 136. 1981; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 424. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 465. 2020.

Occurrence: Dibang Valley, East Siang, Kurung Kumey, Lohit, Lower Dibang Valley, Lower Subansiri, Papum Pare, Shi Yomi, Tirap, West Kameng, West Siang.

56. ***Potentilla monanthes*** Lindl. ex Lehm., in Nov. Strip. Pug. 3: 33. 1831; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons) 1: 466. 2020.

57. ***Potentilla monanthes*** var. ***monanthes***

Occurrence: West Kameng.

58. ***Potentilla monanthes*** var. ***sibthorpioides*** Hook.f., Fl. Brit. India 2: 358. 1878; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 426 (1996); Dikshit & Panigrahi, The Family Rosaceae in India 4: 220. 1998; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 466. 2020.

Occurrence: West Kameng, Tawang.

59. ***Potentilla nepalensis*** Hook., Exot. Fl. 2. Pl. 88. 1824; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 427. 1996; Dikshit &Panigrahi, The Family Rosaceae in India 4: 174. 1998; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 175. 2013.

Occurrence: Kameng, Siang, Upper Subansiri, Tawang, Tirap.

60. ***Potentilla saundersiana*** Royle, III. Bot. Himal. Mts. 1: 207. 1839; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 428. 1996; Dikshit &Panigrahi, The Family Rosaceae in India 4: 192. 1998; Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 70. 2015-16; Lidén & Bharali, Symbolae Botanicae Upsalienses 40: 104. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 468. 2020.

Occurrence: Kameng, Shi Yomi, Siang, Subansiri, West Kameng, Tawang.

61. ***Potentilla sundaica*** (Blume) W.Theob., Burmah [Mason], ed. 3. 2: 490. 1883; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 428. 1996; Dikshit & Panigrahi, The Family Rosaceae in India 4: 223. 1998; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 175. 2013; Pal, Fl. Arunachal Pradesh (India) 1: 282. 2013; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 499. 2017. *Potentilla kleiniana* Wight &Arn., in Prodr. Fl. Ind. Orient. 1: 300. 1834; Panigrahi& Naik, Bull. Bot. Surv. India 3 (3&4): 369. 1961; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 469. 2020.

Occurrence: Anjaw, Kurung, Kumey, Lower Subansiri, Tirap, Upper Siang, Upper Subansiri, West Kameng.

62. ***Potentilla supina*** L., Sp. Pl. 1: 497. 1753; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 469. 2020.

63. ***Potentilla supina*** subsp. ***supina***

Status: Least Concern (IUCN).

64. ***Pourthiaea arguta*** (Wall. ex Lindl.) Decne, Nouv. Arch. Mus. Hist. Nat. 10: 147. 1874; Panigrahi & Naik, Bull. Bot. Surv. India 3 (3&4): 370. 1961; *Photinia hookeri* (Decne.) Merrill, Brittonia 4(1): 82. 1941; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 422. 1996.

Occurrence: Subansiri.

Status: Least Concern (IUCN).

65. ***Prinsepia utilis*** Royle, Ill. Bot. Himal. Mts. 1: 206. 1839; Ghora & Panigrahi, The Family Rosaceae in India 2: 174. 1995. Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 74.2015-16; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 470. 2020.

Occurrence: Shi Yomi.

66. ***Prunus arborea*** var. ***montana*** (Hook. f.) Kalkman, Blumea 13: 99. 1965; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 428. 1996.

Occurrence: West Kameng.

67. ***Prunus campanulata*** Maxim., Bull. Acad. Imp. Sci. St. Petersburg 29: 103. 1883; Ghora & Panigrahi, The Family Rosaceae in India 2: 79. 1995; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 470. 2020.

68. ***Prunus cerasoides*** Buch.-Ham. ex D.Don, Prodr. Fl. Nep. 239. 1825; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 429. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District) 176. 2013; Pal, Fl. Arunachal Pradesh (India) 1: 283. 2013. *Maddenia pedicellata* Hook. f., Fl. Brit. India 2: 318. 1878.

Occurrence: Anjaw, Dibang Valley, Lower Subansiri, Lohit, Tawang, Upper Subansiri, West Kameng.

Status: Least Concern (IUCN).

69. ***Prunus ceylanica*** (Wight) Miq., Fl. Ned. Ind. 1(1): 366. 1855; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 429. 1996. *Pygeum glaberrimum* Hook. f., Fl. Brit. India 2: 319. 1878; Rao & Joseph, Bull. Bot. Surv. India, 7 (1-4): 144. 1965.

Occurrence: Kameng, Siang.

Status: Endangered (IUCN).

70. ***Prunus cornuta*** (Wallich ex Royle) Steud., Nom. Bot. ed. 2, 2: 403. 1841; Ghora & Panigrahi, The Family Rosaceae in India 2: 108. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 429. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 176. 2013; Pal, Fl. Arunachal Pradesh (India) 1: 284. 2013.

Occurrence*:* Anjaw, Lower Subansiri, Shi Yomi, Upper Subansiri.

71. ***Prunus domestica*** L., Sp. Pl. 475. 1753; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 429. 1996.

Note: Cultivated taxa.

72. ***Prunus gongshanensis*** J.Wen, Phytokeys 11: 54. 2012.

Occurrence: West Kameng.

73. ***Prunus jenkinsii*** Hook.f. & Thomson, Hook.f., Fl. Brit. India 2: 317. 1878; Deb, Bull. Bot. Surv. India 3(3&4): 259. 1961; Ghora&Panigrahi, The Family Rosaceae in India 2: 137. 1995; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 472. 2020.

74. ***Prunus napaulensis*** (Ser.) Steud., Nomencl. Bot. ed. 2. 2: 403. 1841 as '*nepaulensis*'; Ghora & Panigrahi, The Family Rosaceae in India 2: 118. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 430. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 176. 2013; Pal, Fl. Arunachal Pradesh (India) 1: 284. 2013; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 500. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 472. 2020.

Occurrence: Anjaw, Changlang, Kurung Kumey, Upper Subansiri, West Kameng.

75. ***Prunus persica*** (L.) Batsch, Beytr. Entw. Gewachsreich: 30. 1801; Ghora & Panigrahi, The Family Rosaceae in India 2: 56. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 430. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 177. 2013.

Note: Cultivated taxa.

76. ***Prunus phaeosticta*** (Hance) Maxim., Bull. Acad. Imp. Sci. Saint-Petersbourg, ser. 3, 29: 110. 1883; Ghora & Panigrahi, The Family Rosaceae in India 2: 143. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 430. 1996; Pal, Fl. Arunachal Pradesh (India) 1: 285. 2013.

Occurrence: Lower Subansiri.

77. ***Prunus rufa*** Wall. [Cat. no. 721. 1829, *nom. nud.*] ex Hook.f., Fl. Brit. India 2: 314. 1878; Ghora & Panigrahi, The Family Rosaceae in India 2: 91. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 431. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 177. 2013; Pal, Fl. Arunachal Pradesh (India) 1: 285. 2013; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 500. 2017.

Occurrence: Kurung Kumey, Lower Subansiri, Shi Yomi, Upper Subansiri.

78. ***Prunus salicina*** Lindl., in Trans. Hort. Soc. London 7: 239. 1830; Ghora & Panigrahi, The Family Rosaceae in India 2: 43. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 431. 1996.

Occurrence: Tirap.

79. ***Prunus stipulacea*** Maxim., Bull. Acad. Imp. Sci. Saint-Petersbourg, ser. 3, 29: 97. 1883. *Cerasus stipulacea* (Maxim.) T.T.Yu & C.L.Li in Fl. Reipubl. Popularis Sin. 38: 68. 1986; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 500. 2017.

Occurrence: Kurung Kumey.

80. ***Prunus undulata*** Buch.-Ham. ex D.Don, Prodr. Fl. Nepal: 239. 1825; Ghora & Panigrahi, The Family Rosaceae in India 2: 151. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 43. 1996;

Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 177. 2013; Pal, Fl. Arunachal Pradesh (India) 1: 286. 2013; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 500. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 473. 2020.

Occurrence: Kurung Kumey, Lohit, Lower Subansiri, Tirap, Upper Subansiri, West Kameng.

Status: Least Concern (IUCN).

81. ***Pyracantha angustifolia*** (Franch.) C.K.Schneid., Ill.Handb. Laubholzk. 1: 761. 1906; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 473. 2020.

Status: Least Concern (IUCN).

82. ***Pyracantha crenulata*** (D.Don) M.Roem., Fam. Nat. Syn. Monogr. 3: 220. 1847; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 432. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 473. 2020.

Occurrence: West Kameng.

Status: Least Concern (IUCN).

83. ***Pyrus communis*** L. Sp. Pl.: 479. 1753.

Note: Cultivated Taxa.

84. ***Pyrus pashia*** Buch.-Ham. ex D.Don, Prodr. Fl. Nepal.: 236. 1825; Panigrahi & Naik, Bull. Bot. Surv. India 3 (3&4): 370. 1961; Ghora & Panigrahi, The Family Rosaceae in India 2: 400. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 432. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 178. 2013; Pal, Fl. Arunachal Pradesh (India) 1: 287. 2013.

Occurrence: Lower Subansiri, Upper Siang, Upper Subansiri, West Kameng.

Status: Least Concern (IUCN).

85. ***Rosa brunonii*** Lindl., Ros. Monogr.:120. 1820; Ghora & Panigrahi, The Family Rosaceae in India 2: 328. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 433. 1996; Pal, Fl. Arunachal Pradesh (India) 1: 289. 2013; Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 74.2015-16; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 475. 2020.

Occurrence: Kameng, Lower Subansiri, Shi Yomi, Subansiri.

86. ***Rosa indica*** L., Sp. Pl. 492. 1753; Panigrahi & Naik, Bull. Bot. Surv. India 3 (3 & 4): 369. 1961; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 434. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 179. 2013.

Note: Cultivated taxa

87. ***Rosa leschenaultiana*** (Redout. & Thory) Wight & Arn., Prodr. Fl. Ind. Orient. 1: 301. 1834; Ghora & Panigrahi, The Family Rosaceae in India 2: 337. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 434. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District) 179. 2013.

Occurrence: Upper Subansiri.

88**.** ***Rosa longicuspis*** Bertol., in Misc. Bot. 21: 15. 1861; Hook. f., Fl. Brit. India 2: 367. 1878; Ghora & Panigrahi, The Family Rosaceae in India 2: 340. 1995.

Occurrence: Anjaw, Kurung Kumey, Lower Subansiri, Shi Yomi, West Kameng.

89. ***Rosa omeiensis*** Rolfe in Bot. Mag. 138: t. 8471. 1912; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 434. 1996.

Occurrence: Kameng, Tawang.

90. ***Rosa sericea*** Lindl., in Ros. Monogr.: 105. 1820; Ghora & Panigrahi, The Family Rosaceae in India 2: 306. 1995; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 434. 1996; Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 74. 2015-16; Dash & Singh, Fl. KurungKumey District, Arunachal Pradesh: 500. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 477. 2020.

Occurrence: Kurung Kumey, Lower Dibang Valley, Shi Yomi, Tawang, West Kameng.

91. ***Rosa soulieana*** Crep. in Bull. Soc. Roy. Bot. Belgique 35: 21. 1896; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 478. 2020.

92. ***Rubus acuminatus*** Smith in Cycl. 30: no. 43. 1819; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 435. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District) 180. 2013; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons) 1: 478. 2020.

93. ***Rubus acuminatus*** var. ***acuminatus***
Occurrence: Tawang, West Kameng.

94. ***Rubus alceifolius*** Poir., J. B. A. M. de Lamarck, Encycl. 6: 247. 1804; Chauhan et al. in Hajra, Fl. of Namdapha, Arunachal Pradesh: 161. 1996; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 435. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 180. 2013; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 478. 2020.
Occurrence: Changlang, Shi Yomi.

95. ***Rubus alpestris*** Blume, Bijdr. Fl. Ned. Ind.: 1108. 1826.
Occurrence: Lower Subansiri.
Note: The specimen had been collected by G. D. Pal (ARUN, collection no. 181) from Lower Subansiri District of Arunachal Pradesh.

96. ***Rubus assamensis*** Focke in Abh. Naturwiss. Vereins Bremen 4: 197. 1874; Hook. f., Fl. Brit. India 2: 328. 1878; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 435. 1996; Pal, Fl. Arunachal Pradesh (India) 1: 292. 2013; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 502. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 479. 2020.
Occurrence: Lower Subansiri, West Kameng.

97. ***Rubus biflorus*** Buch.-Ham. ex Sm., in A. Rees, Cycl. 30: no. 9. 1819; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 435. 1996; Bhuyan, L. R., Pangu, Y. & Tam, N in Bull. Arunachal Forest Research, 30 & 31 (1&2), 74. 2015-16; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 479. 2020.

98. ***Rubus biflorus*** var. ***biflorus***
Occurrence: Shi Yomi.

99. ***Rubus biflorus*** var. ***adenophorus*** Franch., Pl. Delavay.: 207. 1890; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 479. 2020.

100. ***Rubus birmanicus*** Hook.f., Fl. Brit. India 2: 331. 1878; Panigrahi & Joseph, Bull. Bot. Surv. India 8 (2): 146. 1966; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 436. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District) 181. 2013. Pal, Fl. Arunachal Pradesh (India) 1: 292. 2013; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 502. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 479. 2020.
Occurrence: Tirap, Upper Subansiri, Lower Subansiri, Kurung Kumey.

101. ***Rubus burkillii*** Rolfe in Bull. Misc. Inform. Kew 1920: 109. 1920; Kanjilal & al., Fl. Assam 2: 202. 1938; Panigrahi & Joseph, Bull. Bot. Surv. India 8(2): 146. 1966; Chauhan et al. in Hajra, Fl. of Namdapha, Arunachal Pradesh: 161. 1996; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 436. 1996; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 502. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 479. 2020.
Occurrence:Changlang, East Siang, Kurung Kumey.

102. ***Rubus calophyllus*** C.B.Clarke in J. Linn. Soc., Bot. 25: 19. 1889; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 181. 2013; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 479. 2020.
Occurrence: Lower Dibang Valley, Shi Yomi, Upper Subansiri.

103. ***Rubus calycinoides*** Kuntze, Meth.Sp.-Beschr. Rubus: 67. 1879; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 479. 2020.
Occurrence: Lower Subansiri.

104. ***Rubus calycinus*** Wall. [Cat. no. 737. 1829, nom. nud.] ex D. Don, Prodr. Fl. Nepal. 235. 1825; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 436. 1996; Pal, Fl. Arunachal Pradesh (India) 1: 293. 2013; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 503. 2017.
Occurrence: Kameng, Kurung Kumey, Lower Subansiri.

105. ***Rubus cooperi*** D.G.Long, Notes Roy. Bot. Gard. Edinburgh 44: 259. 1987; Bhaumik in Taiwania 58(3): 199. 2013; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 479. 2020.
Occurrence: Lower Dibang Valley, Shi Yomi.

106. ***Rubus efferatus*** Craib, Fl. Siam. 1: 570. 1931. *Rubus kurzii* N.P.Balakr., J. Bombay Nat. Hist. Soc. 67: 58. 1970; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 439. 1996.

Occurrence: Tirap, West Kameng, Lower Dibang Valley.

107. ***Rubus ellipticus*** Sm., in A. Rees, Cycl. 30:no. 16. 1819; Rao & Joseph, Bull. Bot. Surv. India, 7 (1-4): 144. 1965; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 437. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District) 181. 2013; Pal, Fl. Arunachal Pradesh (India) 1: 294. 2013; Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 74.2015-16; Dash & Singh, Fl. KurungKumey District, Arunachal Pradesh: 503. 2017; Taram et al., in Journal of Threatened Taxa, 12 (17): 17319. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 480. 2020.

108. ***Rubus ellipticus*** var. ***ellipticus***

Occurrence: Lower Subansiri, Papum Pare, Upper Siang.

109. ***Rubus ellipticus*** var. ***obcordatus*** (Franch.) Focke, Sp. Rub.: 199 (1911).

Status: Least Concern (IUCN).

Occurrence: Anjaw, Changlang, Dibang Valley, KurungKumey, Lower Dibang Valley, Lower Subansiri, West Kameng.

110. ***Rubus fairholmianus*** Gardner in Calcutta J. Nat. Hist. 8: 5. 1847; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 437. 1996; Pal, Fl. Arunachal Pradesh (India) 1: 295. 2013; Dash & Singh, Fl. KurungKumey District, Arunachal Pradesh: 503. 2017.

Occurrence: Kurung Kumey, Lower Subansiri.

111. ***Rubus fockeanus*** Kurz in J. Asiat. Soc. Bengal, Pt. 2, Nat. Hist. 44(3): 206. 1876; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 480. 2020.

Occurrence: West Kameng.

112. ***Rubus franchetianus*** H.Lev., in Bull. Acad. Int. Geogr. Bot. 20: 71. 1909; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 480. 2020.

113. ***Rubus franchetianus*** var. ***franchetianus***

Occurrence: Arunachal Pradesh.

114. ***Rubus franchetianus*** var*.* ***fragarioides*** (Focke) Chand. Gupta & S. S. Dash in Nelumbo 58: 45. 2016; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 480. 2020.

Occurrence: Tawang, Shi Yomi.

115. ***Rubus ghanakantae*** R.S.Rao & J.Joseph in Bull. Bot. Surv. India 12(1-4): 261. 1972; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 437. 1996; Pal, Fl. Arunachal Pradesh (India) 1: 296. 2013; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 481. 2020.

Occurrence: West Kameng, Lower Subansiri.

Note: Endemic to Arunachal Pradesh.

116. ***Rubus hamiltonii*** Hook.f., Fl. Brit. India 2: 328. 1878 as '*hamiltoni*'; Chauhan et al. in Hajra, Fl. of Namdapha, Arunachal Pradesh: 161. 1996; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 438. 1996; Pal, Fl. Arunachal Pradesh (India) 1: 297. 2013; Dash & Singh, Fl. KurungKumey District, Arunachal Pradesh 504. 2017.

Occurrence: Changlang, Lower Subansiri, Kurung Kumey, Siang, West Kameng.

117. ***Rubus hapoliensis*** G.D.Pal, Fl. Arunachal Pradesh (India) 1: 298. 2013; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 481. 2020.

Note: Endemic to Arunachal Pradesh.

118. ***Rubus hexagynus*** Roxb. ex Wall, Numer. List: 22, no. 725. 1829; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 438. 1996; Pal, Fl. Arunachal Pradesh (India) 1: 298. 2013; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 481. 2020.

Occurrence: Lower Subansiri.

119. ***Rubus inopertus*** (Focke) Focke, Sp. Rub.: 182. 1911; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 481. 2020.

Occurrence: Tawang.

120. ***Rubus insignis*** Hook.f., Fl. Brit. India 2: 329. 1878; Panigrahi & Joseph, Bull. Bot. Surv. India 8 (2): 146. 1966; Chauhan et al. in Hajra, Fl. of Namdapha, Arunachal Pradesh: 162. 1996; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 439. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 182. 2013; Pal, Fl. Lower Subansiri District, Arunachal Pradesh (India) 1: 300. 2013; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 504. 2017; Bhuyan & Pangu, Bull. Arunachal Pradesh

Forest Research 35 (1&2): 37. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 482. 2020.

Occurrence: Changlang, East Kameng, KurungKumey, Lower Subansiri, Papum Pare, Tirap, Upper Subansiri, West Siang.

121. ***Rubus kumaonensis*** N.P.Balakr., in J. Bombay Nat. Hist. Soc. 67. 58. 1970; Grierson & Long, Fl. Bhutan 1(3): 554. 1987.

122. ***Rubus lasiostylus*** Focke, Hooker's Icon. Pl. 20: t. 1951. 1891; Dash & Gupta, Blumea 62: 122. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 482. 2020.

123**. *Rubus lasiostylus*** var. ***lasiostylus***

Occurrence: West Kameng.

124. ***Rubus lineatus*** Reinw. ex Blume, Bijdr. Fl. Ned. Ind.: 1108. 1826; Chauhan et al. in Hajra, Fl. of Namdapha, Arunachal Pradesh: 162. 1996; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 440. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 482. 2020.

Occurrence: Anjaw, Changlang, Lohit, Lower Dibang Valley, Shi Yomi, Tirap.

125. ***Rubus lucens*** Focke in Abh. Naturwiss. Vereins Bremen 4: 199. 1874; Hook. f., Fl. Brit. India 2: 338. 1878; Rao & Joseph, Bull. Bot. Surv. India, 7 (1-4): 144. 1965; Panigrahi & Joseph, Bull. Bot. Surv. India 8 (2): 146. 1966; Chauhan et al. in Hajra, Fl. of Namdapha, Arunachal Pradesh: 162. 1996; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 440. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 182. 2013; Pal, Fl. Lower Subansiri District, Arunachal Pradesh (India) 1: 301. 2013; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 504. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 482. 2020.

Occurrence: Lower Subansiri, Lower Dibang Valley, Papum Pare, Pakke Kessang, Shi Yomi, Tirap, Upper Siang, Upper Subansiri, West Kameng, West Siang.

126. ***Rubus macilentus*** Cambess., Jacquem. Voy. Inde 4: 49. 1841; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 440. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 482. 2020.

Occurrence: Dibang Valley, Shi Yomi, Upper Siang, West Kameng.

127. ***Rubus mesogaeus*** Focke in Bot. Jahrb. Syst. 29: 399. 1900; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 441. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 482. 2020.

Occurrence: Shi Yomi, West Kameng.

128. ***Rubus moluccanus*** L., Sp. Pl.: 1197. 1753; Panigrahi & Naik, Bull. Bot. Surv. India 3 (3&4): 369. 1961; Rao & Joseph, Bull. Bot. Surv. India, 7 (1-4): 144. 1965; Taram et al., in Journal of Threatened Taxa, 12 (17): 17319. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 482. 2020.

Occurrence: Anjaw, Dibang, Valley, Lower Subansiri, Upper Siang, West Kameng.

129. ***Rubus niveus*** Thunb., in De Rubo: 9. 1813; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 441. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District): 183. 2013; Pal, Fl. Lower Subansiri District, Arunachal Pradesh (India) 1: 302. 2013; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 505. 2017; Taram et al., in Journal of Threatened Taxa, 12 (17): 17319. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 483. 2020.

130. ***Rubus niveus*** var. ***micranthus*** (D.Don) H.Hara, Enum. Fl. Pl. Nepal 2: 146. 1979.

Occurrence: Anjaw, West Kameng Lower Subansiri

Note: The specimen had been collected by G. V. S. Rao (ASSAM, collection no. 24713) from Lower Subansiri District of Arunachal Pradesh.

131. ***Rubus niveus*** var. ***niveus***

*Rubus lasiocarpus* var. *furfuraceus* Hook.f., in Fl. Brit. India 2: 339. 1878; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 439. 1996.

Occurrence: Anjaw, East Siang, Lower Subansiri, Shi Yomi, Upper Siang, West Kameng.

132. ***Rubus opulifolius*** Bertol., in Misc. Bot. 22: 16. 1862; Adhikary & Gajurel in Pleione 17(3): 329. 2023.

Occurrence: Anjaw.

133. ***Rubus paniculatus*** Sm. in A.Rees, Cycl. 30. no. 41. 1815; Panigrahi & Naik, Bull. Bot. Surv. India 3 (3&4):

369. 1961; Chauhan et al. in Hajra, Fl. of Namdapha, Arunachal Pradesh: 163. 1996; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 442. 1996; Pal, Fl. Lower Subansiri District, Arunachal Pradesh (India) 1: 302. 2013; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 505. 2017; Taram et al., in Journal of Threatened Taxa, 12 (17): 17319. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 483. 2020.

Occurrence: Changlang, East Siang, Kurung Kumey, Lower Subansiri, Lower Dibang Valley, Shi Yomi, Tawang.

134. ***Rubus pectinarioides*** H.Hara in J. Jap. Bot. 47(4): 111. 1972; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons) 1: 484. 2020.

135. ***Rubus pectinaris*** Focke, Sp. Rub.: 21. 1910;Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 442. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 484. 2020.

Occurrence: Kameng, Tawang.

136. ***Rubus pedunculosus*** D.Don, Prodr. Fl. Nepal. 234. 1825; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 484. 2020.

137. ***Rubus pentagonus*** Wall. [Cat. no. 731. 1829, *nom. nud.*]ex Focke, Sp. Rub.: 145. 1911; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 484. 2020.

Occurrence: Tawang.

138. ***Rubus polyodontus*** Hand.-Mazz., Symb. Sin. 7: 484. 1933; Bhaumik in Taiwania, 58(3): 199. 2013; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 484. 2020.

Occurrence: Shi Yomi.

139. ***Rubus quinquefoliolatus*** T.T.Yu & L.T.Lu in Acta Phytotax. Sin. 20: 306. 1982; Bhaumik in Taiwania, 58(3): 203. 2013; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 484. 2020.

Occurrence: Shi Yomi.

140. ***Rubus ramachandrae*** S.S.Dash & Chand.Gupta in Blumea 63: 26. 2018; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 484. 2020.

Occurrence: Upper Subansiri.

Note: Endemic to Arunachal Pradesh.

141. ***Rubus rosifolius*** Sm., Pl. Icon. Ined. 3: t. 60. 1791 as '*rosaefolius*'; Panigrahi & Naik, Bull. Bot. Surv. India 3 (3&4): 369. 1961; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 442. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District) 184. 2013; Pal, Fl. Lower Subansiri District, Arunachal Pradesh (India) 1: 304. 2013; Dash & Singh, Fl. KurungKumey District, Arunachal Pradesh: 506. 2017; Taram et al., in Journal of Threatened Taxa, 12 (17): 17319. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons) 1: 484. 2020.

Occurrence: East Siang, KurungKumey, Lower Subansiri, Papum Pare, Shi Yomi, Upper Siang, Upper Subansiri.

142. ***Rubus rugosus*** Sm. in A.Rees, Cycl. 30: no. 34. 1815; Chauhan et al. in Hajra, Fl. of Namdapha, Arunachal Pradesh: 163. 1996; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 506. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 484. 2020.

Occurrence: East Siang, KurungKumey, West Kameng.

143. ***Rubus sengorensis*** D.G.Long & Grierson, Notes Roy. Bot. Gard. Edinburgh 40: 122. 1982; Dash & Gupta, Blumea 62: 122. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 485. 2020.

Occurrence: West Kameng.

Status: Least Concern (IUCN).

144. ***Rubus sikkimensis*** Hook.f. in Fl. Brit. India 2: 336. 1878. Kumar, Turczaninowia 26 (4): 16-21. 2023.

Occurrence: Tawang.

145. ***Rubus splendidissimus*** H.Hara, J. Jap. Bot. 40: 327. 1965; Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 74. 2015-16; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 485. 2020.

Occurrence: Lower Subansiri, Shi Yomi.

146. ***Rubus sumatranus*** Miq., Fl. Ned. Ind., EersteBijv. 307. 1861; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 443. 1996; Ambrish, Floristic Diversity of Arunachal Pradesh (Upper Subansiri District) 184. 2013; Dash& Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 506. 2017; Taram et al. in Journal of Threatened Taxa, 12 (17): 17319. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist

(Dicotyledons*)* 1: 485. 2020. *Rubus indotibetanus* Koidz., in Fl. Symb. Orient.-Asiat.: 65. 1930; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 439. 1996.

Occurrence: Anjaw, East Siang, KurungKumey, Lower Dibang Valley, Lower Subansiri, Upper Subansiri, West Kameng.

147. ***Rubus thomsonii*** Focke, Abh. Naturwiss. Vereins Bremen 4: 198. 1874; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 485. 2020.

Occurrence: Lower Dibang Valley, Shi Yomi.

148. ***Rubus wallichianus*** Wight & Arn., Prodr. Fl. Ind. Orient. 1: 298. 1834. *Rubus duthieanus* Balakr., in J. Bombay Nat. Hist. Soc. 67: 58. 1970; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 437. 1996.

Occurrence: Lower Subansiri.

149. ***Rubus wardii*** Merr., Brittonia 4: 84. 1941. *Rubus gigantiflorus* H. Hara, J. Jap. Bot. 40: 327. 1965; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 438. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 485. 2020.

Occurrence: Kameng, Lower Subansiri, Shi Yomi.

150. ***Rubus yunanicus*** Kuntze, Meth. Sp.-Beschr. Rubus: 71. 1879; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 507. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 485. 2020.

Occurrence: Kurung Kumey.

151. ***Sibbaldia cuneata*** Edgew. in Trans. Linn. Soc. London 20: 44. 1846; Lidén & Bharali, Symbolae Botanicae Upsalienses 40: 105. 2020; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 486. 2020. *Sibbaldia parviflora* var. *micrantha* (Hook. f.) Dikshit & Panigrahi in Proc. Indian Acad. Sci., Pl. Sci. 90: 264. 1981; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 487. 2020.

Occurrence: West Kameng.

152. ***Sibbaldia cuneifolia*** (Bertol.) Paule & Soják, Čas. Nár. Muz., Rada Přír. 178: 16. 2009. *Potentilla cuneifolia* Bertol. in Misc. Bot. 24: 15. 1863; Dikshit & Panigrahi, The Family Rosaceae in India 4: 67. 1998; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 464. 2020.

153. ***Sorbus foliolosa*** (Wall.) Spach, Hist. Nat. Veg. 2: 96. 1834;Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 444. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 488. 2020.

154. ***Sorbus foliolosa*** var. ***foliolosa***

*Pyrus wenzigiana* (C.K.Scheid.) Bennet & Raizada in Indian J. Forest. 4: 68. 1981; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 433. 1996.

Occurrence: Anjaw.

Status: Least Concern (IUCN).

155. ***Sorbus himalaica*** Gabrieljan, Bot. Zhurn. (Moscow & Leningrad) 56(5): 658. 1971; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 508. 2017.

Occurrence: Kurung Kumey.

156. ***Sorbus insignis*** (Hook.f.) Hedl., Kongl. Svenska Vetensk. Acad. Handl., n. f., 35 (1): 32. 1901; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 444. 1996; Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 77.2015-16.

Occurrence: Kameng, Shi Yomi.

Status: Least Concern (IUCN).

157. ***Sorbus kurzii*** (G.Watt ex Prain) C. K. Schneid., Bull. Herb. Boiss. ser. 2, 6: 315. 1906; Dash & Singh, Fl. KurungKumey District, Arunachal Pradesh: 509. 2017.

Occurrence: Kurung Kumey.

158. ***Sorbus microphylla*** Wenz., in Linnaea 38: 76. 1873; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 444. 1996; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 509. 2017; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 489. 2020.

Occurrence*:* Anjaw, Kameng, Lohit, Kurung Kumey, West Kameng.

Status*:* Least Concern (IUCN).

159. ***Sorbus rufopilosa*** C.K.Schneid., Bull. Herb. Boiss. Ser. 2, 6: 317. 1906; Dash & Singh, Fl. Kurung Kumey District, Arunachal Pradesh: 509. 2017.

Occurrence: Kurung Kumey.

Status*:* Least Concern (IUCN).

160. ***Sorbus ursina*** (Wall. ex G.Don) S.Schauer in Ubers. Arbeiten Verand. Schles. Ges. Vaterl. Cult. 1847: 292. 1848; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 489. 2020.

161. ***Sorbus wallichii*** (Hook.f.) T.T.Yu in Fl. Reipubl. Popularis Sin. 36: 329. 1974; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 445. 1996; Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 77.2015-16; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 489. 2020.

Occurrence: Anjaw, Kameng, Subansiri, Shi Yomi.

Status*:* Least Concern (IUCN).

162. ***Sorbus wilsoniana*** C.K.Schneid., Bull. Herb. Boissier, ser. 2, 6: 312. 1906; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons*)* 1: 489. 2020.*Pyrus expansa* (Koehne) Bennet in Indian J. Forest. 4: 68. 1981; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 432. 1996.

Status: Least Concern (IUCN).

163. ***Spiraea arcuata*** Hook.f., Fl. Brit. India 2: 325. 1878; Purohit & Panigrahi, The Family Rosaceae in India 1: 100. 1991; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 445. 1996.

Occurrence*:* Kameng, Tawang.

164. ***Spiraea bella*** Sims in Bot. Mag. 50: t. 2426. 1823; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 490. 2020.

165. ***Spiraea bella*** var. ***bella***

Status*:* Least Concern (IUCN).

166. ***Spiraea canescens*** D.Don, Prodr. Fl. Nepal. 227. 1825; Purohit & Panigrahi, The Family Rosaceae in India 1: 64. 1991; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 447. 1996.

Occurrence*:* West Kameng.

Status*:* Least Concern (IUCN).

167. ***Spiraea cantoniensis*** Lour., Fl. Cochinch.: 322. 1790; Purohit & Panigrahi, The Family Rosaceae in India 1: 64. 1991; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 447. 1996.

Occurrence*:* Tawang.

Status*:* Least Concern (IUCN).

168. ***Spiraea expansa*** Wall. ex K.Koch, Index Seminum (B, Berolinensis) 1853(App.): 12. 1853. *Spiraea arunachalensis* Panigrahi & K. M. Purohit in Bull. Bot. Surv. India 26 (1-2): 83. 1985; Purohit &Panigrahi, The Family Rosaceae in India 1: 59. 1991; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 445. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 490. 2020.

Occurrence:Kameng.

169. ***Spiraea japonica*** L.f., Suppl. Pl.: 262. 1782; Bhuyan, L. R., Pangu, Y. & Tam, N, Bull. Arunachal Forest Research, 30 & 31 (1&2), 74. 2015-16.

170. ***Spiraea japonica*** var. ***japonica***

*Spiraea callosa* Thunb. in J. A. Murray (ed.), Syst. Veg., ed. 14.: 471. 1784; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 445. 1996.

Occurrence:West Kameng.

171. ***Spiraea micrantha*** Hook.f., Fl. Brit. India 2: 325. 1878; Purohit & Panigrahi, The Family Rosaceae in India 1: 77. 1991; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 447. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 491. 2020.

Occurrence: West Kameng.

172. ***Spiraea robusta*** Hand. Mazz., Symb. Sin. 7: 453. 1933; Purohit & Panigrahi, The Family Rosaceae in India 1: 85. 1991; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 492. 2020.

173. ***Spiraea subdioica*** Purohit & Panigrahi in Bull. Bot. Surv. India 26 (1-2): 86. 1985; Purohit & Panigrahi, The Family Rosaceae in India 1: 87. 1991; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 447. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 492. 2020.

Occurrence*:* West Kameng.

Note: Endemic to Arunachal Pradesh.

174. ***Spiraea vacciniifolia*** D.Don, Prodr. Fl. Nepal. 227. 1825 as '*vacciniafolia*'; Purohit & Panigrahi, The Family Rosaceae in India 1: 92. 1991; Chowdhery et al. in Hajra et al., Mat. Fl. Arunachal Pradesh 1: 448. 1996; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 492. 2020.

Occurrence: Kameng.

175. ***Thomsonaria corymbifera*** (Miq.) Rushforth, Phytologia 100: 239. 2018. *Sorbus corymbifera* (Miq.) T. H. Nguyen & Yakovlev, Bot. Zhurn. (Moscow & Leningrad) 66: 1188. 1981; Dash & Singh, Fl. KurungKumey District, Arunachal Pradesh: 508. 2017.

Occurrence: Kurung Kumey.


Image 1. A—*Argentina peduncularis* (D.Don) Soják | B—*Cotoneaster acuminatus* Lindl. | C—*Fragaria daltoniana* J.Gay | D—*Malus indica* (Wall.) B.B.Liu | E—*Neillia thyrsiflora* D.Don | F—*Potentilla sundaica* (Blume) W.Theob. | G—*Prunus cerasoides* Buch.-Ham. ex D.Don | H—*Pyrus pashia* Buch.-Ham. ex D.Don | I—*Photinia integrifolia* Lindl. | J—*Rosa omeiensis* Rolfe | K—*Sorbus foliolosa* (Wall.) Spach | L—*Spiraea micrantha* Hook.f. © Pinaki Adhikary.

**Image 2.** A—*Rubus lucens* Focke | B—*Rubus insignis* Hook.f. | C—*Rubus paniculatus* Sm. | D—*Rubus sumatranus* Miq.| E—*Rubus rosifolius* Sm. | F—*Rubus ellipticus* Sm. | G—*Rubus niveus* Thunb. | H—*Rubus opulifolius* Bertol. | I—*Rubus lineatus* Reinw. ex Blume, | J—*Rubus macilentus* Cambess. | K—*Rubus calycinus* Wall. ex D.Don | L—*Rubus cooperi* D.G.Long. © Pinaki Adhikary.

176. ***Thomsonaria granulosa*** (Bertol.) Rushforth, Phytologia 100(4): 239. 2018; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons) 1: 492. 2020.

177. ***Thomsonaria thomsonii*** (King ex Hook.f.) Rushforth, Phytologia 100(4): 237. 2018; Dash in Mao et al., Flowering Plants of India: An Annotated Checklist (Dicotyledons)1: 492. 2020.

Occurrence: West Kameng

**DISCUSSION**

The present study revealed the occurrence of a total 158 species under 27 genera of Rosaceae from the state of Arunachal Pradesh. However, Halder et al. (2024) in their floristic revisionary work reported the occurrence of 137 species of Rosaceae in the state. In this study, 21 species have been added to the list. After critical scrutiny of the available literature, it is found that out of 158 species, *Rubus ghanakantae, Rubus hapoliensis, Rubus ramachandrae,* and *Spiraea subdioica* are found as endemic only to the state. The occurrence of the three taxa namely *Rubus niveus* var. *micranthus*, *Rubus alpestris*, and *Potentilla fulgens* have been reported as new distribution records for the state of Arunachal Pradesh through the scrutiny of the herbarium specimens as the available literature did not include these taxa. The richness of the species diversity is directly influenced by the diversified climatic conditions and availability of the preferred habitats. The temperate, subalpine, and alpine forests prevailing throughout the state with normally cold and low temperature provide the best conditions for the luxuriant growth and adaptation of the species. The genus *Rubus* was reported to be the most dominant one with more than 49 species representing almost 30% of the total species. The study of Ansari (2014) also revealed the rich species diversity of the family particularly the genus *Rubus* from Sikkim Himalaya. The rich taxonomic diversity and distribution of the Rosaceae in the state with domination of the genera like *Potentilla, Fragaria, Rubus, Malus,* and *Prunus* are also reported in the earlier works (Panigrahi & Joseph 1966; Chauhan et al. 1996; Chowdhery et al. 1996).

In our study, it is also found that botanical names used as accepted species name in the earlier floristic works like Flora of Arunachal Pradesh (Chowdhery et al. 1996), Flora of Namdapha (Chauhan et al. 1996), Flora of Kurung Kumey District (Dash & Singh 2017), and Flora of Lower Subansiri District (Pal 2013) are found now as synonyms. The names such as *Potentilla leuconota, Potentilla lineata, Potentilla microphylla, Cotoneaster bacillaris, Sorbus cuspidata, Docynia indica, Photinia cuspidata, Potentilla khasiana, Rubus kurzii*, *Rubus indotibetanus, Rubus duthieanus, Rubus gigantiflorus*, *Pyrus expansa, Spiraea arunachalensis*, *Sorbus corymbifera* documented in Flora of Arunachal Pradesh are now confirmed as synonyms.

**CONCLUSION**

The Himalayan state of Arunachal Pradesh is one of the main region of the Indian species diversity of the Rosaceae. The checklist prepared through this study will be helpful to understand the species richness and biogeographic patterns of Rosaceae in the state. The data of distribution and occurrence of the species will facilitate the development of evidence-based plans and practical conservation frameworks to protect the diversity of Rosaceae species in the state. The findings of this study will also provide essential baseline information to support conservation strategies and sustainable utilization of resources. Moreover, the data accumulated through this study hold significant potential to inform future research and development initiatives. However, the complete taxonomic and ecological data to support proper identification and understanding the population status of species would be more valuable for the utilization and conservation of the species.

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ARTICLE

# Restoring biodiversity: case studies from two sacred groves of Kozhikode District, Kerala, India

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**Abstract:** Floristic studies were conducted at Mannur Shiva Temple (MST) and Vadayil Kavu (VDK), two eco-restoration sites (*Pachathuruthu*) established by the Haritha Keralam Mission of the Government of Kerala in the sacred groves of Kadalundi Grama Panchayath, Kozhikode District, Kerala, India. A total of 171 plant species were identified from both the study areas, of which 41 were found in both sites. Most of these plants were Indo-Malesian in distribution. Tropical American or Pantropical distribution came in second and third. There were 45 medicinal plants and 25 endemics in MST, compared to 49 medicinal plants and nine endemics in VDK. About 25 species reported from MST, and 17 from VDK were not represented in the published Flora of Calicut. All these indicate the conservation importance of the area. The importance of conducting comprehensive biodiversity research, continuous monitoring, need for maintenance, and expansion of these eco-restoration zones, and the conservation value of such "Pachathuruthu" are also discussed.

**Keywords**: Conservation, eco-restoration sites, floristic studies, Haritha Keralam Mission, Kadalundi, Mannur Shiva Temple, Pachathuruthu, Vadayil Kavu.

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## INTRODUCTION

Biodiversity is important for a variety of reasons, including enhancing the aesthetic value of the natural environment and advancing our material well-being through utilitarian values by supplying food, fuel, fodder, lumber, medicine, and other resources (Rawat & Agarwal 2015). Effective conservation of biodiversity is essential to the survival of humans and environmental processes (Paoli et al. 2010). Due to human activity, thousands of species are in danger of becoming extinct. Future population growth and economic prosperity are expected to push extinction to previously unheard-of levels (Tilman et al. 2017). Future extinction rates will be ten times higher than present rates if every species currently classified as threatened goes extinct during the next century (Pimm et al. 1995). In this context, ecological restoration is becoming increasingly popular worldwide.

### Ecological Restoration and The 'Pachathuruthu' Project of Kerala State

The UN General Assembly in New York announced in 2019, that the years 2021–2030 will be known as the "UN Decade on Ecosystem Restoration" (Waltham et al. 2020; Singh et al. 2021). The goal of this call to action is to raise awareness of the urgent need to combat climate change, restore damaged ecosystems worldwide at a dramatically accelerated pace, improve food security, ensure clean water, and safeguard the planet's biodiversity. The Haritha Keralam Mission formed by the Kerala Government has also launched an ecological restoration initiative known as 'Pachathuruthu' which translates to 'Green Islands' (In Malayalam: Pacha = green, thuruthu = island).

In addition to creating and maintaining natural biodiversity groves by incorporating distinctive trees and native flora, the Pachathuruthu project seeks to identify and preserve arid areas, especially those found in public spaces. It is implemented with the cooperation of local self-governing bodies, several government funded schemes, various government departments, environmental organizations, educational institutions, and people's representatives.

This project is planned to be implemented in 500 acres of land spread across 250 village panchayats. Saplings of indigenous trees and plants are planted in fallow lands and vacant spots available in public places, which are identified by the local bodies (Seema 2019, 2020). According to government records, a total of 3,551 Pachathuruthu have been established across the State of Kerala by November 2024, covering about 1,073 acres of land to date (https://nkp.kerala.gov.in, https://haritham.kerala.gov.in).

In Kozhikode District, there are 224 Pachathuruthu which are spread over a total area of 54.92 acres (2,22,253 $m^2$). Among these, there are big Pachathuruthu areas such as Navodaya Vidyalayam (Maniyoor), Devaharitham 1 (Kodiyathur), Devaharitham 2 (Mavooor), and Kallikkunnu (Kozhikode corporation) which have an area of 200 cents (~8,100 $m^2$) to small areas such as Ormmathuruth (Valayam), Payimbra school (Kuruvattoor), and Makkootam (Kunnamangalam) which have only one cent (40.5 $m^2$) area. Some of these conservation areas are located in well protected sacred groves, which are patches of forests preserved by communities as sanctified natural spaces, often associated with spiritual beliefs and cultural traditions (Seema 2020). After the establishment of various Pachathuruthu areas in Kerala (mostly in 2019), only a single survey was conducted to evaluate their status. In Kozhikode District, this survey was conducted in February 2021 during the COVID period by the author himself, as per the request of the Haritha Keralam Mission. Since it was summer, the majority of the herbaceous and other ephemeral plants were either in the dried or dead condition. Hence, a comprehensive picture of the biodiversity was lacking in the report published after the survey by the Government of Kerala (Seema 2022).

It was in this context, this study was planned to cover both the monsoon and winter seasons, so that the paucity of the information is resolved. Moreover, this study conducted in two sacred groves where eco-restoration is done, will help to bring out the biodiversity potential of these areas. If such studies are carried out in all the Pachathuruthu areas of the state, they will yield good information on these ecorestoration areas, thereby helping the authorities to plan environmentally sustainable policies and programmes for their conservation and management.

### Study Area

Both the Pachathuruthu areas where the studies were conducted are located in the Kadalundi Gram Panchayat of Kozhikode District, Kerala State, India. The panchayat is situated in a coastal zone, facing the Arabian Sea on the west and Kadalundi River on the south. It has an area of 11.83 $km^2$. According to the 2011 census, the population of the panchayat is 42,516 (Ref: https://dop.lsgkerala.gov.in).

**Mannur Siva Temple Pachathuruthu (Image 1)**

Established on 25 September 2019, it consists of 20 cents of land and is situated in the Ward – 6 (Vadakkumbad ward) of the Panchayat. The site is located at the entrance of the Mannur Shiva temple, on its left side (Image 1). This old and beautiful Shiva temple is very unique in its shape, having a sanctum sanctorum in the shape of the backside of an elephant. It is about 5 km away from the Feroke railway station and 18 km away from Karippur International Airport. It is located at an altitude of 11.58 m in the geo-cordinates of $11.152^{o}$ N & $75.833^{o}$ E.

About 55 seedlings of different species were planted here during 2019, at the time of its establishment. During the survey conducted by the author on 13 February 2021, a total of 37 species which included two herbs, six shrubs, three climbers, and 26 trees could be enumerated (Seema 2022).

**Vadayil Kavu Pachathuruthu (Image 2)**

The Pachathuruthu, which consists of 50 cents of land was established on 07 September 2020 and is situated in the Ward – 14 (Kadalundi East) of the panchayat. It is situated on the premises of the Vadayilkavu Bhagavathy temple, less than 1 km away from the Kadalundi Railway gate. Towards the south, it is bordered by the Kadalundi River with a lot of mangrove species growing in the borders. It is located at an altitude of 11.52 m in the geo-cordinates of $11.132^{0}$N & $75.830^{0}$E. During monsoon, the area near the shores remain flooded.

Approximately 180 seedlings of various species were planted in this area in 2020 as part of an active restoration effort, but many failed to establish due to saltwater intrusion. During the survey conducted by the author on 13 February 2021, a total of 22 species which included four herbs, two shrubs, one climber, and 15 trees were enumerated (Seema 2022).

## MATERIALS AND METHODS

Several field trips were conducted to both the study areas, especially during the monsoon and winter seasons of 2022–2023 to enumerate the ephemerals and

Image 1. Mannur Siva Temple Pachathuruthu – location photos. © K. Kishore Kumar.

Image 2. Vadayil Kavu Pachathuruthu – location photos. © K. Kishore Kumar.

annuals (a tree survey during summer was conducted in 2021 also). The Haritha Keralam Mission authorities and ward members were interviewed to learn the history of the locality and to collect other relevant information regarding the planting activities done in the area. The plants were identified using the floras by Manilal & Sivarajan (1982), Sasidharan (2004), and Gamble & Fischer (1915–1936); their world distribution statuses were collected from the websites such as powo.science.kew.org, keralaplants.in, eflorakerala.com and indiabiodiversity.org. The threatened and endemic plants were evaluated using publications such as Henry et al. (1979), Ahmedulla & Nayar (1987), Basha & Nair (1991), Karunakaran et al. (1991), and online information systems like Environmental Information System (ENVIS). The medicinal plants were analyzed using Neshamani (1985) and Sasidharan (2011).

## RESULTS AND DISCUSSION

Altogether a total of 171 species of angiosperms, one gymnosperm, and seven pteridophytes were enumerated from both the study areas (Table 1). The species are tabulated in the alphabetical order of family and species names, and their presence in the study areas is indicated by an asterisk (*) mark. The phenology and world distribution of the species is also provided. The study areas, Mannur Siva Temple Pachathuruthu and Vadayil Kavu Pachathuruthu are abbreviated as MST and VDK respectively. Other abbreviations used in the table are H—Herb, S—Shrub, T—Tree, C—Climber, M—Medicinal, E—Endemic, TTY – Throughout the year, MST—Mannur Siva Temple Pachathuruthu, and VDK—Vadayil Kavu Pachathuruthu.

### Habit and Family Status

At Mannur Siva Temple Pachathuruthu (MST), 59 species of herbs, 18 shrubs, 15 climbers, and 34 small or medium trees could be enumerated. At the same time, at Vadayil Kavu Pachathuruthu (VDK), there were 36 species of herbs, 11 shrubs, 10 climbers, and 29 small or medium trees.

At MST, there were 126 flowering plant species, which belonged to 118 genera under 52 families. There were 105 dicots and 21 monocots. The most dominant dicot family was Fabaceae, represented by 12 species, followed by Asteraceae (11), Poaceae (10), and Euphorbiaceae (7), while the most dominant genera were *Lindernia*, *Blumea, Dioscorea, Leucas, Phyllanthus, Spermacoce,* and *Terminalia*. Among the monocots, there were eight families, the dominant ones being Poaceae (10 spp.), Araceae (3 spp.), and Commelinaceae (2 spp.). There were five pteridophyte species and one gymnosperm species (*Cycas circinalis*) also.

At VDK, 86 flowering plant species (61 dicots and 25 monocots) could be enumerated, which belonged to 81 genera under 37 families. The most dominant family was Poaceae, represented by 12 species, followed by Fabaceae (9), Asteraceae (7), and Euphorbiaceae (4), while the most dominant genera were *Terminalia*, *Clerodendrum, Cyperus* and *Eragrostis*. Two pteridophyte species (*Stenochlaena palustri* and *Acrostichum aureum*) could also be enumerated.

### Distributional Status of The Species and Endemism

At MST, the majority of the plants studied exhibited Indo-Malesian distribution (25 nos. / 20% of the total). Sixteen species (12.7%) had tropical American distribution and 13 (10.3%) species showed pantropical distribution.

At VDK also, the majority of the plants exhibited Indo-Malesian distribution (20 nos. / 23% of the total). Ten species (11.6%) had pantropical distribution and eight (9.3%) species showed tropical American distribution. For details see Tables 1 & 2.

At MST, out of the total 126 species, 25 were endemics. Three species were endemic to India (*Dipteracanthus prostratus, Dioscorea alata*, & *Olea dioica*), while seven species had an extended distribution to Sri Lanka. About six species had distribution extending from Peninsular India to Sri Lanka. While four species had distribution restricted to the Western Ghats, another three endemic species were found only in the southern Western Ghats region.

At VDK, out of the total 86 species, nine were endemics. One species was found endemic to India (*Olea dioica*), while six species had an extended distribution to Sri Lanka. The wild orchid *Bulbophyllum sterile* is a peninsular Indian endemic, while the poisonous tree *Holigarna arnottiana* is a narrow endemic, found only in the southern Western Ghats region (Ahmedullah & Nayar 1987). For details see Tables 1 & 2.

Upon comparing the list of the collected species with Manilal & Sivarajan (1982), it was found that 25 species enumerated from MST were not reported in it. Similarly, 17 species enumerated from VDK were also not represented in the flora (Table 1). These species would have been remained overlooked in this study, or may be recenty introduced to this areas.

**Table 1. Details regarding the flora of Mannur Siva Temple and Vadayil Kavu Pachathuruthus.**

**A. ANGIOSPERMS**

| | Scientific name | Habit | Family | Flowering & Fruiting | World distribution | MST | VDK | Remarks |
|---|---|---|---|---|---|---|---|---|
| 1 | *Acanthus ilicifolius* | S | Acanthaceae | Dec–Jul | Indo-Malesia and Australia | | * | |
| 2 | *Andrographis paniculata* | H | Acanthaceae | Mar–Dec | Peninsular India and Sri Lanka | * | | M, E |
| 3 | *Asystasia dalzelliana* | H | Acanthaceae | Sep–Jan | Tropical Asia and Africa | * | * | |
| 4 | *Dipterocanthus prostratus* | H | Acanthaceae | Oct–Apr | India | * | | E |
| 5 | *Justicia procumbens* | H | Acanthaceae | Jun–Dec | Indo-Malesia and Australia | * | * | NR |
| 6 | *Rhinacanthus nasutus* | S | Acanthaceae | Nov–Feb | India, Sri Lanka, Java, and Madagascar | * | | M |
| 7 | *Achyranthes aspera* | H | Amaranthaceae | Oct–Mar | Pantropical | * | | M |
| 8 | *Alternanthera bettzickiana* | H | Amaranthaceae | Oct–Feb | Native of tropical America; now invasive in Asia | * | * | NR |
| 9 | *Pancratium triflorum* | H | Amaryllidaceae | Mar–May | India and Sri Lanka | * | | M, E |
| 10 | *Anacardium occidentale* | T | Anacardiaceae | Nov–Apr | Native of South America; now widely cultivated in Asia and Africa | * | | M |
| 11 | *Holigarna arnottiana* | T | Anacardiaceae | Jan–Jul | Southern Western Ghats | * | * | M, E |
| 12 | *Alstonia scholaris* | T | Apocynaceae | Oct–Feb | Southern and southeastern Asia to Australia | * | | M |
| 13 | *Cerbera odollam* | T | Apocynaceae | Jul–Nov | Indo-Malesia | | * | M |
| 14 | *Ichnocarpus frutescens* | C | Apocynaceae | Aug–Mar | Indo-Malesia and Australia | * | * | M |
| 15 | *Tabernaemontana divaricata* | S | Apocynaceae | TTY | Native of southern Himalaya | * | | |
| 16 | *Thevetia peruviana* | S | Apocynaceae | TTY | Native of tropical Peru, widely invasive | * | | |
| 17 | *Arisaema leschenaultii* | H | Araceae | Jul–Sep | Southern Western Ghats | * | | M, E, NR |
| 18 | *Colocasia esculenta* | H | Araceae | May–Oct | Pantropical | * | * | M |
| 19 | *Pothos scandens* | C | Araceae | Oct–Nov | India to Malesia and Madagascar | * | * | |
| 20 | *Areca catechu* | T | Arecaceae | TTY | Cultivated from India to the Solomon Islands and less commonly in Africa and tropical America | | * | M |
| 21 | *Caryota urens* | T | Arecaceae | Jan–Apr | Indo-Malesia | * | | |
| 22 | *Cocos nucifera* | T | Arecaceae | TTY | Cultivated throughout the tropic, | | * | M |
| 23 | *Ageratum conyzoides* | H | Asteraceae | Aug–Dec | Pantropical | * | * | M |
| 24 | *Blumea axillaris* | H | Asteraceae | Jan–Nov | Indo-Malesia to Australia and Africa | * | | |
| 25 | *Blumea oxyodonta* | H | Asteraceae | Oct–May | Indo-Malesia and southern China | * | | |
| 26 | *Chromolaena odorata* | S | Asteraceae | Nov–May | Native of America; naturalised in Tropical Asia | * | | |
| 27 | *Eclipta prostrata* | H | Asteraceae | TTY | Pantropical | * | * | M |
| 28 | *Elephantopus scaber* | H | Asteraceae | Jan–Oct | Pantropical | * | * | M |
| 29 | *Eleutheranthera ruderalis* | H | Asteraceae | May–Nov | Native of tropical America; now established in several Asian countries | | * | NR |
| 30 | *Emilia sonchifolia* | H | Asteraceae | Jul–Dec | Tropical and subtropical Africa and Asia | * | | M |
| 31 | *Sphaeranthus indicus* | H | Asteraceae | Jan–Apr | Indo-Malesia, Australia, and Africa | * | | M |
| 32 | *Synedrella nodiflora* | H | Asteraceae | TTY | Native of West Indies | * | | |
| 33 | *Tridax procumbens* | H | Asteraceae | TTY | Native of tropical America; now widespread throughout tropics and subtropics | * | * | |
| 34 | *Vernonia cinerea* | H | Asteraceae | TTY | Pantropics | * | * | M |
| 35 | *Sphagneticola trilobata* | H | Asteraceae | Jun–Sep | Native of tropical America | | * | NR |
| 36 | *Avicennia officinalis* | T | Avicenniaceae | Apr–Nov | Indo-Malesia to Pacific Oceans | | * | M |
| 37 | *Impatiens flaccida* | H | Balsaminaceae | Jul–Oct | Southern India and Sri Lanka | * | | E |
| 38 | *Tecoma stans* | S | Bignoniaceae | Dec–Apr | Native of South America; now widely cultivated | * | | |
| 39 | *Cleome burmannii* | H | Capparaceae | Feb–Aug | Indo-Malesia | * | | |

| | Scientific name | Habit | Family | Flowering & Fruiting | World distribution | MST | VDK | Remarks |
|---|---|---|---|---|---|---|---|---|
| 40 | *Carica papaya* | T | Caricaceae | TTY | Native of Tropical America cultivated in the topics and subtropics | * | * | M |
| 41 | *Calycopteris floribunda* | C | Combretaceae | Jan–May | Indo-Malesia | * | | M |
| 42 | *Terminalia bellirica* | T | Combretaceae | Dec–Jan | Indo-Malesia | * | * | M |
| 43 | *Terminalia catappa* | T | Combretaceae | Mar–Jan | Malaysia to northern Australia and in the tropic | | * | |
| 44 | *Terminalia chebula* | T | Combretaceae | Feb–Aug | South Asia | | * | M, NR |
| 45 | *Terminalia cuneata* | T | Combretaceae | Nov–Jun | India and Sri Lanka | * | | M, E, NR |
| 46 | *Commelina paludosa* | H | Commelinaceae | Nov–Dec | Himalaya and India | * | | NR |
| 47 | *Cyanotis arachnoidea* | H | Commelinaceae | Aug–Nov | Peninsular India and Sri Lanka | * | | E, NR |
| 48 | *Connarus wightii* | S | Connaraceae | Mar–May | Western Ghats | * | | E, NR |
| 49 | *Costus speciosus* | H | Costaceae | Jul–Oct | Indo-Malesia | * | * | M |
| 50 | *Cyperus iria* | H | Cyperaceae | Nov–Dec | Tropical Asia and eastern Africa; introduced in U.S.A and West Indies | * | * | |
| 51 | *Cyperus tenuispica* | H | Cyperaceae | TTY | Tropical and subtropical Africa and Asia | | * | |
| 52 | *Fimbristylis dichotoma* | H | Cyperaceae | Mar –Dec | Pantropical | | * | |
| 53 | *Kyllinga nemoralis* | H | Cyperaceae | Jul–Nov | Pantropical | * | | M |
| 54 | *Dioscorea alata* | C | Dioscoreaceae | TTY | India | * | | M, E, NR |
| 55 | *Dioscorea bulbifera* | C | Dioscoreaceae | Sep–Oct | Paleotropics | * | | M |
| 56 | *Dioscorea spicata* | C | Dioscoreaceae | Aug–Dec | India and Sri Lanka | | * | E, NR |
| 57 | *Elaeocarpus serratus* | T | Elaeocarpaceae | Apr–Sep | Indo-Malesia | * | | NR |
| 58 | *Antidesma montanum* | T | Euphorbiaceae | Jan–Dec | Indo-Malesia and eastern Himalaya | * | * | |
| 59 | *Briedelia retusa* | T | Euphorbiaceae | Aug–Dec | Indo-Malaya | * | | |
| 60 | *Euphorbia hirta* | H | Euphorbiaceae | TTY | Native of tropical America; now pantropical | | * | M |
| 61 | *Macaranga peltata* | T | Euphorbiaceae | Jan–Feb | India, Sri Lanka and Andamans | * | * | M |
| 62 | *Mallotus philippensis* | T | Euphorbiaceae | Oct–Mar | Indo-Malesia and Australia | * | | M |
| 63 | *Microstachys chamaelea* | H | Euphorbiaceae | Jul–Dec | Indo-Malesia to Australia | * | | M, NR |
| 64 | *Phyllanthus emblica* | T | Euphorbiaceae | Jul–Feb | Throughout the tropics | * | | M |
| 65 | *Phyllanthus urinaria* | H | Euphorbiaceae | Jul–Oct | Native of tropical eastern Asia; now a circumtropical weed | * | | M |
| 66 | *Tragia involucrata* | H | Euphorbiaceae | Jul–Dec | India and Sri Lanka | | * | M, E |
| 67 | *Saraca asoca* | T | Fabaceae | Feb–Aug | India and Myanmar | * | | |
| 68 | *Bauhinia variegata* | T | Fabaceae | Sep–May | Possibly native of China; wild in sub Himalaya and India | * | | NR |
| 69 | *Cassia fistula* | T | Fabaceae | Feb–Sep | Indo-Malesia | * | * | M |
| 70 | *Saraca asoca* | T | Fabaceae | Feb–Aug | India and Myanmar | | * | M |
| 71 | *Abrus precatorius* | C | Fabaceae | Oct–May | Pantropical | | * | M NR |
| 72 | *Centrosema molle* | C | Fabaceae | Sep–Jan | Native of America, indroduced in India | * | | |
| 73 | *Dalbergia latifolia* | T | Fabaceae | Aug–Sep | Indo-Malesia | | * | NR |
| 74 | *Derris trifoliata* | C | Fabaceae | Jan–Oct | Paleotropic | | * | M |
| 75 | *Desmodium triflorum* | H | Fabaceae | Jul–Dec | Indo-Malesia and Australia | * | | M |
| 76 | *Galactia tenuiflora* | C | Fabaceae | Oct–Feb | Indo-Malesia, Australia, and Africa | * | | NR |
| 77 | *Gliricidia sepium* | T | Fabaceae | Mar–May | Native of South America; Introduced and now widely grown in India | * | | |
| 78 | *Pongamia pinnata* | T | Fabaceae | Apr–Dec | Indo-Malesia | * | * | M |
| 79 | *Pterocarpus marsupium* | T | Fabaceae | Sep–Oct | India and Sri Lanka | * | * | M, E, NR |
| 80 | *Vigna umbellata* | C | Fabaceae | Oct–Dec | Indo-Malesia | * | | NR |
| 81 | *Adenanthera pavonina* | T | Fabaceae | Jan–Sep | Sri Lanka, North East India, Myanmar, China Thailand and Malesia | * | * | |

| | Scientific name | Habit | Family | Flowering & Fruiting | World distribution | MST | VDK | Remarks |
|---|---|---|---|---|---|---|---|---|
| 82 | *Mimosa pudica* | H | Fabaceae | Jul–Jan | Native of South America; now Pantropical | * | * | M |
| 83 | *Canscora pauciflora* | H | Gentianaceae | Oct–Nov | Endemic to Western ghats | * | | M, E |
| 84 | *Rhynchoglossum notonianum* | H | Gesneriaceae | Jul–Dec | South West India and Sri Lanka | * | | E |
| 85 | *Curculigo orchioides* | H | Hypoxidaceae | Jun–Dec | Indo-Malesia | | * | M |
| 86 | *Hyptis suaveolens* | S | Lamiaceae | Aug–Feb | Originally from America now Pantropical | * | | |
| 87 | *Leucas aspera* | H | Lamiaceae | Sep–Jan | Indo-Malesia | * | | M |
| 88 | *Leucas lavandulifolia* | H | Lamiaceae | Jul–Oct | Indo-Malesia and East Asia | * | | M, NR |
| 89 | *Ocimum tenuiiflorum* | S | Lamiaceae | TTY | Palaeotropic | * | * | M |
| 90 | *Platostoma hispidum* | H | Lamiaceae | Sep–Dec | Indo-Malesia | * | | |
| 91 | *Pogostemon atropurpureus* | S | Lamiaceae | Feb–May | Southern Western Ghats | * | | M, E, NR |
| 92 | *Careya arborea* | T | Lecythidaceae | Feb–Jul | Tropical Areas | * | | M |
| 93 | *Asparagus racemosus* | C | Liliaceae | Jul–Aug | Paleotropical | | * | M |
| 94 | *Gloriosa superba* | C | Liliaceae | Jul–Dec | Paleotropical | | * | M |
| 95 | *Hugonia mystax* | C | Linaceae | Aug–Oct | India and Sri Lanka | * | | M, E |
| 96 | *Strychnos nux-vomica* | T | Loganiaceae | Mar–Dec | Indo-Malesia | | * | M |
| 97 | *Lagerstroemia speciosa* | T | Lythraceae | Mar–Nov | Indo-Malesia | * | | M |
| 98 | *Hibiscus rosa-sinensis* | S | Malvaceae | TTY | Native of Pacific Islands; cultivated in tropical and subtropical countries | * | * | M |
| 99 | *Malvaviscus penduliflorus* | S | Malvaceae | TTY | Native of tropical America | * | | |
| 100 | *Sida cordata* | H | Malvaceae | Jan–Apr | Pantropical | * | | M |
| 101 | *Thespesia populnea* | T | Malvaceae | Mar–Jun | Pantropical | | * | M |
| 102 | *Azadirachta indica* | T | Meliaceae | Feb–Sep | Indo-Malesia | * | | M |
| 103 | *Swietenia macrophylla* | T | Meliaceae | Apr–Mar | Native of Central America | | * | NR |
| 104 | *Anamirta cocculus* | C | Menispermaceae | Aug–Dec | Indo-Malesia | * | * | M |
| 105 | *Cyclea peltata* | C | Menispermaceae | Apr–May | India and Sri Lanka | * | | M, E |
| 106 | *Tiliacora acuminata* | C | Menispermaceae | Apr–Dec | India, Sri Lanka, and southeastern Asia | | * | M |
| 107 | *Artocarpus heterophyllus* | T | Moraceae | Nov–Apr | Widely cultivated in the tropics, origin probably southern India | * | | |
| 108 | *Artocarpus incisus* | T | Moraceae | Jan–Jun | Native of Pacific Islands | | * | |
| 109 | *Ficus religiosa* | T | Moraceae | Nov–Feb | Eastern Himalaya; invasive in India and neighbouring countries | * | * | M |
| 110 | *Musa paradisiaca* | H | Musaceae | TTY | Cultivated throughout the tropic | | * | M |
| 111 | *Syzygium cumini* | T | Myrtaceae | Dec–Apr | Indo-Malesia | * | * | M |
| 112 | *Jasminum angustifolium* | C | Oleaceae | Nov–Mar | Peninsular India and Sri Lanka | | * | M, E |
| 113 | *Jasminum malabaricum* | S | Oleaceae | Mar–Nov | Western Ghats | * | | E |
| 114 | *Olea dioica* | T | Oleaceae | Nov–Apr | India | * | * | M, E |
| 115 | *Cansjera rheedei* | C | Opiliaceae | Nov–Feb | India through Malaya to Hong Kong and North Australia | * | | |
| 116 | *Bulbophyllum sterile* | H | Orchidaceae | Dec –Jan | Peninsular India | | * | E, NR |
| 117 | *Vanda testacea* | H | Orchidaceae | Apr–May | India, Myanmar, and Sri Lanka | * | | M, NR |
| 118 | *Biophytum sensitivum* | H | Oxalidaceae | Feb–Sep | Peninsular India and Sri Lanka | * | | M, NR |
| 119 | *Peperomia pellucida* | H | Piperaceae | Sep–Dec | Native of tropical America; now Pantropical | * | | |
| 120 | *Piper nigrum* | C | Piperaceae | Jul–Mar | Peninsular India and Sri Lanka | | * | M, E |
| 121 | *Alloteropsis cimicina* | H | Poaceae | Jul–Nov | Paleotropical | | * | |
| 122 | *Axonopus compressus* | H | Poaceae | TTY | Tropics and subtropics | * | | NR |
| 123 | *Bambusa bambos* | S | Poaceae | Jul–Feb | India and Sri Lanka | * | | M, E |
| 124 | *Brachiaria miliiformis* | H | Poaceae | Jul–Oct | Indo-Malesia | | * | NR |

| | Scientific name | Habit | Family | Flowering & Fruiting | World distribution | MST | VDK | Remarks |
|---|---|---|---|---|---|---|---|---|
| 125 | *Cynodon dactylon* | H | Poaceae | Mar–Oct | Tropical and warm temperate regions of the world | * | * | M |
| 126 | *Cyrtococcum trigonum* | H | Poaceae | Sep–Oct | Southeastern Asia, Sri Lanka, and Peninsular India | | * | |
| 127 | *Dactyloctenium aegyptium* | H | Poaceae | TTY | Native of South America, invasive in Paleotropics | * | * | M |
| 128 | *Eleusine indica* | H | Poaceae | TTY | Pantropical | * | * | |
| 129 | *Eragrostis tenella* | H | Poaceae | Jul–Nov | Paleotropic, introduced in America | | * | |
| 130 | *Eragrostis unioloides* | H | Poaceae | TTY | Southeastern Asia, India, and Africa | * | * | |
| 131 | *Isachne miliacea* | H | Poaceae | TTY | India, China, and southeastern Asia | | * | NR |
| 132 | *Oplismenus burmannii* | H | Poaceae | Sep–Nov | Pantropical | * | * | |
| 133 | *Pennisetum polystachyon* | H | Poaceae | Apr–Dec | Paleotropical | * | | |
| 134 | *Sacciolepis indica* | H | Poaceae | Jun–Feb | Tropical Asia, Australia and introduced in Africa and America | | * | |
| 135 | *Setaria pumila* | H | Poaceae | Jul–Oct | Paleotropical | * | * | |
| 136 | *Ziziphus oenoplia* | S | Rhamnaceae | Nov–Mar | Tropical Asia and Australia. Throughout the hotter parts of India | * | | M |
| 137 | *Bruguiera cylindrica* | T | Rhizophoraceae | Dec –Oct | Indo-Malesia | | * | NR |
| 138 | *Carallia brachiata* | T | Rhizophoraceae | Oct–Apr | Indo-Malesia and Australia | * | * | |
| 139 | *Chassalia curviflora* var. *ophioxyloides* | S | Rubiaceae | Jul–Feb | Indo-Malesia | * | * | NR |
| 140 | *Ixora coccinea* | S | Rubiaceae | TTY | Peninsular India and Sri Lanka | | * | M, E |
| 141 | *Knoxia sumatrensis* | H | Rubiaceae | Aug–Sep | Indo-Malesia and Australia | * | * | NR |
| 142 | *Mitracarpus hirtus* | H | Rubiaceae | Jul–Dec | Tropical Africa and America | * | | |
| 143 | *Morinda citrifolia* | S | Rubiaceae | Jul–Nov | Indo-Malesia | | * | M |
| 144 | *Oldenlandia corymbosa* | H | Rubiaceae | Apr–Sep | Pantropical | * | | M, NR |
| 145 | *Spermacoce latifolia* | H | Rubiaceae | Aug–Oct | Native of tropical America; now established in tropical Africa and Asia | * | | |
| 146 | *Spermacoce ocymoides* | H | Rubiaceae | Nov–Dec | Indo-Malesia and tropical Africa | * | | |
| 147 | *Aegle marmelos* | T | Rutaceae | Mar–May | India and Sri Lanka; widely cultivated in South East Asia | * | | M, E |
| 148 | *Zanthoxylum rhetsa* | T | Rutaceae | Mar–Nov | Indo-Malesia | * | | M |
| 149 | *Santalum album* | T | Santalaceae | Nov–Dec | Peninsular India and Malesia | * | | M |
| 150 | *Allophylus subfalcatus* var. *distachyus* | S | Sapindaceae | Nov–Mar | India, Bangladesh, and Indo-Malaya | * | | NR |
| 151 | *Cardiospermum halicacabum* | C | Sapindaceae | Jul–Feb | Pantropical | * | | M |
| 152 | *Chrysophyllum cainito* | T | Sapotaceae | Jul–Sep | Native of West Indies | | * | |
| 153 | *Mimusops elengi* | T | Sapotaceae | Dec–Aug | Indo-Malesia | | * | M |
| 154 | *Lindernia anagallis* | H | Scrophulariaceae | Jul–Dec | Indo-Malesia | * | * | |
| 155 | *Lindernia ciliata* | H | Scrophulariaceae | Jun–Oct | Indo-Malesia | * | | |
| 156 | *Lindernia crustacea* | H | Scrophulariaceae | Aug–Nov | Africa, America, and tropical and subtropical Asia | * | | |
| 157 | *Scoparia dulcis* | H | Scrophulariaceae | TTY | Native of tropical America; now pantropical | * | | M |
| 158 | *Helicteres isora* | S | Sterculiaceae | Sep–Mar | Indo-Malesia, China, and Australia | | * | M |
| 159 | *Melochia corchorifolia* | H | Sterculiaceae | Jul–Apr | Pantropical | * | | |
| 160 | *Sterculia guttata* | T | Sterculiaceae | Sep–Mar | Indo-Malesia | * | | M |
| 161 | *Grewia nervosa* | S | Tiliaceae | Aug–Apr | Tropical Asia | * | | M |
| 162 | *Trema orientalis* | T | Ulmaceae | Sep–Dec | Tropical Africa, Asia, and Australia | * | | |
| 163 | *Pouzolzia zeylanica* | H | Urticaceae | Aug–Dec | Tropical Asia | * | * | M |

| | Scientific name | Habit | Family | Flowering & Fruiting | World distribution | MST | VDK | Remarks |
|---|---|---|---|---|---|---|---|---|
| 164 | *Clerodendrum inerme* | S | Verbenaceae | Nov –Dec | Coastal India and Sri Lanka; now invasive on the shores of Myanmar, Australia, China | | * | |
| 165 | *Clerodendrum infortunatum* | S | Verbenaceae | Dec–Feb | Indo-Malesia | * | * | M |
| 166 | *Gmelina arborea* | T | Verbenaceae | Jan–Jun | Indo-Malesia | | * | M, NR |
| 167 | *Vitex negundo* | T | Verbenaceae | Feb–Jul | Indo-Malesia and China, cultivated in the tropics | * | | M |
| 168 | *Ampelocissus indica* | C | Vitaceae | Mar–Sep | Peninsular India and Sri Lanka | * | | M, E |
| 169 | *Cissus glyptocarpa* | C | Vitaceae | Apr–Oct | Peninsular India and Sri Lanka | * | | E, NR |
| 170 | *Leea indica* | S | Vitaceae | Mar–Aug | Indo-Malesia, China, and Australia | | * | M |
| 171 | *Zingiber nimmonii* | H | Zingiberaceae | Jul–Oct | Western Ghats | * | | M, E, NR |
| Total number of species | | | | | | **126** | **86** | |

# Abbreviations uses in the table: H—Herb | S—Shrub | T—Tree | C—Climber | M—Medicinal | TTY – Throughout the year | E—Endemic | MST—Mannur Siva Temple Pachathuruthu | VDK—Vadayil Kavu Pachathuruthu.

### B. GYMNOSPERMS

| | Scientific name | Habit | Family | World distribution | MST | VDK | Remarks |
|---|---|---|---|---|---|---|---|
| 1 | ***Cycas circinalis*** | T | Cycadaceae | Indo-Malesia and tropical eastern Africa | * | | |
| **Total number of species** | | | | | **1** | **0** | |

### C. PTERIDOPHYTES

| | Scientific name | Habit | Family | World distribution | MST | VDK | Remarks |
|---|---|---|---|---|---|---|---|
| 1 | ***Adiantum philippense*** | H | Adiantaceae | Tropics and subtropics | * | | |
| 2 | ***Drynaria quercifolia*** | H | Polypodiaceae | Asia, Papua New Guinea, Fiji, Polynesia, and tropical Australia | * | | |
| 3 | ***Pteris confusa*** | H | Pteridaceae | Tropics and subtropics of the world | * | | |
| 4 | ***Pteris quadriaurita*** | H | Pteridaceae | Tropics and sub,tropics | * | | |
| 5 | ***Selaginella delicatula*** | H | Selaginellaceae | Widely cultivated in India | * | | |
| 6 | ***Acrostichum aureum*** | H | Pteridaceae | Tropics of the world | | * | M |
| 7 | ***Stenochlaena palustris*** | C | Blechnaceae | Australia, Myanmar, Fiji, Malaysia, Polynesia and China | | * | |
| **Total number of species** | | | | | **5** | **2** | |

## Phenological Status

In both the study areas, the majority of the species studied (nearly 30%) started flowering with the onset of the southwest monsoon period (June–August) and continued to bear flowers during the entire monsoon period. At MST, 25 species (~20%) started flowering during the north-east monsoon period while at VDK, 10 species (~12%) behaved like that. This shows that 40–50 % of the species start and often complete their reproductive cycles during the monsoon period before the area dries up, which highlights the importance of this study. In both areas, nearly 20% of species (mainly shrubs and tees) started flowering during the summer months and 16 species bear flowers throughout the year (Table 3).

## Medicinal Uses

It is well known that out of the 5,679 documented species in Kerala, approximately 873 plants are used for various medicinal purposes (www.eflorakerala.com – 08 Nov 2024). This explains why the Ayurvedic medical system is so successful in Kerala State. It was understood that, in the Pachathuruthu areas under investigation, roughly 68 species (54% of the 126 listed) at the MST were medicinal plants (Sasidharan 2011). In the same way, 49 species (57% of the 86 species) in VDK were medicinal plants. This emphasizes how important it is to preserve these areas, when even the sacred groves face

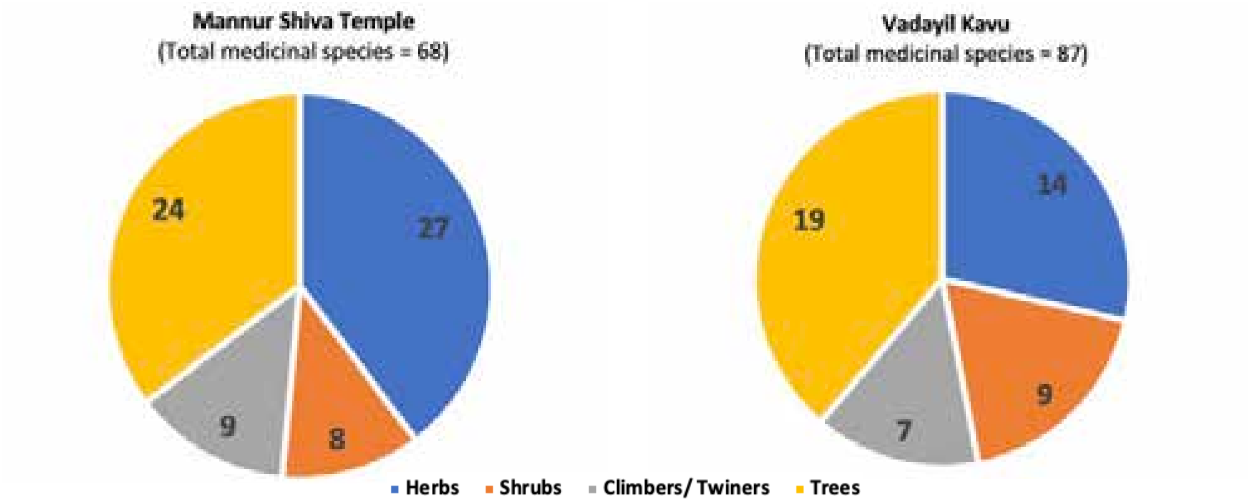


**Figure 1. Habits of the medicinal plants enumerated from the two study areas.**

**Table 2. Distribution of the species enumerated from the two study areas.**

| | Mannur Siva Temple (MST) | | | Vadayil Kavu (VDK) | | |
|---|---|---|---|---|---|---|
| | **Distribution** | **No of species** | **%** | **Distribution** | **No of species** | **%** |
| 1 | India | 3 | 2.4 | East Himalaya | 1 | 1.2 |
| 2 | India and Sri Lanka | 7 | 5.6 | India | 1 | 1.2 |
| 3 | Indo-Malesia | **25** | **19.8** | India and Myanmar | 1 | 1.2 |
| 4 | Indo-Malesia and Australia | 8 | 6.3 | India and Sri Lanka | 3 | 3.5 |
| 5 | Indo-Malesia and China | 3 | 2.4 | India to Malesia and Madagascar | 1 | 1.2 |
| 6 | Indo-Malesia to Australia and Africa | 5 | 4.0 | India, China, and southeastern Asia | 2 | 2.3 |
| 7 | Native of China | 1 | 0.8 | Indo-Malesia | **20** | **23.3** |
| 8 | Native of Himalaya | 2 | 1.6 | Indo-Malesia and Australia | 6 | 7.0 |
| 9 | Native of Pacific Islands | 1 | 0.8 | Indo-Malesia, China, and Australia | 2 | 2.3 |
| 10 | Native of tropical America | **16** | **12.7** | Native of Pacific Islands | 2 | 2.3 |
| 11 | Paleotropics | 4 | 3.2 | Native of tropical America | **8** | **9.3** |
| 12 | Pantropics | **13** | **10.3** | Paleotropics | **7** | **8.1** |
| 13 | Peninsular India and Sri Lanka | 5 | 4.0 | Pantropics | **10** | **11.6** |
| 14 | Southern and southeastern Asia to Australia | 2 | 1.6 | Peninsular India | 1 | 1.2 |
| 15 | South India and Sri Lanka | 3 | 1.6 | Peninsular India and Sri Lanka | 3 | 3.5 |
| 16 | Southern Western Ghats | 3 | 2.4 | Southeastern Asia, Sri Lanka, and Peninsular India | 3 | 3.5 |
| 17 | Throughout the tropics | 3 | 2.4 | Southern Western Ghats | 1 | 1.2 |
| 18 | Tropical Asia | 2 | 1.6 | Tropics | 3 | 3.5 |
| 19 | Tropical Asia and Africa | 3 | 2.4 | Tropical Asia | 3 | 3.5 |
| 20 | Tropics and subtropics | 1 | 0.8 | Others | 8 | 9.3 |
| 21 | Western Ghats | 4 | 3.2 | | | |
| 22 | Others | 13 | 10.3 | | | |
| | **TOTAL** | **126** | **100** | **TOTAL** | **86** | **100** |

**Table 3. Phenological status of the species (adapted from Sasidharan 2011).**

| | Flowering months/ periods | Mannur Siva Temple | | Vadayil Kavu | |
|---|---|---|---|---|---|
| | | No of species | % | No of species | % |
| 1 | **June–August** (South-west monsoon) | **35** | **27.8** | **26** | **30.2** |
| 2 | **September** (Light rain, mild weather) | 11 | 8.7 | 4 | 4.7 |
| 3 | **October–November** (North-east monsoon) | **25** | **19.8** | **10** | **11.6** |
| 4 | **December–January** (Winter) | 13 | 10.3 | 14 | 16.3 |
| 5 | **February–May** (Summer) | **26** | **20.6** | **16** | **18.6** |
| 6 | **Throughout the year** | 16 | 12.7 | 16 | 18.6 |
| | **TOTAL** | **126** | **100** | **86** | **100** |

severe threats of destruction nowadays.

The Asteraceae and Fabaceae families had the most number of medicinal plants at MST (6 spp. each), followed by the Euphorbiaceae (5) and Lamiaceae (4). However, the Fabaceae family possessed the most medicinal plants (7 spp.) at VDK, followed by the Asteraceae (4) and Euphorbiaceae (3), demonstrating the significance of these three families in terms of their adaptability and distribution in these areas. Moreover, a good majority of these species were herbs (Figure 1), which were neglected during the earlier studies, which highlights the importance of this study (Table 1).

### Biodiversity Threats and Conservation Issues

From the study conducted, it became evident that both the study areas, MST and VDK being temple premises are considered highly sacred and do not have many conservation issues. Lack of funding for maintenance poses problems in the conservation efforts at MST. As a result, numerous weeds have overtaken the area, which limit the growth of seedlings that have been planted. Even though many medicinal plants (more than 50% of the total species) are flourishing in the region, improper care by removing the so-called ‘unwanted plants’ ruin the diversity.

In contrast, the number of planted seedlings and other species at VDK has significantly decreased as a result of routine cleaning and maintenance operations in the temple grounds, where many devotees congregate. As this Pachathuruthu is situated on the Kadalundi River’s bank, saline water intrusion during monsoon and high tides, affects the growth of the plants.

## CONCLUSIONS

It was understood that the conservation of these two ecorestoration areas, MST and VDK which are rich in rare, endemic, and medicinal plants holds profound ecological and cultural significance. Such areas, especially located in sacred groves, act as vital reservoirs of biodiversity, safeguarding unique species that are often adapted to specific ecological niches and are irreplaceable in their native environments. The preservation of rare and endemic plants contributes to the resilience of local ecosystems, supporting diverse wildlife and stabilizing soil and water quality. Additionally, medicinal plants in these areas are invaluable not only for traditional healing practices but also as sources for modern pharmaceuticals, offering untapped potential for new therapeutic compounds. Protecting and restoring this biodiversity-rich area is crucial to ensure ecological balance, preserving genetic resources, and sustaining the cultural and medicinal heritage that these plants embody.

It was also understood that there is a lack of proper funding for the maintenance and development, which poses problems in the conservation of these areas. Due to the negligence in maintenance, many weeds have invaded the area, thereby restricting the growth of the planted seedlings. Improper weeding done by inexperienced labourers, may also destroy the diversity, since a lot of medicinal plants (>50%) are found growing in the area.

It also became evident that, if similar studies are carried out in all the Pachathuruthu areas of the state, covering the monsoon, winter, and summer seasons, they will yield fantastic information about these eco-restoration areas, thereby helping the authorities to plan better environmentally sustainable policies and programmes for their conservation and management.

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ARTICLE



# A preliminary investigation on wing morphology, flight patterns, and flight heights of selected odonates

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**Abstract:** Wing shape and its individual structural components are a major contributor to the flight performance of odonates. Two essential components of wing structure are the nodus and the pterostigma. Our study showed that the position of the nodus (expressed as the nodal index) in the forewings and hindwings of dragonflies show subtle, but functionally important differences, whereas on a broader scale, dragonflies and damselflies show characteristic differences in accordance with their specific flight requirements. The position of the pterostigma expressed as the pterostigmatal index was observed to be optimized close to the wing tip across all odonates and unlike the nodus, there were no characteristic differences between dragonflies and damselflies in this regard. In addition to describing wing shape using aspect ratio, our study presents a geometric morphometric analysis of wing shape across flying and perching behaviour and across flight heights of odonates. It was found that wing shape does not significantly differ between fliers and perchers. However, certain species namely *Crocothemis servilia*, *Tholymis tillarga*, and *Gynacantha bayadera* showed notable deviations in wing shape. These deviations indicate that the dichotomous classification of odonates into perchers and fliers is too broad, possibly overlooking the nuanced flight patterns adopted by these insects. On the other hand, a significant association was found between wing shape and flight heights of odonates. These results suggest that behavioural factors may influence odonate wing shape, while also highlighting the importance of wing shape in flight efficiency. Consequently, the flight performance of biomimetic devices modelled after odonate flight, may be enhanced by optimizing wing shape in accordance with the heights above ground at which these devices are intended to operate.

**Keywords:** Aspect ratio, damselflies, dragonflies, Epiprocta, flight behaviour, geometric morphometrics, Nodal Index, Pterostigmatal Index, wing shape, wing venation, Zygoptera.

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**Author contributions:** AP—methodology, formal analysis, investigation, writing original draft, visualization. CS—conceptualization, validation, resources, writing, review and editing, supervision, funding acquisition.

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## INTRODUCTION

The order Odonata, consisting of dragonflies (Suborder Epiprocta) and damselflies (Suborder Zygoptera), is comprised of 6,442 described species worldwide, with a near cosmopolitan distribution (Paulson et al. 2024). Odonates are characterized by their distinctive morphology, with adults exhibiting elongated bodies and complex veined membranous wings, which support their exceptional flight capabilities. These insects inhabit a wide range of habitats. India, in particular, hosts a high odonate diversity, with a total record of 504 species belonging to 17 families (Subramaniam & Babu 2024). Odonates are important contributors to ecosystem functioning and occupy an important position in the food web, both as predator and prey (May 2019). Adult odonates are voracious opportunistic predators, feeding on a wide variety of prey organisms, particularly small dipterans belonging to Chironomidae, Sciaridae, and Cecidomyiidae (Arnaud et al. 2022) and are hence, believed to contribute to natural pest control (May 2019), especially in riparian habitats. Their hemimetabolous life cycle, comprising of an aquatic larval stage and a terrestrial adult stage depends on the availability of good riparian microhabitats and hence, odonates have been studied as bioindicators for the monitoring of ecosystem health (Subramanian et al. 2008).

The aerodynamic performance of odonates, enabled by the distinctive morphology of their wings and powerful thoracic musculature, has been extensively studied (Wotton 2009; Fauziyah et al. 2014; Bomphrey et al. 2016; Rajabi et al. 2018; Wotton 2020), and widely explored as models for the development of biomimetic devices (Khaheshi et al. 2021a,b,c). A key factor contributing to their flight efficiency is the complex wing morphology (Wootton 1991). The nodus and the pterostigma are two key components of wing structure (Rajabi & Gorb 2020). Located between two leading-edge spars (the stiff antenodal spar and the flexible postnodal spar), the nodus serves as a one-way hinge that regulates wing deformations (Rajabi et al. 2017, 2018). The pterostigma serves as an inertial regulator of wing pitch, preventing structural damage from self-excited wing vibrations and raising the critical speeds of flight (Norberg 1972).

Wing shape plays a critical role in the aerodynamic performance of odonates, influencing flight mechanics, and energy efficiency. Understanding variation in wing shape is important, especially in the context of the various flight strategies that odonates adopt. Odonates can be broadly classified into 'fliers' and 'perchers' based largely on distinct flight behaviours and thermoregulatory strategies used (Corbet 1980). Fliers are endothermic species that remain on the wing during active periods (patrolling, mating, and foraging), while perchers are ectotherms and spend most of their time on a perch, taking only short flights (Corbett & May 2008). These behavioural types also differ in their characteristic energy requirements, with fliers consuming more metabolic energy than perchers (Corbet & May 2008). Additionally, odonates have been observed to fly at various heights above the ground (Mitra et al. 1998; Miller 2007; Subramanian 2012), which may further influence energy consumption. Given that wing shape directly impacts aerodynamic performance and energy efficiency (Luo & Sun 2005; Shahzad et al. 2016; Fu et al. 2018), it can be hypothesized that wing shape will differ between flying and perching behaviours and across flight height preferences. Flight height in particular remains largely unexplored and not documented among odonates.

To better understand the variation in wing shape and to make a meaningful comparison across species, wing shape needs to be quantified. Aspect ratio (AR) is one of the most commonly used measures of wing shape in aerodynamics (Phillips et al. 2015) and a key morphological descriptor of a wing (Bhat et al. 2019). It is a critical factor influencing flight dynamics and hence, wing AR has been well studied to gain insights into the influence of wing shape on the flight performance of odonates and insects in general (May 1981; Wakeling 1997; Wakeling & Ellington 1997a,b,c; Johansson et al. 2009; Phillips et al. 2015; Li & Nabawy 2022). However, studies suggest that wing AR being a single numerical quantity is not a robust measure of wing shape (Wakeling 1997; Betts & Wootton 1998; Johansson et al. 2009). Addressing this limitation, geometric morphometrics (GM) has emerged as a robust tool, providing a multivariate description of wing shape (Johansson et al. 2009) as it is comprehensive enough to detect subtle, yet significant variations in wing shape (Hassall 2015; Tatsuta et al. 2018; MacLeod 2022; Tarrís-Samaniego et al. 2023; Xi et al. 2024).

## MATERIAL AND METHODS

The study sample consisted of 25 individual specimens belonging to 19 odonate species collected from Greater Hyderabad and deposited at the Natural

History Museum, Department of Zoology, Osmania University, Hyderabad, Telangana. Located on the Deccan Plateau, Greater Hyderabad covers an area of 650 $km^2$ and is one of the largest metropolitan areas in India. The city experiences a hot semi-arid climate, receiving most of its annual rainfall from June to October (Anon. 2024). Although being a landlocked region, Greater Hyderabad has a considerable number of lakes, both natural and man-made. Hyderabad's lakes along with its predominantly sloping terrain, supports a broad spectrum of biodiversity. However, due to a rapidly growing human population and subsequent urbanization, the city has lost about 61% of its lake area in last 44 years. Conservation initiatives and efforts continue to be made to preserve and restore the green cover and freshwater ecosystems.

Of the 19 species collected, 16 were dragonflies and three were damselflies (Table 1). The flight behaviour and the flight heights of the species were determined based on field guides, manuals, and research papers (Sakagami et al. 1974; Mitra 1994; Mitra et al. 1998; Mitra 2006; Miller 2007; Andrew et al. 2008; Corbet & May 2008; Subramanian 2012; Sharma & Oli 2022).

The wings of each individual specimen were photographed using a digital camera (Sony DSC-WX7). The wing length (WL), wing area (WA), distance of the nodus and distance of the pterostigma from the wing base of both the forewings and hindwings of each individual were measured using ImageJ ver. 1.54g (Schneider et al. 2012). Data obtained from the forewings and hindwings were analyzed separately throughout this study. For damselflies, only the forewings were considered for analyses.

The morphometric measurements obtained were then used to calculate the nodal index (NI), the pterostigmatal index (PI) and aspect ratio (AR). The NI was calculated as distance of the nodus from the wing base as a fraction of wing length (Wootton 2020), using the formula:

$$NI = \frac{\textit{Distance of the nodus from the wing base (mm)}}{\textit{Wing length (mm)}}$$

The PI was calculated as distance of the pterostigma from the wing base as a fraction of wing length, using the formula:

$$PI = \frac{\textit{Distance of the pterostigma from the wing base (mm)}}{\textit{Wing length (mm)}}$$

**Table 1. List of species included in the study sample.**

| Family | Species | Flight behaviour | Flight height |
|---|---|---|---|
| Libellulidae | *Acisoma panorpoides* | Percher | Low |
| Aeshnidea | *Anax guttatus* | Flier | High |
| Libellulidae | *Crocothemis servilia* | Percher | Medium |
| Libellulidae | *Diplacodes trivialis* | Percher | Medium |
| Aeshnidea | *Gynacantha bayadera* | Flier | Medium |
| Gomphidae | *Ictinogomphus rapax* | Percher | Low |
| Libellulidae | *Orthetrum glaucum* | Flier | Medium |
| Libellulidae | *Orthetrum sabina* | Percher | Medium |
| Libellulidae | *Orthetrum taeniolatum* | Percher | Medium |
| Libellulidae | *Pantala flavescens* | Flier | High |
| Gomphidae | *Paragomphus lineatus* | Percher | Low |
| Libellulidae | *Tholymis tillarga* | Flier | Low |
| Libellulidae | *Tramea basilaris* | Flier | High |
| Libellulidae | *Tramea limbata* | Flier | Medium |
| Libellulidae | *Trithemis aurora* | Flier | Low |
| Libellulidae | *Trithemis pallidinervis* | Percher | Low |
| Coenagrionidae | *Ceriagrion coromandelianum* | Percher | Low |
| Coenagrionidae | *Ischnura senegalensis* | Percher | Low |
| Lestidae | *Lestes elatus* | Percher | Low |

Wing AR was calculated as two times the square of wing length divided by wing area (Bhat et al. 2019), using the formula:

$$AR = 2\left(\frac{\text{wing length}^2}{\text{wing area}}\right)$$

Regression tests were performed to determine the relationship between wing AR and flight behaviour, and wing AR and flight height.

A GM analysis of wing shape was performed to comprehensively analyse wing shape. A landmarks-based approach was adopted, wherein appropriate landmarks were placed on the digitized wing images (Figure 1) and the corresponding coordinates obtained using ImageJ software. The landmark-coordinates were standardized using generalized procrustes fitting. A procrustes ANOVA was then conducted to determine the statistical significance of wing shape differences among the groups being compared. Additionally, a principal component analysis (PCA) was performed to visualize patterns of variation and similarity in wing shape. All analyses were performed on MorphoJ ver. 1.08.02 (Klingenberg 2011).

## RESULTS

Obtained measurements of wing length and nodal distance from the wing base were used to calculate the NI. Dragonflies exhibit a NI range of 0.40–0.53 (Table 2) indicating a centred nodal position. Furthermore, the hindwing is consistently observed to have a lower NI compared to the forewing across all individual dragonflies. Damselflies on the other hand are observed to have a particularly low NI compared to dragonflies (Table 2). They exhibit a NI range of 0.32–0.37, indicating an extremely proximal nodal position.

Measurements of wing length and pterostigmatal distance from the wing base were used to calculate the PI. All odonates exhibit a PI range of 0.80–0.93, with no significant variation observed between dragonflies and damselflies (Table 2).

Wing AR was calculated from wing length and wing area. Among dragonflies, the forewings exhibit an AR range of 9.0–11.2, while the hindwings have an AR range of 7.2–8.5 (Table 2). The hindwings have a broad expanded anal lobe which lowers the AR compared to the narrower forewings. Damselflies on the other hand have particularly narrow wings and hence, exhibit extremely high wing AR (Table 2).

Wing AR did not differ significantly between fliers and perchers (Regression test; non-significant; forewing AR: $p = 0.293$, hindwing AR: $p = 0.592$) and across flight heights (Regression test; non-significant; forewing AR: $p = 0.224$, hindwing AR: $p = 0.463$).

However, a GM analysis of wing shape provided notable results. While wing shape did not differ significantly between fliers and perchers (Procrustes ANOVA; non-significant; $p = 0.141$), a significant association was observed between wing shape and the flight heights of odonates (Procrustes ANOVA; significant; $p = 0.021$).

Additionally, the PCA plots for forewing and hindwing shape analysis of dragonflies (Figure 2b & c) revealed significant deviations in wing shape for certain species, namely *Crocothemis servilia*, *Tholymis tillarga,* and *Gynacantha bayadera*.

Although *Crocothemis servilia* is classified as a percher, its forewing shape appears to be closely similar to that of *Pantala flavescens*, a typical flier. On the other hand, its hindwing shape was found to significantly deviate from all related libellulids.

*Tholymis tillarga* and *Gynacantha bayadera* are

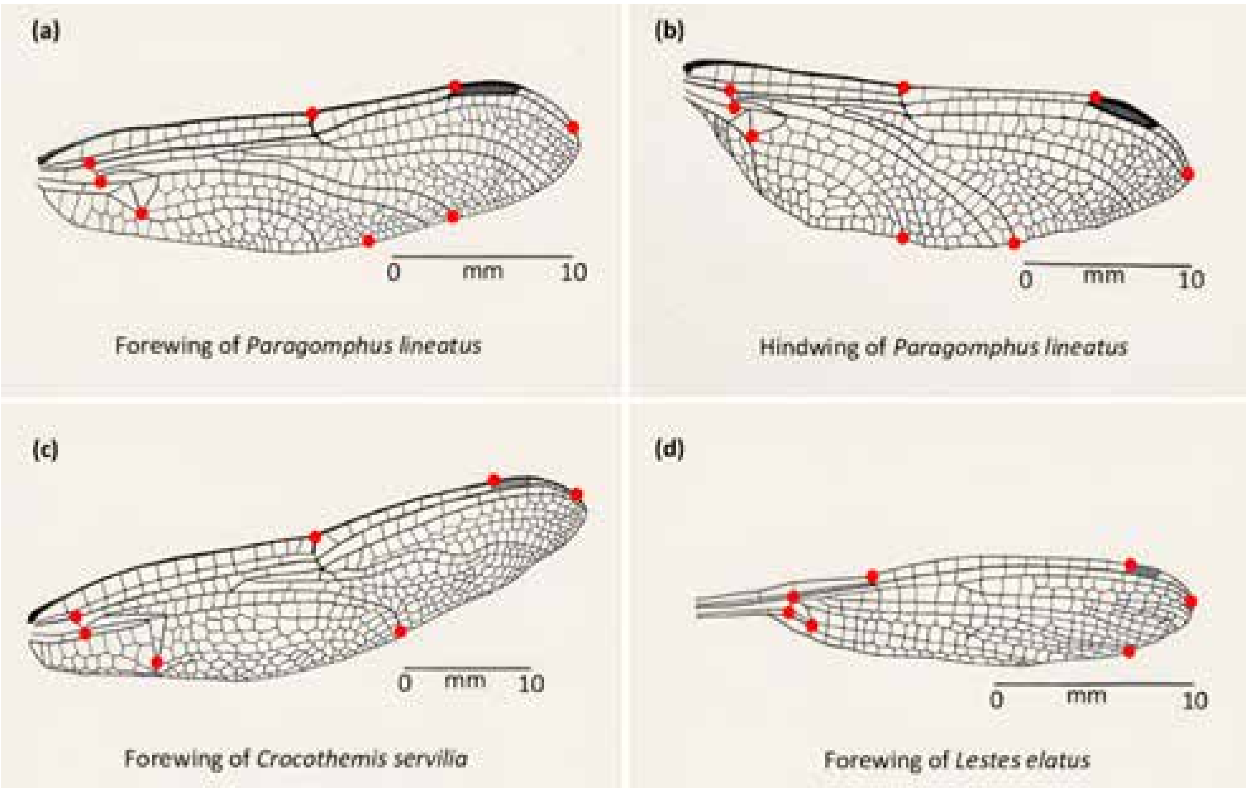


**Figure 1. Landmark positions for: a—Forewing | b—Hindwing shape analysis of dragonflies | c&d—Forewing shape analysis of damselflies. Original drawings by Ananditha Pascal.**

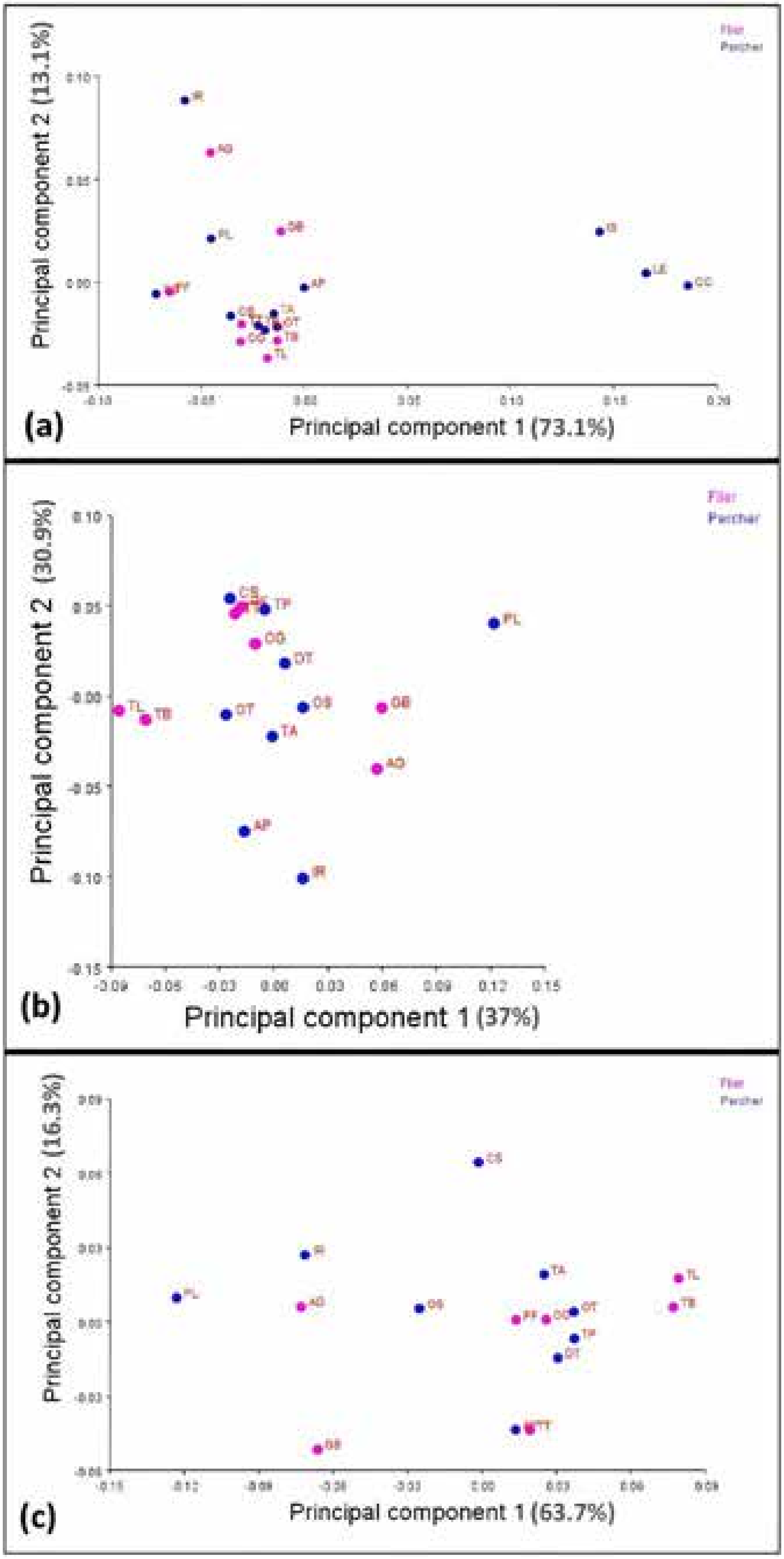


**Figure 2. Principal component analysis plots of: a—Forewing shapes of dragonflies and damselflies | b—Forewing shape of dragonflies | c—Hindwing shape of dragonflies**

**Table 2. Morphometric measurements of forewing and hindwing of Odonates.**

| Species | Forewing | | | | | Hindwing | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | WL (mm) | WA (mm²) | AR | NI | PI | WL (mm) | WA (mm²) | AR | NI | PI |
| *Acisoma panorpoides* | 19.725 | 85.648 | 9.086 | 0.469 | 0.878 | 19.626 | 104.937 | 7.347 | 0.417 | 0.857 |
| *Anax guttatus* | 53.837 | 554.288 | 10.458 | 0.496 | 0.805 | 51.691 | 659.963 | 8.097 | 0.418 | 0.791 |
| *Crocothemis servilia* | 45.953 | 375.438 | 11.249 | 0.533 | 0.879 | 41.652 | 412.128 | 8.419 | 0.403 | 0.877 |
| *Diplacodes trivialis* | 23.5455 | 119.052 | 9.381 | 0.478 | 0.891 | 23.192 | 149.171 | 7.254 | 0.445 | 0.893 |
| *Gynacantha bayadera* | 45.033 | 425.879 | 9.524 | 0.478 | 0.635 | 45.683 | 575.496 | 7.253 | 0.406 | 0.859 |
| *Ictinogomphus rapax* | 58.313 | 604.567 | 11.249 | 0.519 | 0.831 | 54.449 | 659.442 | 8.992 | 0.436 | 0.828 |
| *Orthetrum glaucum* | 31.758 | 202.603 | 9.956 | 0.508 | 0.908 | 31.813 | 256.175 | 7.901 | 0.486 | 0.912 |
| *Orthetrum sabina* | 36.15 | 250.017 | 10.481 | 0.489 | 0.878 | 34.580 | 292.737 | 8.239 | 0.452 | 0.883 |
| *Orthetrum taeniolatum* | 30.403 | 163.613 | 11.299 | 0.494 | 0.906 | 29.598 | 218.821 | 8.007 | 0.445 | 0.896 |
| *Pantala flavescens* | 40.187 | 308.330 | 10.476 | 0.530 | 0.878 | 40.184 | 420.816 | 7.674 | 0.434 | 0.873 |
| *Paragomphus lineatus* | 29.953 | 186.399 | 9.626 | 0.498 | 0.846 | 28.547 | 191.113 | 8.528 | 0.416 | 0.844 |
| *Tholymis tillarga* | 36.006 | 261.698 | 9.956 | 0.502 | 0.880 | 37.665 | 385.244 | 7.436 | 0.426 | 0.880 |
| *Tramea basilaris* | 43.941 | 381.812 | 10.114 | 0.503 | 0.932 | 44.689 | 498.008 | 8.020 | 0.438 | 0.909 |
| *Tramea limbata* | 41.699 | 330.970 | 10.507 | 0.494 | 0.922 | 43.596 | 460.122 | 8.261 | 0.441 | 0.924 |
| *Trithemis aurora* | 33.45 | 209.589 | 10.677 | 0.485 | 0.896 | 33.116 | 259.842 | 8.441 | 0.434 | 0.891 |
| *Trithemis pallidinervis* | 34.947 | 250.817 | 9.739 | 0.505 | 0.902 | 34.560 | 318.341 | 7.504 | 0.445 | 0.902 |
| *Ceriagrion coromandelianum* | 20.692 | 59.605 | 14.367 | 0.322 | 0.925 | 20.692 | 59.605 | 14.367 | 0.322 | 0.925 |
| *Ischnura senegalensis* | 14.517 | 32.504 | 12.967 | 0.370 | 0.891 | 14.994 | 34.840 | 12.906 | 0.364 | 0.936 |
| *Lestes elatus* | 24.405 | 84.647 | 14.073 | 0.357 | 0.912 | 24.405 | 84.647 | 14.073 | 0.357 | 0.912 |

WL—Wing length | WA—Wing area | AR—Aspect ratio | NI—Nodal index | PI—Pterostigmatal index.

crepuscular dragonflies. *Tholymis tillarga*, which belongs to the family Libellulidae and is classified as a flier, is observed to have a forewing shape similar to other libellulids such as *Pantala flavescens*, as expected. However, its hindwing shape appears to be closely similar to that of *Acisoma panorpoides*, which is a typical percher. *Gynacantha bayadera*, which is an aeshnid and is classified as a flier, significantly deviates in its hindwing shape from that of *Anax guttatus*, which is also an aeshnid and a flier.

## DISCUSSION

The objectives of our study were to record and compare the position of the nodus and the position of the pterostigma among members of different families of Odonata and to analyse wing shape in the context of flight patterns and flight heights.

The nodus is located between two leading-edge spars with distinct properties – the thick antenodal spar which provides stiffness and the flexible postnodal spar which is the principal area of wing torsion (Wootton 1991). Therefore, the position of the nodus determines the degree of wing torsion that can develop, thereby influencing the amount of lift generated during flight (Wootton & Newman 2008), and the NI which indicates the location of the nodus is useful to compare the species in this regard (Wootton 2020).

The results of the present study show that, in the case of dragonflies, the forewing nodus is positioned anywhere between 0.46 and 0.53 (approximately 50%) of the wing length from the base. On the other hand, it is observed that the hindwing nodus of dragonflies is positioned between 0.40 and 0.48 of the wing length from the base, i.e., less than 50% of the wing length. Additionally, when compared with the forewings, the hindwings have a low AR range, at which flight efficiency is low (Ennos 1988). However, it is likely that the hindwing's proximally positioned nodus, which allows for greater wing torsion and better aerodynamic lift (Ennos 1988; Wootton 2020), compensates for this reduced flight efficiency.

Unlike dragonflies, damselflies are found to have an extremely low NI of 0.3 on average. Such a proximally positioned nodus has been suggested to aid the habitually slow flight characteristic of the families Coenagrionidae and Lestidae (Wootton 2020).

The PI(s) calculated in the present study indicate that the pterostigma is consistently positioned at around 0.80–0.93 of the wing length in both the forewings and hindwings, across all odonates. This supports the conclusion that for the pterostigma to contribute to efficient flight, it has to be positioned close to the wing tip (Norberg 1972). Unlike the position of the nodus, the position of the pterostigma did not show significant variation between dragonflies and damselflies.

The wing AR(s) calculated in the present study show that dragonfly forewings do not exceed an AR of around 10. This validates earlier studies which have suggested that aerodynamic efficiency is achieved at intermediate AR(s) of around 5 for a single wing (Ennos 1989; Phillips et al. 2015; Li & Nabawy 2022).

On the other hand, the damselflies have been observed to have high AR wings exceeding the AR of 5 for a single wing. At such high AR values, the amount of lift generated falls down significantly (Phillips et al. 2015; Li & Nabawy 2022). This is likely responsible for the lower flight heights of damselflies, compared to dragonflies.

Additionally, the present study found no significant relationship between wing AR and flying and perching behaviour, and wing AR and flight heights. This aligns with studies which found no significant association between wing AR and the flight patterns of odonates (Wakeling 1997; Johansson et al. 2009). This indicates that AR being a single numerical quantity may not be robust enough to quantify and detect subtle variations in wing shape (Betts & Wootton 1998).

To address this limitation of using wing AR as a descriptor of wing shape, the present study additionally employed GM analysis to examine variation in wing shape across flying and perching behaviour and across flight heights of odonates. The results revealed no significant variation in wing shape between fliers and perchers.

The PCA plots revealed certain notable deviations in wing shape (see Figure 2). While *Crocothemis servilia* is classified as a percher, its forewing shape appears to be closely similar to *Pantala flavescens*, which is a typical flier. On the other hand, its hindwing shape deviates significantly away from all related libellulids considered in this study. This supports behavioural observations that *Crocothemis servilia* can switch flight behaviours, spending almost equal amounts of time perched and in flight, thereby deviating from the dichotomous classification of odonates into distinct behavioural types (Parr 1983; Corbet & May 2008).

*Tholymis tillarga* and *Gynacantha bayadera* are crepuscular dragonflies. *Tholymis tillarga*, which belongs to the family Libellulidae and is classified as a flier, is observed to have a forewing shape similar to other libellulid fliers such as *Pantala flavescens*, as expected. However, its hindwing shape appears to be closely similar to that of *Acisoma panorpoides*, a typical percher. This result supports observational records indicating that while *T. tillarga* exhibits rapid incessant flight during its crepuscular phase of peak activity, it tends to perch and rest among dense vegetation during the rest of the day (Miller & Miller 1985; Mitra 2005; Corbet & May 2008).

*Gynacantha bayadera*, which is an aeshnid and is classified as a flier, significantly deviates in its hindwing shape from that of *Anax guttatus*, which is also an aeshnid and a flier. This can be attributed to the difference in flight styles between the two aeshnids – *A. guttatus* tends to soar and fly at larger heights than *G. bayadera* (Miller 2007). Additionally, similar to the case of *T. tillarga*, observational studies have recorded *Gynacantha* spp. being inactive and perching under vegetation during mid-day hours and flying rapidly only during the active crepuscular phase (Clausnitzer 1999; Miller 2007).

Such deviations in wing shape being apparently associated with observable specialised behaviour, indicate that the dichotomous classification of odonates into perchers and fliers is too broad, possibly overlooking the nuanced flight patterns adopted by these insects. This demands a more comprehensive and detailed approach to understanding the flight patterns of odonates.

Wind speeds are known to influence the flight of insects, with greater heights experiencing greater wind speeds (Engels et al. 2016). Therefore, it can be hypothesized that odonates require adaptations in wing shape to optimize flight efficiency in accordance with their characteristic flight heights. Supporting this, our results revealed a significant variation in wing shape across flight heights. These results suggest that behavioural factors, especially flight heights may influence odonate wing shape, while also highlighting the importance of wing shape in flight efficiency. Consequently, the flight performance of biomimetic devices modelled after odonatan flight, can be enhanced by optimizing wing shape in accordance with the heights above ground at which these devices are intended to operate.

It is worth mentioning that the current study analysed a relatively small sample of 19 odonate species from the Hyderabad region. Although our results show significant correlations between wing shape and flight heights, and intriguing deviations in the wing shapes of some species, the sample size may limit generalization of the results to all odonates. A more extensive study would be valuable by including a higher number of species from different geographical regions, belonging to various families and genera, for the validation of these findings. Such an increase in sampling might uncover further patterns in wing morphology and their relation to flight behaviour and height preference, thus bringing more robust information about the evolutionary history of odonate wing architecture.

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ARTICLE

# Phylogenetic confirmation of generic allocation and specific distinction of Mawphlang Golden-cheeked Frog *Odorrana mawphlangensis* (Pillai & Chanda, 1977) (Amphibia: Anura: Ranidae) and its updated distribution records

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**Abstract:** We report on the phylogenetic position (16S rRNA) of the Mawphlang Golden-cheeked Frog *Odorrana mawphlangensis* collected from Meghalaya (topotypical) and Mizoram, northeastern India. Morphologically, our new specimens agreed with the original description and subsequent redescription of *O. mawphlangensis*, thus ratifying the generic placement of *O. mawphlangensis* and its specific distinction from *O. grahami*, to which it was hypothesized to be a synonym owing to morphological similarities. The observed interspecific genetic distances within the genus *Odorrana* from our study ranged from 0.00% (*O. mawphlangensis*) to 11% (*O. fengkaiensis*). The uncorrected K2p-distance of 16S rRNA among *Odorrana* species revealed *O. mawphlangensis* is closest to its sister species *O. jingdongensis,* with a genetic distance of 3.7%. This study identifies and confirms the collected samples from Mizoram as *O. mawphlangensis* and also presents an updated distribution record from northeastern Indian state of Mizoram apart from its type locality in Meghalaya.

**Keywords:** Distribution records, frog, holotype, type locality, mitochondrial DNA, Mizoram, molecular phylogeny, morphology, northeastern India, taxonomy.

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**Author contributions:** ADT conceived and led the study, undertaking the collection of specimens, conducting detailed morphological examinations, taking photographs of the samples and drafting the complete manuscript. MV was responsible for executing the molecular analyses and contributed to the interpretation of genetic data. FM developed the geographical distribution map and assisted in visual representation of the findings. HTL provided critical scholarly guidance throughout the study, offered substantive inputs to strengthen the manuscript, and oversaw the overall research process. All authors contributed to refining the final version of the manuscript and approved its submission.

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## INTRODUCTION

*Odorrana mawphlangensis* (Pillai & Chanda, 1977) commonly known as the Mawphlang Golden-cheeked Frog (Dinesh et al. 2023), is a large sized frog species belonging to the family Ranidae, first described by Pillai & Chanda (1977), from Mawphlang Sacred Forest in Khasi Hills, Meghalaya, India, on the basis of an adult female bearing museum number, ZSI A 6979 (ex ZSI/ERS 803). In subsequent observations, this species was reported from other northeastern Indian states of Nagaland, Arunachal Pradesh, Manipur, and Mizoram as well as from West Bengal (Frost 2025). The description of the species was based solely on the holotype which led to it being misleadingly placed as a close relative of several species, namely *Limnonectes doriae* (Boulenger, 1887) and *Limnonectes modestus* (Boulenger, 1882). This misplacement was followed in the subsequent reports by Tiwari (1981) and Dubois (1987) with Ohler & Dubois (1999) transferring this species to the genus *Limnonectes* (*Elachyglossa*) (Anderson, 1916), including the originally proposed "possible relative" of *L. modestus.* Ao et al. (2003) indicated its close resemblance to *Rana* (*Odorrana*) *andersoni*. However, there was not enough explanation to support this inference. Mahony (2008), encountered similar-looking ranid frogs at the type locality Mawphlang Sacred Forest that not only resembled *Odorrana* but also produced secretions having a distinct odour. Against the back drop of these sightings, Mahony (2008) redescribed the holotype (ZSI/K) which re-allocated it from *Limnonectes,* to *Odorrana* based on morphological and geographical grounds.

The Ranid genus *Odorrana* comprises of 69 recognized species (Frost 2025), widely distributed in montane streams and rivers in the subtropical and tropical regions of eastern and southeastern Asia (Fei et al. 2012; AmphibiaChina 2021; Frost 2025). High-gradient streams, often located in mountain environments, are typical habitats of the *Odorrana* species, although *O. mutschmanni* (Pham et al. 2016), *O. wuchuanensis* (Xu 1983), and *O. lipuensis* (Mo et al. 2015) have been found to otherwise inhabit karstic limestone caves, with an elevation range of 447–728 m (Fei et al. 2012; Pham et al. 2016; Liu et al.2021; Frost 2025). The distributional range of the genus comprises of the Ryukyu Archipelago (Japan), southern China, northeastern India, and the Thai-Malay Peninsula, and further extending southwards to the two large southeastern Asian islands, Sumatra and Borneo (Frost 2025). Considering the peculiar ecological niche where this species resides, there could possibly be inter- or intra-specific divergence through geographical isolation, especially given the species complex with a wide geographical range covering varied mountain ranges and variable habitats (Wang et al. 2015). The phylogeny and diversity of *Odorrana* and the systematic status of taxa within the genus have been a matter of constant debate by taxonomists (Frost et al. 2006; Che et al. 2007; Fei et al. 2009; Kurabayashi et al. 2010; Chen et al. 2013; Li et al. 2015).

In spite of treating *Odorrana* as a subgenus of *Rana* (Dubois 1992) and expanding the genus *Huia* to include both *Odorrana* and *Rana* (*Eburana*) (Frost et al. 2006), the monophyly of *Odorrana* was finally supported by analysing mtDNA data and nuclear data separately as well as subsequent analyses of the combinations of mtDNA and nuclear data. Thus, the controversies revolving around the systematic status of *Odorrana* to be considered as a subgenus of *Rana* (*Eburana*), as well as being included with *Rana* as subgenus of *Huia* were subsequently abandoned (Matsui et al. 2005; Stuart 2008; Pyron & Wiens 2011). Recent phylogenetic studies have confirmed that *Odorrana* is monophyletic and consists of at least seven clades (Chen et al. 2013). In this study, we successfully conducted a detailed phylogenetic analysis and assessment of *O. mawphlangensis* based on 16S rRNA in addition to studying the morphological parameters of the collected samples to resolve the confusion revolving around its taxonomic position and identity.

## MATERIALS AND METHODS

### Survey and morphometric analysis

Visual encounter surveys (VES) were conducted in 2022 and 2023 (August to September) and a total of 12 specimens were collected during the field surveys from the Indian states of Mizoram and Meghalaya. Ten specimens were collected from Mizoram and two specimens were collected from Meghalaya (Figure 1). Out of the 10 specimens obtained from Mizoram, eight specimens were found from Murlen National Park (23.673° N, 93.293° E; 1,050 m) and two specimens were obtained from Hmuifang Community Reserve Forest (23.355° N, 92.753° E; 1,458 m). The other two specimens of Meghalaya were collected from Malki Forest in East Khasi Hills District (25.562° N, 91.893° E; 1,549.5 m). They were found in their natural habitats, i.e., on rocks near the riverbeds and in seasonal intermittent stream below hilly grass-covered

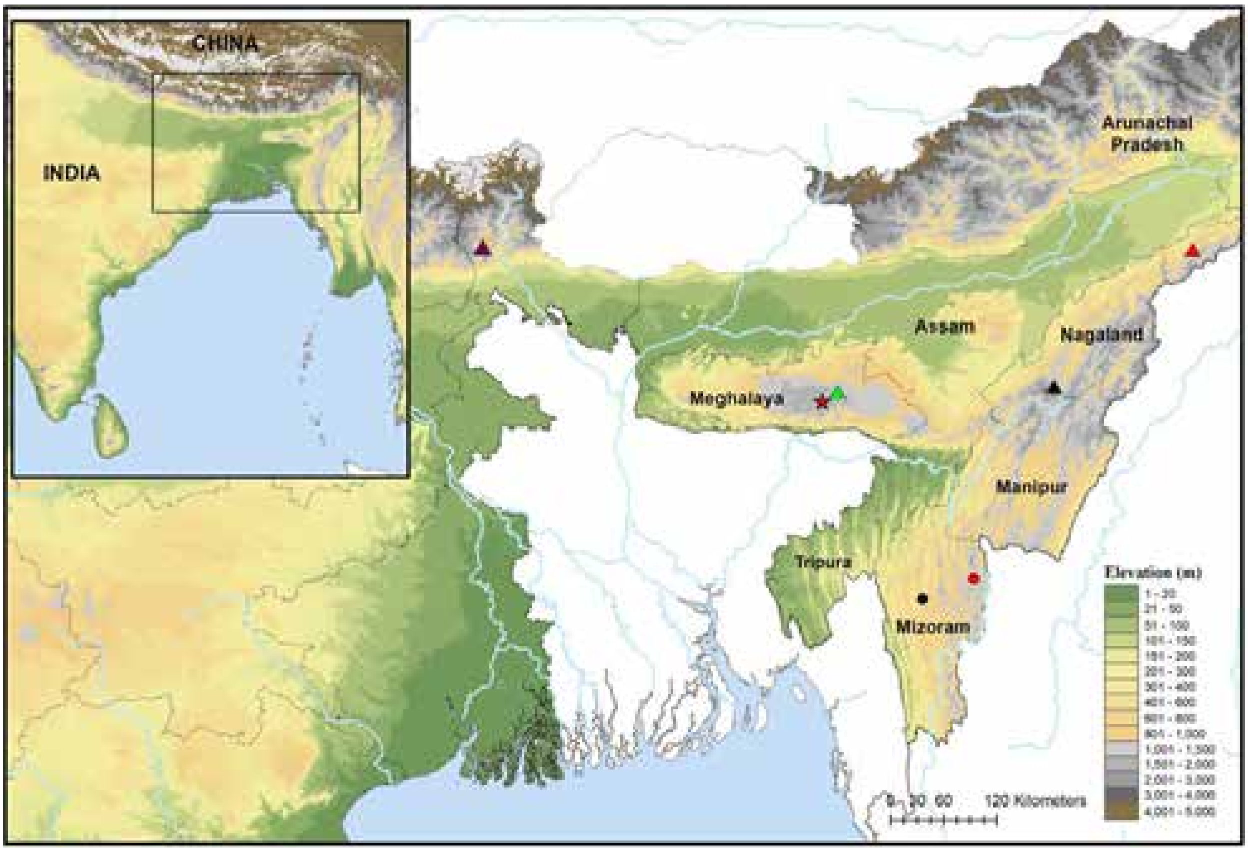


**Figure 1. Map showing the known distribution with exact locality of the Mawphlang Odorous frog (*Odorrana mawphlangensis*) from Mizoram and Meghalaya. The red star mark ✸ denotes the type locality of the species i.e. Mawphlang Sacred Forest in East Khasi Hills, Meghalaya. The study area for this research are designated as follows: Green triangle mark ▲ represents Malki Forest (Meghalaya), Black circle mark ● represents Hmuifang Community Reserve Forest (Mizoram), and Red circle mark ● designates Murlen National Park (Mizoram). The other highlighted marks ▲ ▲ ▲ represent the distributional records of *O. mawphlangensis* from different states of India (Frost 2025).**

terrain (Frost 2025). The specimens were deposited, catalogued, and fixed in 70% ethanol solution in the Departmental Museum of Zoology, Mizoram University (MZMU). Individuals were identified using the literature of Kiyasetuo & Khare (1986) and Chanda (2002). Morphometric measurements (Table 1) follow Sengupta et al. (2010). Measurements to the nearest 0.1 mm were taken using a dial calliper (Mitutoyo™ 505-507) (Table 1). Photographic vouchers were submitted to the Natural History Museum of Mizoram, Mizoram University, Aizawl, Mizoram, India (NHMM/G/2–4).

**DNA extraction, PCR amplification and sequencing**

We extracted genomic DNA from the liver tissues of *Odorrana* using QIAamp DNA Mini Kit (Qiagen Cat. No. 51306) following the standard protocol provided by the manufacturer. DNA integrity was analysed on 0.8% (w/v) agarose gel containing ethidium bromide. Polymerase chain reaction (PCR) was prepared for 20 µL reaction mixture containing 1X amplification buffer, 2.5 mM $MgCl_2$, 0.25 mM dNTPs, 0.2 pM each forward and reverse primer, 1 µL genomic DNA, and 1U Taq DNA polymerase with a pair of partial 16S rRNA primers: forward (L02510- CGC CTG TTT ATC AAA AAC AT) (Palumbi 1996) and reverse (H03063- CTC CGG TTT GAA CTC AGA TC) (Rassmann et al. 1997). The PCR thermal regime for amplification was 5 min at 95°C for initial denaturation, followed by 35 cycles of 1 min at 95°C for denaturation, 30s for annealing at 50.3°C, elongation for 1 min at 72°C, and a final elongation for 5 min at 72°C. Amplicons were observed through gel electrophoresis using a 1.5% agarose gel containing ethidium bromide. Samples were sequenced using Sanger's dideoxy method and sequencing was carried out for both forward and reverse directions (Barcode Bioscience, Bangalore, India). The newly generated partial 16S rRNA sequences were deposited in the GenBank repository to obtain the accession number.

**Phylogenetic analyses**

The phylogenetic relationships among the genus *Odorrana* were assessed based on the 16S rRNA partial gene sequence. For the analysis of our dataset of 16S rRNA, we included three newly generated *O. mawphlangensis* sequences from Mizoram (MZMU 138, MZMU 139, & MZMU 2267) along with the sequence of the holotype samples collected from Meghalaya (MZMU 3020 & MZMU 3021); 21 sequences were retrieved from NCBI database, and one sequence of *Amolops indoburmanensis* (MT790757) sample was used for this study as an out-group. The sequences were aligned by using Muscle algorithm in Molecular Evolutionary Genetics Analysis 7 (MEGA 7) (Kumar et al. 2016), the mean uncorrected genetic distances (Kimura 2 parameter, K2P) (Kimura 1980) were calculated in MEGA 7 (Kumar et al. 2016). The final aligned dataset contains 535 positions of 16S rRNA gene sequences. The best-fitting models of DNA evolution was performed according to the modeltest - NG (Darriba et al. 2020), and selected GTR+G model suggested by models with the lowest Bayesian information criterion (BIC) and Akaike information criterion (AIC) scores. The phylogenetic tree was inferred using Bayesian inference (BI) and maximum likelihood (ML) approaches. ML analysis was performed in raxmlGUI-2 with one-thousand bootstrap replicates (Silvestro & Michalak 2012). The BI phylogenetic tree was reconstructed in MrBayes 3.2.5 using GTR+G model. The Markov Chain Monte Carlo (MCMC) (one cold and three hot chains) was run for 10,000,000 generations by sampling every 100 generations and set the burn-in to 25%. The analysis was terminated when the standard deviation of split frequencies was less than 0.001. The percentage of trees in which the associated taxa clustered together is shown next to the branches (Ronquist & Huelsenbeck 2003). The generated phylogenetic tree was further illustrated using Figtree v1.4.4 software (Rambaut 2018).

**Genetic distances**

The resulting sequences were deposited in GenBank depository (OP979109, OP979112, MZ229896, MT814039, & MT814038). The GenBank accession numbers and other details of the species involved in the phylogenetic Bayesian inference tree have been presented in Figure 2. The uncorrected pairwise divergences in the 16S rRNA gene fragment among the members of the *Odorrana* sp. were summarised in Table 3. The observed interspecific genetic distances within the genus *Odorrana* from our study ranged from 0.00% (*O. mawphlangensis*) to 11.00% (*O. fengkaiensis*_KT31538). Moreover, an intraspecific genetic distance of *O. mawphlangensis* was detected in the range of 0.00–0.011 between the specimens from Mizoram and type locality, i.e., Meghalaya.

**RESULTS**

**a) Morphology (also see Mahony 2008)**

*Odorrana mawphlangensis* has some distinguishing morphological characters which are exclusive to this species, such as: the head length > head width, snout length > eye diameter, inter-orbital distance < internasal distance, forelimb length < hand length, colouration of



**Image 1. A—Amplexus between a male and female *Odorrana mawphlangensis* in their natural habitat | B—An adult male *Odorrana mawphlangensis* on a rock beside a narrow stream in the forest. © H.T. Lalremsanga.**

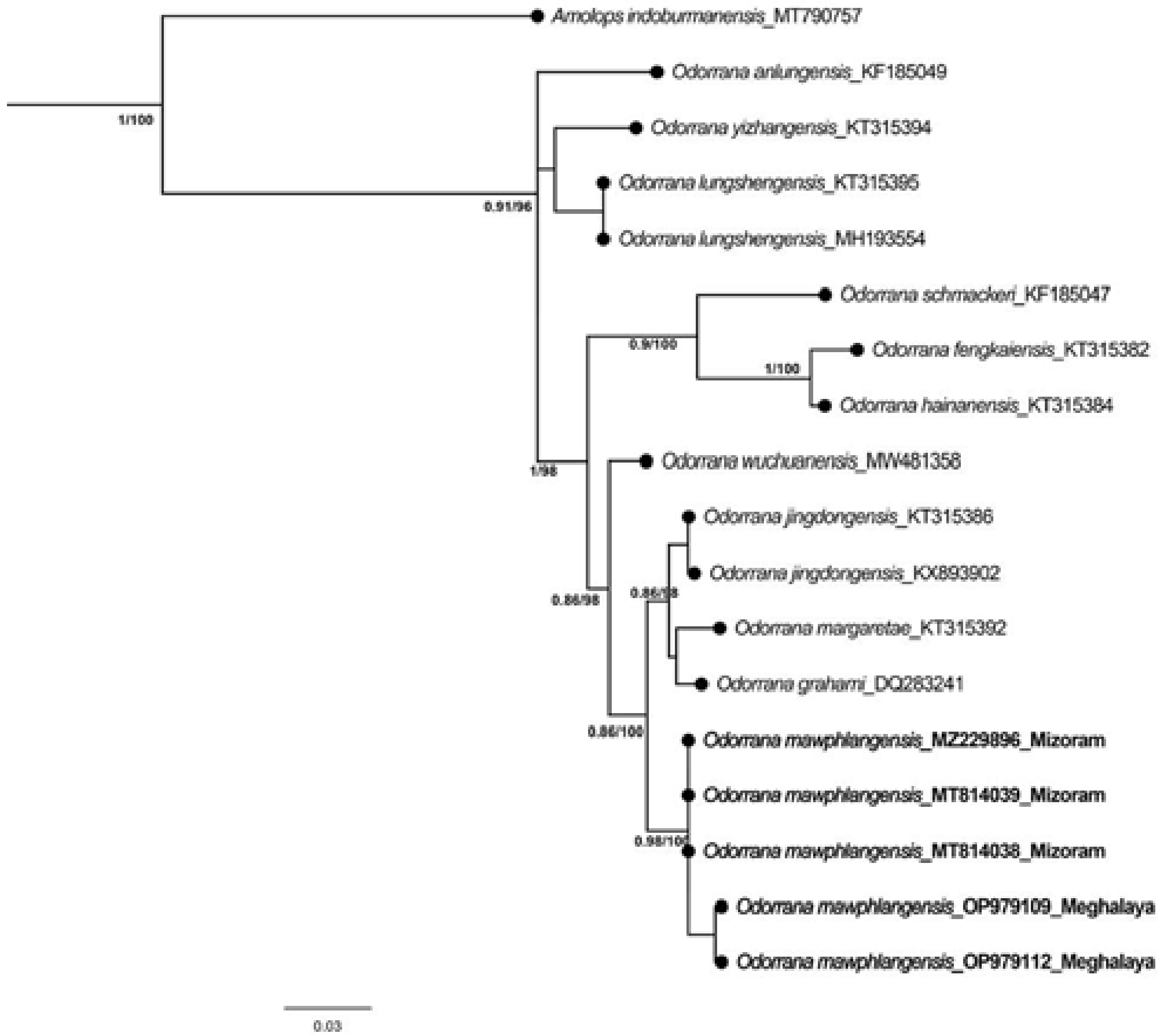


**Figure 2. Phylogenetic Bayesian inference tree of Odorrana based on the 16S rRNA partial gene fragment sequence. Numbers at tree nodes indicated to BI/BS support values, respectively; values above 90 considered well-supported and below 90 considered moderately supported. The species in bold text denote the samples collected and examined from Mizoram and Meghalaya. The GenBank accession numbers have been mentioned alongside the various species.**

the body, which is dorsally primarily green anteriorly, with large randomly spaced brown spots, lip-stripe yellow to bronze/brown in adult. The body colouration of the collected samples was green at the anterior part of the dorsum with large brownish spots randomly spaced and the posterior part of the dorsum was brownish in colour. In all the collected specimens, it was observed that the head is longer than its width (i.e. HL > HW) with the HL/HW ratio of 22.12 : 17.51 and the snout length is longer than the eye diameter (i.e., SL > ED) with the SL/ED ratio of 6.57 : 5.58. Moreover, it was observed that the inter-orbital distance is less than the internasal distance and the length of the forelimb is shorter than the hindlimb length. All these observed morphological parameters indicated that the collected samples were *O. mawphlangensis.* The tympanum diameter (TYD) constituted 60.24% of the eye length (EL). Image 2 depicts a preserved sample of *O. mawphlangensis* (MZMU 138) collected from Mizoram.

From our collected specimens of *O. mawphlangensis,* morphometric analyses resulted in the following comparisons (vs. Chanda 1994; Ao et al. 2003; Mahony 2008):

(i) Snout-vent length (SVL) was in the range of 31.8–94.4 mm. The largest male among the collected specimens had SVL of 80.0 mm. Chanda (1994) provided

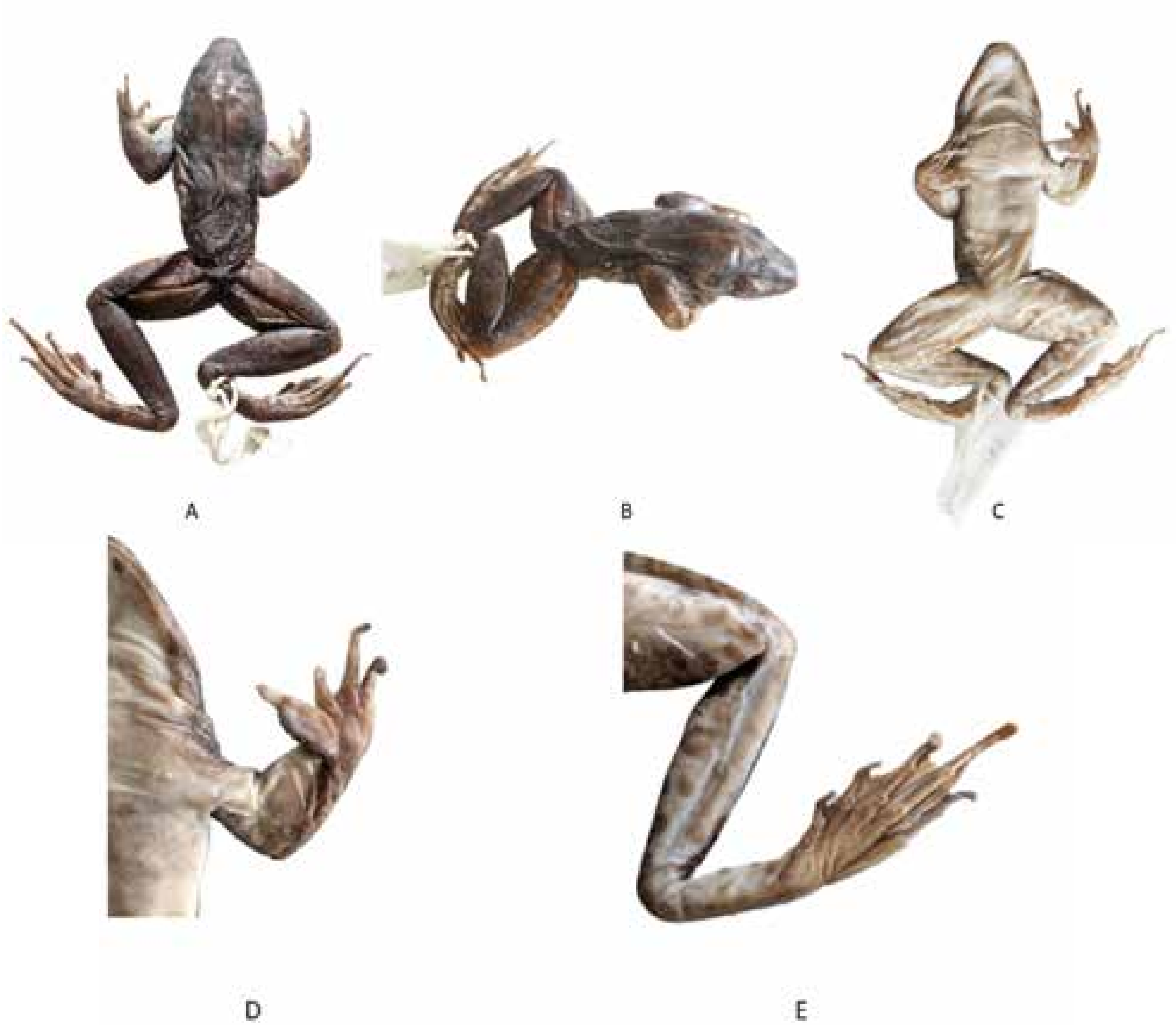


**Image 2. Preserved *Odorrana mawphlangensis* sample (MZMU 138) collected from Hmuifang Community Reserve Forest (Mizoram) showing: A—Dorsal view | B—Lateral view | C—Ventral view | D—Forelimb | E—Hindlimb. © Angshuman Das Tariang.**

SVL in the range of 60.0–90.0 mm. Ao et al. (2003) reported SVL of 80.0 mm in males and a range of 96–106 mm for females while Mahony (2008) redescribed the holotype from Mawphlang Sacred Forest by reporting an adult female with SVL of 84.3 mm.

(ii) Head width (HW) ranged from 11.2–31.7 mm and Head length (HL) ranged from 14.2–41.9 mm. As per Mahony (2008), HW was reported as 31.0 mm and HL as 34.4 mm.

(iii) The range of eye diameter (ED) or eye length (EL) was 3.7–11.2 mm and Mahony (2008) reported ED of 10.1 mm.

Internasal distance (IN) was in the range of 1.7–9.9 mm whereas Mahony (2008) reported it at 10.8 mm.

(iv) Eye-nostril distance (EN) was in the range of 1.9–6.2 mm against 7.1 mm as per Mahony (2008).

(v) The greatest tympanum diameter (TYD) was in the range of 1.9–5.4 mm against 5.3 mm by Mahony (2008).

(vi) The mean inter-orbital distance (IUE) was found to be 3.7 mm which is shorter than the mean internasal space (IN), i.e., 4.4 mm (i.e., IUE < IN).

(vii) The forelimb length (FLL) ranged 5.2–19.7 mm and was shorter in length than the hand length (HAL) which was in the range of 8.0–26.0 mm (i.e., FLL < HAL).

(viii) Tibia length (TL) was observed to be longer than the femur length (FL) (i.e., TL > FL), ranging 16.0–49.7 mm and 14.8–40.1 mm, respectively. Mahony (2008) had reported TL of 51.6 mm and FL of 47.5 mm.

**Table 1. Morphometric measurements (in mm) of the specimens of *Odorrana mawphlangensis* collected from Mizoram (Murlen National Park and Hmuifang Community Reserve Forest) and Meghalaya (Malki Reserve Forest).**

| Locality | Murlen NP | | | | | | | | Hmuifang RF | | Malki RF | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Museum number | MZMU 1836 | MZMU 1995A | MZMU 2129 | MZMU 2856 | MZMU 2858 | MZMU 2859 | MZMU 2861 | MZMU 2866 | MZMU 138 | MZMU 139 | MZMU 3020 | MZMU 3021 |
| SVL | 57.3 | 54.6 | 43.2 | 38.8 | 36.3 | 31.8 | 31.9 | 32.8 | 80.0 | 94.4 | 44.3 | 46.1 |
| HW | 21.3 | 21.0 | 18.7 | 14.4 | 12.1 | 11.8 | 11.2 | 11.2 | 27.8 | 31.7 | 16.9 | 11.9 |
| HL | 25.3 | 21.8 | 22.2 | 17.1 | 14.4 | 15.0 | 14.2 | 15.7 | 37.0 | 41.9 | 20.8 | 20.3 |
| MN | 21.4 | 19.1 | 19.6 | 14.1 | 13.6 | 14.0 | 11.7 | 13.2 | 33.7 | 34.4 | 18.6 | 17.8 |
| MFE | 18.6 | 15.8 | 15.8 | 10.3 | 9.2 | 11.3 | 10.7 | 9.8 | 26.8 | 29.4 | 15.3 | 14.1 |
| MBE | 11.9 | 11.1 | 10.5 | 7.1 | 7.5 | 7.0 | 6.6 | 6.7 | 19.2 | 20.2 | 9.8 | 8.3 |
| IFE | 7.4 | 6.2 | 6.4 | 6.3 | 5.6 | 5.5 | 5.2 | 6.1 | 13.7 | 14.8 | 8.0 | 8.4 |
| IBE | 10.3 | 10.1 | 10.2 | 9.4 | 9.9 | 9.7 | 8.5 | 9.1 | 19.6 | 22.3 | 11.7 | 13.0 |
| IN | 1.7 | 2.2 | 1.8 | 3.5 | 3.4 | 3.5 | 3.6 | 3.6 | 7.8 | 9.9 | 6.0 | 5.5 |
| EN | 3.2 | 3.1 | 2.8 | 2.2 | 2.0 | 1.9 | 2.4 | 2.4 | 6.2 | 6.2 | 3.2 | 3.2 |
| ED | 5.1 | 5.4 | 5.0 | 3.7 | 3.9 | 4.2 | 3.7 | 4.4 | 8.0 | 11.2 | 6.4 | 5.9 |
| SN | 2.3 | 2.7 | 3.2 | 1.9 | 1.9 | 2.2 | 2.0 | 2.4 | 2.9 | 4.5 | 3.0 | 2.7 |
| SL | 6.8 | 6.6 | 7.0 | 4.6 | 5.3 | 4.9 | 4.6 | 5.1 | 8.6 | 11.7 | 7.0 | 6.5 |
| TYD | 4.8 | 4.9 | 3.8 | 2.4 | 2.1 | 2.4 | 1.9 | 2.3 | 4.8 | 5.4 | 3.1 | 2.4 |
| TYE | 1.7 | 1.8 | 1.3 | 2.0 | 1.6 | 0.9 | 0.7 | 1.1 | 2.6 | 2.2 | 1.9 | 1.6 |
| IUE | 2.2 | 2.1 | 1.8 | 3.7 | 3.1 | 2.8 | 2.6 | 4.6 | 4.1 | 7.9 | 4.4 | 4.3 |
| UEW | 3.2 | 3.7 | 3.4 | 3.4 | 2.7 | 2.3 | 2.1 | 2.1 | 6.2 | 6.1 | 3.4 | 3.6 |
| FLL | 8.9 | 8.6 | 9.4 | 9.4 | 7.9 | 5.3 | 5.2 | 6.1 | 16.0 | 19.7 | 9.2 | 10.1 |
| HAL | 14.3 | 11.9 | 11.7 | 11.8 | 9.4 | 8.0 | 8.0 | 9.3 | 18.1 | 26.0 | 13.0 | 12.0 |
| TFL | 10.4 | 7.2 | 7.9 | 7.2 | 6.6 | 4.5 | 4.3 | 6.3 | 10.5 | 17.9 | 7.7 | 8.0 |
| FL | 30.6 | 27.4 | 24.7 | 16.3 | 17.0 | 15.2 | 14.8 | 16.9 | 37.1 | 40.1 | 20.8 | 21.0 |
| TL | 26.7 | 24.6 | 20.4 | 17.8 | 16.0 | 18.4 | 16.4 | 19.0 | 42.9 | 49.7 | 24.4 | 25.6 |
| TFOL | 40.0 | 33.9 | 32.6 | 27.3 | 24.0 | 23.8 | 21.9 | 26.1 | 57.6 | 59.1 | 34.3 | 34.4 |
| FOL | 30.6 | 26.2 | 22.9 | 17.3 | 16.4 | 15.9 | 14.3 | 16.8 | 38.1 | 39.5 | 24.1 | 23.7 |
| FTL | 24.4 | 22.2 | 21.3 | 13.2 | 14.5 | 12.5 | 10.1 | 13.4 | 33.0 | 32.1 | 20.5 | 19.8 |

SVL—Snout-vent length | HW—Head width | HL—Head length | MN—Distance from the back of the mandible to the nostril | MFE—Distance from the back of the mandible to the front of the eye | MBE—Distance from the back of the mandible to the back of the eye | IFE—Distance between the front of the eyes | IBE—Distance between the back of the eyes | IN—Internasal space | EN—Distance from the front of the eye to the nostril | ED—Eye diameter | SN—Distance from the nostril to the tip of the snout | SL—Distance from the front of the eye to the tip of the snout | TYD—Greatest tympanum diameter | TYE—Distance from tympanum to the back of the eye | IUE—Minimum distance between upper eyelids | UEW—Maximum width of inter upper eyelid | FLL—Forelimb length | HAL—Hand length | TFL—Third finger length | FL—Femur length | TL—Tibia length | TFOL—Length of tarsus and foot | FOL—Foot length | FTL—Fourth toe length.

### b) Field observations and comparisons

The largest specimen was a female, catalogued as MZMU 138. From our collected specimens of *O. mawphlangensis,* morphometric analyses have revealed that the largest specimen was obtained from Hmuifang Community Reserve Forest with SVL of 94.4 mm (an adult female) and the smallest specimen belonged to Murlen National Park with SVL of 31.8 mm (a juvenile). A number of adult specimens of *O. mawphlangensis* that were encountered at Malki Reserve Forest and Hmuifang Community Reserve Forest (Image 1A,B). Amplecting behaviour between two adults was also observed (Image 1A).

### c) Phylogenetic Relationships

In phylogenetic reconstructions (Figure 2) using both BI and ML analyses, the trees revealed identical topologies that support the relationships of the genus *Odorrana*. All 17 sequences of *Odorrana* sp. were clustered and formed distinct monophyletic clade from an out-group, *Amolops indoburmanensis* (Figure 2). The samples used for phylogenetic analysis have been mentioned in Table 2. From our analysis, *Odorrana mawphlangensis* nested different from other species

**Table 2. Samples used for phylogenetic analysis with their GenBank accession numbers and other details.**

| Taxa | Voucher number | Locality | Accession number | Reference |
|---|---|---|---|---|
| *A. indoburmanensis* | MZMU 1650 | Mizoram, India | MT790757 | - |
| *O. anlungensis* | HNNU 1008-109 | China | KF185049 | Chen et al. 2013 |
| *O. yizhangensis* | SYSa001870 | China | KT315394 | Wang et al. 2015 |
| *O. lungshengensis* | SYSa002229 | China | KT315395 | Wang et al. 2015 |
| *O. lungshengensis* | 806 | China | MH193554 | Li et al. 2018 |
| *O. schmackeri* | HNNU 0908-349 | China | KF185047 | Chen et al. 2013 |
| *O. fengkaiensis* | SYSa001025 | China | KT315382 | Wang et al. 2015 |
| *O. hainanensis* | SYSa000636 | China | KT315384 | Wang et al. 2015 |
| *O. wuchuanensis* | GZNU20180608019 | China | MW481358 | Luo et al. 2021 |
| *O. jingdongensis* | SYSa002995 | China | KT315386 | Wang et al. 2015 |
| *O. jingdongensis* | IEBR 3948 | Vietnam | KX893902 | Ngo et al. 2016 |
| *O. margaretae* | SYSa002317 | China | KT315392 | Wang et al. 2015 |
| *O. grahami* | CAS 207504 | China | DQ283241 | Frost et al. 2006 |
| *O. mawphlangensis* | MZMU 2267 | Mizoram, India | MZ229896 | - |
| *O. mawphlangensis* | MZMU 139 | Mizoram, India | MT814039 | - |
| *O. mawphlangensis* | MZMU 138 | Mizoram, India | MT814038 | - |
| *O. mawphlangensis* | MZMU 3021 | Meghalaya, India | OP979109 | - |
| *O. mawphlangensis* | MZMU 3020 | Meghalaya, India | OP979112 | - |

with well supported bootstrap values (Figure 2; Table 3).

**d) Conservation Status**

With the recent amendment of the Wildlife Protection Act in 2022, 37 species of amphibians have been protected under Schedule-I and Schedule-II categories. *Odorrana mawphlangensis* has been included in Schedule-II category. This species is currently listed as 'Data Deficient' and needs further research and assessment (IUCN 2023).

## DISCUSSIONS

There were numerous brief accounts and reports on the occurrence of this species in the past (Chanda 1990; Sarkar et al. 1992; Dutta 1997; Chanda 2002; Ao et al. 2003; Devi & Shamungou 2006; Sarkar & Ray 2006; Das & Dutta 2007; Ahmed et al. 2009; Matthew & Sen 2010; Lalremsanga 2017; Siammawii et al. 2021). However, these studies were reports solely based on the external morphological characters and a detailed phylogenetic analysis was not performed in any of the studies. Thus, there was confusion on its identity and a detailed confirmation was awaited.

Mahony (2008) redescribed the species based on re-examination of its holotype, illustrated the same and transferred it to the genus *Odorrana*. Mahony (2008) also suggested that it might be conspecific with *O. grahami,* based on some morphological similarities. He stated that further studies on the phylogenetic position and distinction are required so as to confirm the monophyly as well as establishing the taxonomic identity of the species involved.

In the present study, based on 16s rRNA data, we ratify the generic allocation of *Odorrana mawphlangensis* (see Mahony 2008) and establish that its closest sister taxon is the Yunnanese species *O. jingdongensis* (Fei et al. 2001) with a genetic distance of 3.7%. The hypothesis that *O. mawphlangensis* might be a junior synonym of *O. grahami* (Mahony 2008) is not supported from this study. It is noteworthy that *O. mawphlangensis* forms a distinct clade separate from sister taxa *O. grahami* and *O. jingdongensis* (Boulenger 1917; Fei et al. 2001).

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**Table 3. The uncorrected K2p -distance of 16S rRNA partial gene sequence among members of the *Odorrana* sequences.**

| | Taxon | K2p distance | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 1 | *O. mawphlangensis*_ OP979109_Meghalaya | | | | | | | | | | | | | | | | | |
| 2 | *O. mawphlangensis*_ OP979112_Meghalaya | 0.004 | | | | | | | | | | | | | | | | |
| 3 | *O. mawphlangensis*_ MZ229896_Mizoram | 0.011 | 0.011 | | | | | | | | | | | | | | | |
| 4 | *O. mawphlangensis*_ MT814039_Mizoram | 0.011 | 0.011 | 0.000 | | | | | | | | | | | | | | |
| 5 | *O. mawphlangensis*_ MT814038_Mizoram | 0.011 | 0.011 | 0.000 | 0.000 | | | | | | | | | | | | | |
| 6 | *O. fengkaiensis*_KT315382 | 0.110 | 0.110 | 0.096 | 0.096 | 0.096 | | | | | | | | | | | | |
| 7 | *O. hainanensis*_KT315384 | 0.108 | 0.108 | 0.093 | 0.093 | 0.093 | 0.020 | | | | | | | | | | | |
| 8 | *O. jingdongensis*_KT315386 | 0.037 | 0.037 | 0.025 | 0.025 | 0.025 | 0.099 | 0.092 | | | | | | | | | | |
| 9 | *O. wuchuanensis*_MW481358 | 0.049 | 0.049 | 0.036 | 0.036 | 0.036 | 0.091 | 0.083 | 0.034 | | | | | | | | | |
| 10 | *O. margaretae*_KT315392 | 0.051 | 0.051 | 0.039 | 0.039 | 0.039 | 0.120 | 0.112 | 0.022 | 0.043 | | | | | | | | |
| 11 | *O. yizhangensis*_KT315394 | 0.083 | 0.083 | 0.070 | 0.070 | 0.070 | 0.112 | 0.099 | 0.068 | 0.060 | 0.073 | | | | | | | |
| 12 | *O. lungshengensis*_KT315395 | 0.078 | 0.078 | 0.065 | 0.065 | 0.065 | 0.088 | 0.076 | 0.063 | 0.055 | 0.073 | 0.041 | | | | | | |
| 13 | *O. grahami*_DQ283241 | 0.042 | 0.042 | 0.029 | 0.029 | 0.029 | 0.110 | 0.102 | 0.018 | 0.034 | 0.022 | 0.078 | 0.073 | | | | | |
| 14 | *O. schmackeri*_KF185047 | 0.093 | 0.093 | 0.079 | 0.079 | 0.079 | 0.076 | 0.073 | 0.092 | 0.084 | 0.102 | 0.104 | 0.086 | 0.087 | | | | |
| 15 | *O. jingdongensis*_KX893902 | 0.039 | 0.039 | 0.027 | 0.027 | 0.027 | 0.102 | 0.094 | 0.002 | 0.036 | 0.020 | 0.070 | 0.065 | 0.020 | 0.095 | | | |
| 16 | *O. lungshengensis*_MH193554 | 0.078 | 0.078 | 0.065 | 0.065 | 0.065 | 0.088 | 0.076 | 0.063 | 0.055 | 0.073 | 0.041 | 0.000 | 0.073 | 0.086 | 0.065 | | |
| 17 | *O. anlungensis*_KF185049 | 0.082 | 0.082 | 0.068 | 0.068 | 0.068 | 0.105 | 0.100 | 0.071 | 0.068 | 0.079 | 0.061 | 0.056 | 0.076 | 0.100 | 0.069 | 0.056 | |
| 18 | *Amolops indoburmanensis*_ MT790757 | 0.186 | 0.186 | 0.168 | 0.168 | 0.168 | 0.180 | 0.177 | 0.171 | 0.165 | 0.177 | 0.160 | 0.161 | 0.172 | 0.186 | 0.168 | 0.161 | 0.171 |

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ARTICLE



# Phenotypic and genotypic variability in the Snowtrout *Schizothorax richardsonii* (Cypriniformes: Cyprinidae) wild populations from central Himalayan tributaries of the Ganga River basin

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**Abstract:** *Schizothorax richardsonii* (Gray, 1832), commonly known as Snowtrout, is widely distributed in the Himalayan region of India, particularly in the Ganga River basin tributaries, including Mandakini, Nandakini Pindar, and Alaknanda. Habitat isolation among river ecosystems often drives phenotypic and genotypic differences, leading to changes in fish population structure. In the present study, intraspecific phenotypic and genetic variation in Snowtrout populations from tributaries of the Ganga River basin was assessed to understand their diversity and evolutionary dynamics. Phenotypic and genotypic data were analyzed using a geometric morphometrics approach and the mitochondrial COX1 gene marker. One-hundred-and-ninety specimens were collected from four tributaries of the Ganga River basin. The canonical variates analysis (CVA) confirmed the existence of four phenotypically distinct populations within the Ganga River basin. Principal component one (PC1) based shape wireframe revealed the positions of the pelvic fin, caudal peduncle, and anal fin origin to be important parameters in differentiating these phenotypes. The COX1 sequences revealed three polymorphic sites and five haplotypes overall, including the highest genetic diversity in the Mandakini population (h = 0.67 & $\pi$ = 0.001). Phylogenetic analysis and Fst-based heatmap showed clear genetic differentiation among the four populations. The distinct phenotypic and genotypic patterns observed among *S. richardsonii* populations may reflect the combined effects of ecological adaptation and restricted gene flow resulting from anthropogenic barriers, such as dams and altered flow regimes. This study represents the first effort to examine the phenotypic and genotypic variability of *Schizothorax richardsonii* using an integrated approach that combines geometric morphometrics with the mitochondrial COX1 gene marker, focusing on populations from the Ganga River basin. The observed variations among *S. richardsonii* populations highlight the importance of maintaining genetic diversity in future management and conservation planning.

**Keywords:** Canonical variates analysis, environmental isolation, evolutionary adaptation, genetic divergence, geometric morphometrics, habitat fragmentation, intraspecific diversity, mitochondrial COX1 marker, phylogenetic differentiation, principal component analysis.

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**Author contributions:** YK collected the fish samples, analyzed the generated data, and wrote the manuscript. MS guided during the isolation and sequencing of the DNA samples of the fish. DS supervised the study, reviewed it, and finalized the manuscript.

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## INTRODUCTION

Fish contribute 18% of animal protein intake globally (Devlin & Nagahama 2002), and in 2020 worldwide aquatic production reached approximately 178 million tonnes, as reported by the Food and Agriculture Organization of the United Nations (FAO 2022). *Schizothorax richardsonii,* also known as "Asela" in central Himalaya, is a member of the Cypriniformes order within the Cyprinidae family and the Schizothoracinae subfamily (Mir et al. 2013). It is found in the cold waters of the rivers, streams, tributaries, and lakes of the Himalayan and sub-Himalayan mountains and foothills at elevations of 1,000–3,300 m, is an important cold-water fish species widely distributed across India, Tibet, Nepal, Bhutan, Pakistan, and Afghanistan (Vishwanath 2010; Qi et al. 2012; Xiao et al. 2020). In the recent past, populations of this species have been under severe threat due to rapid industrial growth, alterations in the natural habitat due to physicochemical changes, and various human activities, leading to a significant decline in numbers and genetic diversity (Mir et al. 2013).

Morphometry is one of the most commonly utilized and cost-effective methods for assessing fish stocks and examining phenotypic variation. Many fish stocks have been successfully discriminated by traditional and truss morphometric approaches, which account for size and shape variation, but have recently been criticized for their concentration along the body axis with depth, breadth measurements, and size (Turan et al. 2004; Ingram 2015; Reiss & Grothues 2015). To overcome the limitations of traditional and truss-based morphometric methods, image-processing techniques like 'Geometric Morphometrics' have been developed to analyze shape variations across different populations. This approach has proved effective in identifying stocks, population structure, and species identification. It also enhances the biological understanding necessary for effective fish stock management (Cadrin et al. 2005). It has been predicted that rates of morphological and genetic changes should be positively correlated with rates of species emergence in several evolutionary theories (Rabosky 2013). Thus, in addition to the morphometric study, a genetic assessment was conducted to provide a comprehensive understanding of the stock structure of *S. richardsonii*. Mitochondrial DNA (mtDNA) marker, particularly the cytochrome oxidase subunit I (COX1) gene, is a powerful tool for genetic analysis in fish (Ward et al. 2005). The COX1 gene is an established and reliable genetic marker for identifying highly diversified ichthyofauna at the molecular level. It provides valuable information on genetic diversity and phylogenetic relationships among populations (Lakra et al. 2011).

In recent years, several studies have highlighted the decline in populations of *S. richardsonii* and the need for urgent conservation measures (Sharma et al. 2021). These studies have underscored the importance of preserving genetic diversity as a buffer against environmental changes and anthropogenic pressures. The genetic diversity of *S. richardsonii* in various river systems has been linked to their resilience and ability to adapt to changing conditions (Mir et al. 2013). However, there is limited information on the phenotypic plasticity and genetic structure of *S. richardsonii* in the Indian Himalaya, necessitating comprehensive studies in this region (Negi & Negi 2010; Sharma & Metha 2010; Mir et al. 2013; Rajput et al. 2013; Dwivedi 2022).

In this study, an integrated approach combining geometric morphometrics with the mitochondrial COX1 gene marker was used to assess the phenotypic and genotypic variability of *S. richardsonii* from the Indian Himalayas, specifically in tributaries of the Ganga River basin. This study represents the first attempt to investigate these variations in this region. The findings will help clarify the phenotypic and genotypic complexity of the stocks, which may aid in developing effective management plans for these stocks. Similar integrative approaches combining morphometric and genetic data have informed conservation for native fish species such as *Silonia silondia* (Mandal et al. 2021), in Indian river systems.

## MATERIALS AND METHODS

### Collection and identification of samples

Freshly dead fish specimens were collected from local fishermen from February 2022 to April 2023. One hundred ninety adult specimens were collected from four tributaries of the Ganga River: Mandakini, Nandakini, Pindar, and Alaknanda (Figure 1). The taxonomic keys of Day (1878), Talwar & Jhingran (1991), and Mirza (1991) were used to identify the collected specimens. All the specimens were collected after the spawning season and before the breeding season. After photographs were taken for morphometric analysis, the fish specimens were preserved in 10% formalin. For molecular analysis, 100 mg tissue samples from dorsal muscle and fins were preserved in a 1:5 ratio with 95% ethanol and stored at $4^{0}$C. Voucher specimens of *S. richardsonii* preserved in a 10% formalin solution were also deposited in the museum of the Department of Zoology, HNB Garhwal

University, Srinagar (Garhwal), for future reference.

**Morphological analysis**

**Sample collection and data generation**

Collected specimens were cleaned under running water, dried with blotting paper, and placed on a flat surface with laminated graph paper as the background for digital imaging. The fins were erected to aid in clear display of insertion points, and each specimen was assigned a unique identification code. A Nikon D3400 digital camera was used to capture lateral images of the left side of each specimen. To maintain consistency and minimize errors, all photographs were taken by the same individual from the same angle and height. Further morphometric data were generated by employing fourteen landmarks on lateral side photographs of each fish (Image 1). This data was generated with the help of software tpsUtil ver. 1.52 (Rohlf 2008a) and tpsDig ver. 2.16 (Rohlf 2008b). The landmarks-based data were converted to shape coordinates through Procrustes superimposition (Rohlf & Slice 1990), standardizing each specimen to unit centroid size, which estimates overall body size (Bookstein 1991).

**Statistical procedures**

The morphometric data were analyzed to identify and describe potential morphological differences among the four populations. To focus solely on shape information, procrustes superimposition was used to remove variations related to size, position, and orientation (Rohlf & Slice 1990; Bookstein 1991). Procrustes ANOVA was conducted to assess the significance of overall size and shape variations. Shape variables were then used for further analysis. Principal component analysis (PCA) was employed to investigate shape variation's key characters, and explore relationships among the specimens (Veasey et al. 2001). Canonical variates analysis (CVA) was used to identify groups of populations, and discriminant function

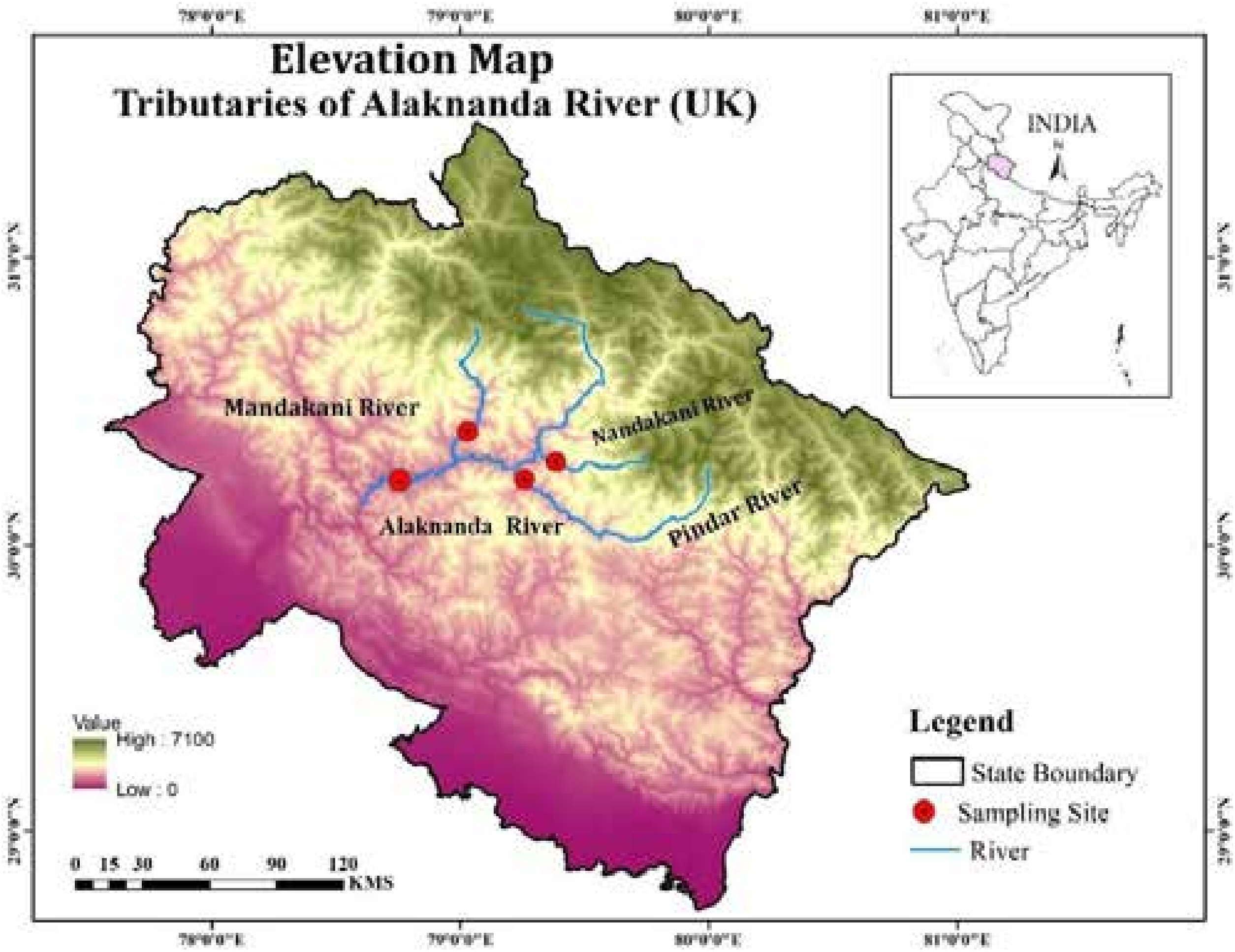


**Figure 1. Map showing four sampling sites on the tributaries of the Ganga River basin.**

analysis (DFA) was also applied to compare body shape differences between the populations. Additionally, specimens were classified into their original groups. All analyses were conducted using MorphoJ version 1.06d (Klingenberg 2011), a software package designed for geometric morphometrics.

### Molecular analysis

**DNA extraction, amplification, and sequencing:** Approximately, 25 mg of tissue was utilized for DNA isolation using a modified version of the standard phenol: chloroform: isoamyl alcohol method, with some adjustments made during the initial homogenization step. After DNA isolation, the DNA pellet was dissolved in TE buffer, which consists of a 10 mM Tris–HCl and 0.1 mM EDTA solution with a pH of 8. In the PCR reaction for COX1 amplification, a 50 µl volume was used. The reaction mixture included 10X Taq polymerase buffer (5 µl), 50 mM $MgCl_2$ (2 µl), 0.05 mM dNTP (0.25 µl), 0.01 mM primer (0.5 µl), Taq polymerase (1.5 IU), and 200 ng genomic DNA template (2 µl). Amplifications were carried out in the Veriti 96 fast thermal cycler from Applied Biosystems, Inc., USA. The primer pair utilized for the COX1 was FishF1 5'TCAACCAACCACAAAGACATTGGCAC3' and FishR15'TAGACTTCTGGG TGGCC AAAGAATCA3' (Ward et al. 2005). The temperature conditions for PCR for COX1 involve an initial denaturation period of 3 minutes at $94^0$ C. Following the initial denaturation, there are 35 cycles of 1 min at $94^0$ C, followed by annealing at $54^0$ C for 45 s, extension at $72^0$ C for 1 min, and final extension at $72^0$ C for 10 min. A 1.5% agarose gel stained with ethidium bromide was prepared to visualize the PCR products of COX1 using a gel documentation system (Biovis). The PCR products were sequenced using the di-deoxynucleotide chain termination method, as described by Sanger et al. (1977). The sequencing was performed on an automated ABI-3500 Genetic Analyzer. The PCR products were fluorescently labelled using the BigDye Terminator V.3.1 Cycle Sequencing Kit (Applied Biosystems, Inc.). The composition of the cycle sequencing PCR reaction of 10 µl involved the use of Big Dye reaction mix (2.5 ×) 4 µl, sequencing buffer (5 ×) 2 µl, purified PCR product (50 ng/µl) 1 µl, primer (10 µM) 0.5 µl, and nuclease-free water 2.5 µl. The PCR cycle sequencing conditions involved a series of temperature changes to facilitate amplification, i.e., 25 cycles of $96^0$C for 20 s, $50^0$C for 15 s, and $60^0$C for 4 min. This work was carried out at the DNA Barcoding Laboratory of the Indian Council of Agricultural Research (ICAR) National Bureau of Fish Genetic Resources (NBGFR) in Lucknow, India.

### Genetic data analysis

For the analysis of sequence composition, genetic variation, and constructing a phylogenetic tree, the COX1 gene of all 12 samples from the Ganga River basin was sequenced. The forward sequence and inverted (reversed and complemented) reverse sequences were aligned to make a consensus sequence for each sample. Ambiguous bases were checked manually against the raw sequencing electropherogram files and corrected accordingly. Sequence alignment was performed using Clustal-W, included in the Molecular Evolutionary Genetics Analysis (MEGA) software version 11 (Tamura et al. 2021). The obtained consensus sequences were blasted in the National Centre for Biotechnology Information (NCBI) GenBank for the nearest similar sequence matches and submitted to NCBI GenBank. The accession numbers for the sequences range from PQ134998 to PQ135009 (Table 5). For phylogenetic analyses, COX1 partial gene sequences of *Schizothorax richardsonii* populations were generated in this study, along with additional sequences retrieved from NCBI (Table 5). Phylogenetic trees were constructed using the maximum likelihood (ML) method in MEGA 11 with 1000 bootstrap replications. The best-fit nucleotide substitution model was selected based on the Akaike information criterion (AIC) in MEGA X, and the Hasegawa-Kishino-Yano (HKY) model was identified as optimal. Since the analysis was based only on the COX1 gene, codon partitioning ($1^{st}$, $2^{nd}$, and $3^{rd}$ positions) was applied to account for variation in substitution rates across codons. Further haplotype diversity, nucleotide diversity, genetic differentiation, Fst values, and demographic history were calculated using DnaSP v.5.10.01 (Librado & Rozas 2009) and Arlequin 3.5.2.2 (Excoffier & Lischer 2010). Heat maps showing genetic differentiation among populations were generated using pairwise Fst scores from an online database (http://www.hiv.lanl.gov/content/ sequence/HEATMAP/ heatmap.html).

## RESULTS

### Geometric morphometrics analyses

A total of 190 fish specimens were analyzed, comprising 87 males and 103 females, with 50 specimens each from the Mandakini, Nandakini, and Pindar rivers. Forty specimens were collected from the Alaknanda River. Shape variations were examined using coordinates derived from a two-dimensional landmark dataset and aligned through Procrustes transformation. This alignment process removed size effects, as indicated by the Procrustes ANOVA results, which revealed a non-significant difference in overall size (F = 2.37, p > 0.05) but a significant difference in shape coordinates (F = 4.52, p < 0.05) among sites. This suggests that size-related variation was largely minimized. Partial least squares (PLS) analysis of the superimposed shapes and log centroid sizes revealed a significant correlation (R = 0.62; p < 0.05) between groups, indicating a notable positive relationship between shape and size. In PCA, the first two PCs explained 52.5% of the total variance, with PC1 accounting for 36.1% and PC2 accounting for 16.4% (Figure 4). Most variations observed in the shape wireframe based on PC1 were related to landmarks 7, 8, 9, 10, and 12 (Figure 5). However, there was considerable overlap among populations along the first and second PC axes in the PCA plot (Figure 4), indicating minimal shape variation between them. Further analyses were performed using CVA and DFA. The shape coordinate data yielded three CVs. The first Canonical Variate (CV1) explained 57.91% of the total variance, while the second and third canonical variates (CV2 and CV3) accounted for 24.29% and 17.79%, respectively (Table 1). The CVA plot revealed a clear separation between populations based on shape (Figure 5). The Mahalanobis distances (Table 2) and Procrustes distances (Table 3) extracted from CVA were found to be significant (p < 0.001) among all four populations of *S. richardsonii* from Alaknanda, Mandakini, Nandakini, and Pindar Rivers, indicating shape heterogeneity among the populations of these four tributaries.

The DFA accurately classified 87.4% of individuals into their original groups. A cross-validation test using the leave-one-out procedure confirmed that 73.7% of individuals were correctly classified into their original groups. Moderate mixing of individuals was also observed between the Alaknanda & Mandakini rivers,

**Table 1. Eigenvalues and total variance explained by three canonical variates extracted from four riverine populations of *Schizothorax richardsonii*.**

| CVs | Eigenvalues | % Variance | Cumulative % |
|---|---|---|---|
| CV1 | 2.52177150 | 57.910 | 57.910 |
| CV2 | 1.05795057 | 24.295 | 82.204 |
| CV3 | 0.77493328 | 17.796 | 100.000 |

**Table 2. Mahalanobis distances (lower diagonal) and p-value (upper diagonal) of canonical variate analysis among *Schizothorax richardsonii* populations.**

| | Mandakini | Nandakini | Pindar | Alaknanda |
|---|---|---|---|---|
| **Mandakini** | | < 0.0001 | < 0.0001 | < 0.0001 |
| **Nandakini** | 3.5456 | | < 0.0001 | < 0.0001 |
| **Pindar** | 2.6739 | 3.3538 | | < 0.0001 |
| **Alaknanda** | 3.1472 | 4.4769 | 2.8788 | |

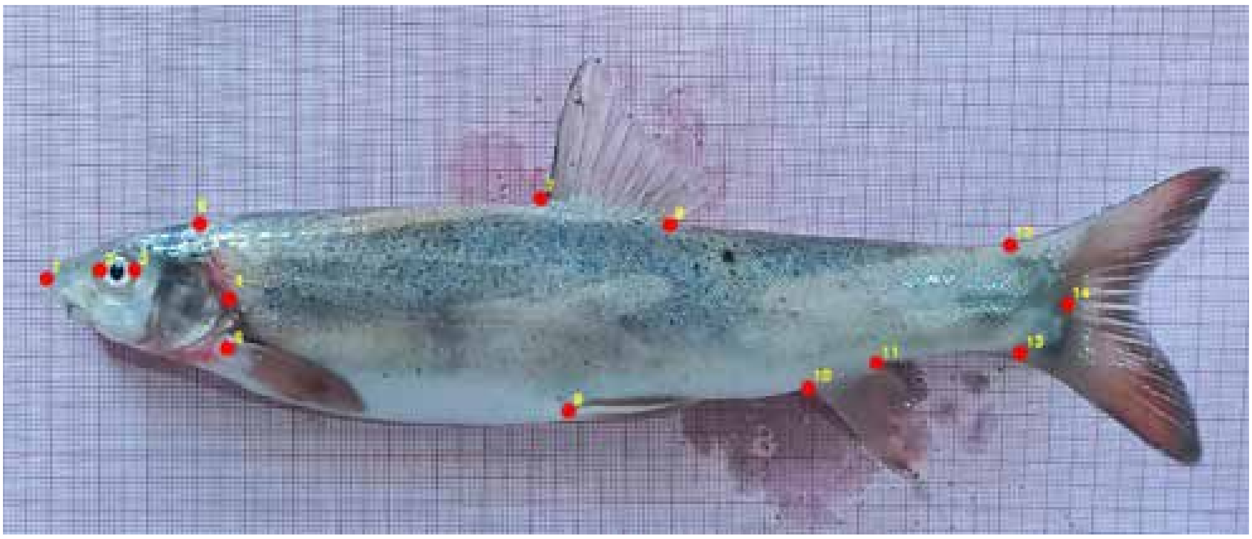

**Image 1. Image of *Schizothorax richardsonii* showing the 14 landmarks used to compare among the populations: 1—tip of snout | 2—anterior border of the eye | 3—posterior border of the eye | 4—posterior border of operculum | 5—forehead (end of frontal bone) | 6—pectoral-fin origin | 7—dorsal fin origin | 8—pelvic fin origin | 9—dorsal fin termination | 10—origin of anal fin | 11—termination of anal fin | 12—dorsal side of caudal peduncle | 13—ventral side of caudal peduncle | 14—termination of lateral line.**

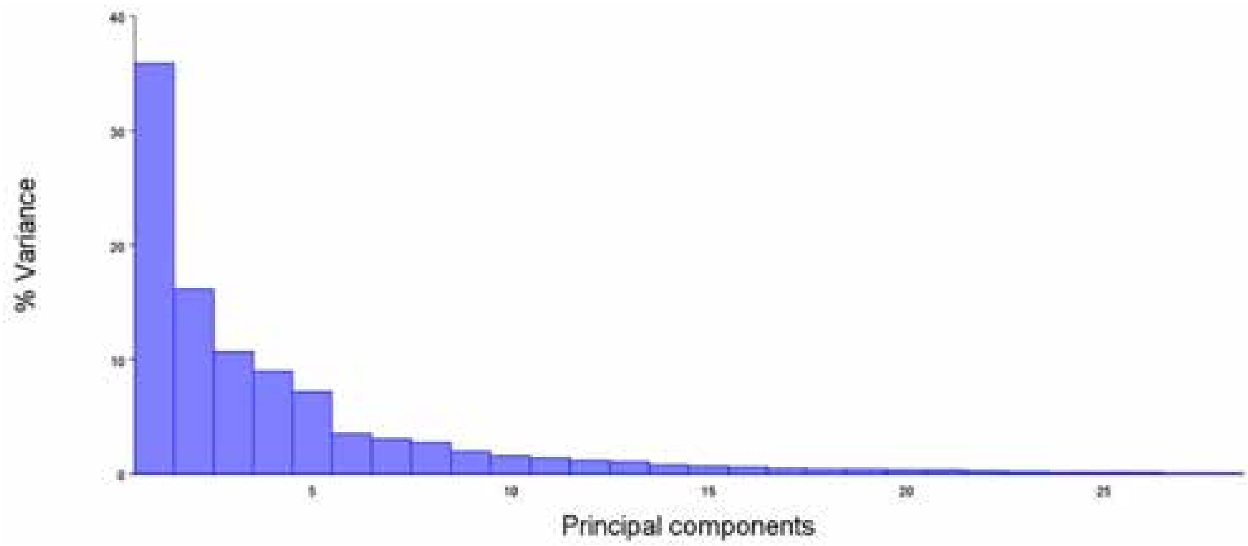


**Figure 2. Scree plot of percentage variance and principal components in *Schizothorax richardsonii*.**

PC1

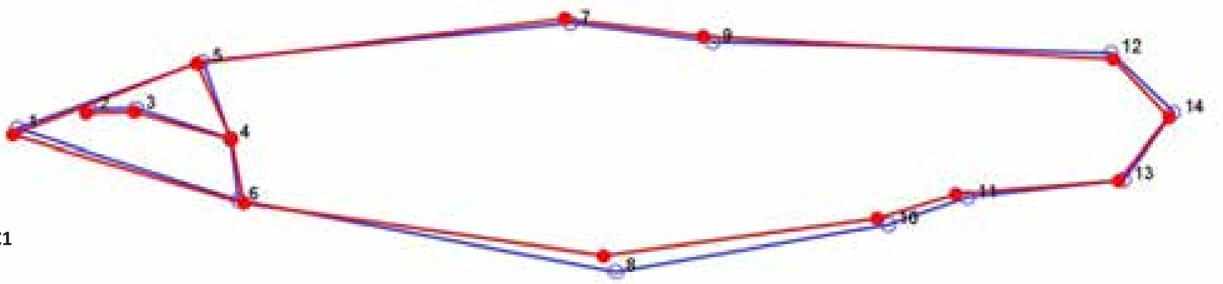

**Figure 3. Wireframes displaying the shape changes associated with PC1 of *Schizothorax richardsonii* populations; red wireframe shows the original position of landmarks; blue wireframe shows variation in landmark position.**

the Nandakini & Mandakini rivers, and the Nandakini & Pindar rivers. A lower level of mixing was observed between individuals from the Alaknanda & Nandakini, and the Alaknanda & Pindar rivers (Figure 6). These findings were congruent with the variations depicted by the deformed shape wireframe of the average shape, which highlighted differences among the four populations of *S. richardsonii.* The shape differences observed between populations of the Alaknanda and Mandakini rivers were primarily based on landmarks 6 and 3–4; for Alaknanda and Nandakini populations 3–4, 7, 8, and 9; for Alaknanda and Pindar populations variations were seen at landmarks 2–3, 7, 8, and 9; differences between Mandakini and Nandakini populations were based on landmarks 6, 7, 8, 9, 12, 13, and 3–4; for Mandakini and Pindar populations 2–3, 7, 8, 9, 12, and 13; lastly for Nandakini and Pindar 2–3, 3–4, 6, and 8 (Figure 7). It was observed that most of the variations occurred in the diameter of the eye, the anterior and posterior origins of the dorsal fin, and the origins of the pelvic and caudal fin. These morphometric measurements indicate that they are useful for describing morphological variation and offer insights into population distinctiveness within the tributaries of the Ganga River basin. The CVA results aligned with the DFA results, highlighting variations in body shape among the *S. richardsonii* populations. Overall, both analyses indicated the presence of four distinct populations of *S. richardsonii* in the selected rivers, based on their shape: 1. Alaknanda, 2. Mandakini, 3. Nandakini, and 4. Pindar.

**Genetic diversity and phylogenetic tree**

After excluding the primer sequences and performing equal-length alignment, each sequence was 655 bp. No insertions, stop codons, or deletions were detected, confirming that all amplified sequences derived from a functional mitochondrial COX1 gene. Analysis of the COX1 sequences revealed the average nucleotide composition

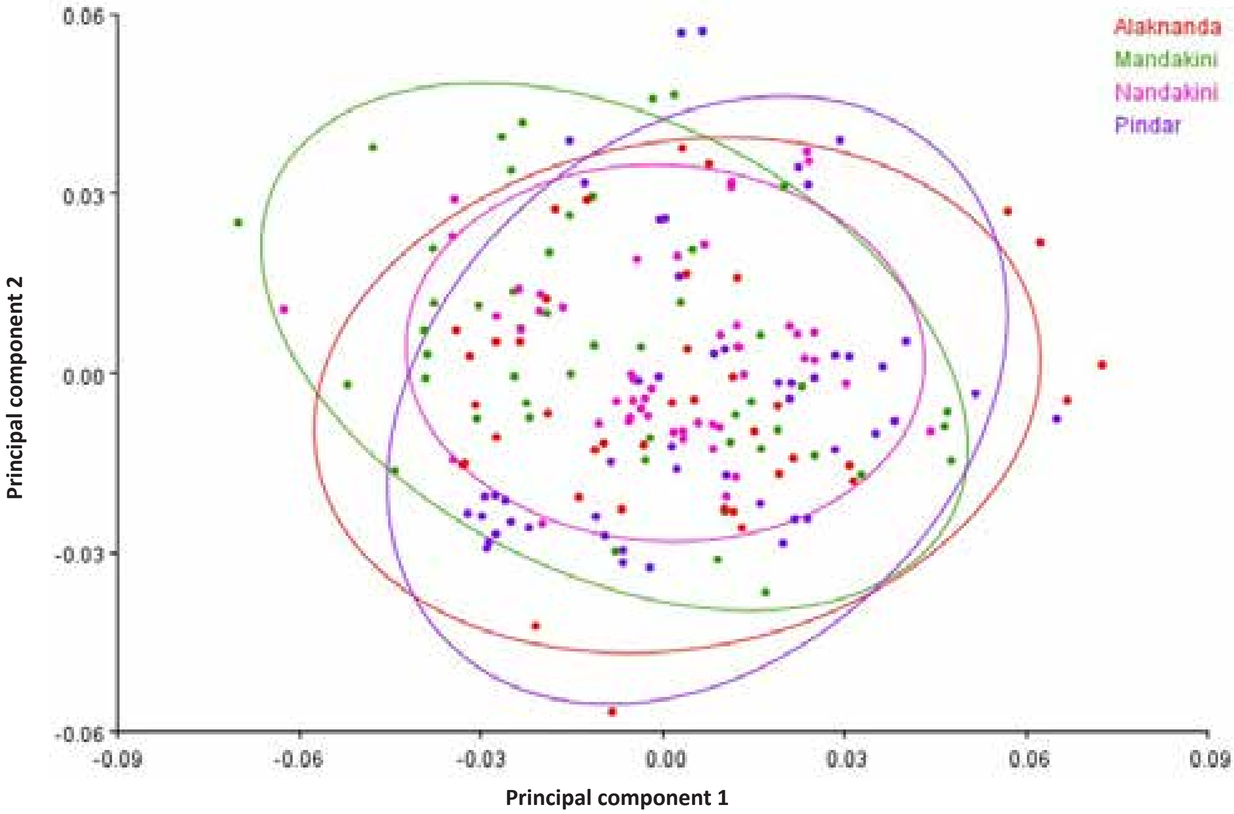


**Figure 4. The principal component analysis plot of *Schizothorax richardsonii*, showing loadings of each sample on the first two principal components.**

**Table 3. Procrustes distances (lower diagonal) and p-value (upper diagonal) of canonical variates analysis among *Schizothorax richardsonii* populations.**

| | Mandakini | Nandakini | Pindar | Alaknanda |
|---|---|---|---|---|
| **Mandakini** | | < 0.0001 | < 0.0001 | < 0.0001 |
| **Nandakini** | 0.0156 | | < 0.0001 | < 0.0001 |
| **Pindar** | 0.0222 | 0.0165 | | < 0.0001 |
| **Alaknanda** | 0.0214 | 0.0273 | 0.0227 | |

**Table 4. Intrapopulation, haplotype (individuals' frequency), haplotype (h), and nucleotide (π) diversities for the COX1 mitochondrial partial gene in four riverine populations of *Schizothorax richardsonii*.**

| Locations | Sample size (N) | Haplotype (individuals frequency) | Haplotype diversity (h) | Nucleotide diversity (л) |
|---|---|---|---|---|
| Mandakini | 3 | Hap_1(1), Hap_2 (2) | 0.66667 | 0.00105 |
| Nandakini | 3 | Hap_1 (1) | 0.00000 | 0.0000 |
| Pindar | 3 | Hap_4 (3), | 0.20000 | 0.0060 |
| Alaknanda | 3 | Hap_5 (3) Hap_2 (1) | 0.40000 | 0.00063 |
| Overall | 12 | Hap_1-Hap5 | 0.844848 | 0.00212 |

in *S. richardsonii* from the Ganga River tributaries as 25.79% (A), 27.79% (T/U), 28.17% (C), and 18.25% (G). The COX1 gene analysis identified three variable polymorphic sites and three parsimony-informative sites in the specimens from the Ganga River tributaries. Five distinct haplotypes were observed among the *S. richardsonii* populations in the present study. The highest haplotype (h) diversity and nucleotide diversity (л) (0.66667 & 0.00105) were found in the Mandakini River (Table 4). Further, a phylogenetic tree was constructed by MEGA 11, using the maximum likelihood (ML) method with 1000 bootstrap replications, based on the Hasegawa-Kishino-Yano (HKY) model, keeping *Rita rita* (NC023376) as an outgroup to provide an external reference point for the tree root. While other highly specialized Schizothoracine (NC025650, NC024537) and specialized Schizothoracine (NC021420) species were incorporated to strengthen the evolutionary framework and improve the resolution of relationships within *Schizothorax richardsonii* populations. The

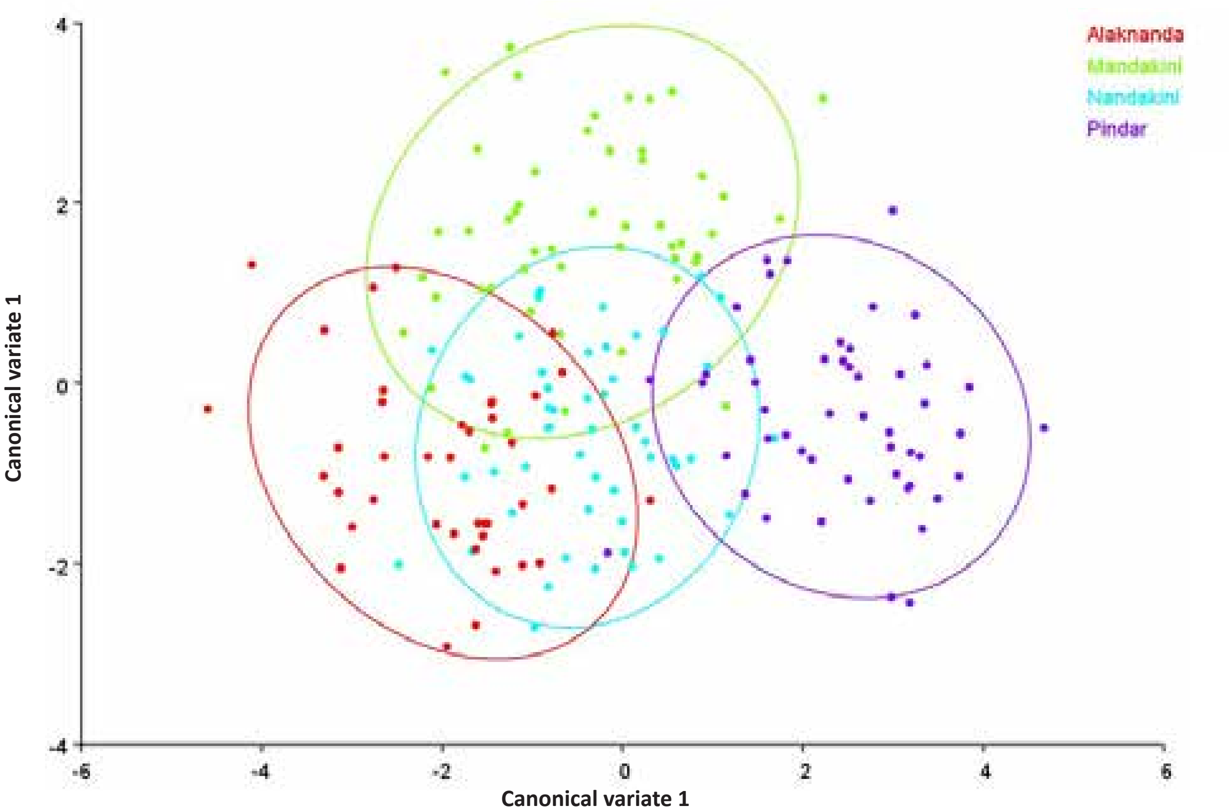


**Figure 5. Geometric morphometric-based canonical variates analysis plot of *Schizothorax richardsonii* showing the frequency of specimen distribution in respective groups on the first two axes.**

**Table 5. Accession numbers and voucher specimen numbers of *Schizothorax richardsonii* individuals collected from tributaries of the Ganga River Basin, and reference sequences retrieved from NCBI.**

| | Accession No. | Voucher specimen |
|---|---|---|
| 1 | PQ134998 | SrHNBGUM1 |
| 2 | PQ134999 | SrHNBGUM2 |
| 3 | PQ135000 | SrHNBGUM3 |
| 4 | PQ135001 | SrHNBGUN3 |
| 5 | PQ135002 | SrHNBGUN5 |
| 6 | PQ135003 | SrHNBGUN6 |
| 7 | PQ135004 | SrHNBGUP1 |
| 8 | PQ135005 | SrHNBGUP4 |
| 9 | PQ135006 | SrHNBGUP8 |
| 10 | PQ135007 | SrHNBGUA2 |
| 11 | PQ135008 | SrHNBGUA4 |
| 12 | PQ135009 | SrHNBGUA7 |
| 13 | OQ130193 | *Schizothorax richardsonii* (NCBI) |
| 14 | PV643387 | *Schizothorax richardsonii* (NCBI) |
| 15 | PV643388 | *Schizothorax richardsonii* (NCBI) |
| 16 | PV643389 | *Schizothorax richardsonii* (NCBI) |
| 17 | PV643390 | *Schizothorax richardsonii* (NCBI) |

ML phylogenetic tree based on mitochondrial COX1 sequences revealed four distinct groups within a single clade of *S. richardsonii*, representing populations from the Alaknanda, Mandakini, Pindar, and Nandakini rivers. Notably, NCBI retrieved sequences of *S. richardsonii* clustered with the Alaknanda and Nandakini populations (Figure 8). Based on the Fst scores, the heatmap shows clear genetic differentiation among the Pindar & Alaknanda, Nandakini & Alaknanda, and Mandakini & Pindar populations (Figure 9). Tajima's D neutrality test (D = 1.72912, P = 0.10) provides a positive but non-significant value, indicating a weak tendency toward balancing selection, population contraction, or a potential bottleneck effect.

## DISCUSSION

Species population structure and composition are crucial indicators for assessing freshwater biodiversity (Turek et al. 2016). Fish serve as excellent model systems for studying interspecific and intraspecific divergences, providing insights into the ecological factors driving

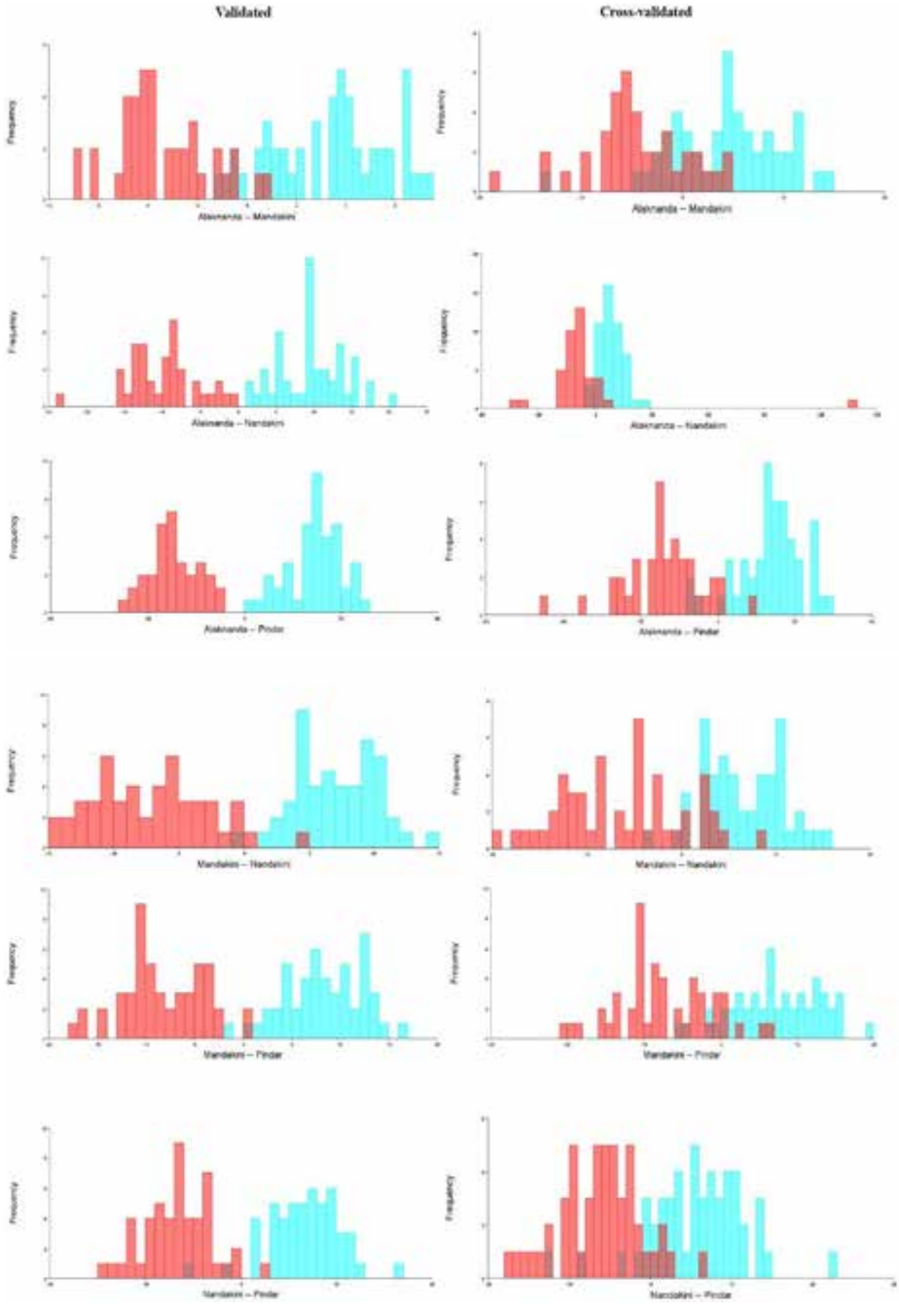


**Figure 6. Graphs of discriminant function analysis between the *Schizothorax richardsonii* populations from four tributaries of the Ganga River basin.**

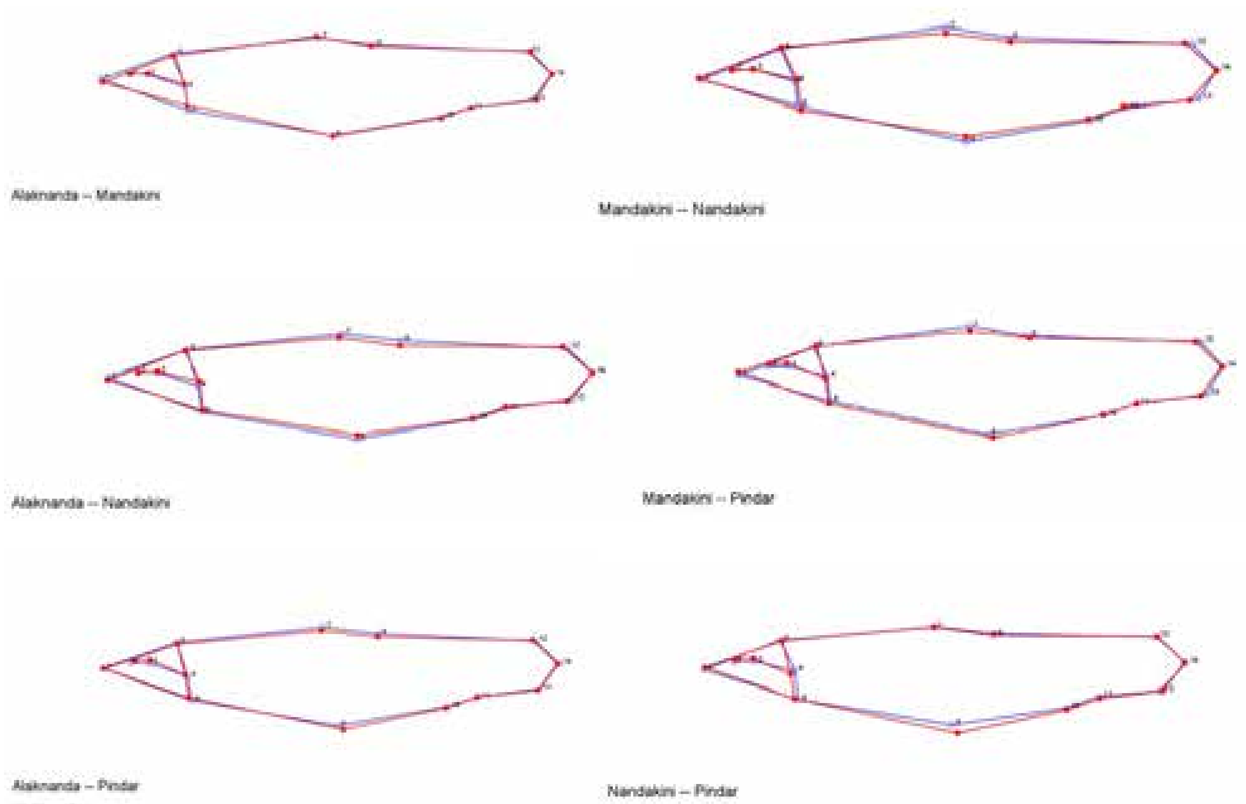


**Figure 7. Wireframes showing the shape changes associated with discriminant scores among four populations of *Schizothorax richardsonii* (blue wireframe shows the original position of landmarks, the red wireframe shows variation in landmark position).**

morphological and genetic diversification. Neglecting to address stock complexity within management units has resulted in the depletion of spawning components, leading to a loss of genetic diversity and potentially other ecological effects (Begg et al. 1999). The present study combines geometric morphometric and mitochondrial DNA (COX1) analyses to evaluate phenotypic and genetic variations among wild populations of *S. richardsonii* from the Ganga River basin.

The study results revealed morphological differences among *S. richardsonii* populations from four tributaries of the Ganga River basin. The PCA indicates phenotypic plasticity, with the first three principal components accounting for a combined variance of 63% among the four populations. The PC1 described shape variation mainly associated with shifts in the pelvic fin, caudal peduncle, and anal fin positions. These differences were most pronounced among the four phenotypic stocks, suggesting population-level morphological differentiation. These measurements likely reflect adaptations to distinct ecological conditions in their habitats, such as different flow regimes, predation pressures, and food availability. Geometric morphometrics effectively delineates populations based on shape variations using CVA (Cadrin & Silva 2005; Maderbacher et al. 2008).

Overall, CVA shows a significant difference among populations of S. *richardsonii* from four distinct tributaries of the Ganga River basin, and four different populations were identified phenotypically. The CVA plot further indicated that the Pindar population showed greater morphological divergence from the Mandakini and Alaknanda populations than from the Nandakini, suggesting stronger phenotypic differentiation among populations inhabiting more geographically isolated rivers. The CVA plot also distinguished the Pindar and Alaknanda populations from the others, possibly due to anthropogenic disturbances such as water diversion for irrigation and domestic use, as well as the extraction of construction materials from riverbeds, which are common in these regions. Intense human intervention also resulted in habitat loss and degradation of the freshwater ecosystem, thus affecting the fish species, especially in regions with high water demand (Sarkar et al. 2012). Dwivedi (2022), while studying the phenotypic variation in *S. richardsonii* from the Indian Himalaya, also revealed the existence of four different stocks from seven Indian rivers using CVA and DFA. However, he

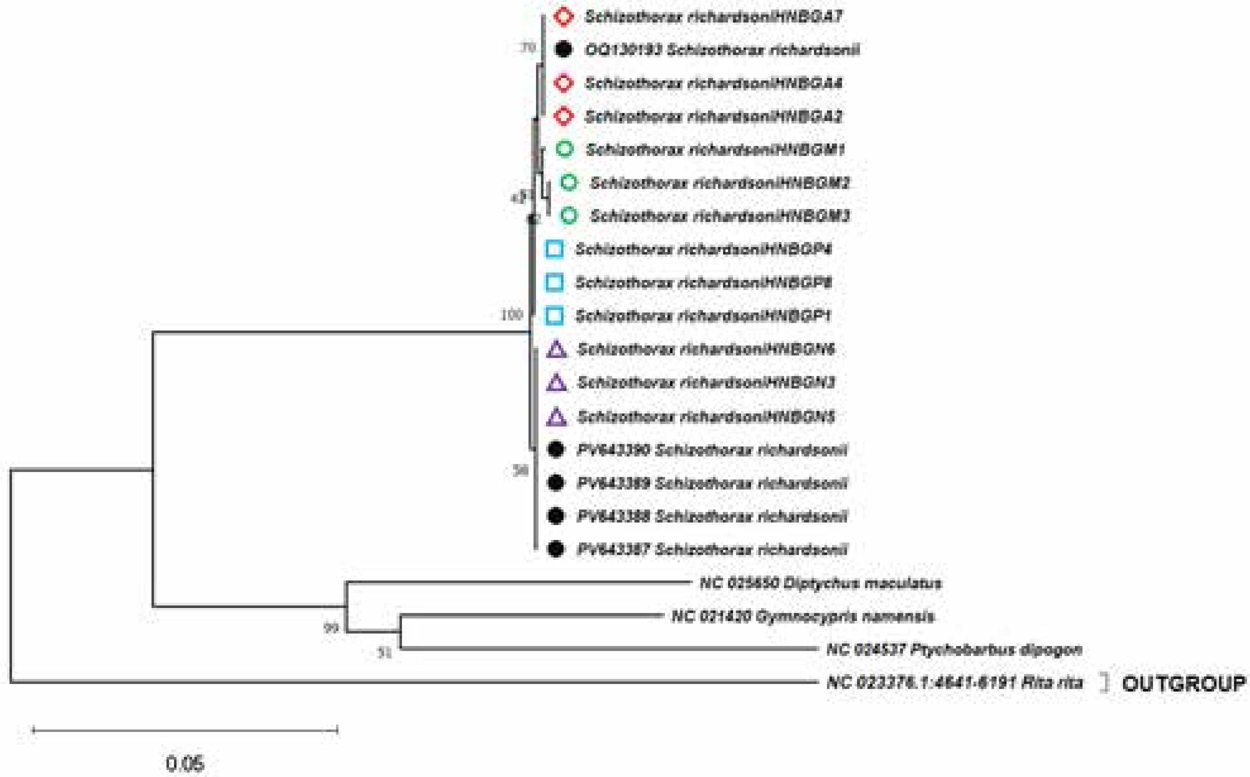


**Figure 8. Maximum likelihood type of phylogenetic tree for the natural population of *Schizothorax richardsonii* based on mitochondrial COX1 partial gene sequences from four different tributaries of the Ganga River basin: circle represents the populations from the Mandakini River, Triangle Nandakini River, Square Pinder River, diamond Alaknanda river and Black drop represents the reference sequences retrieved from NCBI.**

did not specify the key morphometric measurements that differentiate these populations. In this study, the Mahalanobis and Procrustes distances confirm the heterogeneity among these populations. The results of the present study align with those of Mejia & Reis (2024), who found notable morphological differences among *Otocinclus cocama* populations in Amazon River tributaries and suggested that environmental factors play a crucial role in the isolation and movement of fish stocks.

The DFA can effectively differentiate stocks within the same species (Karakousis et al. 1991). In this study, the leave-one-out cross-validation test accurately assigned 73.7% of individuals to their original groups, indicating intermingling among some populations, i.e., Nandakini with Pindar and Mandakini with Nandakini. The Ganga River is an ancient river that originated in the late Pleistocene, while its tributaries formed more recently as lateral rivers (Daniel 2001). It has been suggested that fish stocks are distributed along a spatial gradient, leading to frequent fish mixing within the basin (Murta et al. 2008). However, in the present study, a close resemblance between the two populations from Pindar and Nandakini was noticed, probably due to the proximity in terms of geographical location. The local migration of the species may also result in the mixing of the Nandakini population with Mandakini. Some other researchers also reported morphological closeness within the basin due to seasonal migration and similar ecological conditions between sites for spawning (Murta et al. 2008). Mir et al. (2013) identified three key morphometric characteristics, eye diameter, body depth, and caudal peduncle, that contribute to population variations in snow trout from the Indian Himalayas based on DFA, using a truss-based morphometric approach. In contrast, the present study found that the anterior and posterior origins of the dorsal fin, origin position of the pelvic fin, anal fin, caudal peduncle, and eye diameter exhibited significant variation based on discriminant scores using geometric morphometrics. These morphometric measurements serve as crucial morphological descriptors, offering valuable insights into the distinctiveness of populations within the tributaries of the Ganga River basin. The PC1-based shape wireframe also supported this result. Osburn (1906) noted that pelvic fins assist fish in maintaining

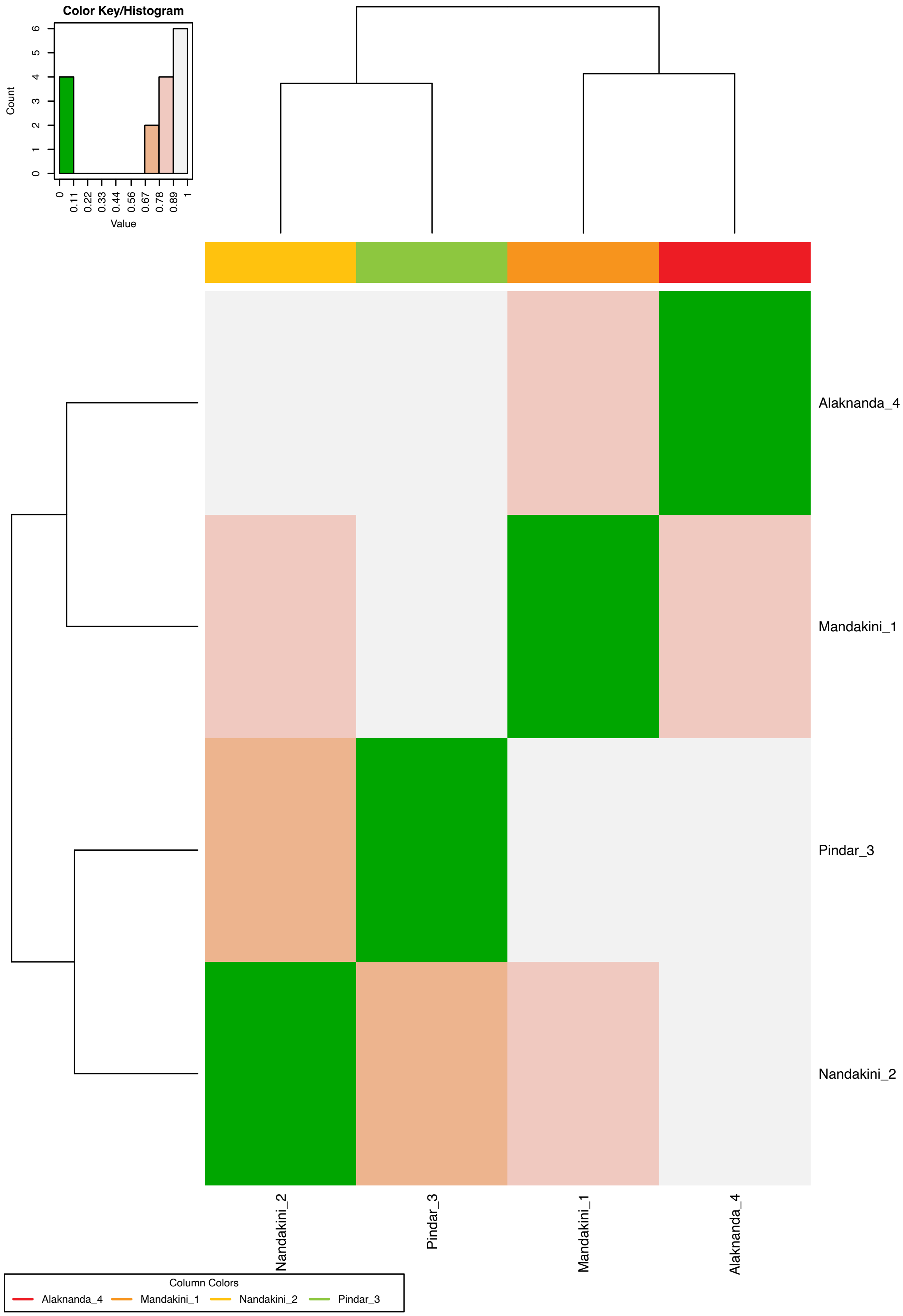


**Figure 9 . Fst scores-based heatmap showing genetic differentiation among the *Schizothorax richardsonii* population based on the mitochondrial COX1 partial gene.**

balance while swimming. Harris (1936) observed that many teleost fish raise their dorsal fins while gliding, enabling them to change direction quickly. This suggests that the dorsal and pelvic fins contribute to population-level morphological variations by influencing movement and control during swimming.

To assess genetic variability and establish the phylogenetic relationship among the *S. richardsonii* populations, this study used the mitochondrial marker COX1, which revealed three polymorphic sites, three parsimony sites, and five haplotypes. Interestingly, the highest genetic variability was observed in the Mandakini population, which generally indicates a stable and resilient gene pool crucial for adaptability and long-term survival. Genetic differentiation plays a vital role in comprehending the evolutionary dynamics of fish populations (Stange 2021). In the present study, the phylogenetic analysis based on the ML method showed one clade and four separate groups, depicting the clear distinction among the four populations of *S. richardsonii* from the Ganga River basin and justifying their separate management strategies. The genetic distance between these populations of *S. richardsonii* is very small, 0.020%, which is considerably lower than the standard threshold used for species discrimination through DNA barcoding (Hebert 2003). This suggests that the genetic differentiation between these populations has not reached the level required for speciation. Populations with such differentiation may be at risk of genetic erosion, loss of genetic diversity, and other potential ecological impacts (Begg et al. 1999). ML phylogenetic analysis also suggested that the Mandakini and Alaknanda populations were closely related to each other compared to other populations. All the sequences were adenine and thymine-rich, consistent with earlier reports in fish (Johns & Avise 1998). The average A+T content was 53.58%, and the GC content was 46.42%, similar to the results reported by Ward et al. (2005), Lakra et al. (2011), and Vineesh et al. (2013). Min & Hickey (2007) demonstrated a strong correlation between the GC content of the COX1 gene and that of the entire mitochondrial genome. Fst scores also indicated clear genetic differentiation among river Alaknanda & Pindar populations, Nandakini & Alaknanda, and Mandakini & Pindar populations based on mitochondrial COX1 partial gene. This differentiation could be due to the hydro-power projects built over the Alaknanda River in the central Himalaya, which have disrupted the natural habitat by blocking the fish migratory routes. The government of India has issued policies to exploit the riverine system of the Indian Himalaya, which is hypothetically proven to cause serious damage to biodiversity and changes in the ecosystem (Pandit & Grumbiene 2012).

An interesting finding in this study is that the Pindar population shows highest morphometric and genetic variability among all the three tributaries of the Ganga River basin due to the difference in habitat conditions, environmental factors, and anthropogenic effects such as overfishing, household wastage, water withdrawal, and pollution from plastics among these tributaries. However, a low level of genetic diversity was observed in the Nandakini population. Interestingly, most of the sequences retrieved from NCBI clustered with the Nandakini population, while one sequence clustered with the Alaknanda population, likely due to its origin from the same stream, indicating genetic similarity. A decline in genetic variation within any population reduces the fish's ability to adapt to environmental changes and decreases the species' chances of long-term survival (Tickner et al. 2020). In our study, the COX1 marker clearly showed the population delineation of *S. richardsonii* from four tributaries of the Ganga River basin. As documented in previous studies, alteration in fish population structure can result from river fragmentation caused by physical barriers such as dams and barrages (Anvarifar et al. 2011). In the present study, Tajima's D analysis yielded a positive but non-significant value, suggesting a weak tendency toward balancing selection, population contraction, or a potential bottleneck effect. However, the results tentatively suggest recent expansion; we emphasize that broader sampling and the use of nuclear markers are needed to provide stronger evidence for demographic processes.

Kousar et al. (2025) studied mitochondrial DNA variability in *S. richardsonii* using the COX1 marker from tributaries of the Chenab river and reported limited gene flow between populations. In contrast, our results identified four distinct population groups and revealed no gene flow between the Pindar River and the remaining tributaries. Moreover, the COX1 base composition observed in the present study (A+T = 53.58% and G+C = 46.42%) differs slightly from that reported by Kousar et al. (2025) from the Western Indian Himalayan population (A+T = 53.63% and G+C = 46.37%). Overall, in the present study, the geometric morphometrics analysis based on multivariate analysis and mtDNA COX1-based sequences analysis revealed a clear phenotypic and genotypic heterogeneity among *S. richardsonii* populations from four distinct tributaries within the Ganga River basin.

## CONCLUSION

The results of the present study provide compelling evidence of phenotypic and genotypic differences among *S. richardsonii* populations in the tributaries of the Ganga River basin. Key phenotypic traits such as the origins of the pelvic fin, dorsal fin, anal fin, and caudal peduncle were critical for morphological descriptions. Additionally, a genetically low percentage of nucleotide base composition was observed. These variations may be influenced by dam construction, anthropogenic disturbances like water diversion for irrigation & drinking, extraction of building materials from riverbeds, differences in flow regimes, genetic isolation, and evolutionary pressures. Integrating morphometric and genetic data enhances our understanding of the species diversity and evolutionary dynamics in the central Himalaya. It underscores the need for population-specific conservation and management strategies, including implementing the closed season during breeding periods for *S. richardsonii* in the Ganga River basin, emphasizing ecosystem-based approaches to protect this valuable genetic resource.

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ARTICLE

# Avian composition and distribution in the bird sanctuary planning zone of Can Gio Mangrove Biosphere Reserve, Ho Chi Minh City, Vietnam

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**Abstract:** Six field surveys were conducted from July 2024 to May 2025 in six sessions (three during dry and three during wet seasons) along 10 fixed transects (five in the core zone and five in the buffer zone) to assess the bird species composition and spatial distribution in the bird sanctuary planning zone of the Can Gio Mangrove Biosphere Reserve, after 47 years of restoration (1978–2025). A total of 57 bird species, representing 11 orders, 32 families, and 45 genera were recorded, including 18 waterbird species. Four species are listed as threatened and prioritized for conservation by the IUCN Red List: *Porzana paykullii* as Near Threatened, Vietnam Red List Book: *Anhinga melanogaster* and *Mycteria leucocephala as* Vulnerable, and Vietnamese law: *Milvus migrans and Anhinga melanogaster* as prioritized for conservation. The order Passeriformes was the most species-rich (21 species), while Pelecaniformes had the highest number of individual encounters (2,427). Overall, bird diversity in the area was relatively high (Shannon-Wiener index H' = 2.60 ± 0.34), with a moderate level of dominance (Simpson D = 0.12 ± 0.06). Species abundance was uneven across seasons and transects, with higher diversity and abundance during the wet season, although the differences were not statistically significant. Only the transect L8 in the buffer zone showed statistically significant differences in diversity and abundance, representing a newly recorded breeding area dominated by waterbird species such as *Nycticorax nycticorax*, *Egretta garzetta*, *Ardea intermedia*, and *Microcarbo niger*. Compared to a 2019 study, the number of breeding species in the core zone declined to seven species with approximately 1,000 individuals, while a new breeding area in the buffer zone was identified with eight breeding species and approximately 1,500 individuals. Continuous monitoring and conservation efforts are necessary to sustain and manage avian biodiversity in this critical wetland ecosystem.

**KEYWORDS:** Species diversity, biological index, breeding ecology, habitat use, core and buffer zones, conservation priority species, seasonal variation, waterbirds, avifauna.

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## INTRODUCTION

Waterbirds are key indicators of wetland health and play critical ecological roles as predators, seed dispersers, and contributors to nutrient cycling (Byju et al. 2025a). Across Asia, particularly along coastal zones, wetlands support rich avifaunal diversity but are increasingly threatened by habitat loss, pollution, and human disturbance. Long-term monitoring in India has revealed marked declines in the abundance and breeding success of both migratory and resident waterbirds due to anthropogenic pressures (Byju et al. 2025b,c). These findings underscore the urgent need to assess and monitor waterbird communities in other Asian coastal ecosystems, where comparable data remain scarce.

Vietnam is one of the 22 countries along the East Asian-Australasian Flyway Partnership (EAAFP), which supports the diversity of migratory birds and hosts about 40% of the world's migratory bird species (Yamaura et al. 2017). Vietnam's avifauna is highly diverse, with over 900 species documented (Le 2020), including 53 species listed as threatened in the country (Ministry of Science and Technology 2007) and 10 endemic species (Tran 2020). However, despite Vietnam's strategic importance along the flyway, comprehensive site-based assessments of waterbird communities remain limited.

The Can Gio Mangrove Biosphere Reserve (CGMBR) in southern Vietnam represents the largest rehabilitated mangrove forest in southeastern Asia and serves as a critical breeding and stopover site for numerous waterbird species. Previous surveys documented 164 bird species across 51 families and 15 orders (Le 2021), including five nationally protected and 16 globally threatened species (IUCN 2025). Yet, these studies were spatially and temporally restricted, focusing mainly on the core zone (Huynh et al. 2019). Consequently, current knowledge about the distribution and composition of waterbirds across the broader bird sanctuary planning zone—including both core and buffer zones—remains incomplete.

Given the ongoing coastal development and mounting anthropogenic pressures on mangrove ecosystems, updated information is urgently needed to evaluate the outcomes of nearly five decades of forest restoration and to guide effective conservation management. This study aims to (1) document the current species composition and distribution of waterbirds in the bird sanctuary planning zone of CGMBR, and (2) provide baseline data for long-term monitoring and habitat management.

## MATERIALS AND METHODS

Can Gio Mangrove Biosphere Reserve (CGMBR) is Vietnam's first UNESCO Biosphere Reserve, recognized on 21 January 2000 and is part of the "discontinuous biodiversity corridor" planning initiative for the 2020–2030 period under decision no. 1250/QD-TTg of the Vietnam Prime Minister on 31 July 2013 (Can Gio District Forest Protection Management Board 2025). As part of CGMBR, the bird sanctuary planning zone, located at Vam Sat in subzone 15a, encompasses 602.5 ha buffer zone and 126.2 ha in the core zone. The entire bird sanctuary planning zone was designated for protection by Decision No. 27/QD-UB on 06 January 2004 (Chairman of Ho Chi Minh City People's Committee 2004).

Ten fixed transects were established across the bird sanctuary planning zone, covering different habitat types: natural forest (4 transects), plantation forest (3 transects), and other land types, including pond banks, and salt fields adjacent to forested areas (3 transects) (Figure 1). Five transects were in the core zone in the same area as Huynh et al. (2019) (L1–5), and five in the buffer zone (L6–10). Each transect was 500 m in length with a 20 m observation radius.

Field surveys were conducted in six sessions: three in the dry season (November 2024–April 2025) and three in the wet season (May–October 2025), with monthly intervals. Observations were carried out from 0700 h to 1130 h. Birds were identified based on morphology, size, plumage, and vocalizations. Unidentified species were documented with photographs and sound recordings for later verification using field guides (Vo 1981; King et al. 1997; Nguyen et al. 2000; Koshiyama & Asano 2019) and the Birds of South East Asia website (Vietnam Wildlife Photography Club 2025). Taxonomy followed the Avibase.

Collected data were analysed using BioDiversity Professional 2.0 (McAleece et al. 1997) and Statgraphics XIX (Nguyen 2009). Three biodiversity indices were used to assess community structure, including Shannon-Wiener index (H', to evaluate species diversity) (Shannon & Wiener 1963), Simpson's dominance index (D, to measure species dominance) (Simpson 1949), and Sorensen similarity index (SI, to compare species similarity among transects) (Shannon & Wiener 1963). Diversity categories followed standard classifications: $H' < 0.6$ = low diversity; $0.6 \le H' \le 1.5$ = moderate; $1.5 < H' \le 2.5$ = high; $2.5 < H' \le 3.5$ = very high; $H' > 3.5$ = extremely high diversity. The lower the Simpson's D, the higher the diversity. Sorensen Index was used to classify pairwise similarity from very low (<20%) to very high (≥80%).

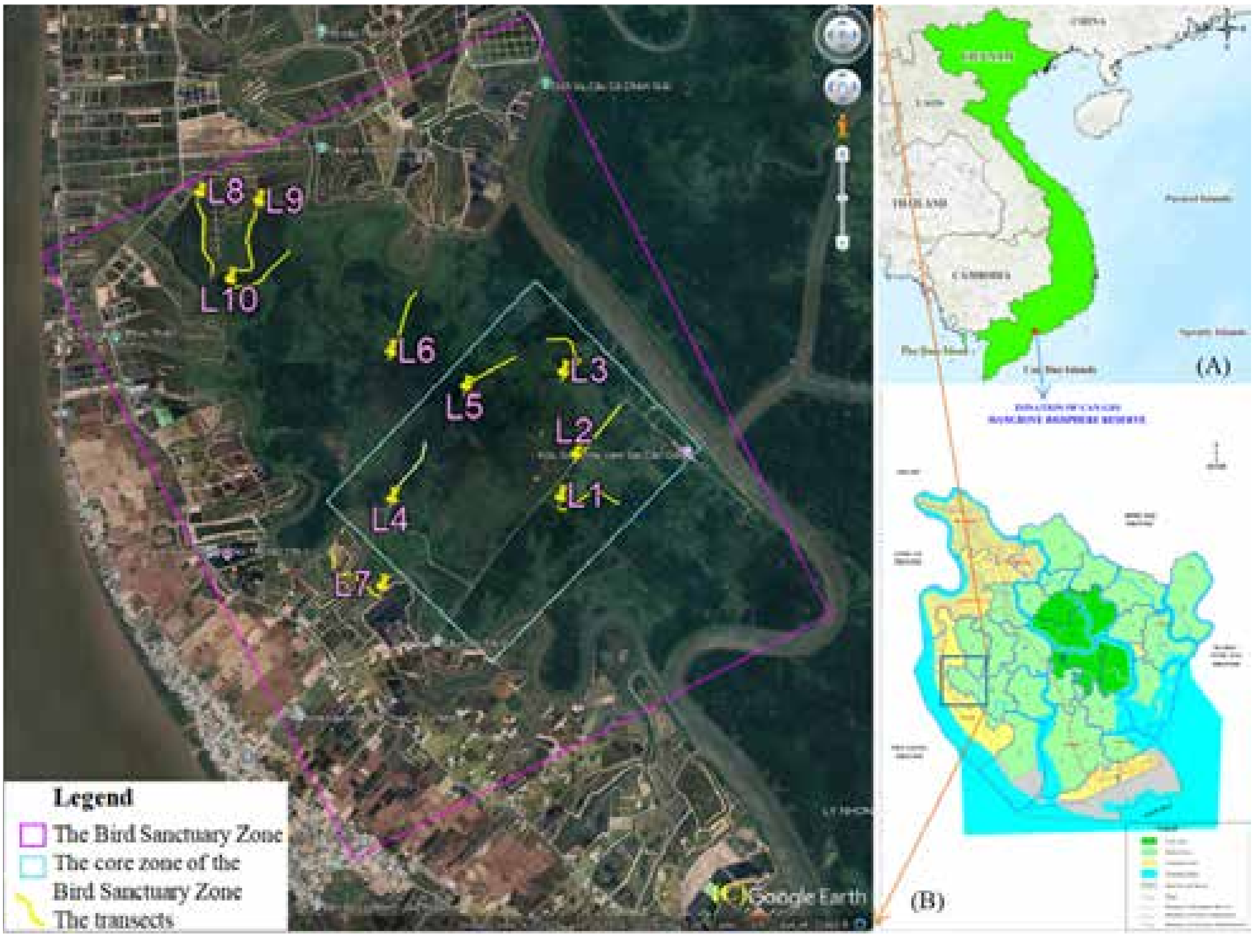


**Image 1. Map of the study area: A—Location of Can Gio Mangrove Biosphere Reserve on a map of Vietnam | B—the study area on the Can Gio Mangrove Biosphere Reserve, the map was provided by Can Gio Mangrove Biosphere Reserve | C—ecosystems and survey areas within Can Gio Mangrove Biosphere Reserve. The map was created with QGIS software version 3.34.11. The ecosystem layer data for Google Earth Pro version 7.3.6.10201. The base map of Vietnam was sourced from GADM (Global Administrative Areas). https://gadm.org/download_country.html**

In addition, biodiversity indices were compared between the wet and dry seasons to examine temporal variation in bird communities. Differences among habitat types (core zone vs. buffer zone; mixed vegetation, waterbody, and edge habitats) were also analysed to evaluate spatial patterns in avian diversity and composition. This allowed us to assess not only overall community structure but also seasonal and habitat-specific differences that may influence waterbird assemblages. Breeding bird populations were assessed by comparing current observations with data from a 2019 study.

## RESULTS AND DISCUSSION

### Avian composition

A total of 57 bird species belonging to 45 genera, 32 families, and 11 orders were recorded across the bird sanctuary planning zone in the Can Gio Mangrove Biosphere Reserve (CGMBR) during six surveys from July 2024 to May 2025 (July, September 2024 and May 2025 represent wet season and November 2024 and January, March 2025 represent dry season) (Table 1). The wet season (July, September 2024, and May 2025) had more species and showed higher individual encounters than the dry season (November 2024, January and March 2025), with 54 vs. 42, and 2.779 vs. 1.899, respectively (Appendix 1). Among all recorded species, 18 species were waterbirds, including four of conservation concern—*Anhinga melanogaster*, *Milvus migrans*, *Mycteria leucocephala*, and *Porzana paykullii*—listed as Near Threatened or Vulnerable by the IUCN Red List, the Vietnam Red Data Book, and Vietnamese law (Prime Minister of Vietnam 2019, 2021). Their presence underscores the ecological and conservation importance

**Table 1. Bird species composition in the bird sanctuary planning area.**

| | Scientific name | Dry season | Rainy season | Conservation status | | |
|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 |
| | **I. ACCIPITRIFORMES** | | | | | |
| | **1. Accipitridae** | | | | | |
| 1 | *Milvus migrans* (Boddaert, 1783) | - | 1 | - | LC | IIB |
| | **II. ANSERIFORMES** | | | | | |
| | **2. Anatidae** | | | | | |
| 2 | *Anas platyrhynchos* Linnaeus, 1758* | - | 2 | - | LC | - |
| | **III. APODIFORMES** | | | | | |
| | **3. Apodidae** | | | | | |
| 3 | *Aerodramus germani* Oustalet, 1876 | 278 | 232 | - | - | - |
| | **IV. CHARADRIIFORMES** | | | | | |
| | **4. Laridae** | | | | | |
| 4 | *Chlidonias hybrida* (Pallas, 1811)* | - | 2 | - | LC | - |
| 5 | *Chroicocephalus ridibundus* (Linnaeus, 1766)* | 1 | - | - | LC | - |
| | **5. Recurvirostridae** | | | | | |
| 6 | *Himantopus himantopus* (Linnaeus, 1758)* | 43 | 16 | - | LC | - |
| | **6. Scolopacidae** | | | | | |
| 7 | *Tringa glareola* Linnaeus, 1758* | 16 | 2 | - | LC | - |
| 8 | *Tringa nebularia* (Gunnerus, 1767)* | - | 2 | - | LC | - |
| | **V. COLUMBIFORMES** | | | | | |
| | **7. Columbidae** | | | | | |
| 9 | *Streptopelia chinensis* (Scopoli, 1786) | 33 | 41 | - | - | - |
| 10 | *Streptopelia tranquebarica* (Hermann, 1804) | 2 | 4 | - | LC | - |
| 11 | *Treron bicinctus* (Jerdon, 1840) | 2 | 1 | - | LC | - |
| 12 | *Treron vernans* (Linnaeus, 1771) | 2 | 11 | - | - | - |
| | **VI. CORACIIFORMES** | | | | | |
| | **8. Alcedinidae** | | | | | |
| 13 | *Alcedo atthis* (Linnaeus, 1758) | 9 | 13 | - | LC | - |
| 14 | *Halcyon smyrnensis* (Linnaeus, 1758) | - | 3 | - | LC | - |
| 15 | *Todiramphus chloris* (Boddaert, 1783) | 61 | 98 | - | LC | - |
| | **9. Meropidae** | | | | | |
| 16 | *Merops superciliosus* Linnaeus, 1766 | | 4 | - | LC | - |
| | **VII. CUCULIFORMES** | | | | | |
| | **10. Cuculidae** | | | | | |
| 17 | *Centropus sinensis* (Stephens, 1815) | 9 | 30 | - | LC | - |
| 18 | *Cuculus micropterus* Gould, 1837 | 1 | - | - | LC | - |
| | **VIII. GRUIFORMES** | | | | | |
| | **11. Rallidae** | | | | | |
| 19 | *Amaurornis phoenicurus* Pennant, 1769 | 3 | 3 | - | LC | - |
| 20 | *Porzana fusca* Linnaeus, 1766 | 2 | 1 | - | LC | - |
| 21 | *Porzana paykullii* (Ljungh, 1813) | 2 | - | - | NT | - |
| 22 | *Rallus striatus* (Linnaeus, 1766) | 4 | 5 | - | - | - |
| | **IX. PASSERIFORMES** | | | | | |
| | **12. Acanthizidae** | | | | | |
| 23 | *Gerygone sulphurea* Wallace, 1864 | 78 | 121 | - | LC | - |
| | **13. Cisticolidae** | | | | | |
| 24 | *Orthotomus ruficeps* (Lesson, 1830) | - | 2 | - | LC | - |
| 25 | *Orthotomus sepium* Horsfield, 1821 | 73 | 97 | - | LC | - |
| 26 | *Prinia inornata* Sykes, 1832 | - | 2 | - | LC | - |
| | **14. Corvidae** | | | | | |
| 27 | *Crypsirina temia* (Daudin, 1800) | 13 | 36 | - | LC | - |
| | **15. Dicaeidae** | | | | | |
| 28 | *Dicaeum cruentatum* (Linnaeus, 1758) | - | 16 | - | LC | - |
| 29 | *Dicaeum ignipectus* (Blyth, 1843) | - | 3 | - | LC | - |
| | **16. Estrildidae** | | | | | |
| 30 | *Lonchura punctulata* (Linnaeus, 1758) | 13 | 32 | - | LC | - |
| | **17. Motacillidae** | | | | | |
| 31 | *Motacilla alba* Linnaeus, 1758 | 34 | 30 | - | LC | - |
| | **18. Muscicapidae** | | | | | |
| 32 | *Copsychus malabaricus* (Scopoli, 1786) | - | 1 | - | LC | - |
| 33 | *Copsychus saularis* (Linnaeus, 1758) | 50 | 65 | - | LC | - |
| | **19. Paridae** | | | | | |
| 34 | *Parus minor* Temminck & Schlegel, 1848 | 7 | 5 | - | - | - |
| | **20. Passeridae** | | | | | |
| 35 | *Passer flaveolus* Blyth, 1845 | 13 | 15 | - | LC | - |
| 36 | *Passer montanus* (Linnaeus, 1758) | 5 | 4 | - | LC | - |
| | **21. Pellorneidae** | | | | | |
| 37 | *Graminicola bengalensis* Jerdon, 1863 | - | 5 | - | LC | - |
| | **22. Phylloscopidae** | | | | | |
| 38 | *Phylloscopus fuscatus* (Blyth, 1842) | - | 6 | - | LC | - |
| | **23. Ploceidae** | | | | | |

| | Scientific name | Dry season | Rainy season | Conservation status | | |
|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 |
| 39 | *Ploceus philippinus* (Linnaeus, 1766) | 3 | 2 | - | LC | - |
| | **24. Pycnonotidae** | | | | | |
| 40 | *Pycnonotus goiavier* (Scopoli, 1786) | 62 | 80 | - | LC | - |
| | **25. Rhipiduridae** | | | | | |
| 41 | *Rhipidura javanica* (Sparrman, 1788) | 66 | 49 | - | LC | - |
| | **26. Sturnidae** | | | | | |
| 42 | *Acridotheres grandis* Moore, 1858 | - | 17 | - | LC | - |
| | **27. Zosteropidae** | | | | | |
| 43 | *Zosterops palpebrosus* (Temminck, 1824) | 30 | 27 | - | LC | - |
| | **X. PELECANIFORMES** | | | | | |
| | **28. Anhingidae** | | | | | |
| 44 | *Anhinga melanogaster* Pennant, 1769* | 4 | 3 | - | NT | IB |
| | **29. Ardeidae** | | | | | |
| 45 | *Ardea alba* Linnaeus, 1758* | 105 | 12 | - | LC | - |
| 46 | *Ardea cinerea* Linnaeus, 1758* | 1 | 10 | - | LC | - |
| 47 | *Ardea intermedia* Wagler, 1829* | 180 | 194 | - | LC | - |
| 48 | *Ardea purpurea* Linnaeus, 1766* | 1 | 6 | - | LC | - |
| 49 | *Ardeola bacchus* (Bonaparte, 1855)* | - | 5 | - | LC | - |
| 50 | *Ardeola speciosa* (Horsfield, 1821)* | 1 | 9 | - | LC | - |
| 51 | *Butorides striata* (Linnaeus, 1758)* | 3 | 14 | - | LC | - |
| 52 | *Egretta garzetta* (Linnaeus, 1766)* | 370 | 585 | - | LC | - |
| 53 | *Nycticorax nycticorax* (Linnaeus, 1758)* | 247 | 645 | - | LC | - |
| | **30. Ciconiidae** | | | | | |
| 54 | *Mycteria leucocephala* (Pennant, 1769)* | - | 39 | VU | LC | - |
| | **31. Phalacrocoracidae** | | | | | |
| 55 | *Microcarbo niger* (Vieillot, 1817)* | 60 | 142 | - | LC | - |
| | **XI. PICIFORMES** | | | | | |
| | **32. Picidae** | | | | | |
| 56 | *Chrysocolaptes lucidus* (Scopoli, 1786) | 1 | 11 | - | LC | - |
| 57 | *Picus vittatus* Vieillot, 1818 | 11 | 18 | - | LC | - |

Note: -—unrecorded/not listed in IUCN or Vietnamese law | Conservation status: 1—in Vietnam Red List Book (2007) | 2—in IUCN Red List (2025): VU—Vulnerable | NT—Near Threatened | LC—Least Concern | 3—according to Decree 06/2019/ND-CP dated 22 January 2019 and updated by Decree 84/2021/ND-CP dated 22 September 2021 of the Government | *—waterbird.

of this wetland.

Species richness and diversity indices varied significantly across transects and between seasons (Table 2; Figures 2–3). Shannon–Wiener diversity index (H') ranged from 1.77–2.93, indicating moderate to high diversity. The highest diversity occurred in the core zone (L10, H' = 2.93), while the lowest was in buffer zone (L8, H' = 1.77). In contrast, Simpson's dominance index (D) ranged 0.06–0.16, with highest dominance also observed at L8, where bird communities were strongly dominated by *Nycticorax nycticorax* (827 individuals), *Egretta garzetta* (664), *Ardea intermedia* (283), and *Microcarbo niger* (143). This indicates that while the buffer zone (L8) had fewer species, it supported larger populations of a few dominant waterbird species.

Breeding data further support this pattern. The transect L8 recorded eight breeding bird species with approximately 1,500 individuals, while the core zone supported only seven breeding species with around 1,000 individuals–a decline from 2,000 breeding individuals recorded in 2019 (Huynh Duc Hoan et al. 2019). The Sorensen similarity index also indicated the lowest overlap between transect L8 with others sites (Figure 4), suggesting that L8 represents a distinct habitat type now more suitable for breeding. The shift in breeding activity from the core to the buffer zone may reflect localized habitat changes, possibly linked vegetation structure, prey availability, or anthropogenic disturbance.

Similar spatial and seasonal shifts in waterbird assemblages have been reported in other Asian wetlands, where breeding colonies relocate or decline under human pressure (Byju et al. 2025a,c). For instance, studies from India have shown that lagoon and estuarine with high bird abundance are often sensitive to disturbance, resulting in temporal declines in breeding success (Byju et al. 2024, 2025a,b). In CGMBR, the emergence of transect L8 as a new breeding hotspot reflects the dynamic adaptation of waterbird populations to changing habitat conditions within restored mangrove systems.

Overall, our findings highlight both the resilience and vulnerability of avian communities in the bird sanctuary planning zone. The persistence of threatened species and the establishment of new breeding colonies emphasize the conservation value and ecological recovery potential of restored mangroves. However, the decline of core zone breeders indicates emerging habitats stress. Continuous, long-term monitoring, similar to those conducted in other Asian wetlands (Byju et al. 2025b), is therefore essential to evaluate restoration outcomes,

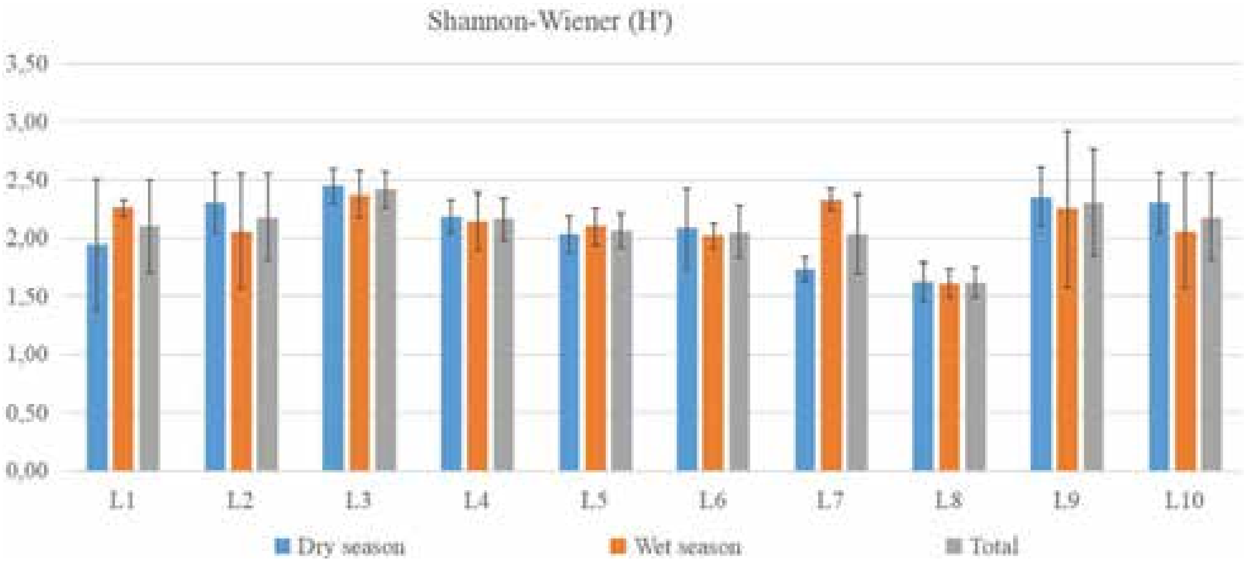


Figure 1. Shannon-Wiener (H') calculated from transect L1–12.

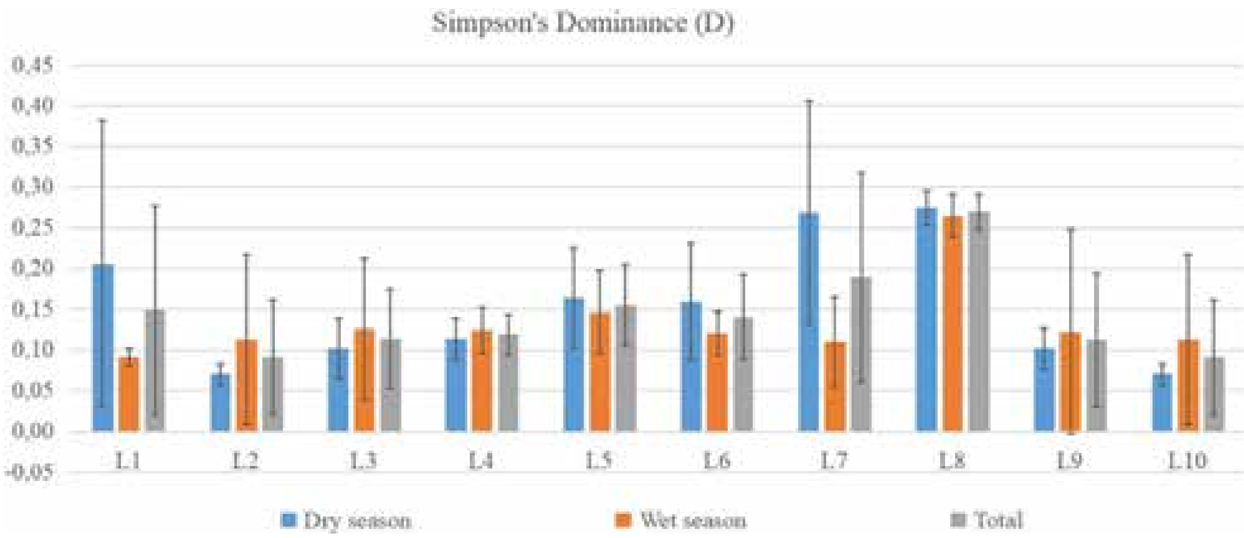


Figure 2. Simpson's dominance (D) calculated from transect L1–12.

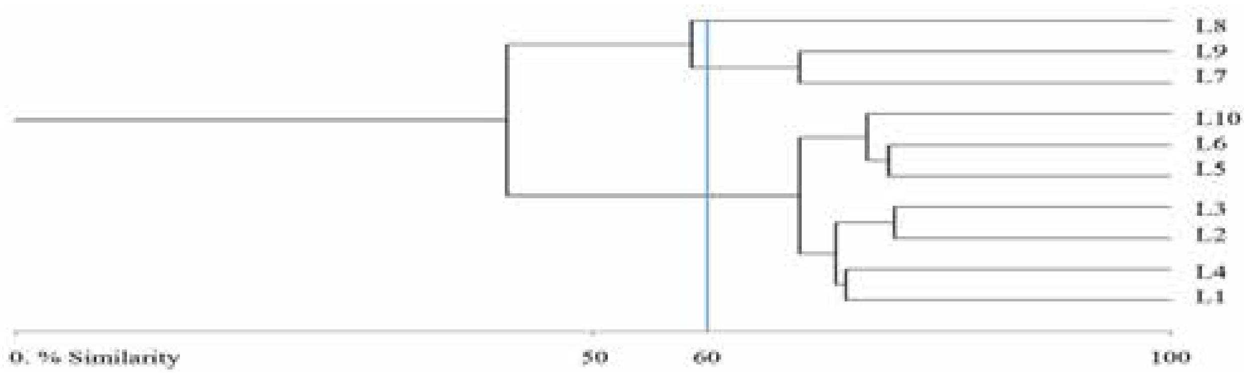


Figure 3. Similarity diagram of bird species composition among 10 transects.

detect ecological shifts, and guide adaptive conservation management in this UNESCO-designated biosphere reserve.

## CONCLUSION

The bird sanctuary planning zone within the Can Gio Mangrove Biosphere Reserve supports a relatively high diversity of bird species including four globally and nationally threatened taxa. The discovery of a new breeding area in the buffer zone (transect L8) and the decline in species abundance in the core zone emphasize the need for adaptive management and continuous monitoring.

Preserving the ecological integrity of this wetland is vital for sustaining its role as a key habitat for waterbirds, especially during the breeding season. Future conservation efforts should prioritize habitat protection, environmental education, and the mitigation of anthropogenic pressures to maintain avian biodiversity in this region.

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**Appendix 1. Species counts (SC) and individual encounters (IE) in survey transects.**

| Transect | | L1 | L2 | L3 | L4 | L5 | L6 | L7 | L8 | L9 | L10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All transects | IE | 204 | 256 | 387 | 219 | 242 | 188 | 327 | 2,197 | 515 | 143 | **4,678** |
| | (%) | 4.4 | 5.5 | 8.3 | 4.7 | 5.2 | 4.0 | 7.0 | 47.0 | 11.0 | 3.1 | **100.0** |
| | SC | 21 | 28 | 32 | 29 | 25 | 24 | 35 | 33 | 36 | 25 | **57** |
| | (%) | 36.8 | 49.1 | 56.1 | 50.9 | 43.9 | 42.1 | 61.4 | 57.9 | 63.2 | 43.9 | **100.0** |
| Dry season | IE | 91 | 135 | 162 | 70 | 83 | 81 | 122 | 726 | 383 | 46 | **1,899** |
| | (%) | 4.8 | 7.1 | 8.5 | 3.7 | 4.4 | 4.3 | 6.4 | 38.2 | 20.2 | 2.4 | **100.0** |
| | SC | 17 | 20 | 22 | 19 | 16 | 14 | 24 | 22 | 23 | 15 | **42** |
| | (%) | 41.5 | 48.8 | 53.7 | 46.3 | 39.0 | 34.1 | 58.5 | 53.7 | 56.1 | 36.6 | **100.0** |
| Rainy season | IE | 113 | 121 | 225 | 149 | 159 | 107 | 205 | 1,471 | 132 | 97 | **2,779** |
| | (%) | 4.1 | 4.4 | 8.1 | 5.4 | 5.7 | 3.9 | 7.4 | 52.9 | 4.7 | 3.5 | **100.0** |
| | SC | 20 | 23 | 28 | 23 | 22 | 21 | 27 | 29 | 32 | 23 | **54** |
| | (%) | 37.7 | 43.4 | 52.8 | 43.4 | 41.5 | 39.6 | 50.9 | 54.7 | 60.4 | 43.4 | **100.0** |

**Vietnamese abstract:** Trong giai đoạn từ tháng 7 năm 2024 đến tháng 5 năm 2025, sáu đợt khảo sát được tiến hành theo định kỳ hai tháng trên 10 tuyến cố định (năm tuyến trong vùng lõi và năm tuyến trong vùng đệm) nhằm đánh giá thành phần loài và sự phân bố của chim tại Khu Quy Hoạch Sân Chim thuộc Khu Dự trữ sinh quyển Rừng ngập mặn Cần Giờ, sau 47 năm phục hồi (1978–2025). Kết quả ghi nhận 57 loài chim thuộc 11 bộ, 32 họ và 45 chi, trong đó có 18 loài chim nước. Bốn loài được xếp vào nhóm nguy cấp, cần ưu tiên bảo tồn theo Danh lục Đỏ IUCN, Sách Đỏ Việt Nam và pháp luật hiện hành, bao gồm: *Porzana paykullii* (Sắp nguy cấp), *Anhinga melanogaster* và *Mycteria leucocephala* (Sẽ nguy cấp), cùng *Milvus migrans* và *Anhinga melanogaster* (được bảo vệ theo pháp luật hiện hành). Bộ Sẻ (Passeriformes) đa dạng loài nhất (21 loài), trong khi bộ Chim điên điển (Pelecaniformes) ghi nhận số cá thể nhiều nhất (2.427 cá thể). Chỉ số đa dạng Shannon-Wiener đạt mức tương đối cao (H' = 2,60 ± 0,34) và chỉ số ưu thế Simpson ở mức trung bình (D = 0,12 ± 0,06). Sự phong phú và đa dạng loài có sự biến động theo mùa và giữa các tuyến khảo sát, trong đó mùa mưa có xu hướng cao hơn, nhưng không khác biệt có ý nghĩa thống kê. Riêng tuyến L8 thuộc vùng đệm thể hiện sự khác biệt rõ rệt, được ghi nhận như một khu sinh sản mới với tám loài chim và khoảng 1.500 cá thể, chủ yếu có sự hiện diện của các loài chim nước như *Nycticorax nycticorax*, *Egretta garzetta*, *Ardea intermedia* và *Microcarbo niger*. So với nghiên cứu năm 2019, số loài chim sinh sản trong vùng lõi giảm xuống còn bảy loài với khoảng 1.000 cá thể, trong khi vùng đệm lại xuất hiện một khu sinh sản mới với quy mô lớn hơn. Kết quả này cho thấy sự thay đổi về phân bố sinh sản của chim trong Khu Quy Hoạch Sân Chim, đồng thời nhấn mạnh sự cần thiết của việc giám sát lâu dài và áp dụng các biện pháp bảo tồn để duy trì và quản lý tính đa dạng chim tại hệ sinh thái đất ngập nước quan trọng này.

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**Author contributions:** Huynh Duc Hieu developed the research idea. Huynh Duc Hieu, Bui Nguyen The Kiet, Dang Ngoc Hiep and Nguyen Thi Phuong Linh collected the data. Dang Ngoc Hiep and Huynh Duc Hieu analysed the data and wrote the first draft. Huynh Duc Hoan, Huynh Duc Hieu and Nguyen Dang Hoang Vu edited the final draft. Nguyen Dang Hoang Vu submitted the manuscript to the journal.

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ARTICLE

# Bat echolocation in South Asia

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**Abstract:** The study of echolocation traits can assist in developing robust tools for the detection and monitoring of bats. The advent of non-invasive and passive acoustic monitoring techniques has increased the availability of echolocation data including in highly diverse regions, such as South Asia, where 145 of the 155 extant bat species are known to use laryngeal, nasal, or lingual echolocation. However, information remains disperse with no existing review of the state of echolocation knowledge in this region. Here we present a review that collates and catalogues echolocation data to facilitate access and reveal general patterns and knowledge gaps. We conducted a systematic review that returned 35 peer-reviewed publications containing echolocation data to which we added ~6,000 unpublished recordings from various collections (including the open-source ChiroVox database). We created a foundational database reporting on six standard echolocation functional traits to be used in identification. The dataset provides data for ~60% (n = 86) of the echolocating bat species in South Asia, with 299 distinct observations (unique combinations of recording techniques, equipment, and conditions for a given species). Mapping data locations we describe spatial biases and propose priority regions for future work in areas where species richness is high, but echolocation knowledge is limited or completely absent. These priority regions largely fell within the Western Ghats and Eastern Ghats of India, northeastern India, and Sri Lanka, with smaller clusters in peninsular, western, and eastern India. Our review offers a first assessment and a ready-to-use echolocation dataset for bats in South Asia. We hope this motivates an appraisal of functional trait data collection in diverse and data-poor regions and facilitates future research.

**Keywords:** Acoustic monitoring, biodiversity hotspots, functional traits, knowledge gaps, research priorities, species identification.

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## INTRODUCTION

South Asia is a large subcontinent comprising Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka, sometimes referred to as the Indian subcontinent. Spanning approximately five million square kilometres, it is bounded by the Himalaya, Hindukush, and Dhaula Dhar mountains to the north, and the Arabian Sea, Lakshadweep Sea, Bay of Bengal, and Indian Ocean to the south. It supports a wide diversity of bats, with 155 species currently described (Srinivasulu et al. 2025). Bats in this region can be found across a wide range of habitats and locations with some species distributed across the entire subcontinent, while others are restricted to single localities (Bates & Harrison 1997; Srinivasulu & Srinivasulu 2012). Owing to their status as ecological indicators and contributors of essential ecosystem services (Jones et al. 2009; Stathopoulos et al. 2018), it is important to understand the diversity, distribution, and traits of bats, and harness suitable tools and methods to effectively monitor changes that can inform management and conservation action.

A widely used approach to detect and monitor bats is based on listening to and analysing echolocation calls (Kunz & Parsons 2009; Fraser et al. 2020; Russ 2021). Echolocation is used for communication and navigation by many taxa including bats, and bat echolocation is unique in its highly complex and diverse design which allows it to not only be used to recognise and identify taxa, but also to understand their ecological function and diversity (Kunz & Parsons 2009; Stathopoulos et al. 2018). Using complex nasal, laryngeal, or facial structures in combination with highly specialised ear neuroanatomy, echolocating bats are able to perceive their environment in a high level of detail, including the range, direction, size, texture, and in many cases the type of objects in their surroundings, especially at night when vision is less effective (Jones 2005; Sulser et al. 2022). Echolocating behaviour has allowed some species to evolve more complex flight patterns, varied diets, and highly specialised ecological interactions, and varies between species to a high degree. Different types of echolocation calls have very different impacts on the flight behaviour and dietary choices of species, which also in turn have impacts on the evolution of their echolocation (Jones 2005). For instance, narrowband echolocation tends to favour longer calls and the detection of targets, while broadband echolocation favours shorter calls, and the localisation of targets in space. Traits describing echolocation (in terms of frequency, call shape, inter-pulse interval, number of passes, duration) have been used in the past to classify taxa and understand their habitat use, diet, and niche breadth, as each taxon has a unique combination of these traits, which often also vary over the taxon's distribution.

In South Asia, 145 bat species are known to use either mouth-emitted or nose-emitted laryngeal echolocation, or click-based lingual echolocation (Bates & Harrison 1997; Srinivasulu & Srinivasulu 2012). Several studies have separately collected, described, and classified echolocation calls from various species in South Asia (most recently including Chakravarty et al. 2020; Raman et al. 2020; Raman & Hughes 2020; Shah & Srinivasulu 2020; Saikia et al. 2020, 2021, 2025; Sharma et al. 2021; Devender & Srinivasulu 2022; Kusuminda et al. 2022; Singh & Sharma 2023; Srinivasulu & Srinivasulu 2023; Saikia & Chakravarty 2024; Sail & Borkar 2024). With the advent of non-invasive passive acoustic monitoring alongside the development of automated call extraction and classification methodologies, echolocation data has become more readily available, and data collection methods are becoming more accessible (López-Baucells et al. 2019; Roemer et al. 2021; Froidevaux et al. 2023), expanding the potential for using echolocation calls in biodiversity monitoring, and research in comparison to morphological characters, which require invasive sampling, and physical handling of animals.

The exploration of functional trait data variations across species, geography, and time has been used effectively to answer ecological questions in many contexts, sometimes offering greater explanatory power than comparable indices of diversity (Kearney et al. 2021; Stewart et al. 2023). Functional trait data (including echolocation for bats) is often collected at local and community levels, and only recently have these data collection & analysis techniques been adapted to continental, and global scales (Etard et al. 2020; Migliavacca et al. 2021; Görföl et al. 2022). Adapting trait-based methods to larger scales and wider species groups comes with the problem of data completeness – trait analyses often rely on incomplete data, which can lead to biases, and uncertainty in inference (Toussaint et al. 2021; Stewart et al. 2023) – this paucity in trait knowledge is referred to as the Raunkiæran shortfall (Malaterre et al. 2019; Gonçalves-Souza et al. 2023). Some estimates of functional diversity are robust enough to withstand data incompleteness in a majority of species (up to 70% in the case of richness and divergence; Stewart et al. 2023), and new methods of imputation are being developed, and advanced to account for missing data (Johnson et al. 2021). Still, it is vital to collect, and catalogue functional trait data in widely accessible dynamic databases, with the aim of quantifying intraspecific variation, and capturing the depth of functional diversity in a group (Stewart et al. 2023). Certain morphological traits in bats are well-reported and relatively consistent - for instance, most species descriptions report the forearm length, and the lengths of the first & second phalanges of the second & third metacarpals (in South Asia often following Bates & Harrison 1997 and Srinivasulu et al. 2010). Various craniodental measurements including condyle-canine length and the lengths of the upper & lower toothrows are also widely used morphometrics to identify species. The translation of such characters to function becomes clear when the diet, behaviour, and life-history of the species is known (Norberg & Rayner 1987; Santana et al. 2010, 2012; Arbour et al. 2019; Luo et al. 2019; Zou et al. 2022). There have been some studies on the wing morphology of bats in comparison to their echolocation (Zou et al. 2022), distribution (Luo et al. 2019), and ecological interactions (Wood & Cousins 2023), but an overview of the state of knowledge for functional traits in bats is lacking in South Asia, especially, for echolocation trait data.

In this study, we assess the current knowledge on South Asian bat echolocation to assess the degree of Raunkiæran shortfall and further our understanding of bat species, and trait diversity in this region, by compiling published & unpublished call data from South Asian echolocating bat species. We assess the taxonomic, functional, and geographic variations in the data, comparing across studies, regions, equipment, and recording conditions, and bring it together into a foundational large-scale dataset, which can be expanded with new data in the future. Using this dataset, we describe the current knowledge gaps, and potential biases in the available echolocation information, and identify knowledge priority regions (i.e., areas with relatively large diversity of extant echolocating bat species but from which little or no call data has been reported) in order to aid future research, and conservation of bats in South Asia.

## METHODS

### Collation of peer-reviewed literature

To assess the current state of knowledge on bat echolocation in South Asia, we first reviewed the existing literature. We conducted an initial naïve search by querying the Semantic Scholar, Google Scholar, and SCOPUS databases using their respective query syntax to recover any publications including all of: the terms "echolocation", "call", or "acoustic", the name of each echolocating bat genus (based on Srinivasulu et al. 2025), the names of all the countries in South Asia, and the term "kHz*" to filter publications where frequency information is given (Table 1). In the case of the Great Evening Bat *Ia io* and the Particoloured Bat *Vespertilio murinus*, we used the entire species name as the relevant search term on all databases, as their respective generic names recovered many irrelevant results. In the case of the genus *Cnephaeus*, we also queried for *Eptesicus*, as before Cláudio et al. (2023) all species currently assigned to *Cnephaeus* in South Asia were assigned to *Eptesicus*. The search was conducted using Publish or Perish v8.17 (Harzing 2007) to allow for repeatable and consistent querying. The studies recovered through the naïve search were then imported into the systematic review software, Rayyan (Ouzzani et al. 2016) for further evaluation, and screening. We initially excluded any irrelevant texts, then excluded any texts with no relevant data, and those which were not peer-reviewed (including preprints), then assessed the full texts of each included study to exclude studies with unclear or absent data and also recover any additional sources from cited references. The process of the literature search and screening was recorded using a PRISMA flow diagram (Supplementary Material 1). The family Pteropodidae was excluded from the naïve search; although some bats in the genus *Rousettus* are known to use tongue-click echolocation (Waters & Vollrath 2003; Holland et al. 2004; Yovel et al. 2011; Smarsh et al. 2021), these calls tend to fall within the audible frequencies, are fundamentally different to echolocation calls seen in other echolocating bats, and are difficult to distinguish from noise, and identify accurately in passive acoustic monitoring, requiring much more detailed analysis.

For our final screening, we used three filters: first, we only selected studies focused on exploration- and orientation-based calls in the species' typical habitat – these are most useful for species identification (Kunz & Parsons 2009) compared to social, and interaction calls, which can differ significantly, and are considered less useful (Pfalzer & Kusch 2003; López-Bosch et al. 2021). Second, studies were filtered based on appropriate recording conditions (contexts in which recordings were made), depending on the call types. We selected studies reporting calls recorded in free flight, after release, or hand-held conditions for species which use constant-frequency (CF) echolocation (Rhinolophids and hipposiderids). As calls are known to vary greatly between recording conditions in non-CF species (Fraser

**Table 1. List of search terms and strings used for each database in the literature search.**

| Database | Search string format |
|---|---|
| Google Scholar | "*Genus*" AND (“echolocation" OR "call" OR "acoustic") AND "kHZ" AND intitle: ("Afghanistan" OR "Bangladesh" OR "Bhutan" OR "India" OR "Nepal" OR "Pakistan" OR "Sri Lanka") |
| SCOPUS | Keywords: "*Genus*" AND (“echolocation" OR "call" OR "acoustic") AND "kHZ"<br>Title words: ("Afghanistan" OR "Bangladesh" OR "Bhutan" OR "India" OR "Nepal" OR "Pakistan" OR "Sri Lanka") |
| SemanticScholar | "*Genus*" AND "echolocation" OR "call" OR "acoustic" AND "kHz" AND ("afghanistan" OR "bangladesh" OR "bhutan" OR "india" OR "nepal" OR "pakistan" OR "sri lanka") |

et al. 2020), for these species we considered only studies reporting calls recorded after release or in free flight (once identity was confirmed), and excluded hand-held recordings unless no other information was available (as happened for one species, see Results). Third, we selected studies that provided numeric information for all of the following four call characters: frequency of maximum energy (FMAXE, defined as the frequency containing the highest energy in the call, in kHz), highest frequency (HF, the highest frequency value of the call, in kHz), lowest frequency (LF, the lowest frequency value of the call, in kHz), and duration (D, the duration of a single call, in milliseconds). From D, HF, and LF we then calculated bandwidth (B, the difference between the highest and lowest frequencies of a call, in kHz), and sweep rate (SR, the ratio between the bandwidth and the duration, with higher values representing steeper calls).

**Collation of unpublished data**

Additional data were obtained by searching for echolocating bat species found in South Asia on ChiroVox, a large open-access database of original bat call recordings (Görföl et al. 2022) with highly detailed metadata on detectors used, and recording conditions. We also compiled unpublished calls from various surveys conducted between 2000 and 2023 by the authors, and collaborators. For these unpublished calls, we gathered metadata on recording condition, detectors used, and the geolocation of the recording. All unpublished calls were then analysed in Batsound Pro v4.0 (FFT size 512, Hanning window; Pettersson Elektronik AB) for full-spectrum or time-expansion recordings, and AnalookW (default parameters; Titley Scientific) for zero-crossing recordings. We selected calls with high signal-to-noise ratio (assessed using the visual clarity of the call signal in the spectrogram), choosing 3–5 ‘passes’ (where a pass is defined as a single sequence of 3 or more signals signifying a single crossing of the bat through the zone of detection; following Fraser et al. 2020), and selecting 5–10 ‘pulses’ (defining a pulse as a single call signal with a clearly identifiable start and end, and at least one clearly visible harmonic) from each set depending on the signal-to-noise ratio. We followed well-defined pre-existing methods (e.g., Jones et al. 2000; Holland et al. 2004; Papadatou et al. 2008; Hackett et al. 2017; Srinivasulu et al. 2017; Chakravarty et al. 2020; Fraser et al. 2020; López-Bosch et al. 2021; Rai et al. 2021; Győrössy et al. 2024; Saikia et al. 2025) to extract the call characters FMAXE, HF, LF, and D from unpublished recordings, then deriving the character B from HF & LF, and SR from B & D as described above. Where recordings were available for peer-reviewed published data, we prioritised the published data.

**Dataset of call parameters**

For call description and cataloguing, we organised the collected published and unpublished data into ‘observations’, where each observation was defined as a unique combination of call parameters, location, detector used, and recording condition for any given species. This allows us to not only compare the call parameters of various species, but also assess intra-specific differences caused by using different detectors in different recording conditions, and in different regions. As such, a published study used as a source may contain multiple unique observations depending on the diversity of species, locations, recording conditions, and detectors used.

Based on visual assessment of call shape and grouping similar call characters, we identified major sonotypes. All assessed calls from both published and unpublished data could be classified based on a visual assessment into the sonotypes, but many species showed overlapping call characters that do not permit unambiguous species-level classification. To further support species identification, a comprehensive dataset was generated describing seven main variables for each identified observation: HF (in kHz), LF (in kHz), B (in kHz), FMAXE (in kHz), D (in milliseconds), SR (in kHz/milliseconds), number of pulses recorded, and sonotype (Figure 1). From published sources, we used the average values, and standard deviations for each parameter as published; from unpublished data, we summarised all recordings made as part of the single observation into mean, and standard deviation values for each parameter. We also collected eight metadata variables for each observation, describing: the detector used, the country & region where the recording was made, the identified taxonomic family and species name, the species' IUCN status as of January 2025, and the full citation or source information for the data. We also classified recording conditions for published data based on the available information written in the source publication's methodology; conditions were classified into one of five categories: hand-held (where the recording was made while the bat was held in hand), flight-clutter (recordings made in free flight in a cluttered environment), flight-open (recordings made in free flight in an open environment), release-clutter (recordings made shortly after the bat was released in a cluttered environment), release-open (recordings made shortly after the bat was released in an open environment).

**Traits, distribution, and knowledge gaps**

The comprehensive dataset of echolocation observations allowed us to explore the availability of call data across taxonomic families (Srinivasulu et al. 2025), IUCN status as of January 2025 (IUCN 2025), call families, methodologies (detector and conditions as described by the data collectors), and data sources (published, unpublished, ChiroVox), and assess representation, potential biases, and knowledge gaps in trait data.

We explored spatial coverage in available call data, and proposed priority areas for future bat call data collection. We used QGIS v3.40.6 and the *terra* package (Hijmans 2024) in R 4.4.1 (R Core Team 2024) to match the locations of all collected observations onto a 0.5° x 0.5° grid covering South Asia. From this map, we estimated the per-cell metric 'species with call data' (SCD) as the number of distinct species with at least one observation reported in each grid cell. We then matched occurrence point localities from a dataset of compiled published and unpublished distribution data (expanded from Srinivasulu et al. 2024) to the same 0.5° x 0.5° grid to calculate the per-cell metric 'species richness' as the number of distinct bat species reported as occurring in each cell. Finally, we characterised 'echolocation knowledge ratio' (EKR) as the proportion of species in a cell for which at least one observation was available. EKR values could range from 0 representing no echolocation knowledge for any extant echolocating species, to 1 representing at least one observation reported for each extant echolocating species, and were calculated per-cell using the formula:

$$\text{Echolocation knowledge ratio} = \frac{\text{Species with call data}}{\text{Species richness}}$$

Finally, regional priorities for future data collection were identified by classifying grid cells into three species richness categories: none (no echolocating bats present), low (< 10 species present), or high (≥ 10 species); and three EKR categories: none (EKR = 0), low (0 < EKR < 0.25), and high (EKR ≥ 0.25, representing more than ¼ of extant echolocating bat species in that cell with available call data). Based on combinations of these categories we defined six cell types that represent potential research priorities and opportunities. In particular, we classified all areas with species richness = none as no species recorded/unknown species richness, where the priority would be basic biodiversity surveys in these areas to ascertain true species diversity. We then separated areas with low species richness into three categories depending on EKR values: Low survey priority areas are those with EKR = 0, where future studies are needed but not a top priority, both to assess the true species richness in the region, and to collect echolocation data for known species; low knowledge priority areas are those with low EKR where, future studies could be valuable to supplement echolocation data, and potentially understand the true species richness in the region; and good knowledge, areas with high EKR where future work could expand from existing knowledge to study behaviour, diet, or implement passive acoustic monitoring (Darras et al. 2025). Finally, we also separated areas of high species richness into three categories depending on EKR values: High survey priority are those areas where despite the occurrence of many species we found no echolocation data (EKR = 0) and thus, areas we see as key locations for targeted studies to prioritise collecting echolocation data; High knowledge priority areas are those with low EKR that present good opportunities to collect echolocation data for more species; and good knowledge areas, as above, reflect those with high EKR where future work could focus on more detailed studies. Each of these priority categories represent regions that are best suited for various types of research questions and can be associated with separate potential research actions (Table 2). We show the locations of areas within these categories using a bivariate choropleth map generated in QGIS v3.40.6.

**Table 2. Priority categories for regions across South Asia, based on their Species Richness and Echolocation Knowledge Ratio (EKR).**
*For all levels of species richness knowledge, true species diversity may be underestimated especially in unstudied areas. Gathering more data on extant species diversity is thus a universal priority in all categories.

| Priority category | Research opportunity | Species richness | EKR | Knowledge gaps | Data collection priority | |
|---|---|---|---|---|---|---|
| | | | | | Biodiversity | Echolocation |
| No species recorded/ Unknown species richness | Discovery | None | None | True diversity may be underestimated in unstudied areas*. | High priority in unstudied areas | If species are detected |
| Low Survey Priority | Biodiversity and echolocation knowledge | Low (< 10 spp.) | None | Lack of echolocation data. | Medium priority in unstudied areas | Medium priority |
| High Survey Priority | Priority echolocation research | High (≥ 10 spp.) | None | Lack of echolocation data. | Low priority | High priority |
| Low Knowledge Priority | Biodiversity knowledge | Low | Low (0 – 0.25) | Limited echolocation data. | Medium priority in unstudied areas | Low priority |
| High Knowledge Priority | Echolocation research | High | Low | Limited echolocation data. | Low priority | Medium priority |
| Good Knowledge | Deepen knowledge | Low or High (> 0 species) | High (≥ 0.25) | True diversity may be underestimated in understudied areas*.<br><br>Echolocation knowledge strong, but incomplete. | Medium priority in understudied areas | Low priority<br><br>Potential for other studies using echolocation (e.g., behaviour, diet, interactions) |

## RESULTS

### Collation of existing knowledge

The initial searches of the Semantic Scholar, Google Scholar, and SCOPUS databases resulted in an initial set of 76 publications (Supplementary Material 1), including duplicates, and irrelevant studies. After the screening process, we selected a final set of 35 peer-reviewed publications for further assessment. From these publications, we recovered a total of 185 unique observations of 86 species from India, Pakistan, Nepal, and Sri Lanka (Supplementary Material 2). From the ChiroVox database, we recovered seven unique observations of five species across Bangladesh. Finally, from our analysis of a total of 6,190 unpublished calls, we recovered a total of 107 unique observations of 36 species from India. This resulted in a combined database of 299 observations of 86 species across Bangladesh, India, Nepal, Pakistan, Sri Lanka, sourced from published, and unpublished data (Supplementary Material 3).

From our assessment of the call shape and characters of all collected calls, we grouped South Asian bat echolocation calls into eight sonotypes (Figure 1; Supplementary Material 3). These sonotypes are defined within the context of South Asian bat echolocation:

**1. Short Constant Frequency** (SCF; genus *Hipposideros*; 68 observations of 13 species): pulses comprising a short (< 15 ms) constant frequency (CF) component followed by a steep frequency-modulated (FM) downward sweep.

**2. Long Constant Frequency** (LCF; genus *Rhinolophus*; 56 observations of 11 species): pulses comprising a CF component preceded and followed by a FM downward sweep.

**3. Frequency Modulation** (FM; genera *Harpiocephalus*, *Hesperoptenus*, *Kerivoula*, *Miniopterus*, *Murina*, *Myotis*, *Phoniscus*, and *Submyotodon*; 58 observations of 28 species): pulses comprising a short and steep, broadband FM component (in cluttered free flight) or a short and relatively steep FM component (in open flight).

**4. Frequency Modulation with Quasi-CF** (FM-QCF; genera *Arielulus*, *Cnephaeus*, *Eudiscopus*, *Hypsugo*, *Mirostrellus*, *Nyctalus*, *Pipistrellus*, *Scotophilus*, and *Tylonycteris*; 50 observations of 20 species): pulses comprising a short and relatively steep FM component (in cluttered flight), or a short and relatively shallow FM component (in open flight), both followed by a distinct short and shallow quasi-CF component; call shape sometimes resembles a hockey stick.

**5. Long Multiharmonic** (LMH; genera *Mops*, *Otomops*, *Rhinopoma*, *Tadarida*, *Taphozous;* 44 observations of 10 species): calls of long duration (> 5 ms) with one or occasionally more harmonics seen; number of harmonics seen depends on distance of the bat from the detector. These calls are hard to distinguish from each other based on call shape and characters alone; species range and habitat must be considered when inferring species presence based on these calls. The degree of clutter also impacts the sweep rate (slope) and the general shape of the call: for instance, free-flying *Mops plicatus* from Sigiriya (Sri Lanka; Kusuminda

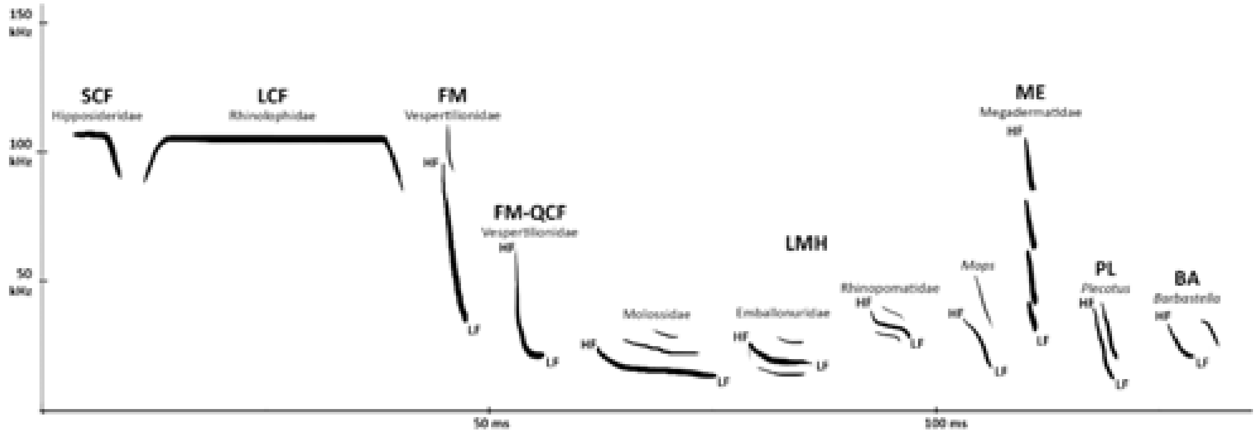


**Figure 1. Representative spectrograms of echolocation sonotypes of South Asian bats. Highest frequency (HF) and lowest frequency (LF) are indicated for frequency modulated calls.**

& Yapa 2017) called using characteristically-shaped long yet steep multiharmonic pulses (Figure 1).

**6. Megadermatid** (ME; genera *Lyroderma* and *Megaderma*; 16 observations of 2 species): characteristic short (duration often < 2 ms) and broadband (BW often > 50 kHz) pulses of three or more harmonics of similar amplitude seen close together.

**7. Plecotine** (PL; genus *Plecotus*; 2 observations of 2 species): relatively short (duration < 5 ms) multiharmonic calls comprising downward sweeps of one or two harmonics of almost equal amplitude (Chakravarty et al. 2020). Call shape & characters tend to overlap both within the genus, and with other FM, and FM-QCF species.

**8. Barbastelle** (BA; genus *Barbastella*; 2 observations of 1 species, *B. darjelingensis*): calls vary highly based on environmental clutter, flight behaviour, and vegetation structure (see Denzinger et al. 2001), ranging from short steep narrowband multiharmonic FM pulses as recorded by Chakravarty et al. (2020) and Wordley (2014), to characteristic alternating FM pulses of two distinct shapes, and amplitudes (Denzinger et al. 2001; Seibert et al. 2015). Barbastelle pulses are of relatively low amplitude (< 110 dB; Lewanzik et al. 2023), but this is not fully explored in South Asia.

HF may vary greatly, especially in broadband FM & FM-QCF calls, due to atmospheric attenuation and the distance between the bat and the detector. Additionally, both HF & LF, and also B & D, and thus SR greatly vary based on the degree of clutter in the location where the bat is flying, ranging from shallow and low-SR calls in open areas to steep and high-SR calls in cluttered areas.

**Variations in call characters**

The echolocation data for several species were highly varied based on geography, in some cases including distinct phonic types of the same species, possibly indicating cryptic diversity – more detailed call data is required to establish more robust diagnostic boundaries for species identity. Thabah et al. (2006) reported two distinct phonic types of *Hipposideros larvatus* in Meghalaya, India, each using an FMAXE of around 85 kHz and 98 kHz, respectively. They did not report the durations of these distinct calling types and thus it is hard to infer whether this may be an artifact of environmental clutter or a distinct group of individuals. Similarly, Chattopadhyay et al. (2010) reported a distinct phonic type of *Rhinolophus rouxii* from across Tamil Nadu, India, calling at an FMAXE of around 94 kHz. This is higher than seen elsewhere in southern India – e.g., 82 kHz reported from Kerala by Raman & Hughes (2020) – and Sri Lanka – e.g., 74 kHz reported across the country by Kusuminda et al. (2018). A similarly high frequency (92 kHz) was reported from the Valparai Plateau in the southern Western Ghats (Wordley 2014), we also report similarly high frequencies (91–94 kHz) from the southern Western Ghats in Kerala (Supplementary Material 3). This distinct phonic type was assigned the name *Rhinolophus indorouxii* by Chattopadhyay et al. (2012), however this species is a nomen nudum and therefore synonymised under *R. rouxii*.

There is also considerable variation and overlap in the call characters of many species, especially FM and FM-QCF bats. In our experience (and corroborated by published data), we have found that the calls of *Pipistrellus ceylonicus* tend to vary widely across its distribution, with mean FMAXE values ranging around

35–45 kHz. Saikia et al. (2025) have reported *Pipistrellus babu* from Himachal Pradesh, India, calling at an average FMAXE of 40 kHz, which falls within the range for *P. ceylonicus*. Hence, in cases such as these, care must be taken to either confirm species-level identity through other means or to refer to call identities as pertaining to species-groups. Additionally, Raghuram et al. (2014) report calls of *Pipistrellus tenuis* from Kudremukh National Park (Karnataka, India) at an FMAXE of 38 kHz. These calls were recorded only in flight and could be misidentified, instead representing *P. ceylonicus*, as they are very different from the expected FMAXE around 50 kHz for *P. tenuis* (Supplementary Material 3). Finally, there is a high degree of inconsistency in megadermatid call characters between regions (Supplementary Material 3). This is likely due to the characteristic short multiharmonic nature of the calls, and that the FMAXE tends to fall within one or more harmonics. More investigation is needed to ascertain the various situations in which specific harmonics are produced with more energy, and thus we recommend treating echolocation calls of megadermatids (including those presented in this study) with care.

Intraspecific variability in call characters differed between species – enough data was available to assess intraspecific variations in characters recorded in the same recording condition for 31 species; It is important to note that our collected data does not account for variations between detectors and other such impacting factors, and much more detailed data is needed to analyse such variations. The most data-rich species were *Hipposideros speoris* (15 observations) and *Rhinolophus rouxii* (12 observations; variation detailed above). Duration in all calls varied between recording conditions – as different environmental structures and degrees of clutter impact pulse duration and inter-pulse interval (Fraser et al. 2020) – but remained relatively consistent between locations within species, with shorter calls sometimes associated with higher mean FMAXE; however, this relationship was not consistently observed. Variation of mean FMAXE in most CF species was under 5 kHz between locations, with some notable exceptions. For instance, in cluttered flight recordings, the mean FMAXE of the Havelock Island population of *Hipposideros gentilis* is approximately 10 kHz higher than its sister Andaman Islands populations (Srinivasulu et al. 2017); in cluttered flight recordings recorded on the Pettersson D500X, the mean FMAXE of Indian *Hipposideros speoris* varied between 128 kHz in Andhra Pradesh and 138 kHz in Telangana (present study); and mean FMAXE in cluttered flight recordings of Indian *Rhinolophus rouxii* in Kerala was 10–12 kHz higher than those recorded in Karnataka and Maharashtra on the same detectors (Pettersson D500X and Wildlife Acoustics SM3BAT respectively; present study). In FM bats, FMAXE variation was under 10 kHz (except in the case of *Miniopterus phillipsi*, for which the mean FMAXE in Maharashtra, India, recorded on a Wildlife Acoustics SM3 was 18 kHz lower than calls recorded on a Pettersson D500X in a different location in Maharashtra and calls recorded on a Pettersson M500 in Uva, Sri Lanka; Kusuminda et al. 2022; present study). HF, LF, and D (and consequently B) all varied widely between locations in some species, in the same recording conditions. This may be due to differing attenuation of calls based on various conditions present in the recording location including foliage and habitat structure, flight elevation, and individual variations, but could also reflect difficulties in establishing species identity based on calls alone, especially in regions of overlapping distribution of species with similar calls.

**Patterns and gaps in metadata**

The published data comprised 185 observations of 86 species, of which the calls of Kelaart's pipistrelle *Pipistrellus ceylonicus* were reported by the most studies – seven in total, of which six were from India and one from Sri Lanka. Of the 86 species, 43 were reported only in one study each (50%; Supplementary Material 3). The data were mostly distributed in India (26 out of 35 studies; 74%), and the greatest number of studies per region was six studies from the south Indian state of Karnataka (Chattopadhyay et al. 2012; Raghuram et al. 2014; Srinivasulu et al. 2015, 2016; Deshpande & Kelkar 2015; Srinivasulu & Srinivasulu 2023). The greatest number of total unique observations reported from any region was from Uttarakhand (n = 34; Chakravarty 2017; Chakravarty et al. 2020; Singh & Sharma 2023).

Unfortunately, detailed information was lacking in some published studies. For instance, Raman & Hughes (2020) compiled the calls of 48 species from the Western Ghats, but recording locations were not provided. Kusuminda et al. (2022) described the new species Phillips' Bent-winged Bat *Miniopterus phillipsi* but provided only the FMAXE and no other characters from Sri Lanka, similarly to those of *Hipposideros larvatus* from Meghalaya, reported by Thabah et al. (2006). Unpublished data was found for 36 species from the authors' field recordings across India, which were analysed according to consistent standardised methods (see Methods). All of these species were previously reported in published data, but our unpublished data covers some spatial gaps in the distribution of

**Table 3. Number of echolocation observations recorded in each recording condition (rows), described by sonotype (columns).**

| Recording Condition vs Sonotype | | Sonotype | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SCF | LCF | FM | FM-QCF | LMH | ME | PL | BA |
| Recording Condition | Flight – Clutter | 28 | 27 | 19 | 13 | 18 | 10 | 0 | 0 |
| | Flight – Open | 18 | 6 | 10 | 19 | 15 | 2 | 0 | 0 |
| | Release – Clutter | 5 | 6 | 15 | 9 | 1 | 3 | 0 | 1 |
| | Release – Open | 2 | 3 | 3 | 11 | 10 | 1 | 2 | 1 |
| | Hand-held | 15 | 15 | 1 | 0 | 0 | 0 | 0 | 0 |
| | Total | 68 | 57 | 48 | 52 | 44 | 16 | 2 | 2 |

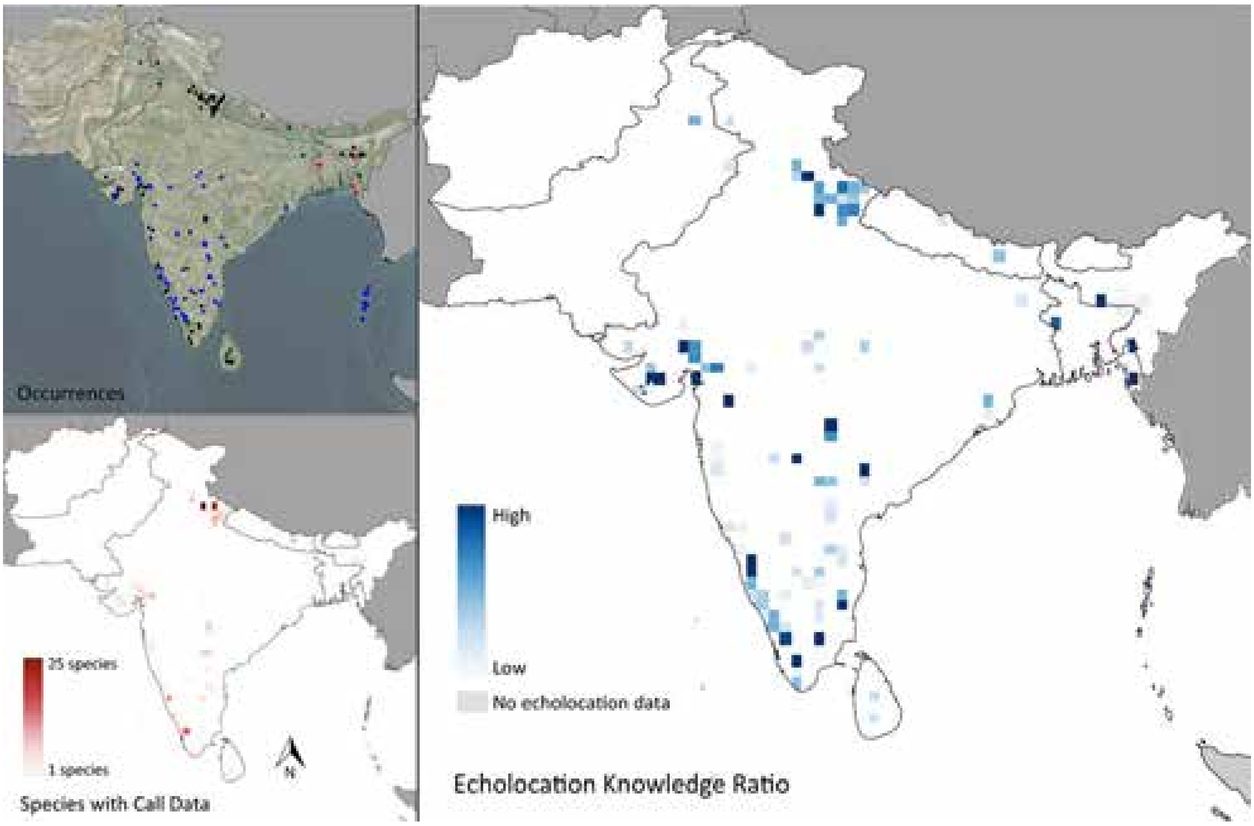


**Figure 2. Maps of the study area indicating occurrences (where each point represents a location where echolocation data was recorded; black, blue and red points represent published, newly reported, and ChiroVox data, respectively); species with call data (where darker red colours represent more species with call data per cell); and echolocation knowledge ratio (where darker blue colours represent a higher echolocation knowledge ratio, and grey cells are those with no echolocation data recorded for any species).**

knowledge, especially in Peninsular India (Figure 2). Additional unpublished records were found on the ChiroVox database and were distributed in India, and Bangladesh. The calls from India corresponded to those published in Chakravarty et al. (2020), and thus, we prioritised published information, and the calls from Bangladesh included in this study represented six species recorded in various conditions (Supplementary Material 3; Figure 2).

Nearly three-quarters of the species for which echolocation data was found (63 out of 86 species) are assessed as Least Concern (LC) in the IUCN Red List (IUCN 2025), with eight others listed in more at-risk categories (Hodgson's Myotis *Myotis formosus* and Painted Bat *Kerivoula picta* as 'Near Threatened'; Durga Das' Roundleaf Bat *Hipposideros durgadasi*, Rickett's Big-footed Myotis *Myotis pilosus*, and Mandelli's Myotis *Myotis sicarius* as 'Vulnerable'; Pomona Roundleaf Bat

*Hipposideros pomona* and the Andaman Horseshoe Bat *Rhinolophus cognatus* as 'Endangered'; and the Kolar Roundleaf Bat *Hipposideros hypophyllus* as 'Critically Endangered'. Of the 19 remaining species with echolocation data, eight are 'Data Deficient', and 11 have not been assessed yet (NA; Supplementary Material 3; Figure 3). There were more species with echolocation data than without in all Red List assessment categories except NT (two species with data and four species without data) and DD (eight species with data and 10 species without data; Supplementary Material 3; Figure 3). Approximately two-thirds of all extant LC, NA, and EN species, and all extant VU and CR species, have echolocation data.

It is vital to understand the variations in echolocation data that arise due to differences in the recording location, as both the degree of clutter in the environment and the specific type of recording (hand-held, in-flight, or at-release) greatly influence the shape and parameters of echolocation calls for certain species (Hiryu et al. 2006; Fraser et al. 2020). Of the 299 unique observations, 185 observations corresponding to 64 species (around 61% of the total data) were recorded in flight in either cluttered or open environments – usually in-situ near the bats' roosts or foraging sites, or in clearings, and open fields (Figure 3; Table 3). Many of these species (31 species) were urban-resilient vespertilionids recorded in urban/semi-urban ecotone areas (e.g., Kelaart's Pipistrelle *Pipistrellus ceylonicus*), forest-associated vespertilionids recorded in clearings (e.g., Horsfield's Myotis *Myotis horsfieldii*), scrubland-associated hipposiderids (e.g., Schneider's Roundleaf Bat *Hipposideros speoris*), or high-flying molossids (e.g., Egyptian Free-tailed Bat *Tadarida aegyptiaca*). Release calls made up 83 observations corresponding to 61 species – the process of recording these involved capturing the bat, confirming its identity, and then releasing it either in a cluttered (40 observations of 33 species) or open environment (43 observations of 37 species). The remaining 31 observations of 19 species were recorded while the bat was held in hand – these species were all CF bats, excepting the Kachin Woolly Bat *Kerivoula kachinensis* from Meghalaya, India (Uttam Saikia et al. 2020), a FM species for which no other recording was available (Table 3; Table 4; Supplementary Material 3). For 16 species (*Eudiscopus denticulus*, *Harpiocephalus harpia*, *Hippsosideros ater*, *Hipposideros lankadiva*, *Kerivoula crypta*, *K. picta*, *Miniopterus magnater*, *Mops plicatus*, *Myotis pilosus*, *Myotis sicarius*, *Otomops wroughtoni*, *Pipistrellus babu*, *Rhinolophus macrotis*, *Tadarida aegyptiaca*, *Tylonycteris fulvida*, *Tylonycteris malayana*), the only observations available were recorded in-flight, in all cases after the species identity was confirmed (Supplementary Material 3). Despite flight data being the most accurate representation of the species' actual echolocation calls, the data for these 16 species must be used with caution as misidentification is possible in areas with multiple species.

**Distribution and knowledge gaps**

Most of the published data was distributed across mainland India, with additional locations in the Andaman Islands and the Lakshadweep Islands, as well as in Nepal, Pakistan, and Sri Lanka (Figure 2). Most localities were in northern India (Himachal Pradesh and Uttarakhand states), western India (Gujarat), and peninsular India (Andhra Pradesh, Karnataka, Kerala, Maharashtra, Tamil Nadu, and Telangana states; Figure 2). Some data was also distributed in eastern India (Bihar, Meghalaya, and Mizoram states). New data reported as part of this study was mostly distributed in peninsular India, with some records from central India (Madhya Pradesh; Figure 2). Especially in the Western Ghats and the Deccan Plateau, unpublished data covered gaps in the existing published data. Unpublished ChiroVox data was only distributed in Bangladesh and was also the only data we found from the country (Figure 2).

Species with Call Data (SCD; the number of distinct species with at least one observation reported in each grid cell; see Methods) varied across South Asia, with hotspots of call data richness in Uttarakhand (India; 25 species near Dehradun and 15 species near Kedarnath Wildlife Sanctuary), the southern Western Ghats (India; 14 species in the Valparai Plateau), and the central Western Ghats (India; 12 species in and around Kudremukh National Park). It must be noted that, as the resolution of the spatial analyses is relatively coarse (0.5° approximately corresponding to 50 km on average in South Asia), each hotspot represents a very wide region of approximately 2,500 $km^2$. Echolocation Knowledge Ratio (EKR; the proportion of extant echolocating species in each cell for which echolocation data was found) also ranged across the region, with much of South Asia having at least one reported echolocating species but no echolocation data (Figure 3). Similarly to SCD, hotspots where EKR was 1 – i.e. all the reported echolocating species had echolocation data available – were seen in India: in Gujarat, Himachal Pradesh, central coastal Karnataka, the Western Ghats in Kerala, northern & southeastern Maharashtra, the Khasi & Garo Hills in Meghalaya, the Eastern Ghats & Nilgiris in Tamil Nadu, northern & eastern Telangana, and Uttarakhand; and in

Table 4. Number of echolocation observations recorded in each recording condition (rows), described by the detector used (columns).

| Recording Condition vs Detector | | Anabat SD1 | Anabat Walkabout | Pettersson D240X | Pettersson D500X | Pettersson D980 | Pettersson D1000X | Pettersson M500-384 | Pettersson M500 | Wildlife Acoustics EchoMeter Touch 2 | Wildlife Acoustics EchoMeter Touch 2 Pro | Wildlife Acoustics SM3BAT | Wildlife Acoustics SM4BAT | Ultrasound-Advice S25 | Ultrasound-Advice SM2 | Ultrasound-Advice U30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Detector | | | | | | | | | | | | | | |
| Recording Condition | Flight – Clutter | 14 | 16 | 4 | 27 | 11 | 5 | 1 | 11 | 2 | 2 | 19 | 0 | 0 | 0 | 3 |
| | Flight – Open | 10 | 5 | 7 | 13 | 1 | 1 | 16 | 2 | 1 | 0 | 12 | 0 | 0 | 1 | 1 |
| | Release – Clutter | 1 | 7 | 0 | 22 | 0 | 2 | 1 | 0 | 0 | 0 | 2 | 5 | 0 | 0 | 0 |
| | Release – Open | 2 | 22 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 |
| | Hand-held | 9 | 8 | 0 | 3 | 0 | 4 | 0 | 2 | 0 | 0 | 1 | 0 | 4 | 0 | 0 |
| | Total | 36 | 58 | 11 | 75 | 12 | 12 | 18 | 15 | 3 | 2 | 43 | 5 | 4 | 1 | 4 |

the eastern Chittagong Division of Bangladesh (Figure 2).

More than 90% of the study area was either classified as having 'No Species Recorded/Unknown Species Richness' (i.e., there is no knowledge of either species richness or echolocation data from the region; 65%; approximately 3.4 million km$^2$; Table 2), or as low survey priority regions (i.e., regions with low species richness and no EKR; 27%; approximately 1.4 million km$^2$; Table 2). These regions are widespread across South Asia, comprising almost all of Afghanistan and Bangladesh, all of Bhutan, large areas of northern & central India, western Nepal, central & southern Pakistan, and northern Sri Lanka (Figure 4). Regions of 'good knowledge' (i.e., regardless of high or low species richness, more than ¼ of the extant echolocating bats have echolocation data reported; Table 2) only comprised around 3% of the study area (approximately 165,000 km$^2$). These regions were seen in large contiguous clusters south of the Himalaya (Himachal Pradesh and Uttarakhand, India) and in the central & southern Western Ghats (Karnataka and Kerala, India). Smaller fragmented clusters were seen across the region, including in the Indus Valley and Hindukush Range (Punjab, Pakistan), western & central India (Gujarat and Madhya Pradesh), peninsular India (Maharashtra, Odisha, Tamil Nadu, and Telangana), northeastern India (Meghalaya), eastern Nepal (Bagmati), western Bangladesh (Rajshahi), and southeastern Bangladesh (Chittagong; Figure 4). Regions of 'low knowledge priority' (i.e., where species richness and EKR are low) comprised 1.6% of South Asia (approximately 85,000 km$^2$), and were seen in small, fragmented clusters across the entire study region, with a higher density in peninsular India (Figure 4).

Regions of 'high knowledge priority' (i.e., where the per-cell echolocating species richness is more than 10 species, but EKR is less than ¼; Table 2) comprised 1% of the study area (around 54,000 km$^2$). These regions were mostly seen in contiguous clusters with regions of 'high survey priority' (where the per-cell echolocating species richness is more than 10 species, but no echolocation knowledge exists for any of them from that cell; Table 2), which comprised 2.6% of the study area (around 135,000 km$^2$; Figure 4). Combined clusters of 'high knowledge priority' and 'high survey priority' were seen in northeastern India, the Western Ghats, the Eastern Ghats, the Brahmani-Mahanadi doab (Odisha, India), and in the Central, Sabaragamuwa, Southern, Uva, and Western provinces of Sri Lanka (Figure 4). Regions of 'moderate knowledge priority' alone were seen in southern India (Tamil Nadu and Kerala), northern India (Uttarakhand), and western India (Gujarat;

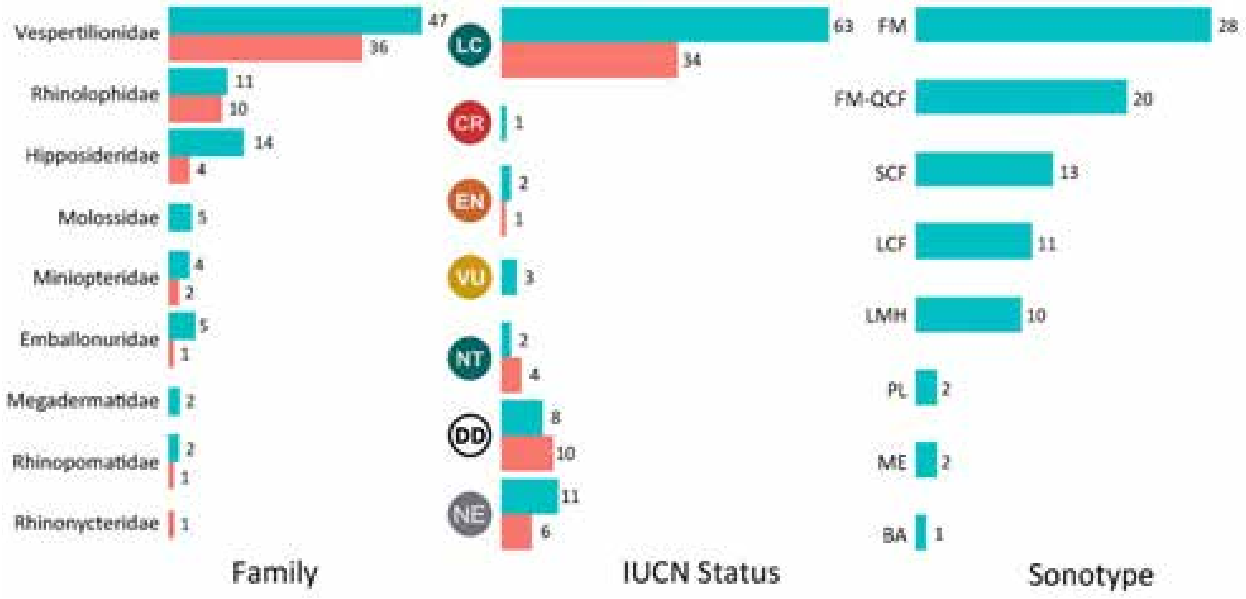


**Figure 3. South Asian bat species with echolocation data (in blue) and without echolocation data (in red) in each taxonomic family, IUCN status, and sonotype; numbers next to bars represent individual species.**

Figure 4). Finally, regions of 'high survey priority' alone were seen in various regions of Afghanistan (Faryab, Kabul, Kandahar, and Nangarhar provinces), India (Assam, Gujarat, Himachal Pradesh, Jammu & Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Meghalaya, Mizoram, Nagaland, Rajasthan, Sikkim, Tamil Nadu, Telangana, Uttarakhand, and West Bengal states), Nepal (Bagmati, Gandaki, and Koshi provinces), Pakistan (Khyber Pakhtunkhwa and Punjab provinces), and the disputed territories of Gilgit-Baltistan and Azad Kashmir (Figure 4).

## DISCUSSION

This study reviews bat echolocation research in South Asia, collating 299 unique observations of echolocation characters for 86 species by integrating published literature, unpublished recordings, and data from the ChiroVox database. It is the first compilation of its kind for South Asia, exploring data gaps, geographic variations (species characters differing from location to location), and situational variations (species characters being collected using various combinations of techniques, equipment, and conditions) in the echolocation characters for bats, supporting the development of non-invasive acoustic monitoring techniques in the region. It also identifies geographic regions of high and low echolocation knowledge density, importantly identifying research priority regions – where species diversity is relatively high and echolocation knowledge is low – for the prioritisation of future research efforts to increase our knowledge of bat echolocation in South Asia.

Data represented nearly all families, without strong taxonomic biases, except in the case of Hipposideridae (which only lack data for four out of 18 extant species) and Emballonuridae (which only lack data for one out of six extant species). No echolocation data has been reported from South Asia for the Trident Bat *Triaenops persicus*, the only species representing the family Rhinonycteridae in the region. In some small families (Molossidae and Megadermatidae) data were found for all species. Most observations represented species in Vespertilionidae, the most diverse family in the region with 84 extant species, of which we have data for 48. Vespertilionid bats are highly diverse, and some species are widespread across the region; species like Kelaart's Pipistrelle *Pipistrellus ceylonicus* and Least Pipistrelle *Pipistrellus tenuis* are commonly found in or near human settlements (Bates & Harrison 1997), increasing the likelihood of recording their echolocation during surveys that are not targeted or species-specific. However, just over half of the species in this family are represented in our echolocation dataset, representing a large knowledge gap of 36 species from one family alone. Despite their widespread distribution and high diversity (Bates & Harrison 1997; Srinivasulu & Srinivasulu 2012), much is still unknown about vespertilionid species, and future species-specific research must be directed towards this family.

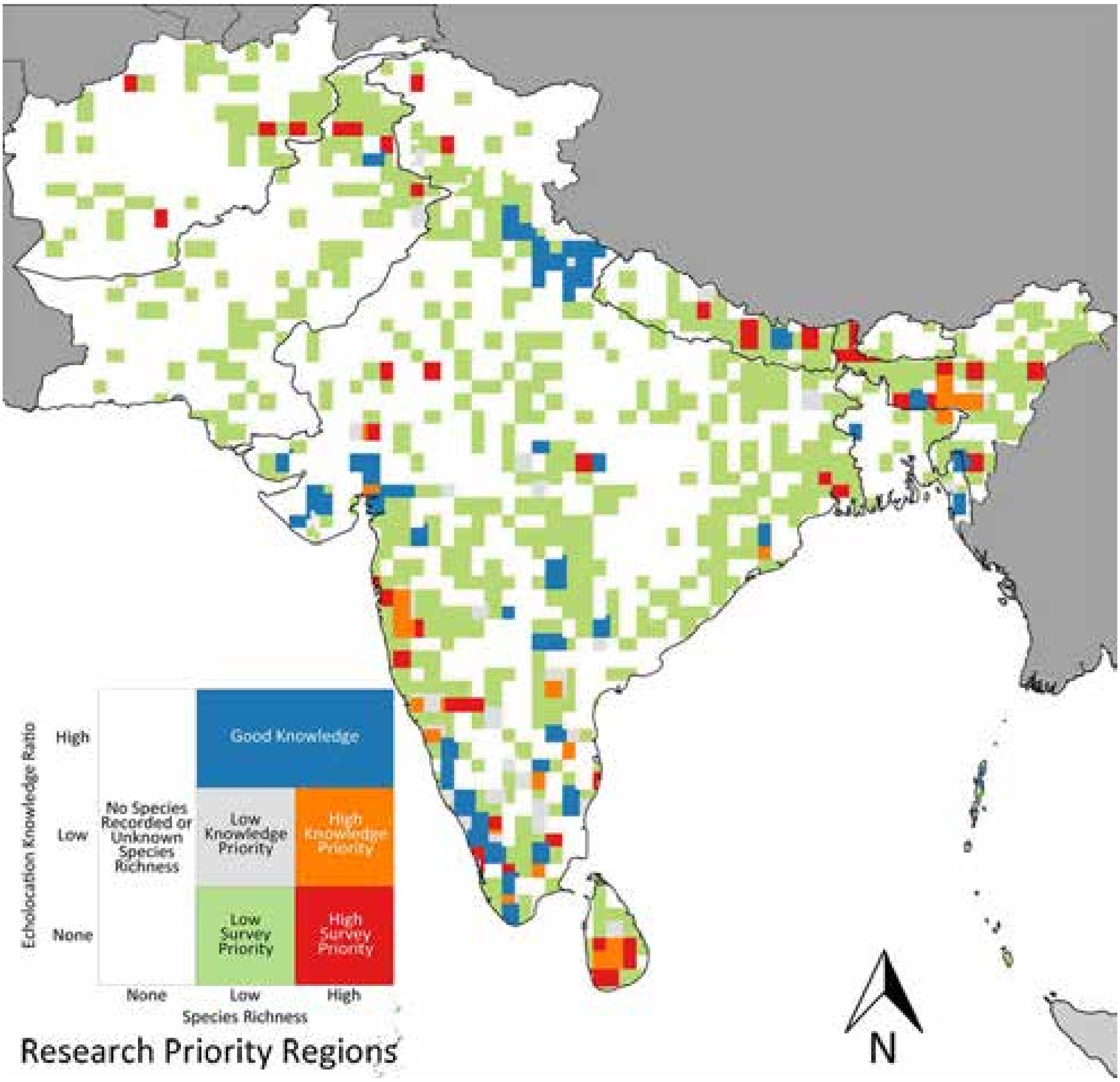


**Figure 4. Bivariate map representing research priority regions, based on combinations of species richness and echolocation knowledge ratio. Cells with 0, <10 species, and ≥10 species are represented as none, low, and high species richness, respectively; cells with 0, <0.25, and ≥0.25 echolocation knowledge ratio are classified as none, low, and high, respectively.**

Data were also available for species in various categories of extinction risk (IUCN Red List status), although we note that data was unavailable for four of the six species listed as Near Threatened, 10 out of the 18 Data Deficient species, and six out of the 17 species Not Evaluated. Additionally, 34 out of the 97 Least Concern species have no data; surveys targeted towards filling these gaps are vital. It is also important to note that over 60% of the observations in our dataset (n = 185) were collected in flight after species identity was confirmed using physical identification and (in most cases) release calls were recorded (Supplementary Material 3). For 16 species however, flight calls were the only call type available, either in published or unpublished data (*see* Results; Supplementary Material 3; Table 3). Care must be taken to ensure the species identity of an individual is established firmly before recording free-flying calls, as while call data from free-flying bats is more representative of actual calls recorded during acoustic monitoring, reference calls cannot be published based on echolocation-derived species identity alone due to variations in call characters. Ideally, an individual must be identified to species level, and both release and flight calls (and in the case of CF bats hand-held calls) must be recorded from the individual in as quiet a location as possible. If possible, multiple detectors (calibrated appropriately according to each detector's specific settings and the recording conditions, as different detectors and different calibrations can introduce variation; Adams et al. 2012) and multiple recording conditions may also be employed to capture a breadth of data. In regions where reference calls are available however, calls based on release and free-flight (which were recorded on the same detector in the same condition; Table 4) can be used as references to identify bats at least to sonotype- and family-level, though the authors advise caution with species-level identification using ambiguous and overlapping species characters.

The availability of echolocation data was highly varied across South Asia. In many regions, limited or no data was available, and most of the study area has low species richness but no echolocation data. However, in some parts of South Asia, especially in northeastern, northern, western, and peninsular India, all occurring species had echolocation data reported (Figure 4). Many more records were obtained from India than other countries, but this may be due in part to the size of the country itself, and due to all our unpublished data being from central, western, and peninsular India. We did not find published echolocation data for many extant species in large regions of Afghanistan, Bangladesh, Nepal, Pakistan, and Sri Lanka, even those which have relatively high species richness, but ChiroVox data covered several species across Bangladesh. Within India as well, the Gangetic Plains, the northern Deccan and central India, the Nilgiri Hills, the central Western Ghats, and northeastern India have relatively sparse echolocation data despite being relatively species-rich (Bates & Harrison 1997; Srinivasulu & Srinivasulu 2012). Data availability may be affected in some cases by the accessibility of study sites to researchers, a bias which is not uncommon in empirical data (González-Suárez et al. 2012; Hughes et al. 2021), but there are variations across the region. In Tamil Nadu, Uttarakhand, and Telangana, there are clusters of high data density near Madurai, Dehradun, and Hyderabad, all which contain major academic institutions – however, there are also regions like Valparai, the Garo and Khasi Hills, and most of the Gujarat peninsula, where this bias of availability is not seen (Figure 4). There are also sites of special interest, like Kolar in southern India, where the presence of the Critically Endangered Kolar Roundleaf Bat *Hipposideros hypophyllus*, has promoted site- and species-specific surveys since 2014 (Srinivasulu et al. 2014, 2016). To support future surveys and data collection, we identified 'high survey priority' and 'high knowledge priority regions' (with low or high species richness but low or no call data availability) where field surveys could lead to new data for several species. Two main priority areas fall in the Western Ghats and Sri Lanka and the Himalaya hotspots of biodiversity (Myers et al. 2000). Surveys in these areas of high ecological importance could contribute to expand our understanding of bat echolocation and diversity. Itis important to keep in mind that regions of high echolocation knowledge ratio (classified as good knowledge) still do not necessarily represent areas where we have enough data to be able to identify species to high certainty from echolocation calls alone – more work is needed to understand trait variations, and the specific identification boundaries between species based on echolocation must be analysed in further detail before we can truly confirm that the knowledge in regions identified as 'good knowledge' is enough for species-level identification. Future efforts to gather echolocation data should combine site- and species-targeted surveys with clear knowledge priorities, and our study identifies groups and areas where those efforts may be directed based on the priority of the study.

Research using functional traits to examine species interactions in ecosystems has been consistently advancing, starting with studies by early ecologists including Elton, Hutchinson, and Raunkiær (Malaterre et al. 2019). Recent work has developed newer protocols for the standardisation of functional traits in invertebrates (Moretti et al. 2017) and birds (Tobias et al. 2022), and the evaluation of the impact of anthropogenic activities on functional diversity (Carmona et al. 2021). Despite this breadth of research, the use of functional traits in animal studies has been criticised for its arbitrariness (Kearney et al. 2021), and the need for structured approaches to the collection, collation, and selection of trait data has often been recommended (Gonçalves-Souza et al. 2023). Echolocation has been long known as a vital trait in bat biology (Griffin 1953). Variation in echolocation traits has been explained using several non-exclusive hypotheses including relationships with body size, nasal chamber and laryngeal size, and evolutionary arms-races between hearing-moths and bats (Castro et al. 2024). However, this variation has not been truly quantified or explored across large groups of species, and we only know a small fraction of the echolocation characters of echolocating bat species across the world, especially in regions of high diversity such as South Asia. While our study attempts to reduce this gap by collecting and assessing the state of knowledge for bat echolocation in South Asia, it is deeply limited by the lack of depth in the data itself. The collected data comprises recordings from a limited set of recording conditions, and with the amount of data we have collected it is not possible to fully explore the breadth of all variations in species calls across geography, recording scenarios, and detectors used, amongst other factors. Thus, we only recommend using the collated data as a guideline, to follow standard methodology to collect new data, and to prioritise surveys towards regions of high knowledge and survey priorities in order to collect as much new information as possible and improve the state of echolocation knowledge in this region.

Key to effective conservation planning is a deep understanding of a study region's species diversity, including their distribution and traits (Margules & Pressey 2000). The dataset of echolocation observations and sonotypes in this study offer a foundational knowledge base for bats in South Asia which we hope will form a base for future research. Species-level trait data for South Asian bats is sorely lacking, yet trait data is key to understand the functional dimension of biodiversity (Cernansky 2017; Stewart et al. 2023), which is being eroded (Carmona et al. 2021), and is linked to important ecosystems services and functions (Cadotte et al. 2011). This study aids in the compilation of echolocation call characteristics for South Asian bats contributing understanding to an important dimension of bat functional traits (see Denzinger & Schnitzler 2013). We hope that our research promotes further interest in trait research and data compilation. Moving forward, our bat echolocation database and additional analysis of research priority regions in South Asia can support more targeted research and species- and site-specific survey planning, leading to positive long-term impacts on data collection and collation, conservation prioritisation, and policymaking.

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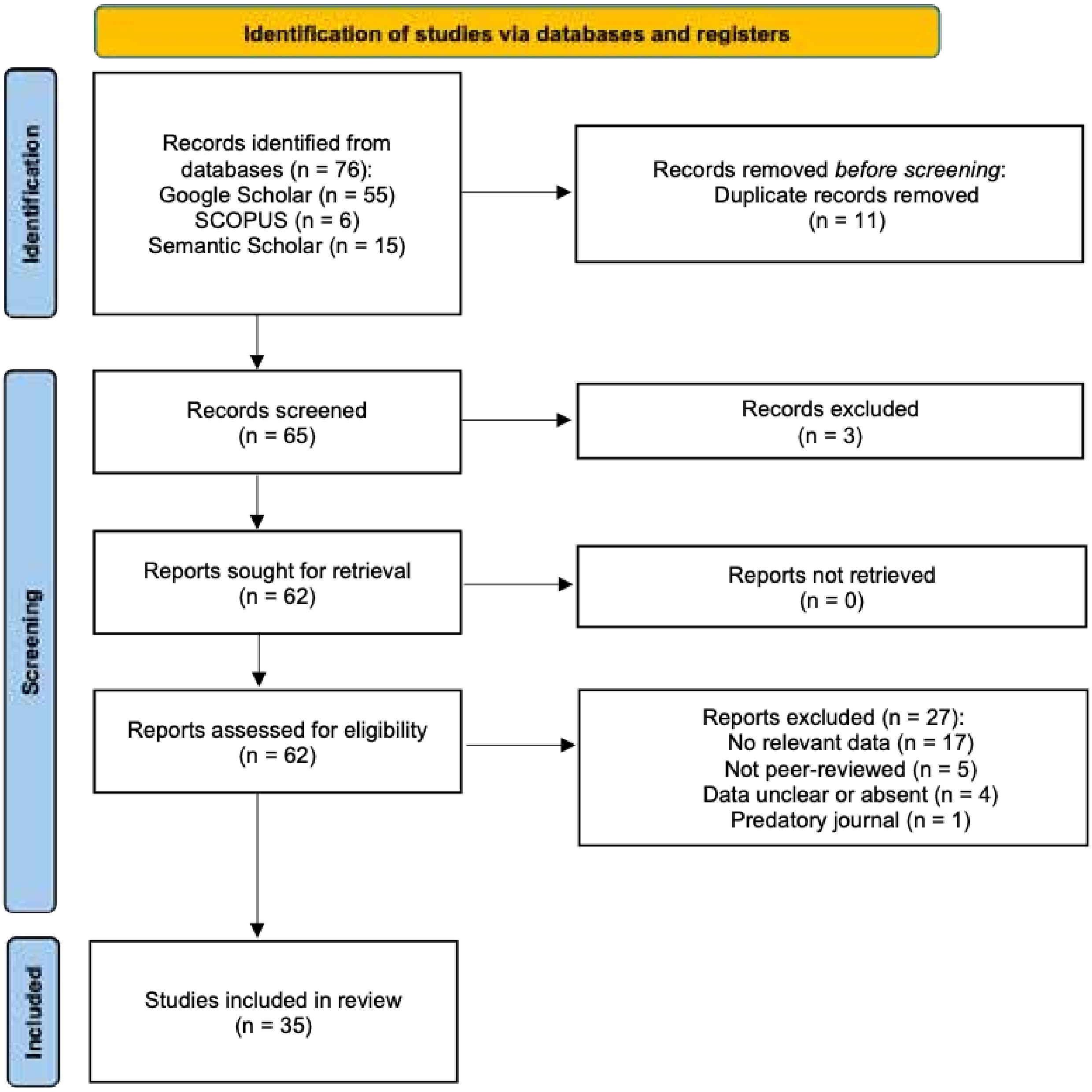


**Supplementary Material 1. PRISMA flow diagram of the systematic literature search used to gather data for this study.**

**Supplementary Material 2. List of species included in the study, with sources from which echolocation data was acquired for each.**

| Family | Species | Source |
|---|---|---|
| Vespertilionidae | *Arielulus circumdatus* | Chakravarty et al. 2020 |
| Vespertilionidae | *Barbastella darjelingensis* | Wordley et al. 2014; Chakravarty et al. 2020; Saikia et al. 2025 |
| Vespertilionidae | *Cnephaeus pachyomus* | Saikia et al. 2025 |
| Vespertilionidae | *Cnephaeus serotinus* | Chakravarty et al. 2020 |
| Vespertilionidae | *Cnephaeus tatei* | Chakravarty et al. 2020 |
| Vespertilionidae | *Eudiscopus denticulus* | Saikia et al. 2021 |
| Vespertilionidae | *Harpiocephalus harpia* | Raghuram et al. 2014; Raman & Hughes 2020 |
| Vespertilionidae | *Hesperoptenus tickelli* | Wordley et al. 2014; Srinivasulu et al. 2017; present study |
| Hipposideridae | *Hipposideros armiger* | Chakravarty et al. 2020; Rai et al. 2021 |
| Hipposideridae | *Hipposideros ater* | Raman & Hughes 2020; present study |
| Hipposideridae | *Hipposideros diadema* | Srinivasulu et al. 2017; present study |
| Hipposideridae | *Hipposideros durgadasi* | Srinivasulu et al. 2016; present study |
| Hipposideridae | *Hipposideros fulvus* | Srinivasulu et al. 2015; Petchiammal et al. 2019; Raman & Hughes 2020; present study |
| Hipposideridae | *Hipposideros brachyotus* | Raghuram et al. 2014; Srinivasulu et al. 2015; Srinivasulu & Srinivasulu 2017; Shah & Srinivasulu 2020; Raman & Hughes 2020; present study |
| Hipposideridae | *Hipposideros gentilis* | Srinivasulu et al. 2017; present study |
| Hipposideridae | *Hipposideros hypophyllus* | Srinivasulu et al. 2016; present study |
| Hipposideridae | *Hipposideros lankadiva* | Srinivasulu et al. 2015; present study |
| Hipposideridae | *Hipposideros grandis* | Srinivasulu et al. 2017; present study |
| Hipposideridae | *Hipposideros larvatus* | Thabah et al. 2006 |
| Hipposideridae | *Hipposideros pomona* | Wordley et al. 2014; Petchiammal et al. 2019; Raman & Hughes 2020; present study |
| Hipposideridae | *Hipposideros speoris* | Pavey et al. 2001; Srinivasulu et al. 2015; Petchiammal et al. 2019; Raman & Hughes 2020; Devender & Srinivasulu 2022; present study |
| Vespertilionidae | *Hypsugo affinis* | Saikia et al. 2025 |
| Vespertilionidae | *Hypsugo savii* | Saikia et al. 2025 |
| Vespertilionidae | *Kerivoula crypta* | Raman & Hughes 2020 |
| Vespertilionidae | *Kerivoula kachinensis* | Saikia et al. 2020 |
| Vespertilionidae | *Kerivoula picta* | Sripathi et al. 2006 |
| Megadermatidae | *Lyroderma lyra* | Raghuram et al. 2014; Devender & Srinivasulu 2022; Singh & Sharma 2023; ChiroVox; present study |
| Megadermatidae | *Megaderma spasma* | Wordley et al. 2014; Srinivasulu et al. 2017; Raman & Hughes 2020; present study |
| Miniopteridae | *Miniopterus fuliginosus* | Chakravarty et al. 2020 |
| Miniopteridae | *Miniopterus magnater* | Saikia et al. 2020 |
| Miniopteridae | *Miniopterus phillipsi* | Wordley et al. 2014; Srinivasulu & Srinivasulu 2017; Kusuminda et al. 2022; present study |
| Miniopteridae | *Miniopterus srinii* | Wordley et al. 2014; Raman & Hughes 2020; Srinivasulu & Srinivasulu 2023; present study |
| Vespertilionidae | *Mirostrellus joffrei* | Chakravarty et al. 2020; Saikia & Chakravarty 2024 |
| Molossidae | *Mops plicatus* | Deshpande & Kelkar 2015; Kusuminda & Yapa 2017 |
| Vespertilionidae | *Murina aurata* | Chakravarty et al. 2020; Saikia et al. 2025 |
| Vespertilionidae | *Murina cyclotis* | Raghuram et al. 2014; Chakravarty et al. 2020 |
| Vespertilionidae | *Murina huttoni* | Chakravarty et al. 2020; Saikia et al. 2025 |
| Vespertilionidae | *Murina leucogaster* | Chakravarty et al. 2020 |
| Vespertilionidae | *Myotis annectans* | Chakravarty et al. 2020; Saikia & Chakravarty 2024 |
| Vespertilionidae | *Myotis blythii* | Chakravarty et al. 2020 |
| Vespertilionidae | *Myotis formosus* | Rai et al. 2021 |
| Vespertilionidae | *Myotis himalaicus* | Chakravarty et al. 2020; Saikia et al. 2025 |
| Vespertilionidae | *Myotis horsfieldii* | Wordley et al. 2014; Srinivasulu et al. 2017; present study |
| Vespertilionidae | *Myotis longipes* | Chakravarty et al. 2020 |

| Family | Species | Source |
|---|---|---|
| Vespertilionidae | *Myotis montivagus* | Wordley et al. 2014; Saikia & Chakravarty 2024 |
| Vespertilionidae | *Myotis muricola* | Chakravarty et al. 2020; Saikia et al. 2025 |
| Vespertilionidae | *Myotis nipalensis* | Chakravarty et al. 2020 |
| Vespertilionidae | *Myotis peytoni* | Srinivasulu & Srinivasulu 2017; Raman & Hughes 2020; present study |
| Vespertilionidae | *Myotis pilosus* | Saikia et al. 2020 |
| Vespertilionidae | *Myotis sicarius* | Saikia et al. 2025 |
| Vespertilionidae | *Nyctalus leisleri* | Chakravarty et al. 2020; Saikia et al. 2025 |
| Vespertilionidae | *Nyctalus montanus* | Chakravarty et al. 2020 |
| Vespertilionidae | *Nyctalus noctula* | Rai et al. 2021 |
| Molossidae | *Otomops wroughtoni* | Ruedi et al. 2014; Deshpande & Kelkar 2015 |
| Vespertilionidae | *Phoniscus jagorii* | Raman & Hughes 2020; Raman et al. 2020 |
| Vespertilionidae | *Pipistrellus babu* | Saikia et al. 2025 |
| Vespertilionidae | *Pipistrellus ceylonicus* | Raghuram et al. 2014; Wordley et al. 2014; Kusuminda et al. 2017; Chakravarty et al. 2020; Raman & Hughes 2020; Shah & Srinivasulu 2020; Devender & Srinivasulu 2022; present study |
| Vespertilionidae | *Pipistrellus coromandra* | Raghuram et al. 2014; Srinivasulu et al. 2017; Raman & Hughes 2020 |
| Vespertilionidae | *Pipistrellus javanicus* | Srinivasulu et al. 2017; present study |
| Vespertilionidae | *Pipistrellus tenuis* | Raghuram et al. 2014; Chakravarty et al. 2020; Devender & Srinivasulu 2022; present study |
| Vespertilionidae | *Plecotus homochrous* | Chakravarty et al. 2020 |
| Vespertilionidae | *Plecotus wardi* | Chakravarty et al. 2020 |
| Rhinolophidae | *Rhinolophus affinis* | Chakravarty et al. 2020; Saikia & Chakravarty 2024; Saikia et al. 2025 |
| Rhinolophidae | *Rhinolophus andamanensis* | Srinivasulu et al. 2017; present study |
| Rhinolophidae | *Rhinolophus beddomei* | Raghuram et al. 2014; Wordley et al. 2014; Srinivasulu et al. 2015; Kusuminda et al. 2019; Raman & Hughes 2020; Sail & Borkar 2024; present study |
| Rhinolophidae | *Rhinolophus cognatus* | Srinivasulu et al. 2017; present study |
| Rhinolophidae | *Rhinolophus lepidus* | Raghuram et al. 2014; Wordley et al. 2014; Chakravarty et al. 2020; Raman & Hughes 2020; Saikia et al. 2025; ChiroVox; present study |
| Rhinolophidae | *Rhinolophus macrotis* | Saikia et al. 2025 |
| Rhinolophidae | *Rhinolophus pearsonii* | Chakravarty et al. 2020; Rai et al. 2021 |
| Rhinolophidae | *Rhinolophus perniger* | Chakravarty et al. 2020; Saikia et al. 2025; present study |
| Rhinolophidae | *Rhinolophus pusillus* | Chakravarty et al. 2020 |
| Rhinolophidae | *Rhinolophus rouxii* | Chattopadhyay et al. 2010; Chattopadhyay et al. 2012; Raghuram et al. 2014; Wordley et al. 2014; Kusuminda et al. 2019; Raman & Hughes 2020; present study |
| Rhinolophidae | *Rhinolophus sinicus* | Chakravarty et al. 2020; Rai et al. 2021; Saikia et al. 2025 |
| Rhinopomatidae | *Rhinopoma hardwickii* | Srinivasulu & Srinivasulu 2017; Shah & Srinivasulu 2020; Devender & Srinivasulu 2022; present study |
| Rhinopomatidae | *Rhinopoma microphyllum* | Shah & Srinivasulu 2020; present study |
| Emballonuridae | *Saccolaimus saccolaimus* | Present study |
| Vespertilionidae | *Scotophilus heathii* | Wordley et al. 2014; Chakravarty et al. 2020; Shah & Srinivasulu 2020; Devender & Srinivasulu 2022; present study |
| Vespertilionidae | *Scotophilus kuhlii* | Javid et al. 2014; Raghuram et al. 2014; Wordley et al. 2014; Devender & Srinivasulu 2022; present study |
| Vespertilionidae | *Submyotodon caliginosus* | Chakravarty et al. 2020; Saikia et al. 2025 |
| Molossidae | *Tadarida aegyptiaca* | Deshpande & Kelkar 2015; present study |
| Molossidae | *Tadarida insignis* | Deshpande & Kelkar 2015; Chakravarty 2017; Chakravarty et al. 2020; Sharma et al. 2021 |
| Emballonuridae | *Taphozous longimanus* | Shah & Srinivasulu 2020; present study |
| Emballonuridae | *Taphozous melanopogon* | Srinivasulu et al. 2017; Shah & Srinivasulu 2020; Devender & Srinivasulu 2022; present study |
| Emballonuridae | *Taphozous nudiventris* | Shah & Srinivasulu 2020; present study |
| Emballonuridae | *Taphozous perforatus* | Mahmood-ul-Hassan et al. 2012 |
| Vespertilionidae | *Tylonycteris fulvida* | Raman & Hughes 2020 |
| Vespertilionidae | *Tylonycteris malayana* | Srinivasulu et al. 2017; present study |

**Supplementary Material 3. Character matrix of 299 observations of 86 species, including descriptors (IUCN Red List status, Country, Region, Detector, Recording Condition, Sonotype), six call characters (HF, LF, B, FMAXE, D, SR), and the number of recordings analysed (N) for each observation.**

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vespertilionidae | Arielulus circumdatus | Ar_circ_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | FM-QCF | 44.8 | 26.8 | 18 | 28.9 | 9.1 | 1.98 | 1 |
| Vespertilionidae | Barbastella darjelingensis | Ba_darj_1 | Wordley et al. 2014 | 2014 | LC | India | Tamil Nadu | D500X | Release - Clutter | BA | 36.46 ± 1.42 | 20.84 ± 0.4 | 15.62 ± 0.91 | 29.23 ± 2.2 | 4.37 ± 0.72 | 3.57 ± 1.26 | 15 |
| Vespertilionidae | Barbastella darjelingensis | Ba_darj_2 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | BA | 37.3 | 26.2 | 11.1 | 33.4 | 2.1 | 5.28 | 3 |
| Vespertilionidae | Barbastella darjelingensis | Ba_darj_3 | Saikia et al. 2025 | 2025 | LC | India | Himachal Pradesh | Anabat Walkabout | Flight - Open | BA | 42.73 ± 4.8 | 21.44 ± 2.15 | 21.29 ± 3.475 | 32.62 ± 5.96 | 6.37 ± 1.71 | 3.34 ± 0.67 | 10 |
| Vespertilionidae | Cnephaeus pachyomus | Cn_pach_1 | Saikia et al. 2025 | 2025 | LC | India | Himachal Pradesh | Anabat Walkabout | Release - Clutter | FM-QCF | 57.87 | 23.48 | 34.39 | 32.02 | 2.71 | 12.69 | 1 |
| Vespertilionidae | Cnephaeus serotinus | Cn_sero_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | FM-QCF | 50 ± 4.45 | 22.9 ± 0.89 | 27.1 ± 2.67 | 29.7 ± 1.5 | 3.7 ± 0.73 | 7.32 ± 0.01 | 2 |
| Vespertilionidae | Cnephaeus tatei | Cn_tate_1 | Chakravarty et al. 2020 | 2020 | DD | India | Uttarakhand | Anabat Walkabout | Release - Open | FM-QCF | 46.5 | 25.3 | 21.2 | 29.5 | 5.2 | 4.08 | 1 |
| Vespertilionidae | Eudiscopus denticulus | Eu_dent_1 | Saikia et al. 2021 | 2021 | LC | India | Meghalaya | Anabat Walkabout | Flight - Open | FM-QCF | 104.82 ± 2.7 | 53.12 ± 5.79 | 51.7 ± 4.25 | 56.81 ± 2.86 | 4.75 ± 0.63 | 10.88 ± 0.4 | 2 |
| Vespertilionidae | Harpiocephalus harpia | Ha_harp_1 | Raghuram et al. 2014 | 2014 | LC | India | Karnataka | D980 | Flight - Clutter | FM | 111.5 | 32.5 | 79 | 57 | 1 | 79 | 1 |
| Vespertilionidae | Harpiocephalus harpia | Ha_harp_2 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Open | FM | 115.8 ± 3.46 | 41.1 ± 1.17 | 74.7 ± 2.32 | 88.1 ± 0.86 | 1.7 ± 0.27 | 43.94 ± 0.01 | 6 |
| Vespertilionidae | Hesperoptenus tickelli | He_tick_1 | Wordley et al. 2014 | 2014 | LC | India | Tamil Nadu | D500X | Release - Clutter | FM | 58.16 ± 2.34 | 20.22 ± 1.31 | 37.94 ± 1.83 | 28.32 ± 1.76 | 5.06 ± 0.7 | 7.5 ± 2.61 | 15 |
| Vespertilionidae | Hesperoptenus tickelli | He_tick_2 | Srinivasulu et al. 2017 | 2017 | LC | India | Andaman & Nicobar Islands | Anabat SD1 | Release - Open | FM | 51.18 ± 2.57 | 26.39 ± 1.56 | 24.79 ± 2.07 | 35.27 ± 6.25 | 4.7 ± 1.12 | 5.27 ± 0.17 | 26 |
| Vespertilionidae | Hesperoptenus tickelli | He_tick_3 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | Anabat SD1 | Flight - Clutter | FM | 51.18 ± 2.58 | 26.39 ± 1.57 | 24.79 ± 3.29 | 35.27 ± 6.26 | 4.71 ± 1.13 | 5.26 ± 25.31 | 26 |
| Hipposideridae | Hipposideros armiger | Hi_armi_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Hand-held | SCF |  |  |  | 68.2 ± 1.9 | 7.8 ± 0.3 |  | 5 |
| Hipposideridae | Hipposideros armiger | Hi_armi_2 | Rai et al. 2021 | 2021 | LC | Nepal | Bagmati | SM4BAT | Release - Clutter | SCF |  |  |  | 69.25 ± 0.37 | 7.81 ± 0.85 |  | 120 |
| Hipposideridae | Hipposideros ater | Hi_ater_1 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Open | SCF |  |  |  | 164.9 ± 0.69 | 3.8 ± 0.49 |  | 10 |
| Hipposideridae | Hipposideros ater | Hi_ater_2 | Present study | 2025 | LC | India | Pondicherry | M500 | Flight - Clutter | SCF |  |  |  | 165.72 ± 1.16 | 4.11 ± 1.14 |  | 45 |
| Hipposideridae | Hipposideros ater | Hi_ater_3 | Present study | 2025 | LC | India | Tamil Nadu | M500 | Flight - Clutter | SCF |  |  |  | 164.38 ± 1.45 | 4.04 ± 0.94 |  | 70 |
| Hipposideridae | Hipposideros brachyotus | Hi_brac_1 | Raghuram et al. 2014 | 2014 | LC | India | Karnataka | D980 | Flight - Clutter | SCF |  |  |  | 126.7 ± 2.1 | 6.5 ± 1.4 |  | 6 |
| Hipposideridae | Hipposideros brachyotus | Hi_brac_2 | Srinivasulu et al. 2015 | 2015 | LC | India | Karnataka | Anabat SD1 | Flight - Open | SCF |  |  |  | 112.48 ± 3.65 | 4.81 ± 0.46 |  | 10 |
| Hipposideridae | Hipposideros brachyotus | Hi_brac_3 | Srinivasulu & Srinivasulu 2017 | 2017 | LC | India | Kerala | D500X | Hand-held | SCF |  |  |  | 113.54 ± 0.43 | 6.65 ± 0.65 |  | 9 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hipposideridae | Hipposideros brachyotus | Hi_brac_4 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Open | SCF | | | | 114.2 ± 0.37 | 6.3 ± 0.59 | | 18 |
| Hipposideridae | Hipposideros brachyotus | Hi_brac_5 | Shah & Srinivasulu 2020 | 2020 | LC | India | Gujarat | SM3BAT | Hand-held | SCF | | | | 108.64 ± 1.03 | 5.8 ± 0.55 | | 49 |
| Hipposideridae | Hipposideros brachyotus | Hi_brac_6 | Present study | 2025 | LC | India | Kerala | D500X | Flight - Clutter | SCF | | | | 113.79 ± 1.05 | 5.95 ± 1.28 | | 50 |
| Hipposideridae | Hipposideros brachyotus | Hi_brac_7 | Present study | 2025 | LC | India | Tamil Nadu | M500 | Flight - Clutter | SCF | | | | 114.99 ± 0.11 | 6.49 ± 0.44 | | 20 |
| Hipposideridae | Hipposideros brachyotus | Hi_brac_8 | Present study | 2025 | LC | India | Gujarat | D500X | Release - Clutter | SCF | | | | 113.56 ± 0.29 | 5.68 ± 0.57 | | 9 |
| Hipposideridae | Hipposideros diadema | Hi_diad_1 | Srinivasulu et al. 2016 | 2016 | LC | India | Andaman & Nicobar Islands | Anabat SD1 | Hand-held | SCF | | | | 59.08 ± 0.24 | 4.77 ± 0.62 | | 5 |
| Hipposideridae | Hipposideros diadema | Hi_diad_2 | Srinivasulu et al. 2017 | 2017 | LC | India | Andaman & Nicobar Islands | Anabat SD1 | Hand-held | SCF | | | | 59.08 ± 0.24 | 4.77 ± 0.62 | | 5 |
| Hipposideridae | Hipposideros diadema | Hi_diad_3 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | Anabat SD1 | Flight - Clutter | SCF | | | | 59.08 ± 0.23 | 4.77 ± 0.59 | | 10 |
| Hipposideridae | Hipposideros durgadasi | Hi_durg_1 | Srinivasulu et al. 2016 | 2016 | VU | India | Karnataka | D500X | Release - Open | SCF | | | | 175.1 ± 0.33 | 7.96 ± 0.94 | | 10 |
| Hipposideridae | Hipposideros durgadasi | Hi_durg_2 | Present study | 2025 | VU | India | Karnataka | D500X | Flight - Clutter | SCF | | | | 171.2 ± 0.55 | 6 ± 1.1 | | 116 |
| Hipposideridae | Hipposideros durgadasi | Hi_durg_3 | Present study | 2025 | VU | India | Karnataka | D500X | Flight - Open | SCF | | | | 170.52 ± 0.63 | 6.17 ± 0.91 | | 116 |
| Hipposideridae | Hipposideros fulvus | Hi_fulv_1 | Srinivasulu et al. 2015 | 2015 | LC | India | Karnataka | Anabat SD1 | Flight - Open | SCF | | | | 155.69 ± 2.09 | 3 ± 1.02 | | 184 |
| Hipposideridae | Hipposideros fulvus | Hi_fulv_2 | Petchiammal et al. 2019 | 2019 | LC | India | Tamil Nadu | Anabat SD1 | Hand-held | SCF | | | | 142 ± 0.4 | 7.4 ± 1.5 | | |
| Hipposideridae | Hipposideros fulvus | Hi_fulv_3 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Open | SCF | | | | 151.3 ± 0.4 | 4.2 ± 0.19 | | 10 |
| Hipposideridae | Hipposideros fulvus | Hi_fulv_4 | Present study | 2025 | LC | India | Andhra Pradesh | M500 | Flight - Clutter | SCF | | | | 152.47 ± 0.2 | 4.83 ± 0.58 | | 82 |
| Hipposideridae | Hipposideros fulvus | Hi_fulv_5 | Present study | 2025 | LC | India | Maharashtra | D500X | Flight - Clutter | SCF | | | | 150.68 ± 0.19 | 2.99 ± 0.38 | | 10 |
| Hipposideridae | Hipposideros fulvus | Hi_fulv_6 | Present study | 2025 | LC | India | Telangana | Anabat SD1 | Flight - Clutter | SCF | | | | 155.69 ± 2.08 | 3 ± 1.02 | | 368 |
| Hipposideridae | Hipposideros fulvus | Hi_fulv_7 | Present study | 2025 | LC | India | Karnataka | D500X | Flight - Open | SCF | | | | 154.13 ± 0.39 | 4.76 ± 0.54 | | 31 |
| Hipposideridae | Hipposideros gentilis | Hi_gent_1 | Srinivasulu et al. 2017 | 2017 | LC | India | Andaman & Nicobar Islands | D500X | Hand-held | SCF | | | | 126.5 ± 4.17 | 5.61 ± 1.84 | | 90 |
| Hipposideridae | Hipposideros gentilis | Hi_gent_2 | Srinivasulu et al. 2017 | 2017 | LC | India | Andaman & Nicobar Islands | Anabat SD1 | Hand-held | SCF | | | | 137.45 ± 2.1 | 3.18 ± 0.37 | | 15 |
| Hipposideridae | Hipposideros gentilis | Hi_gent_3 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | D500X | Flight - Clutter | SCF | | | | 126.85 ± 4.66 | 5.07 ± 1.57 | | 194 |
| Hipposideridae | Hipposideros gentilis | Hi_gent_4 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | Anabat SD1 | Flight - Clutter | SCF | | | | 125.75 ± 10.73 | 4.25 ± 1.68 | | 24 |
| Hipposideridae | Hipposideros gentilis | Hi_gent_5 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | Anabat SD1 | Flight - Open | SCF | | | | 133.82 ± 4.75 | 3.25 ± 1.17 | | 14 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hipposideridae | Hipposideros grandis | Hi_gran_1 | Srinivasulu et al. 2017 | 2017 | LC | India | Andaman & Nicobar Islands | Anabat SD1 | Hand-held | SCF | | | | 94.06 ± 2.21 | 5.95 ± 0.7 | | 69 |
| Hipposideridae | Hipposideros grandis | Hi_gran_2 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | Anabat SD1 | Flight - Clutter | SCF | | | | 93.71 ± 3.78 | 5.88 ± 1.19 | | 132 |
| Hipposideridae | Hipposideros grandis | Hi_gran_3 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | SM3BAT | Flight - Clutter | SCF | | | | 93.84 ± 4.1 | 5.85 ± 1.27 | | 109 |
| Hipposideridae | Hipposideros grandis | Hi_gran_4 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | SM3BAT | Release - Clutter | SCF | | | | 93.09 ± 1.53 | 6.03 ± 0.7 | | 23 |
| Hipposideridae | Hipposideros hypophyllus | Hi_hypo_1 | Srinivasulu et al. 2016 | 2016 | CR | India | Karnataka | D500X | Release - Open | SCF | | | | 103.9 ± 0.82 | 6.3 ± 1.07 | | 15 |
| Hipposideridae | Hipposideros hypophyllus | Hi_hypo_2 | Present study | 2025 | CR | India | Karnataka | D500X | Flight - Clutter | SCF | | | | 105.11 ± 0.49 | 7.56 ± 1.1 | | 149 |
| Hipposideridae | Hipposideros hypophyllus | Hi_hypo_3 | Present study | 2025 | CR | India | Karnataka | D500X | Flight - Open | SCF | | | | 105.11 ± 0.49 | 7.56 ± 1.1 | | 149 |
| Hipposideridae | Hipposideros lankadiva | Hi_lank_1 | Srinivasulu et al. 2015 | 2015 | LC | India | Telangana | Anabat SD1 | Flight - Open | SCF | | | | 78.33 ± 5.28 | 8.87 ± 3.47 | | 427 |
| Hipposideridae | Hipposideros lankadiva | Hi_lank_2 | Present study | 2025 | LC | India | Andhra Pradesh | M500 | Flight - Clutter | SCF | | | | 81.33 ± 0.62 | 8.74 ± 1.13 | | 38 |
| Hipposideridae | Hipposideros lankadiva | Hi_lank_3 | Present study | 2025 | LC | India | Madhya Pradesh | SM3BAT | Flight - Clutter | SCF | | | | 81.91 ± 0.12 | 7.96 ± 0.61 | | 18 |
| Hipposideridae | Hipposideros lankadiva | Hi_lank_4 | Present study | 2025 | LC | India | Odisha | D500X | Flight - Clutter | SCF | | | | 78.78 ± 0.59 | 15.25 ± 3.05 | | 42 |
| Hipposideridae | Hipposideros lankadiva | Hi_lank_5 | Present study | 2025 | LC | India | Telangana | Anabat SD1 | Flight - Clutter | SCF | | | | 77.84 ± 5.87 | 8.9 ± 3.48 | | 201 |
| Hipposideridae | Hipposideros lankadiva | Hi_lank_6 | Present study | 2025 | LC | India | Telangana | D500X | Flight - Open | SCF | | | | 78.26 ± 0.21 | 14.79 ± 0.65 | | 14 |
| Hipposideridae | Hipposideros lankadiva | Hi_lank_7 | Present study | 2025 | LC | India | Telangana | Anabat SD1 | Flight - Open | SCF | | | | 77.84 ± 5.87 | 8.9 ± 3.48 | | 201 |
| Hipposideridae | Hipposideros larvatus | Hi_larv_1 | Thabah et al. 2006 | 2006 | LC | India | Meghalaya | Ultrasound Advice S25 | Hand-held | SCF | | | | 83.7 ± 1.76 | | | 12 |
| Hipposideridae | Hipposideros larvatus | Hi_larv_2 | Thabah et al. 2006 | 2006 | LC | India | Meghalaya | Ultrasound Advice S25 | Hand-held | SCF | | | | 85.1 ± 0.72 | | | 10 |
| Hipposideridae | Hipposideros larvatus | Hi_larv_3 | Thabah et al. 2006 | 2006 | LC | India | Meghalaya | Ultrasound Advice S25 | Hand-held | SCF | | | | 96.7 ± 2.05 | | | 22 |
| Hipposideridae | Hipposideros larvatus | Hi_larv_4 | Thabah et al. 2006 | 2006 | LC | India | Meghalaya | Ultrasound Advice S25 | Hand-held | SCF | | | | 97.96 ± 2.12 | | | 15 |
| Hipposideridae | Hipposideros pomona | Hi_pomo_1 | Wordley et al. 2014 | 2014 | EN | India | Tamil Nadu | D500X | Release - Clutter | SCF | | | | 126.337 ± 1.25 | 8.13 ± 0.94 | | 6 |
| Hipposideridae | Hipposideros pomona | Hi_pomo_2 | Petchiammal et al. 2019 | 2019 | EN | India | Tamil Nadu | Anabat SD1 | Hand-held | SCF | | | | 130 ± 0.2 | 8.8 ± 1.2 | | |
| Hipposideridae | Hipposideros pomona | Hi_pomo_3 | Raman & Hughes 2020 | 2020 | EN | India | Kerala | M500-384 | Flight - Open | SCF | | | | 122.4 ± 3.65 | 6.3 ± 0.92 | | 193 |
| Hipposideridae | Hipposideros pomona | Hi_pomo_4 | Present study | 2025 | EN | India | Kerala | M500 | Flight - Clutter | SCF | | | | 123.58 ± 2.28 | 6.22 ± 1.18 | | 78 |
| Hipposideridae | Hipposideros speoris | Hi_speo_1 | Pavey et al. 2001 | 2001 | LC | Sri Lanka | Central | Ultrasound Advice U30 | Flight - Clutter | SCF | | | | 130.12 ± 1.52 | 6.88 ± 0.44 | | 3 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hipposideridae | Hipposideros speoris | Hi_speo_10 | Present study | 2025 | LC | India | Andhra Pradesh | M500 | Flight - Clutter | SCF | | | | 135.8 ± 2.77 | 6.54 ± 1.34 | | 199 |
| Hipposideridae | Hipposideros speoris | Hi_speo_11 | Present study | 2025 | LC | India | Gujarat | SM3BAT | Flight - Clutter | SCF | | | | 124.75 ± 0.21 | 6.77 ± 0.47 | | 10 |
| Hipposideridae | Hipposideros speoris | Hi_speo_12 | Present study | 2025 | LC | India | Telangana | D500X | Flight - Clutter | SCF | | | | 138.21 ± 0.02 | 8.56 ± 0.47 | | 19 |
| Hipposideridae | Hipposideros speoris | Hi_speo_13 | Present study | 2025 | LC | India | Telangana | Anabat SD1 | Flight - Clutter | SCF | | | | 137.52 ± 3.79 | 6.13 ± 1.22 | | 460 |
| Hipposideridae | Hipposideros speoris | Hi_speo_14 | Present study | 2025 | LC | India | Telangana | D500X | Flight - Open | SCF | | | | 138.21 ± 0.02 | 8.56 ± 0.47 | | 19 |
| Hipposideridae | Hipposideros speoris | Hi_speo_15 | Present study | 2025 | LC | India | Gujarat | SM3BAT | Release - Clutter | SCF | | | | 124.75 ± 0.21 | 6.77 ± 0.47 | | 10 |
| Hipposideridae | Hipposideros speoris | Hi_speo_2 | Pavey et al. 2001 | 2001 | LC | Sri Lanka | Central | Ultrasound Advice U30 | Flight - Clutter | SCF | | | | 128.39 ± 2.18 | 6.86 ± 1.13 | | 11 |
| Hipposideridae | Hipposideros speoris | Hi_speo_3 | Pavey et al. 2001 | 2001 | LC | Sri Lanka | Central | Ultrasound Advice U30 | Flight - Clutter | SCF | | | | 130.55 ± 0.4 | 8.07 ± 0.49 | | 3 |
| Hipposideridae | Hipposideros speoris | Hi_speo_4 | Pavey et al. 2001 | 2001 | LC | Sri Lanka | Central | Ultrasound Advice U30 | Flight - Open | SCF | | | | 131.19 ± 2.18 | 7.59 ± 0.73 | | 6 |
| Hipposideridae | Hipposideros speoris | Hi_speo_5 | Srinivasulu et al. 2015 | 2015 | LC | India | Telangana | Anabat SD1 | Flight - Open | SCF | | | | 138.88 ± 4.02 | 6.09 ± 1.21 | | 469 |
| Hipposideridae | Hipposideros speoris | Hi_speo_6 | Petchiammal et al. 2019 | 2019 | LC | India | Tamil Nadu | Anabat SD1 | Hand-held | SCF | | | | 136 ± 0.3 | 8.1 ± 1.6 | | |
| Hipposideridae | Hipposideros speoris | Hi_speo_7 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Open | SCF | | | | 125.4 ± 4.79 | 5.6 ± 1.26 | | 161 |
| Hipposideridae | Hipposideros speoris | Hi_speo_8 | Devender & Srinivasulu 2022 | 2022 | LC | India | Telangana | SM3BAT | Flight - Open | SCF | | | | 133.57 ± 4.27 | 7.19 ± 1.44 | | 20 |
| Hipposideridae | Hipposideros speoris | Hi_speo_9 | Present study | 2025 | LC | India | Andhra Pradesh | D500X | Flight - Clutter | SCF | | | | 128.01 ± 1.21 | 8.22 ± 0.94 | | 32 |
| Vespertilionidae | Hypsugo affinis | Hy_affi_1 | Saikia et al. 2025 | 2025 | LC | India | Himachal Pradesh | Anabat Walkabout | Release - Clutter | FM-QCF | 66.63 ± 3.88 | 25.89 ± 0.63 | 40.74 ± 2.255 | 30.51 ± 0.45 | 4.67 ± 0.52 | 8.72 ± 0.49 | 10 |
| Vespertilionidae | Hypsugo savii | Hy_savi_1 | Saikia et al. 2025 | 2025 | LC | India | Himachal Pradesh | Anabat Walkabout | Release - Clutter | FM-QCF | 82.34 | 29.2 | 53.14 | 42.11 | 2.75 | 19.32 | 1 |
| Vespertilionidae | Kerivoula crypta | Ke_cryp_1 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Open | FM | 183.3 ± 5.49 | 92.1 ± 6.81 | 91.2 ± 6.15 | 132.2 ± 20.18 | 1.7 ± 0.58 | 53.65 ± 0 | 88 |
| Vespertilionidae | Kerivoula kachinensis | Ke_kach_1 | Saikia et al. 2020 | 2020 | LC | India | Meghalaya | Anabat Walkabout | Hand-held | FM | 212.7 ± 18 | 84 ± 2.7 | 128.7 ± 10.35 | 109.2 ± 1.3 | 3.3 ± 0.4 | 39 ± 0.88 | 10 |
| Vespertilionidae | Kerivoula picta | Ke_pict_1 | Sripathi et al. 2006 | 2006 | NT | India | Tamil Nadu | Ultrasound Advice SM2 | Flight - Open | FM | 140.21 ± 14.13 | 103.57 ± 14.86 | 36.64 ± 14.5 | 115.81 ± 14.81 | 0.58 ± 0.18 | 63.17 ± 80.56 | 74 |
| Megadermatidae | Lyroderma lyra | Ly_lyra_1 | Raghuram et al. 2014 | 2014 | LC | India | Karnataka | D980 | Flight - Clutter | ME | 116.15 ± 4.31 | 33.7 ± 0.14 | 82.45 ± 2.225 | 45.8 ± 1.4 | 0.8 ± 0.28 | 103.06 ± 0.01 | 2 |
| Megadermatidae | Lyroderma lyra | Ly_lyra_10 | Present study | 2025 | LC | India | Telangana | D500X | Flight - Clutter | ME | 99 ± 9.94 | 34 ± 1.41 | 65 ± 9.01 | 43.15 ± 0.93 | 1.87 ± 0.18 | 34.76 ± 5.56 | 13 |
| Megadermatidae | Lyroderma lyra | Ly_lyra_11 | Present study | 2025 | LC | India | Telangana | D500X | Release - Clutter | ME | 99 ± 9.94 | 34 ± 1.41 | 65 ± 9.01 | 43.15 ± 0.93 | 1.87 ± 0.18 | 34.76 ± 5.56 | 13 |
| Megadermatidae | Lyroderma lyra | Ly_lyra_2 | Devender & Srinivasulu 2022 | 2022 | LC | India | Telangana | SM3BAT | Flight - Open | ME | 34.9 ± 0.17 | 25.06 ± 0.51 | 9.84 ± 0.34 | 31.9 ± 0.75 | 3.86 ± 0.15 | 2.55 ± 2.27 | 3 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Megadermatidae | Lyroderma lyra | Ly_lyra_3 | ChiroVox | 2023 | LC | Bangladesh | Rajshahi Division | D1000X | Flight - Clutter | ME | 76.01 ± 16.27 | 36.82 ± 2.29 | 39.19 ± 16.07 | 41.35 ± 1.04 | 1.86 ± 0.30 | 21.07 ± 53.57 | 67 |
| Megadermatidae | Lyroderma lyra | Ly_lyra_4 | ChiroVox | 2023 | LC | Bangladesh | Sylhet Division | D1000X | Flight - Clutter | ME | 81.91 ± 12.37 | 37.39 ± 3.75 | 44.51 ± 11.77 | 44.26 ± 2.49 | 2.09 ± 0.34 | 21.3 ± 34.62 | 72 |
| Megadermatidae | Lyroderma lyra | Ly_lyra_5 | ChiroVox | 2023 | LC | Bangladesh | Chittagong Division | D1000X | Release - Clutter | ME | 72.33 ± 14.07 | 36.17 ± 1.72 | 36.16 ± 14.35 | 43.35 ± 0.83 | 3 ± 0.39 | 12.05 ± 14.75 | 6 |
| Megadermatidae | Lyroderma lyra | Ly_lyra_6 | Singh & Sharma 2023 | 2023 | LC | India | Uttarakhand | Echometer Touch 2 | Flight - Clutter | ME | 108.2 ± 2.51 | 30.76 ± 1.37 | 77.44 ± 1.94 | 50.29 ± 9.18 | 0.9 ± 0.85 | 86.04 ± 0.02 | 20 |
| Megadermatidae | Lyroderma lyra | Ly_lyra_7 | Present study | 2025 | LC | India | Karnataka | D500X | Flight - Clutter | ME | 89.17 ± 7.21 | 33.28 ± 1.97 | 55.89 ± 7.26 | 43.02 ± 1.74 | 2.65 ± 0.57 | 21.09 ± 12.74 | 36 |
| Megadermatidae | Lyroderma lyra | Ly_lyra_8 | Present study | 2025 | LC | India | Maharashtra | D500X | Flight - Clutter | ME | 79.62 ± 18.65 | 26.77 ± 9.86 | 52.85 ± 18.05 | 43.86 ± 2.78 | 2.7 ± 0.79 | 19.57 ± 0.1 | 30 |
| Megadermatidae | Lyroderma lyra | Ly_lyra_9 | Present study | 2025 | LC | India | Odisha | D500X | Flight - Clutter | ME | 93.25 ± 11.13 | 32.25 ± 3.65 | 61 ± 11.07 | 45.34 ± 4.31 | 1.58 ± 0.38 | 38.61 ± 18.42 | 20 |
| Vespertilionidae | Megaderma spasma | Me_spas_1 | Raghuram et al. 2014 | 2014 | LC | India | Karnataka | D980 | Flight - Clutter | ME | 106.6 ± 5.3 | 30.2 ± 8.3 | 76.4 ± 6.8 | 69.2 ± 9.4 | 1 ± 1 | 76.4 ± 6.8 | 3 |
| Megadermatidae | Megaderma spasma | Me_spas_2 | Wordley et al. 2014 | 2014 | LC | India | Tamil Nadu | D500X | Release - Clutter | ME | 99.79 ± 12.37 | 38.87 ± 2.3 | 60.92 ± 7.34 | 55.9 ± 12.3 | 2.06 ± 0.32 | 29.57 ± 22.94 | 5 |
| Megadermatidae | Megaderma spasma | Me_spas_3 | Srinivasulu et al. 2017 | 2017 | LC | India | Andaman & Nicobar Islands | D500X | Release - Open | ME | 67.03 ± 1.86 | 14.9 ± 0.68 | 52.13 ± 1.27 | 21.87 ± 2.36 | 3.77 ± 0.39 | 13.83 ± 3.26 | 21 |
| Megadermatidae | Megaderma spasma | Me_spas_4 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Open | ME | 114.5 ± 5.78 | 35.8 ± 0.76 | 78.7 ± 3.27 | 56 ± 12.04 | 1.1 ± 0.37 | 71.55 ± 0.01 | 26 |
| Megadermatidae | Megaderma spasma | Me_spas_5 | Present study | 2025 | LC | India | Karnataka | D500X | Flight - Clutter | ME | 89.02 ± 12.73 | 35.12 ± 4.64 | 53.91 ± 12.88 | 50.05 ± 7.25 | 1.99 ± 0.46 | 27.09 ± 6.26 | 43 |
| Miniopteridae | Miniopterus fuliginosus | Mi_fuli_1 | Chakravarty et al. 2020 | 2020 | NA | India | Uttarakhand | Anabat Walkabout | Release - Open | FM | 88.9 ± 10 | 47 ± 2.2 | 41.9 ± 6.1 | 53.1 ± 1.3 | 3.8 ± 0.8 | 11.03 ± 7.63 | 11 |
| Vespertilionidae | Mirostrellus joffrei | Mi_joff_1 | Chakravarty et al. 2020 | 2020 | DD | India | Uttarakhand | Anabat Walkabout | Release - Open | FM-QCF | 70.5 | 33.9 | 36.6 | 43.8 | 2.1 | 17.43 | 1 |
| Vespertilionidae | Mirostrellus joffrei | Mi_joff_2 | Saikia & Chakravarty 2024 | 2024 | DD | India | Mizoram | Anabat Walkabout | Flight - Clutter | FM-QCF | 45.07 ± 5.36 | 27.61 ± 0.27 | 17.46 ± 2.815 | 29.78 ± 0.48 | 9.08 ± 0.93 | 1.92 ± 0.88 | 15 |
| Miniopteridae | Miniopterus magnater | Mi_magn_1 | Saikia et al. 2020 | 2020 | LC | India | Meghalaya | Anabat Walkabout | Flight - Open | FM | 117.6 ± 6.7 | 39 ± 0.7 | 78.6 ± 3.7 | 46.5 ± 1.5 | 4.9 ± 0.7 | 16.04 ± 5.29 | 10 |
| Miniopteridae | Miniopterus phillipsi | Mi_phil_1 | Wordley et al. 2014 | 2014 | NA | India | Tamil Nadu | D500X | Release - Clutter | FM | 93.67 ± 13.86 | 48.29 ± 1.32 | 45.38 ± 7.59 | 52.03 ± 1.92 | 4 ± 1.03 | 11.34 ± 7.37 | 31 |
| Miniopteridae | Miniopterus phillipsi | Mi_phil_2 | Srinivasulu & Srinivasulu 2017 | 2017 | NA | India | Kerala | D500X | Release - Open | FM | 97.61 ± 10.35 | 45.8 ± 2.13 | 51.81 ± 6.24 | 53.19 ± 1.65 | 4.08 ± 1.03 | 12.7 ± 208 | 9 |
| Miniopteridae | Miniopterus phillipsi | Mi_phil_3 | Kusuminda et al. 2022 | 2022 | NA | Sri Lanka | Uva | M500 | Flight - Clutter | FM | | | | 52.8 ± 0.72 | | | 15 |
| Miniopteridae | Miniopterus phillipsi | Mi_phil_4 | Present study | 2025 | NA | India | Maharashtra | D500X | Flight - Clutter | FM | 94.32 ± 18.47 | 45.65 ± 1.09 | 48.67 ± 18.44 | 52.35 ± 1.62 | 5.63 ± 1.36 | 8.64 ± 23.44 | 27 |
| Miniopteridae | Miniopterus phillipsi | Mi_phil_6 | Present study | 2025 | NA | India | Kerala | D500X | Release - Clutter | FM | 97.62 ± 10.35 | 45.81 ± 2.14 | 51.81 ± 9.88 | 53.19 ± 1.66 | 4.08 ± 1.03 | 12.7 ± 329.33 | 26 |
| Miniopteridae | Miniopterus srinii | Mi_srin_1 | Wordley et al. 2014 | 2014 | NA | India | Tamil Nadu | D500X | Release - Clutter | FM | 110.92 ± 10.16 | 58.12 ± 1.98 | 52.8 ± 6.07 | 64.13 ± 3.19 | 3.66 ± 1.33 | 14.43 ± 0.21 | 4 |
| Miniopteridae | Miniopterus srinii | Mi_srin_2 | Raman & Hughes 2020 | 2020 | NA | India | Kerala | M500-384 | Flight - Open | FM | 129.6 ± 7.3 | 57.9 ± 2.01 | 71.7 ± 4.66 | 67.8 ± 3.56 | 3 ± 0.94 | 23.9 ± 4.96 | 532 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Miniopteridae | Miniopterus srinii | Mi_srin_3 | Srinivasulu & Srinivasulu 2023 | 2023 | NA | India | Karnataka | D500X | Release - Open | FM | 130 ± 11.16 | 58.38 ± 1.43 | 71.62 ± 6.3 | 77.62 ± 7.98 | 4.18 ± 1.16 | 17.13 ± 39.38 | 230 |
| Miniopteridae | Miniopterus srinii | Mi_srin_4 | Present study | 2025 | NA | India | Karnataka | D500X | Flight - Clutter | FM | 134.8 ± 28.19 | 48.96 ± 8.6 | 85.84 ± 26.09 | 74.62 ± 8.28 | 5.88 ± 1.84 | 14.6 ± 7.25 | 25 |
| Miniopteridae | Miniopterus srinii | Mi_srin_5 | Present study | 2025 | NA | India | Karnataka | D500X | Release - Clutter | FM | 131.98 ± 23.05 | 53.02 ± 8.16 | 78.95 ± 22.71 | 73.28 ± 7.59 | 6.18 ± 1.91 | 12.78 ± 2.98 | 43 |
| Molossidae | Mops plicatus | Mo_plic_1 | Deshpande & Kelkar 2015 | 2015 | LC | India | Kerala | D240X | Flight - Open | LMH | 35.88 ± 6.36 | 19.76 ± 2.91 | 16.12 ± 4.64 | 23.65 ± 3.08 | 12.31 ± 4.03 | 1.31 ± 1.15 | 54 |
| Molossidae | Mops plicatus | Mo_plic_2 | Deshpande & Kelkar 2015 | 2015 | LC | India | Maharashtra | D240X | Flight - Open | LMH | 35.88 ± 6.36 | 19.76 ± 2.91 | 16.12 ± 4.64 | 23.65 ± 3.08 | 12.31 ± 4.03 | 1.31 ± 1.15 | 54 |
| Molossidae | Mops plicatus | Mo_plic_3 | Kusuminda & Yapa 2017 | 2017 | LC | Sri Lanka | Central | M500 | Flight - Open | LMH | 39.7 ± 1.15 | 17.8 ± 0.57 | 21.9 ± 0.86 | 27.6 ± 1.35 | 7.7 ± 0.75 | 2.84 ± 0.01 | 10 |
| Vespertilionidae | Murina aurata | Mu_aura_1 | Chakravarty et al. 2020 | 2020 | DD | India | Uttarakhand | Anabat Walkabout | Release - Clutter | FM | 111.7 | 80.6 | 31.1 | 97.2 | 0.8 | 38.88 | 1 |
| Vespertilionidae | Murina aurata | Mu_aura_2 | Saikia et al. 2025 | 2025 | DD | India | Himachal Pradesh | Anabat Walkabout | Flight - Clutter | FM | 159.8 ± 6.7 | 51.74 ± 11.74 | 108.06 ± 9.22 | 88.91 ± 6.68 | 3.44 ± 2.34 | 31.41 ± 27.12 | 10 |
| Vespertilionidae | Murina cyclotis | Mu_cycl_1 | Raghuram et al. 2014 | 2014 | LC | India | Karnataka | D980 | Flight - Clutter | FM | 135.5 | 49.5 | 86 | 89.2 | 1.4 | #VALUE! | 1 |
| Vespertilionidae | Murina cyclotis | Mu_cycl_2 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Clutter | FM | 120.1 | 68.8 | 51.3 | 95.4 | 1.8 | 28.5 | 1 |
| Vespertilionidae | Murina huttoni | Mu_hutt_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Clutter | FM | 107.5 ± 10.45 | 63.8 ± 10.28 | 43.7 ± 10.37 | 83 ± 17.13 | 1.2 ± 0.09 | 36.42 ± 0.04 | 2 |
| Vespertilionidae | Murina huttoni | Mu_hutt_2 | Saikia et al. 2025 | 2025 | LC | India | Himachal Pradesh | Anabat Walkabout | Flight - Clutter | FM | 117.5 | 49.82 | 67.68 | 62.82 | 2 | 33.84 | 1 |
| Vespertilionidae | Murina leucogaster | Mu_leuc_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | FM | 98.9 | 59.3 | 39.6 | 69.3 | 0.9 | 44 | 1 |
| Vespertilionidae | Myotis annectans | My_anne_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | FM | 61.3 ± 10.09 | 36.22 ± 0.96 | 25.08 ± 5.53 | 41.91 ± 0.55 | 3.33 ± 0.91 | 7.53 ± 6.08 | 3 |
| Vespertilionidae | Myotis annectans | My_anne_2 | Saikia & Chakravarty 2024 | 2024 | LC | India | Mizoram | Anabat Walkabout | Flight - Clutter | FM | 68.69 ± 7.79 | 32.27 ± 1.1 | 36.42 ± 4.445 | 35.74 ± 2.02 | 7.24 ± 1.96 | 5.03 ± 0.46 | 15 |
| Vespertilionidae | Myotis blythii | My_blyt_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | FM | 51.4 | 18.5 | 32.9 | 35.4 | 2.1 | 15.67 | 1 |
| Vespertilionidae | Myotis formosus | My_form_1 | Rai et al. 2021 | 2021 | NT | Nepal | Bagmati | SM4BAT | Release - Clutter | FM | 108.89 ± 3.12 | 36.77 ± 1.23 | 72.12 ± 2.175 | 44.6 ± 3.28 | 3.73 ± 0.65 | 19.34 ± 0.27 | 13 |
| Vespertilionidae | Myotis himalaicus | My_hima_1 | Chakravarty et al. 2020 | 2020 | NA | India | Uttarakhand | Anabat Walkabout | Release - Open | FM | 96.8 ± 3.15 | 47.9 ± 3.13 | 48.9 ± 3.14 | 68 ± 3.86 | 2.52 ± 0.17 | 19.4 ± 0.82 | 4 |
| Vespertilionidae | Myotis himalaicus | My_hima_2 | Saikia et al. 2025 | 2025 | NA | India | Himachal Pradesh | Anabat Walkabout | Flight - Clutter | FM | 82.26 ± 6.69 | 35.28 ± 1.91 | 46.98 ± 4.3 | 40.16 ± 2.62 | 5.69 ± 1.77 | 8.26 ± 5.58 | 36 |
| Vespertilionidae | Myotis horsfieldii | My_hors_1 | Wordley et al. 2014 | 2014 | LC | India | Tamil Nadu | D500X | Release - Clutter | FM | 91.23 ± 15.27 | 41.6 ± 2.65 | 49.63 ± 8.96 | 53.8 ± 5.14 | 2.57 ± 0.6 | 19.31 ± 14.93 | 59 |
| Vespertilionidae | Myotis horsfieldii | My_hors_2 | Srinivasulu et al. 2017 | 2017 | LC | India | Andaman & Nicobar Islands | D500X | Flight - Open | FM | 104.29 ± 5.13 | 42.28 ± 4.29 | 62.01 ± 4.71 | 64.77 ± 3.91 | 3.27 ± 0.49 | 18.96 ± 9.61 | 34 |
| Vespertilionidae | Myotis horsfieldii | My_hors_3 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | D240X | Flight - Clutter | FM | 97.3 ± 26.17 | 49.35 ± 4.47 | 47.96 ± 30.18 | 56.76 ± 1.99 | 3.93 ± 1.17 | 12.2 ± 1.06 | 23 |
| Vespertilionidae | Myotis horsfieldii | My_hors_4 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | D500X | Flight - Clutter | FM | 94.49 ± 23 | 45.06 ± 12.09 | 49.43 ± 29.03 | 57.81 ± 2.41 | 5.57 ± 3.47 | 8.87 ± 19.21 | 35 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vespertilionidae | Myotis horsfieldii | My_hors_5 | Present study | 2025 | LC | India | Karnataka | D500X | Flight - Clutter | FM | 99.52 ± 7.02 | 42.52 ± 1.74 | 57 ± 7.69 | 58.7 ± 4.96 | 2.43 ± 0.37 | 23.46 ± 24.32 | 46 |
| Vespertilionidae | Myotis longipes | My_long_1 | Chakravarty et al. 2020 | 2020 | DD | India | Uttarakhand | Anabat Walkabout | Release - Open | FM | 98.4 ± 11.79 | 60.6 ± 3.6 | 37.8 ± 7.7 | 70 ± 2.46 | 2.9 ± 0.37 | 13.03 ± 0.21 | 10 |
| Vespertilionidae | Myotis montivagus | My_mont_1 | Wordley et al. 2014 | 2014 | DD | India | Tamil Nadu | D500X | Release - Clutter | FM | 81.23 ± 14.67 | 44.95 ± 1.37 | 36.28 ± 8.02 | 49.9 ± 2.09 | 2.57 ± 0.57 | 14.12 ± 14.07 | 3 |
| Vespertilionidae | Myotis montivagus | My_mont_2 | Saikia & Chakravarty 2024 | 2024 | DD | India | Mizoram | Anabat Walkabout | Flight - Clutter | FM | 95.01 ± 4.52 | 43.23 ± 1.01 | 51.78 ± 2.765 | 50.1 ± 3.12 | 2.6 ± 0.26 | 19.92 ± 0.03 | 15 |
| Vespertilionidae | Myotis muricola | My_muri_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | FM | 104.7 ± 2.09 | 47.8 ± 3.66 | 56.9 ± 2.88 | 51.9 ± 2.51 | 4 ± 0.5 | 14.22 ± 5.76 | 2 |
| Vespertilionidae | Myotis muricola | My_muri_2 | Saikia et al. 2025 | 2025 | LC | India | Himachal Pradesh | Anabat Walkabout | Flight - Clutter | FM | 110.11 | 43.37 | 66.74 | 55.17 | 3 | 22.25 | 1 |
| Vespertilionidae | Myotis nipalensis | My_nipa_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | FM | 112.1 | 59.9 | 52.2 | 67.3 | 2.4 | 21.75 | 1 |
| Vespertilionidae | Myotis peytoni | My_peyt_1 | Srinivasulu & Srinivasulu 2017 | 2017 | DD | India | Kerala | D500X | Release - Open | FM | 84.37 ± 1.18 | 40.62 ± 1.18 | 43.75 ± 1.18 | 48.53 ± 0.68 | 3.58 ± 0.26 | 12.22 ± 4.54 | 8 |
| Vespertilionidae | Myotis peytoni | My_peyt_2 | Raman & Hughes 2020 | 2020 | DD | India | Kerala | M500-384 | Flight - Open | FM | 88.9 ± 7.37 | 39.9 ± 1.38 | 49. ± 4.38 | 48.5 ± 1.31 | 2.9 ± 0.92 | 16.9 ± 0.41 | 54 |
| Vespertilionidae | Myotis peytoni | My_peyt_3 | Present study | 2025 | DD | India | Karnataka | Anabat SD1 | Flight - Clutter | FM | 82.88 ± 7.16 | 44.42 ± 2.33 | 38.47 ± 6.29 | 47.75 ± 3.29 | 2.37 ± 0.53 | 16.23 ± 11.87 | 20 |
| Vespertilionidae | Myotis peytoni | My_peyt_4 | Present study | 2025 | DD | India | Karnataka | D500X | Release - Clutter | FM | 86.58 ± 9.76 | 38.92 ± 1.08 | 47.67 ± 9.13 | 50.14 ± 1.91 | 2.85 ± 0.63 | 16.73 ± 14.49 | 12 |
| Vespertilionidae | Myotis peytoni | My_peyt_5 | Present study | 2025 | DD | India | Karnataka | Anabat SD1 | Release - Clutter | FM | 82.43 ± 7.06 | 44.18 ± 2.14 | 38.25 ± 6.39 | 47.29 ± 2.63 | 2.41 ± 0.52 | 15.87 ± 12.29 | 19 |
| Vespertilionidae | Myotis peytoni | My_peyt_6 | Present study | 2025 | DD | India | Kerala | D500X | Release - Clutter | FM | 84.57 ± 1.13 | 40.86 ± 1.07 | 43.71 ± 1.38 | 48.54 ± 0.74 | 3.53 ± 0.23 | 12.38 ± 6 | 7 |
| Vespertilionidae | Myotis pilosus | My_pilo_1 | Saikia et al. 2020 | 2020 | VU | India | Meghalaya | Anabat Walkabout | Flight - Open | FM | 60.7 ± 4.4 | 29.8 ± 1 | 30.9 ± 2.7 | 34.9 ± 0.7 | 6.9 ± 0.5 | 4.48 ± 5.4 | 10 |
| Vespertilionidae | Myotis sicarius | My_sica_1 | Saikia et al. 2025 | 2025 | VU | India | Himachal Pradesh | Anabat Walkabout | Flight - Clutter | FM | 71.96 | 33.14 | 38.82 | 37.41 | 5.12 | 7.58 | 1 |
| Vespertilionidae | Nyctalus leisleri | Ny_leis_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | FM-QCF | 58.7 ± 9.09 | 27.4 ± 2.24 | 31.3 ± 5.67 | 34.2 ± 1.72 | 3.4 ± 0.84 | 9.21 ± 0.01 | 9 |
| Vespertilionidae | Nyctalus leisleri | Ny_leis_2 | Saikia et al. 2025 | 2025 | LC | India | Himachal Pradesh | Anabat Walkabout | Flight - Open | FM-QCF | 52.95 ± 9.34 | 24.35 ± 2.04 | 28.6 ± 5.69 | 27.3 ± 2.32 | 11.56 ± 2.8 | 2.47 ± 0.25 | 5 |
| Vespertilionidae | Nyctalus montanus | Ny_mont_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | FM-QCF | 47.5 ± 7.93 | 21.9 ± 2.69 | 25.6 ± 5.31 | 28.4 ± 1.15 | 3 ± 1 | 8.53 ± 5.31 | 5 |
| Vespertilionidae | Nyctalus noctula | Ny_noct_1 | Rai et al. 2021 | 2021 | LC | Nepal | Bagmati | SM4BAT | Release - Clutter | FM-QCF | 35.64 ± 1.67 | 19.4 ± 0.55 | 16.24 ± 1.11 | 22.92 ± 0.77 | 12.35 ± 1.97 | 1.31 ± 0.56 | 2 |
| Molossidae | Otomops wroughtoni | Ot_wrou_1 | Ruedi et al. 2014 | 2014 | DD | India | Meghalaya | D240X | Flight - Clutter | LMH | 18.5 | 12.4 | 6.1 | 15.3 | 3 | 2.03 | 1 |
| Molossidae | Otomops wroughtoni | Ot_wrou_2 | Deshpande & Kelkar 2015 | 2015 | DD | India | Karnataka | D240X | Flight - Clutter | LMH | 24.9 ± 2.31 | 13 ± 0.98 | 11.9 ± 1.65 | 16.15 ± 0.93 | 11.97 ± 4.3 | 0.99 ± 0.38 | 310 |
| Molossidae | Otomops wroughtoni | Ot_wrou_3 | Deshpande & Kelkar 2015 | 2015 | DD | India | Karnataka | D240X | Flight - Open | LMH | 21.5 ± 3.05 | 12.76 ± 0.99 | 8.74 ± 2.02 | 15.12 ± 0.65 | 23.09 ± 2.5 | 0.38 ± 0.01 | 46 |
| Vespertilionidae | Phoniscus jagorii | Ph_jago_1 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Open | FM | 140.8 ± 4.14 | 80.7 ± 2.79 | 60.1 ± 3.47 | 113.7 ± 4.86 | 1.3 ± 0.15 | 46.23 ± 0.03 | 8 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vespertilionidae | Phoniscus jagorii | Ph_jago_2 | Raman et al. 2020 | 2020 | LC | India | Kerala | M500-384 | Release - Clutter | FM | 140.88 ± 4.14 | 80.75 ± 2.79 | 60.13 ± 3.47 | 113.79 ± 4.86 | 1.39 ± 0.15 | 43.26 ± 23.13 | 15 |
| Vespertilionidae | Pipistrellus babu | Pi_babu_1 | Saikia et al. 2025 | 2025 | NA | India | Himachal Pradesh | Anabat Walkabout | Flight - Clutter | FM-QCF | 82.26 ± 6.69 | 35.28 ± 1.91 | 46.98 ± 4.3 | 40.16 ± 2.62 | 5.69 ± 1.77 | 8.26 ± 5.58 | 36 |
| Vespertilionidae | Pipistrellus ceylonicus | Pi_ceyl_1 | Raghuram et al. 2014 | 2014 | LC | India | Karnataka | D980 | Flight - Clutter | FM-QCF | 101.7 ± 2 | 32.8 ± 0.4 | 68.9 ± 1.2 | 44 ± 4 | 1.4 ± 0.4 | 49.21 ± 3 | 4 |
| Vespertilionidae | Pipistrellus ceylonicus | Pi_ceyl_10 | Present study | 2025 | LC | India | Telangana | SM3BAT | Flight - Open | FM-QCF | 47.94 ± 6.89 | 32.53 ± 1.13 | 15.4 ± 6.28 | 35.39 ± 1.21 | 9.18 ± 1.43 | 1.68 ± 0.65 | 41 |
| Vespertilionidae | Pipistrellus ceylonicus | Pi_ceyl_2 | Raghuram et al. 2014 | 2014 | LC | India | Karnataka | D980 | Flight - Open | FM-QCF | 60.8 ± 11.5 | 35.1 ± 6 | 25.7 ± 8.75 | 37.8 ± 8.4 | 8.6 ± 1.5 | 2.99 ± 1.5 | 3 |
| Vespertilionidae | Pipistrellus ceylonicus | Pi_ceyl_3 | Wordley et al. 2014 | 2014 | LC | India | Tamil Nadu | D500X | Release - Clutter | FM-QCF | 59.45 ± 9.11 | 35.57 ± 1.62 | 23.88 ± 5.37 | 38.64 ± 1.99 | 2.57 ± 0.6 | 9.29 ± 8.95 | 23 |
| Vespertilionidae | Pipistrellus ceylonicus | Pi_ceyl_4 | Kusuminda et al. 2017 | 2017 | LC | Sri Lanka | Central | M500 | Flight - Open | FM-QCF | 64.88 ± 7.28 | 31.96 ± 0.73 | 32.92 ± 4 | 37.21 ± 0.66 | 9.04 ± 0.98 | 36.41 ± 4.08 | 25 |
| Vespertilionidae | Pipistrellus ceylonicus | Pi_ceyl_5 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Clutter | FM-QCF | 67 ± 10.05 | 36.9 ± 0.9 | 30.1 ± 5.48 | 41.4 ± 1.51 | 4.3 ± 1.93 | 7 ± 0.01 | 21 |
| Vespertilionidae | Pipistrellus ceylonicus | Pi_ceyl_6 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Clutter | FM-QCF | 77.6 ± 1.08 | 34.7 ± 0.27 | 42.9 ± 0.68 | 42.3 ± 2.43 | 2.5 ± 0.37 | 17.16 ± 0.02 | 9 |
| Vespertilionidae | Pipistrellus ceylonicus | Pi_ceyl_7 | Shah & Srinivasulu 2020 | 2020 | LC | India | Gujarat | SM3BAT | Release - Open | FM-QCF | 46.5 ± 4.51 | 36.63 ± 1.97 | 9.87 ± 3.24 | 38.09 ± 1.94 | 7.72 ± 1.13 | 1.28 ± 1.85 | 40 |
| Vespertilionidae | Pipistrellus ceylonicus | Pi_ceyl_8 | Devender & Srinivasulu 2022 | 2022 | LC | India | Telangana | SM3BAT | Flight - Open | FM-QCF | 43.84 ± 5.81 | 34.9 ± 3.11 | 8.94 ± 4.46 | 35.46 ± 3.24 | 8.7 ± 1.45 | 1.03 ± 0.01 | 79 |
| Vespertilionidae | Pipistrellus ceylonicus | Pi_ceyl_9 | Present study | 2025 | LC | India | Telangana | Anabat SD1 | Flight - Open | FM-QCF | 46.57 ± 6.43 | 25.72 ± 10.37 | 20.86 ± 11.77 | 34.78 ± 1.56 | 7.68 ± 5.12 | 2.72 ± 14.75 | 184 |
| Vespertilionidae | Pipistrellus coromandra | Pi_coro_1 | Raghuram et al. 2014 | 2014 | LC | India | Karnataka | D980 | Flight - Clutter | FM-QCF | 122.8 ± 3.9 | 38.8 ± 3 | 84 ± 3.45 | 50.2 ± 3.6 | 1.6 ± 0.4 | 52.5 ± 12.5 | 6 |
| Vespertilionidae | Pipistrellus coromandra | Pi_coro_2 | Srinivasulu et al. 2017 | 2017 | LC | India | Andaman & Nicobar Islands | D500X | Release - Clutter | FM-QCF | 57.78 ± 1.82 | 40.73 ± 0.96 | 17.05 ± 1.39 | 42.35 ± 0.86 | 5.86 ± 0.31 | 2.91 ± 4.48 | 12 |
| Vespertilionidae | Pipistrellus coromandra | Pi_coro_3 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Open | FM-QCF | 95.5 ± 13.18 | 49.8 ± 1.97 | 45.7 ± 7.58 | 65.7 ± 6.59 | 1.1 ± 0.36 | 41.55 ± 0.02 | 12 |
| Vespertilionidae | Pipistrellus javanicus | Pi_java_1 | Srinivasulu et al. 2017 | 2017 | LC | India | Andaman & Nicobar Islands | D500X | Release - Open | FM-QCF | 74.49 ± 5.64 | 39.71 ± 0.92 | 34.78 ± 3.28 | 43.64 ± 0.65 | 4.56 ± 0.57 | 7.63 ± 5.75 | 28 |
| Vespertilionidae | Pipistrellus javanicus | Pi_java_2 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | D500X | Flight - Open | FM-QCF | 60.63 ± 9.15 | 42.17 ± 2.16 | 18.46 ± 9.45 | 42.56 ± 2.17 | 1.14 ± 0.62 | 16.19 ± 15.24 | 27 |
| Vespertilionidae | Pipistrellus tenuis | Pi_tenu_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | FM-QCF | 95 ± 5.94 | 49.6 ± 0.41 | 45.4 ± 3.18 | 54.6 ± 1.75 | 3.4 ± 0.91 | 13.35 ± 0 | 2 |
| Vespertilionidae | Pipistrellus tenuis | Pi_tenu_2 | Devender & Srinivasulu 2022 | 2022 | LC | India | Telangana | SM3BAT | Flight - Open | FM-QCF | 55.16 ± 3.83 | 48.96 ± 1.28 | 6.2 ± 2.555 | 49.8 ± 1.42 | 7.84 ± 1.27 | 0.79 ± 203.7 | 79 |
| Vespertilionidae | Pipistrellus tenuis | Pi_tenu_3 | Present study | 2025 | LC | India | Karnataka | D500X | Flight - Open | FM-QCF | 72.28 ± 9.57 | 48.22 ± 0.88 | 24.06 ± 9.21 | 51.65 ± 1.06 | 6.61 ± 1.33 | 3.64 ± 27.91 | 18 |
| Vespertilionidae | Pipistrellus tenuis | Pi_tenu_4 | Present study | 2025 | LC | India | Telangana | D500X | Flight - Open | FM-QCF | 74.58 ± 2.06 | 47.08 ± 0.28 | 27.5 ± 2.11 | 50.93 ± 0.48 | 6.03 ± 1.13 | 4.56 ± 0.85 | 24 |
| Vespertilionidae | Pipistrellus tenuis | Pi_tenu_5 | Present study | 2025 | LC | India | Telangana | Anabat SD1 | Flight - Open | FM-QCF | 59.99 ± 8.41 | 40.41 ± 17.25 | 19.58 ± 20.97 | 50.35 ± 1.89 | 5.65 ± 3.36 | 3.47 ± 2.69 | 242 |
| Vespertilionidae | Plecotus homochrous | Pl_homo_1 | Chakravarty et al. 2020 | 2020 | DD | India | Uttarakhand | Anabat Walkabout | Release - Open | PL | 37 ± 7.45 | 27 ± 9.89 | 10 ± 8.67 | 31.3 ± 7.12 | 1.9 ± 1.39 | 5.26 ± 0.18 | 4 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vespertilionidae | Plecotus wardi | Pl_ward_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | PL | 40 ± 2.69 | 26.9 ± 1.79 | 13.1 ± 2.24 | 31.3 ± 1.72 | 1.8 ± 0.39 | 7.28 ± 0.01 | 4 |
| Rhinolophidae | Rhinolophus affinis | Rh_affi_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Hand-held | LCF | | | | 88 ± 0.3 | 24.3 ± 7.2 | | 7 |
| Rhinolophidae | Rhinolophus affinis | Rh_affi_2 | Saikia & Chakravarty 2024 | 2024 | LC | India | Mizoram | Anabat Walkabout | Flight - Clutter | LCF | | | | 88.79 ± 0.2 | 46.08 ± 5.2 | | 15 |
| Rhinolophidae | Rhinolophus affinis | Rh_affi_3 | Saikia et al. 2025 | 2025 | LC | India | Himachal Pradesh | Anabat Walkabout | Flight - Clutter | LCF | | | | 79.65 | 46 | | 1 |
| Rhinolophidae | Rhinolophus andamanensis | Rh_anda_1 | Srinivasulu et al. 2017 | 2017 | NA | India | Andaman & Nicobar Islands | D500X | Release - Open | LCF | | | | 57.65 ± 0.56 | 46.63 ± 8.59 | | 156 |
| Rhinolophidae | Rhinolophus andamanensis | Rh_anda_2 | Present study | 2025 | NA | India | Andaman & Nicobar Islands | D500X | Flight - Clutter | LCF | | | | 57.29 ± 0.64 | 46.43 ± 9.9 | | 95 |
| Rhinolophidae | Rhinolophus andamanensis | Rh_anda_3 | Present study | 2025 | NA | India | Andaman & Nicobar Islands | Anabat SD1 | Flight - Clutter | LCF | | | | 57.68 ± 1.19 | 34.52 ± 8.18 | | 44 |
| Rhinolophidae | Rhinolophus andamanensis | Rh_anda_4 | Present study | 2025 | NA | India | Andaman & Nicobar Islands | D500X | Flight - Open | LCF | | | | 57.16 ± 1.14 | 40.5 ± 13.61 | | 22 |
| Rhinolophidae | Rhinolophus andamanensis | Rh_anda_5 | Present study | 2025 | NA | India | Andaman & Nicobar Islands | Anabat SD1 | Flight - Open | LCF | | | | 57.68 ± 1.19 | 34.52 ± 8.18 | | 44 |
| Rhinolophidae | Rhinolophus andamanensis | Rh_anda_6 | Present study | 2025 | NA | India | Andaman & Nicobar Islands | D500X | Release - Open | LCF | | | | 57.9 ± 0.07 | 43.85 ± 1.82 | | 13 |
| Rhinolophidae | Rhinolophus beddomei | Rh_bedd_1 | Raghuram et al. 2014 | 2014 | LC | India | Karnataka | D980 | Flight - Clutter | LCF | | | | 38.6 ± 0.14 | 53.1 ± 6.3 | | 2 |
| Rhinolophidae | Rhinolophus beddomei | Rh_bedd_10 | Present study | 2025 | LC | India | Karnataka | Anabat SD1 | Flight - Clutter | LCF | | | | 42.12 ± 0.15 | 37.07 ± 11.37 | | 28 |
| Rhinolophidae | Rhinolophus beddomei | Rh_bedd_11 | Present study | 2025 | LC | India | Kerala | SM3BAT | Flight - Clutter | LCF | | | | 42.89 ± 0.09 | 59.63 ± 6.71 | | 30 |
| Rhinolophidae | Rhinolophus beddomei | Rh_bedd_2 | Wordley et al. 2014 | 2014 | LC | India | Tamil Nadu | D500X | Release - Clutter | LCF | | | | 42.81 ± 0.53 | 47.7 ± 13.62 | | 2 |
| Rhinolophidae | Rhinolophus beddomei | Rh_bedd_3 | Srinivasulu et al. 2015 | 2015 | LC | India | Karnataka | Anabat SD1 | Hand-held | LCF | | | | 43.37 ± 0.28 | 92.94 ± 24.26 | | 20 |
| Rhinolophidae | Rhinolophus beddomei | Rh_bedd_4 | Srinivasulu et al. 2015 | 2015 | LC | India | Karnataka | Anabat SD1 | Hand-held | LCF | | | | 41.07 ± 3.34 | 92.26 ± 8.7 | | 12 |
| Rhinolophidae | Rhinolophus beddomei | Rh_bedd_5 | Kusuminda et al. 2019 | 2019 | LC | Sri Lanka | Central, Northwestern, Sabaragamuwa, Uva | M500 | Hand-held | LCF | | | | 52.7 ± 0.2 | 56.2 ± 3.3 | | 4 |
| Rhinolophidae | Rhinolophus beddomei | Rh_bedd_6 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Open | LCF | | | | 43.5 ± 0.87 | 65.2 ± 8.93 | | 62 |
| Rhinolophidae | Rhinolophus beddomei | Rh_bedd_7 | Sail & Borkar 2024 | 2024 | LC | India | Goa | Echometer Touch 2 | Flight - Clutter | LCF | | | | 41 ± 0.01 | 84.11 ± 7.6 | | 20 |
| Rhinolophidae | Rhinolophus beddomei | Rh_bedd_8 | Present study | 2025 | LC | India | Andhra Pradesh | M500 | Flight - Clutter | LCF | | | | 41.71 ± 0.06 | 92.85 ± 21.25 | | 41 |
| Rhinolophidae | Rhinolophus beddomei | Rh_bedd_9 | Present study | 2025 | LC | India | Karnataka | D500X | Flight - Clutter | LCF | | | | 38.91 ± 1.11 | 63.39 ± 14 | | 58 |
| Rhinolophidae | Rhinolophus cognatus | Rh_cogn_1 | Srinivasulu et al. 2017 | 2017 | EN | India | Andaman & Nicobar Islands | D500X | Hand-held | LCF | | | | 89.92 ± 1.5 | 53.08 ± 9.38 | | 37 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rhinolophidae | Rhinolophus cognatus | Rh_cogn_2 | Present study | 2025 | EN | India | Andaman & Nicobar Islands | D500X | Flight - Clutter | LCF | | | | 89.34 ± 1.86 | 49.17 ± 5.54 | | 46 |
| Rhinolophidae | Rhinolophus cognatus | Rh_cogn_3 | Present study | 2025 | EN | India | Andaman & Nicobar Islands | Anabat SD1 | Flight - Clutter | LCF | | | | 84.55 ± 3.54 | 17.3 ± 6.29 | | 40 |
| Rhinopomatidae | Rhinopoma hardwickii | Rh_hard_1 | Srinivasulu & Srinivasulu 2017 | 2017 | LC | India | Kerala | D500X | Release - Open | LMH | 37.05 ± 0.46 | 26.66 ± 0.94 | 10.39 ± 0.7 | 32.48 ± 0.75 | 2.21 ± 0.44 | 4.7 ± 1.59 | 12 |
| Rhinopomatidae | Rhinopoma hardwickii | Rh_hard_2 | Shah & Srinivasulu 2020 | 2020 | LC | India | Gujarat | SM3BAT | Release - Open | LMH | 34.52 ± 2.4 | 28.23 ± 3.58 | 6.29 ± 2.99 | 31.32 ± 0.93 | 3.86 ± 1.48 | 1.63 ± 2.06 | 58 |
| Rhinopomatidae | Rhinopoma hardwickii | Rh_hard_3 | Devender & Srinivasulu 2022 | 2022 | LC | India | Telangana | SM3BAT | Flight - Clutter | LMH | 34.54 ± 2.45 | 27.84 ± 0.64 | 6.7 ± 1.545 | 31.32 ± 0.95 | 3.74 ± 1.49 | 1.79 ± 0.37 | 55 |
| Rhinopomatidae | Rhinopoma hardwickii | Rh_hard_4 | Present study | 2025 | LC | India | Andhra Pradesh | M500 | Flight - Clutter | LMH | 59.25 ± 17.8 | 28.95 ± 1.86 | 30.31 ± 18.96 | 33.2 ± 0.87 | 1.76 ± 0.41 | 17.22 ± 21.85 | 59 |
| Rhinopomatidae | Rhinopoma hardwickii | Rh_hard_5 | Present study | 2025 | LC | India | Gujarat | SM3BAT | Flight - Clutter | LMH | 80.79 ± 15.11 | 24.59 ± 6.87 | 56.2 ± 12.56 | 33.04 ± 0.44 | 4.5 ± 0.58 | 12.49 ± 0.01 | 23 |
| Rhinopomatidae | Rhinopoma hardwickii | Rh_hard_6 | Present study | 2025 | LC | India | Kerala | D500X | Flight - Clutter | LMH | 47.59 ± 20.89 | 26.68 ± 2.32 | 20.92 ± 21.27 | 32.56 ± 0.88 | 2.47 ± 0.74 | 8.47 ± 1.72 | 64 |
| Rhinopomatidae | Rhinopoma hardwickii | Rh_hard_7 | Present study | 2025 | LC | India | Kerala | SM3BAT | Flight - Clutter | LMH | 91.56 ± 10 | 26.89 ± 1.96 | 64.67 ± 11.48 | 33.02 ± 0.62 | 2.96 ± 0.83 | 21.85 ± 1.78 | 9 |
| Rhinolophidae | Rhinolophus lepidus | Rh_lepi_1 | Raghuram et al. 2014 | 2014 | LC | India | Karnataka | D980 | Flight - Clutter | LCF | | | | 95.2 ± 1.4 | 32.2 ± 9.4 | | 5 |
| Rhinolophidae | Rhinolophus lepidus | Rh_lepi_10 | Present study | 2025 | LC | India | Gujarat | SM3BAT | Release - Open | LCF | | | | 104.98 ± 0.11 | 38.18 ± 6.4 | | 11 |
| Rhinolophidae | Rhinolophus lepidus | Rh_lepi_11 | Saikia et al. 2025 | 2025 | LC | India | Himachal Pradesh | Anabat Walkabout | Flight - Clutter | LCF | | | | 100 | 24.42 | | 1 |
| Rhinolophidae | Rhinolophus lepidus | Rh_lepi_2 | Wordley et al. 2014 | 2014 | LC | India | Tamil Nadu | D500X | Release - Clutter | LCF | | | | 102.31 ± 1.81 | 25.23 ± 11.38 | | 35 |
| Rhinolophidae | Rhinolophus lepidus | Rh_lepi_3 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Hand-held | LCF | | | | 106.3 ± 4.3 | 30.2 ± 11.8 | | 3 |
| Rhinolophidae | Rhinolophus lepidus | Rh_lepi_4 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Open | LCF | | | | 102.5 ± 1.82 | 30.1 ± 11.74 | | 369 |
| Rhinolophidae | Rhinolophus lepidus | Rh_lepi_5 | ChiroVox | 2023 | LC | Bangladesh | Rajshahi Division | D1000X | Flight - Open | LCF | | | | 109.2 ± 1.96 | 31.78 ± 12.69 | | 82 |
| Rhinolophidae | Rhinolophus lepidus | Rh_lepi_6 | Present study | 2025 | LC | India | Gujarat | SM3BAT | Flight - Clutter | LCF | | | | 104.95 ± 0.09 | 42.12 ± 7.08 | | 41 |
| Rhinolophidae | Rhinolophus lepidus | Rh_lepi_7 | Present study | 2025 | LC | India | Madhya Pradesh | Echometer Touch 2 Pro | Flight - Clutter | LCF | | | | 102.69 ± 1.78 | 36.09 ± 10.29 | | 70 |
| Rhinolophidae | Rhinolophus lepidus | Rh_lepi_8 | Present study | 2025 | LC | India | Maharashtra | SM3BAT | Flight - Clutter | LCF | | | | 97.64 ± 0.83 | 43.14 ± 13.53 | | 50 |
| Rhinolophidae | Rhinolophus lepidus | Rh_lepi_9 | Present study | 2025 | LC | India | Odisha | D500X | Flight - Clutter | LCF | | | | 98.77 ± 1.47 | 49.76 ± 6.97 | | 40 |
| Rhinolophidae | Rhinolophus macrotis | Rh_macr_1 | Saikia et al. 2025 | 2025 | LC | India | Himachal Pradesh | Anabat Walkabout | Flight - Clutter | LCF | | | | 62.36 | 18 | | 1 |
| Rhinopomatidae | Rhinopoma microphyllum | Rh_micr_1 | Shah & Srinivasulu 2020 | 2020 | LC | India | Gujarat | SM3BAT | Release - Open | LMH | 31.45 ± 1.11 | 25.18 ± 1.42 | 6.27 ± 1.27 | 29.03 ± 0.89 | 4.21 ± 1.25 | 1.49 ± 1.08 | 51 |
| Rhinopomatidae | Rhinopoma microphyllum | Rh_micr_2 | Present study | 2025 | LC | India | Gujarat | SM3BAT | Flight - Clutter | LMH | 64.94 ± 12.45 | 22.86 ± 4.6 | 42.07 ± 12.17 | 28.79 ± 1.71 | 6.32 ± 2.14 | 6.66 ± 15.5 | 45 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rhinopomatidae | Rhinopoma microphyllum | Rh_micr_3 | Present study | 2025 | LC | India | Madhya Pradesh | SM3BAT | Flight - Clutter | LMH | 53.94 ± 9.1 | 20.06 ± 5.93 | 33.89 ± 11.19 | 28.4 ± 0.81 | 3.24 ± 0.59 | 10.46 ± 2.02 | 16 |
| Rhinopomatidae | Rhinopoma microphyllum | Rh_micr_4 | Present study | 2025 | LC | India | Gujarat | SM3BAT | Flight - Open | LMH | 64.94 ± 12.45 | 22.86 ± 4.6 | 42.07 ± 12.17 | 28.79 ± 1.71 | 6.32 ± 2.14 | 6.66 ± 15.5 | 45 |
| Rhinolophidae | Rhinolophus pearsonii | Rh_pear_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Hand-held | LCF | | | | 61.25 ± 0.3 | 42.5 ± 5.1 | | 4 |
| Rhinolophidae | Rhinolophus pearsonii | Rh_pear_2 | Rai et al. 2021 | 2021 | LC | Nepal | Bagmati | SM4BAT | Release - Clutter | LCF | | | | 59.93 ± 0.02 | 25.72 ± 0.63 | | 24 |
| Rhinolophidae | Rhinolophus perniger | Rh_pern_1 | Chakravarty et al. 2020 | 2020 | NA | India | Uttarakhand | Anabat Walkabout | Hand-held | LCF | | | | 31.3 | 82.2 | | 1 |
| Rhinolophidae | Rhinolophus perniger | Rh_pern_2 | Present study | 2025 | NA | India | Madhya Pradesh | Echometer Touch 2 Pro | Flight - Clutter | LCF | | | | 36.08 ± 0.08 | 54.58 ± 5.62 | | 60 |
| Rhinolophidae | Rhinolophus perniger | Rh_pern_3 | Saikia et al. 2025 | 2025 | NA | India | Himachal Pradesh | Anabat Walkabout | Flight - Clutter | LCF | | | | 31.06 | 36 | | 1 |
| Rhinolophidae | Rhinolophus pusillus | Rh_pusi_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Hand-held | LCF | | | | 111.5 | 28.6 | | 1 |
| Rhinolophidae | Rhinolophus pusillus | Rh_pusi_2 | ChiroVox | 2023 | LC | Bangladesh | Chittagong Division | D1000X | Hand-held | LCF | | | | 101.76 ± 0.04 | 35.32 ± 1.77 | | 56 |
| Rhinolophidae | Rhinolophus rouxii | Rh_roux_1 | Chattopadhyay et al. 2010 | 2010 | LC | India | Tamil Nadu | D1000X | Hand-held | LCF | | | | 93.9 ± 0.5 | 46.1 ± 8.9 | | 621 |
| Rhinolophidae | Rhinolophus rouxii | Rh_roux_10 | Present study | 2025 | LC | India | Kerala | SM3BAT | Flight - Clutter | LCF | | | | 93.24 ± 0.1 | 24.71 ± 9.82 | | 21 |
| Rhinolophidae | Rhinolophus rouxii | Rh_roux_11 | Present study | 2025 | LC | India | Maharashtra | SM3BAT | Flight - Clutter | LCF | | | | 80.89 ± 0.03 | 65 ± 4.62 | | 39 |
| Rhinolophidae | Rhinolophus rouxii | Rh_roux_12 | Present study | 2025 | LC | India | Karnataka | D500X | Release - Clutter | LCF | | | | 81.56 ± 0.25 | 54.38 ± 10.1 | | 40 |
| Rhinolophidae | Rhinolophus rouxii | Rh_roux_2 | Chattopadhyay et al. 2012 | 2012 | LC | India | Karnataka | D1000X | Hand-held | LCF | | | | 82.1 ± 0.84 | 42.7 ± 9.84 | | 45 |
| Rhinolophidae | Rhinolophus rouxii | Rh_roux_3 | Chattopadhyay et al. 2012 | 2012 | LC | India | Tamil Nadu | D1000X | Hand-held | LCF | | | | 94.14 ± 0.37 | 41.51 ± 5.25 | | 52 |
| Rhinolophidae | Rhinolophus rouxii | Rh_roux_4 | Raghuram et al. 2014 | 2014 | LC | India | Karnataka | D980 | Flight - Clutter | LCF | | | | 80 ± 0.1 | 41.4 ± 10.2 | | 6 |
| Rhinolophidae | Rhinolophus rouxii | Rh_roux_5 | Wordley et al. 2014 | 2014 | LC | India | Tamil Nadu | D500X | Release - Clutter | LCF | | | | 92.08 ± 1.06 | 24.44 ± 12.1 | | 41 |
| Rhinolophidae | Rhinolophus rouxii | Rh_roux_6 | Kusuminda et al. 2019 | 2019 | LC | Sri Lanka | Central, Northwestern, Sabaragamuwa, Uva | M500 | Hand-held | LCF | | | | 74 ± 1.1 | 54.9 ± 6.9 | | 19 |
| Rhinolophidae | Rhinolophus rouxii | Rh_roux_7 | Raman & Hughes 2020 | 2020 | LC | India | Kerala | M500-384 | Flight - Open | LCF | | | | 81.6 ± 1.7 | 34.6 ± 13.8 | | 161 |
| Rhinolophidae | Rhinolophus rouxii | Rh_roux_8 | Present study | 2025 | LC | India | Karnataka | D500X | Flight - Clutter | LCF | | | | 81.56 ± 0.25 | 54.38 ± 10.1 | | 40 |
| Rhinolophidae | Rhinolophus rouxii | Rh_roux_9 | Present study | 2025 | LC | India | Kerala | D500X | Flight - Clutter | LCF | | | | 91.48 ± 1.43 | 26.74 ± 12.14 | | 74 |
| Rhinolophidae | Rhinolophus sinicus | Rh_sini_1 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Hand-held | LCF | | | | 87.9 | 42.1 | | 1 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rhinolophidae | Rhinolophus sinicus | Rh_sini_2 | Rai et al. 2021 | 2021 | LC | Nepal | Bagmati | SM4BAT | Release - Clutter | LCF | | | | 83.78 ± 3.55 | 31.57 ± 7.39 | | 66 |
| Rhinolophidae | Rhinolophus sinicus | Rh_sini_3 | Saikia et al. 2025 | 2025 | LC | India | Himachal Pradesh | Anabat Walkabout | Flight - Clutter | LCF | | | | 86.91 | 33 | | 1 |
| Vespertilionidae | Scotophilus heathii | Sc_heat_1 | Wordley et al. 2014 | 2014 | LC | India | Tamil Nadu | D500X | Release - Clutter | FM-QCF | 60.12 ± 5.21 | 37.65 ± 1.12 | 22.47 ± 3.17 | 41.2 ± 1.87 | 2.4 ± 0.54 | 9.36 ± 0.06 | 16 |
| Vespertilionidae | Scotophilus heathii | Sc_heat_2 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | FM-QCF | 52.5 ± 15.28 | 34.1 ± 2.22 | 18.4 ± 8.75 | 37.9 ± 4.74 | 6.7 ± 3.77 | 2.75 ± 0.01 | 3 |
| Vespertilionidae | Scotophilus heathii | Sc_heat_3 | Shah & Srinivasulu 2020 | 2020 | LC | India | Gujarat | SM3BAT | Release - Open | FM-QCF | 55.89 ± 8.68 | 35.13 ± 3.4 | 20.76 ± 6.04 | 37.42 ± 3.89 | 3.1 ± 0.9 | 6.7 ± 6.71 | 12 |
| Vespertilionidae | Scotophilus heathii | Sc_heat_4 | Devender & Srinivasulu 2022 | 2022 | LC | India | Telangana | SM3BAT | Flight - Open | FM-QCF | 50.48 ± 7.2 | 41.83 ± 5.33 | 8.65 ± 6.265 | 43.24 ± 4.96 | 7.08 ± 3.34 | 1.22 ± 779.41 | 30 |
| Vespertilionidae | Scotophilus heathii | Sc_heat_5 | ChiroVox | 2023 | LC | Bangladesh | Rajshahi Division | D1000X | Flight - Clutter | FM-QCF | 61.3 ± 7.18 | 33.7 ± 2.44 | 27.6 ± 8.14 | 41.5 ± 1.69 | 3.30 ± 0.99 | 8.36 ± 8.22 | 146 |
| Vespertilionidae | Scotophilus heathii | Sc_heat_6 | Present study | 2025 | LC | India | Gujarat | SM3BAT | Flight - Clutter | FM-QCF | 69.73 ± 13.9 | 34.19 ± 3.89 | 35.55 ± 12.33 | 39.07 ± 4.2 | 17.09 ± 12.41 | 2.08 ± 0.97 | 66 |
| Vespertilionidae | Scotophilus heathii | Sc_heat_7 | Present study | 2025 | LC | India | Telangana | Anabat SD1 | Flight - Clutter | FM-QCF | 68.29 ± 5.95 | 32.7 ± 12.54 | 35.59 ± 14.78 | 41.02 ± 3.58 | 2.05 ± 2.14 | 17.36 ± 34.14 | 141 |
| Vespertilionidae | Scotophilus heathii | Sc_heat_8 | Present study | 2025 | LC | India | Gujarat | SM3BAT | Flight - Open | FM-QCF | 62.55 ± 8.6 | 30.48 ± 2.99 | 32.07 ± 7.44 | 34.61 ± 2.35 | 30.57 ± 6.44 | 1.05 ± 1.16 | 28 |
| Vespertilionidae | Scotophilus kuhlii | Sc_kuhl_1 | Javid et al. 2014 | 2014 | LC | Pakistan | Punjab | D1000X | Flight - Clutter | FM-QCF | 103.5 ± 12.3 | 50.6 ± 1 | 52.9 ± 6.65 | 56.9 ± 3.6 | 2.5 ± 0.5 | 21.16 ± 13.3 | 25 |
| Vespertilionidae | Scotophilus kuhlii | Sc_kuhl_2 | Raghuram et al. 2014 | 2014 | LC | India | Karnataka | D980 | Flight - Clutter | FM-QCF | 117.4 ± 9.2 | 41 ± 0.6 | 76.4 ± 4.9 | 52.8 ± 4.6 | 8.2 ± 0.5 | 9.32 ± 9.8 | 3 |
| Vespertilionidae | Scotophilus kuhlii | Sc_kuhl_3 | Wordley et al. 2014 | 2014 | LC | India | Tamil Nadu | D500X | Release - Clutter | FM-QCF | 56.67 ± 2.06 | 43.53 ± 0.76 | 13.14 ± 1.41 | 45.26 ± 0.77 | 2.96 ± 0.38 | 4.44 ± 3.71 | 2 |
| Vespertilionidae | Scotophilus kuhlii | Sc_kuhl_4 | Devender & Srinivasulu 2022 | 2022 | LC | India | Telangana | SM3BAT | Flight - Open | FM-QCF | 50.52 ± 2.32 | 47.27 ± 1.09 | 3.25 ± 1.705 | 48.17 ± 1.68 | 8.85 ± 1.43 | 0.37 ± 1639.53 | 64 |
| Vespertilionidae | Scotophilus kuhlii | Sc_kuhl_5 | ChiroVox | 2023 | LC | Bangladesh | Rajshahi Division | D1000X | Flight - Clutter | FM-QCF | 73.5 ± 11.1 | 37.2 ± 2.93 | 36.4 ± 12.00 | 46.8 ± 2.54 | 3.36 ± 0.57 | 10.83 ± 21.05 | 174 |
| Vespertilionidae | Scotophilus kuhlii | Sc_kuhl_6 | Present study | 2025 | LC | India | Madhya Pradesh | SM3BAT | Flight - Clutter | FM-QCF | 66.28 ± 3.6 | 41.2 ± 1.73 | 25.09 ± 3.93 | 44.45 ± 1.41 | 10.91 ± 2.13 | 2.3 ± 1.85 | 33 |
| Vespertilionidae | Submyotodon caliginosus | Su_cali_1 | Chakravarty et al. 2020 | 2020 | NA | India | Uttarakhand | Anabat Walkabout | Release - Open | FM | 96.3 | 46.8 | 49.5 | 60.3 | 3 | 16.5 | 1 |
| Vespertilionidae | Submyotodon caliginosus | Su_cali_2 | Saikia et al. 2025 | 2025 | NA | India | Himachal Pradesh | Anabat Walkabout | Flight - Clutter | FM | 115.01 | 53.6 | 61.41 | 58.28 | 5.62 | 10.93 | 1 |
| Molossidae | Tadarida aegyptiaca | Ta_aegy_1 | Deshpande & Kelkar 2015 | 2015 | LC | India | Karnataka | D240X | Flight - Open | LMH | 24.44 ± 4.86 | 16.67 ± 2.67 | 7.77 ± 3.77 | 19.44 ± 2.31 | 15.5 ± 4.86 | 0.5 ± 0.9 | 120 |
| Molossidae | Tadarida aegyptiaca | Ta_aegy_2 | Deshpande & Kelkar 2015 | 2015 | LC | India | Kerala | D240X | Flight - Open | LMH | 24.44 ± 4.86 | 16.67 ± 2.67 | 7.77 ± 3.77 | 19.44 ± 2.31 | 15.5 ± 4.86 | 0.5 ± 0.9 | 120 |
| Molossidae | Tadarida aegyptiaca | Ta_aegy_3 | Deshpande & Kelkar 2015 | 2015 | LC | India | Maharashtra | D240X | Flight - Open | LMH | 24.44 ± 4.86 | 16.67 ± 2.67 | 7.77 ± 3.77 | 19.44 ± 2.31 | 15.5 ± 4.86 | 0.5 ± 0.9 | 120 |
| Molossidae | Tadarida aegyptiaca | Ta_aegy_4 | Present study | 2025 | LC | India | Telangana | D500X | Flight - Clutter | LMH | 28.11 ± 2.62 | 16.56 ± 1.13 | 11.56 ± 2.4 | 20.59 ± 1.54 | 14.82 ± 2.62 | 0.78 ± 0.92 | 9 |
| Molossidae | Tadarida aegyptiaca | Ta_aegy_5 | Present study | 2025 | LC | India | Andhra Pradesh | D500X | Flight - Open | LMH | 26.29 ± 0.65 | 17.56 ± 0.39 | 8.73 ± 0.59 | 19.81 ± 0.61 | 14.88 ± 2.36 | 0.59 ± 0.25 | 8 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Molossidae | Tadarida aegyptiaca | Ta_aegy_6 | Present study | 2025 | LC | India | Telangana | D500X | Flight - Open | LMH | 27.53 ± 2.47 | 16.79 ± 1.06 | 10.74 ± 2.53 | 20.29 ± 1.42 | 15.37 ± 2.59 | 0.7 ± 0.98 | 12 |
| Molossidae | Tadarida aegyptiaca | Ta_aegy_7 | Present study | 2025 | LC | India | Telangana | SM3BAT | Flight - Open | LMH | 26.58 ± 0.63 | 17.6 ± 0.49 | 8.98 ± 0.54 | 20.06 ± 0.64 | 13.6 ± 1.52 | 0.66 ± 1.04 | 5 |
| Molossidae | Tadarida insignis | Ta_insi_1 | Deshpande & Kelkar 2015 | 2015 | LC | India | Bihar, Kerala | D240X | Flight - Open | LMH | 14.29 ± 3.39 | 10.11 ± 1.29 | 4.18 ± 2.34 | 12.47 ± 1.28 | 19.5 ± 12.92 | 0.21 ± 0.37 | 67 |
| Molossidae | Tadarida insignis | Ta_insi_2 | Chakravarty 2017 | 2017 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | LMH | 23.8 ± 4.3 | 12.7 ± 0.9 | 11.1 ± 2.6 | 14.9 ± 0.73 | 12.8 ± 2.3 | 0.87 ± 1.13 | 34 |
| Molossidae | Tadarida insignis | Ta_insi_3 | Chakravarty et al. 2020 | 2020 | LC | India | Uttarakhand | Anabat Walkabout | Release - Open | LMH | 31.6 ± 2.27 | 9.9 ± 1.01 | 21.7 ± 1.64 | 15.6 ± 0.58 | 8.4 ± 1.24 | 2.58 ± 0.03 | 6 |
| Molossidae | Tadarida insignis | Ta_insi_4 | Sharma et al. 2021 | 2021 | LC | Nepal | Gandaki | Echometer Touch 2 | Flight - Open | LMH | 16.2 ± 2.1 | 10.9 ± 0.9 | 5.3 ± 1.5 | 13 | 20.7 ± 1 | 0.25 ± 1.5 | 420 |
| Emballonuridae | Taphozous longimanus | Ta_long_1 | Shah & Srinivasulu 2020 | 2020 | LC | India | Gujarat | SM3BAT | Release - Open | LMH | 32.85 ± 0.87 | 25.25 ± 1.32 | 7.6 ± 1.1 | 30.35 ± 1.07 | 3.98 ± 0.74 | 1.91 ± 0.14 | 15 |
| Emballonuridae | Taphozous longimanus | Ta_long_2 | Present study | 2025 | LC | India | Gujarat | M500 | Flight - Clutter | LMH | 33.41 ± 1.28 | 25.07 ± 1.18 | 8.34 ± 1.94 | 30 ± 1.08 | 4.48 ± 1.03 | 1.86 ± 31.33 | 22 |
| Emballonuridae | Taphozous longimanus | Ta_long_3 | Present study | 2025 | LC | India | Gujarat | SM3BAT | Flight - Clutter | LMH | 34.63 ± 1.16 | 24.7 ± 0.53 | 9.93 ± 1.12 | 29.23 ± 0.45 | 5.54 ± 0.62 | 1.79 ± 0.19 | 7 |
| Emballonuridae | Taphozous melanopogon | Ta_mela_1 | Srinivasulu et al. 2017 | 2017 | LC | India | Andaman & Nicobar Islands | Anabat SD1 | Release - Open | LMH | 34.01 ± 0.54 | 26.47 ± 0.95 | 7.54 ± 0.75 | 28.16 ± 1.7 | 3.33 ± 0.75 | 2.26 ± 1 | 18 |
| Emballonuridae | Taphozous melanopogon | Ta_mela_2 | Shah & Srinivasulu 2020 | 2020 | LC | India | Gujarat | SM3BAT | Release - Open | LMH | 31.33 ± 1.04 | 22.72 ± 1.42 | 8.61 ± 1.23 | 27.5 ± 0.52 | 6.01 ± 1.44 | 1.43 ± 0.52 | 42 |
| Emballonuridae | Taphozous melanopogon | Ta_mela_3 | Devender & Srinivasulu 2022 | 2022 | LC | India | Telangana | SM3BAT | Flight - Open | LMH | 25.05 ± 2.77 | 19.33 ± 1.56 | 5.72 ± 2.165 | 20.68 ± 1.3 | 11.67 ± 1.52 | 0.49 ± 108.55 | 79 |
| Emballonuridae | Taphozous melanopogon | Ta_mela_4 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | D240X | Flight - Clutter | LMH | 34.5 ± 2.87 | 26.17 ± 3.53 | 8.33 ± 5.28 | 32.42 ± 1.85 | 10.83 ± 4.8 | 0.77 ± 0.06 | 24 |
| Emballonuridae | Taphozous melanopogon | Ta_mela_5 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | D500X | Flight - Clutter | LMH | 30.08 ± 3.13 | 24.67 ± 1.58 | 5.42 ± 2.93 | 26.82 ± 1.57 | 18.33 ± 5.81 | 0.3 ± 0.16 | 24 |
| Emballonuridae | Taphozous melanopogon | Ta_mela_6 | Present study | 2025 | LC | India | Andaman & Nicobar Islands | Anabat SD1 | Flight - Clutter | LMH | 32.92 ± 2.35 | 25.45 ± 2.14 | 7.46 ± 1.45 | 26.83 ± 3 | 4.35 ± 2.07 | 1.71 ± 6.43 | 46 |
| Emballonuridae | Taphozous melanopogon | Ta_mela_7 | Present study | 2025 | LC | India | Karnataka | D500X | Flight - Clutter | LMH | 37.57 ± 7.26 | 20.43 ± 1.51 | 17.13 ± 6.58 | 27.87 ± 1.62 | 5.41 ± 1.71 | 3.17 ± 9.27 | 60 |
| Emballonuridae | Taphozous nudiventris | Ta_nudi_1 | Shah & Srinivasulu 2020 | 2020 | LC | India | Gujarat | SM3BAT | Release - Open | LMH | 31.2 ± 1.04 | 23.39 ± 1.16 | 7.81 ± 1.1 | 27.55 ± 0.65 | 6.19 ± 1.53 | 1.26 ± 2.08 | 35 |
| Emballonuridae | Taphozous nudiventris | Ta_nudi_2 | Shah & Srinivasulu 2020 | 2020 | LC | India | Gujarat | SM3BAT | Release - Open | LMH | 28.25 ± 0.87 | 23.48 ± 0.85 | 4.77 ± 0.86 | 26.16 ± 0.46 | 6.35 ± 1.59 | 0.75 ± 1.46 | 35 |
| Emballonuridae | Taphozous nudiventris | Ta_nudi_3 | Present study | 2025 | LC | India | Gujarat | SM3BAT | Flight - Clutter | LMH | 42.34 ± 8.48 | 17.94 ± 5.59 | 24.39 ± 11.06 | 42.39 ± 62.03 | 7.11 ± 1.77 | 3.43 ± 1.38 | 16 |
| Emballonuridae | Taphozous nudiventris | Ta_nudi_4 | Present study | 2025 | LC | India | Maharashtra | SM3BAT | Flight - Clutter | LMH | 40.66 ± 9.25 | 19.81 ± 4.11 | 20.84 ± 10.77 | 25.64 ± 0.41 | 8.63 ± 1.98 | 2.41 ± 0.79 | 25 |
| Emballonuridae | Taphozous nudiventris | Ta_nudi_5 | Present study | 2025 | LC | India | Gujarat | SM3BAT | Flight - Open | LMH | 31.16 ± 0.91 | 21.91 ± 0.43 | 9.25 ± 1.01 | 25.61 ± 0.5 | 9.46 ± 0.65 | 0.98 ± 0.02 | 8 |
| Emballonuridae | Taphozous perforatus | Ta_perf_1 | Mahmood-ul-Hassan et al. 2012 | 2012 | LC | Pakistan | Punjab | D1000X | Release - Clutter | LMH | 31.4 ± 0.7 | 25.6 ± 0.5 | 5.8 ± 0.6 | 30 ± 0.4 | 14.2 ± 2.7 | 0.41 ± 0.22 | 15 |

| Family | Species | Observation ID | Source | Year | IUCN Status | Country | Region | Detector | Recording Condition | Sonotype | HF | LF | B | FMAXE | D | SR | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vespertilionidae | Tylonycteris fulvida | Ty_fulv_1 | Raman & Hughes 2020 | 2020 | NA | India | Kerala | M500-384 | Flight - Open | FM-QCF | 132.1 ± 2 | 60.5 ± 1.7 | 71.6 ± 1.85 | 72.8 ± 0.79 | 1.1 ± 0.08 | 65.09 ± 0.11 | 7 |
| Vespertilionidae | Tylonycteris malayana | Ty_mala_1 | Srinivasulu et al. 2017 | 2017 | NA | India | Andaman & Nicobar Islands | Anabat SD1 | Flight - Open | FM-QCF | 89.28 ± 8.99 | 39.14 ± 2.06 | 50.14 ± 5.53 | 42.12 ± 3.92 | 1.88 ± 0.65 | 26.67 ± 8.51 | 54 |
| Vespertilionidae | Tylonycteris malayana | Ty_mala_2 | Present study | 2025 | NA | India | Andaman & Nicobar Islands | Anabat SD1 | Flight - Clutter | FM-QCF | 89.28 ± 9 | 39.14 ± 2.06 | 50.14 ± 9.04 | 42.12 ± 3.93 | 1.89 ± 0.65 | 26.53 ± 13.91 | 54 |
| Vespertilionidae | Tylonycteris malayana | Ty_mala_3 | Present study | 2025 | NA | India | Andaman & Nicobar Islands | D500X | Flight - Open | FM-QCF | 89.28 ± 9 | 39.14 ± 2.06 | 50.14 ± 9.04 | 42.12 ± 3.93 | 1.89 ± 0.65 | 26.53 ± 13.91 | 54 |

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**Author contributions:** AS led the conceptualisation, methodology, investigation, formal analysis, data curation, visualisation, writing, and funding acquisition for the study. CS and BS contributed to conceptualisation, investigation, data curation, and writing. DS contributed to methodology, validation, writing, and supervision. MGS contributed to conceptualisation, methodology, formal analysis, visualisation, writing, and funding acquisition.

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ARTICLE

# A checklist of the mammals of Jammu & Kashmir, India

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**Abstract:** Jammu & Kashmir, located at the intersection of the Palearctic and Oriental biogeographic realms, harbors a rich and unique mammalian diversity shaped by its varied topography and climate. Despite extensive faunal studies, a definitive and evidence-based checklist of the region's mammals has been lacking due to unverified species records. This study presents a comprehensive and critically evaluated checklist of the wild mammals of Jammu & Kashmir, India, compiled through a meticulous collation of specimen collections and media evidence. The checklist documents 111 species across eight orders and 28 families, with 94 species verified by specimens and 70 by photographic records. Chiroptera and Rodentia are the most diverse orders, followed by Carnivora and Artiodactyla. Thirteen species are classified as globally threatened by the IUCN Red List of Threatened Species with an additional 10 species listed as Near Threatened. By excluding provisional and doubtful records, discussed in Appendix A, this checklist provides a robust foundation for biodiversity monitoring, conservation prioritization, and ecological research in the region. All supporting data are publicly accessible via a dedicated website, enhancing transparency and enabling future updates. This work aims to guide effective management strategies and contribute to the long-term conservation of mammalian fauna in the region.

**Keywords:** Biodiversity, checklists, conservation, distribution, mammalian fauna, threatened species, western Himalaya.

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**Author contributions:** Conceptualization: MAK, NS, KA; data collection: MAK, AA; writing: MAK, AA; review and editing: all authors.

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## INTRODUCTION

A checklist is a fundamental metric of the biodiversity of an area. It is instrumental in monitoring changes in species populations over time, essential for detecting environmental changes and informing management and conservation strategies. A notable issue with biodiversity checklists is the inclusion of contentious species with uncertain origins which often remain unchallenged (Praveen et al. 2013). In compiling any biodiversity checklist, it is crucial to critically evaluate and often exclude species with uncertain origins or unverified presence. Including such contentious species, whether due to misidentifications, escaped captives, or historical records lacking concrete evidence, can inflate biodiversity estimates and misinform scientific and conservation efforts. Once included, these unverified species often become entrenched in subsequent publications and databases, perpetuating misinformation and clouding our understanding of species distribution, biogeographic patterns, and ecological boundaries. This undermines the scientific integrity of the checklist and can distort conservation priorities, leading to misallocated resources or flawed environmental assessments. It then follows that a checklist ought to be based on indubitable records backed by verifiable evidences (Praveen et al. 2013; Kichloo et al. 2024).

The Union Territory of Jammu & Kashmir is located in the northwestern part of the Himalayan Mountain range, between 32.30–35.12° N & 73.40–76.80° E (Figure 1). Spread in an area of 55,538 km$^2$, it shares borders with the Union Territory of Ladakh to the north and east, and Pakistan to the west. To its south, lies the Indian states of Punjab and Himachal Pradesh. The elevation of Jammu & Kashmir ranges from 247 m to 7,135 m. Geographical location along with a diverse set of physical features characterized by huge snow-capped mountains, lush green forests, extensive drainage and complex geological formations make it a proverbial bridge between two major bio-geographic regions of the world, the Palearctic and the Oriental resulting in a rich mixed fauna (Roberts 1991).

Administratively as well as biogeographically, Jammu & Kashmir is divided into two divisions; Jammu and Kashmir. The southern alluvial plains of Jammu, an extension of the Indo-Gangetic plains, give rise to the Shiwaliks, a range of moderate hills with a gentle slope and elevation rarely exceeding 1,200 m. The Pir-Panjal range, a part of the lesser Himalaya, separates the intermontane valley of Kashmir from the hilly Jammu region. The Great Himalaya (Zanskar range) to the north and north-west separate Kishtwar (in Jammu) and the Valley of Kashmir from Ladakh. The forests in Jammu & Kashmir, sharing 39% of the total geographical area, belong to six major groups that include tropical dry deciduous, subtropical pine, subtropical dry evergreen, Himalayan moist temperate, Himalayan dry temperate, and sub-alpine forests (ISFR 2021). Jammu & Kashmir has a vast protected area network comprising four national parks, 14 wildlife sanctuaries, 16 conservation reserves, 16 wetland reserves including five Ramsar sites, accounting for 11.31% of the total area coverage (J&K Department of Wildlife Protection 2023).

The development of knowledge about the mammalian fauna in Jammu & Kashmir goes back to the British era and started with Moorcroft & Trebeck (1841), Blyth (1841a, 1841b, 1855, 1863), and Vigne (1842). However, the main contributions to the mammalian diversity of Jammu & Kashmir were done by Jerdon (1867), Drew (1875), Dobson (1876), Lydekker (1877), Blanford (1888–1891), True (1894), Pocock (1939, 1941), Ellerman (1947), Ellerman & Morrison-Scott (1951), and Prater (1971). Ward (1905, 1921, 1922a, 1922b, 1922c, 1923, 1924a, 1924b, 1924c, 1925a, 1925b, 1925c, 1926, 1928, 1929) in a series of publications gave a detailed account of the mammalian species particularly large mammals from then Jammu & Kashmir. Mammal surveys by the Bombay Natural History Society (BHNS) could cover only a part of the Anantnag District of the state (Hinton & Thomas 1926).

In addition to these, numerous other publications dealing mainly with the taxonomy, distribution, and conservation of mammals are available, of which Blanford (1875, 1877, 1879, 1898), Thomas (1880, 1888, 1893, 1911, 1917, 1922, 1926), Scully (1881), Miller (1897, 1899, 1911, 1913a, 1913b), Andersen (1905), Bonhote (1905), Pocock (1908, 1930 1932, 1934, 1936), Osmaston (1930), Khajuria (1955), Khan (1970), Sharma & Sharma (1976), and Ahmad (2022) are important. Chakraborty (1983) provided a comprehensive account of 138 species and subspecies of mammalian fauna in Jammu & Kashmir based on specimen collections and literature. Ahmad et al. (2020) published a checklist of 112 mammals belonging to eight orders and 22 families for Jammu, Kashmir, and Ladakh combined. The list is exclusively based on the published records and web sources.

As of today, a definitive checklist of wild mammals of Jammu & Kashmir based on verifiable evidences does not exist leading to misdirected conservation efforts, overlooking of critical species and inefficient resource allocations. In this paper, we have attempted to

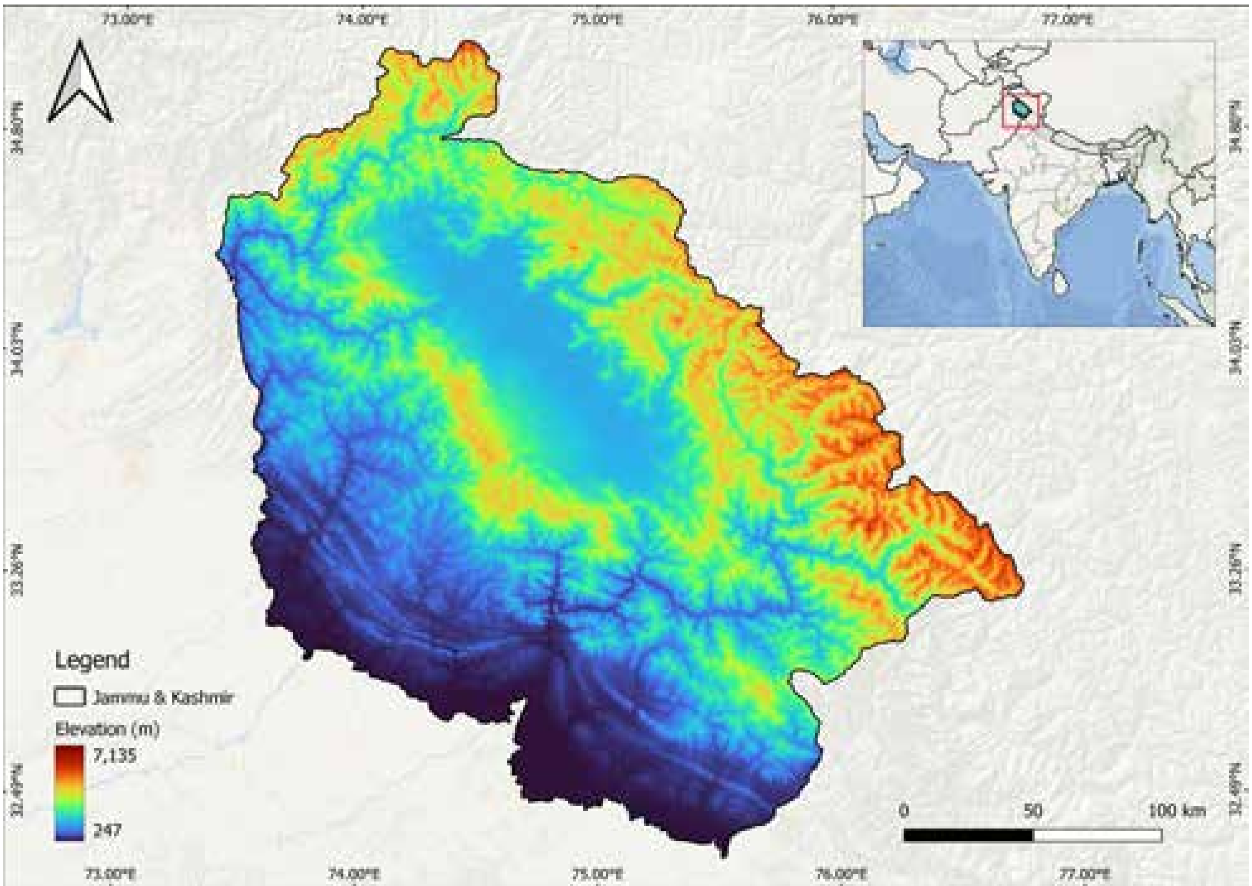


Figure 1. Location and elevation map of Jammu & Kashmir. Inset map shows the location of Jammu & Kashmir in India with respect to South Asia.

compile a checklist of wild mammalian species from the territorial limits of Jammu & Kashmir, as defined by the Government of India (Ministry of Home Affairs 2019).

## METHODS

In order to provide an exact representation of the biodiversity of an area, a checklist should be based on definitive records backed by verifiable evidences. A notable issue with biodiversity checklists is the inclusion of contentious species with uncertain origins which often remain unchallenged. To accept a species for Jammu & Kashmir checklist, it had to meet at least one of the two criteria, i.e., a specimen (either museum or an unpreserved) or a media record. The museum specimen, confirmed by competent taxonomists, was the most preferred criterion whereas the unpreserved specimens included only those duly validated by the knowledgeable field workers. We did not track down the actual specimen but relied on the authenticity of the references, which however were examined and cross-checked. The specimen records were supplemented with relevant records from Global Biodiversity Information Facility (GBIF; https://www.gbif.org), BNHS (Hinton & Thomas 1926), Natural History Museum London (NHM) (Anderson 1912; Lydekker 1913), United States National Museum (USNM) (now National Museum of Natural History) (True 1894; Fisher & Ludwig 2014, 2015), and Zoological Survey of India (ZSI) (Dobson 1876; Anderson 1881; Khajuria et al. 1977; Ghosh 2008). Collectively, the list of the mammalian species with well-documented specimens from all these sources reached 94.

The media record included a photograph or a video available in the public domain as a published record or a web source. The image database incorporated published field guides, books, magazines, newsletters, journals, and web resources like social media groups along with personal collections, which underwent careful examination and scrutiny. A significant effort was made to consolidate and centralize all media records from these scattered sources onto a single platform.

This was achieved by creating a website dedicated to the mammals of Jammu & Kashmir (https://mammalsofjk.in/) and then uploading the photographs of mammals taken by the authors and requesting others to contribute towards the website. In order to ensure data accuracy and reliability, only those photographic records were accepted that were taken within the territorial limits of Jammu & Kashmir. It is noteworthy that all the accepted records are publicly accessible through this website, reinforcing the reliability of the data compilation process.

We exercised caution while accepting species that were supported solely by sight records unless accompanied by media evidence or specimens. This was done to ensure no dubious species find entry in the checklist.

Our checklist follows the taxonomic order and species limits defined by the American Society of Mammologists' Mammal Diversity Database (MDD) version 2.0 (Mammal Diversity Database 2025). While Wilson & Reeder (2005), has long served as a foundational reference for mammalian taxonomy, it has not been revised since 2005 and thus, does not reflect the significant taxonomic changes that have occurred over the past two decades, particularly those informed by molecular phylogenetics and recent field discoveries. In contrast, MDD is actively maintained by the American Society of Mammologists and incorporates the latest peer-reviewed revisions, newly described species, and changes in species-level taxonomy and phylogenetic sequence. Its adoption ensures that the checklist aligns with current scientific consensus and provides the most accurate and contemporary reflection of mammalian diversity in the region. For English names we have followed the IUCN Red List of Threatened Species (IUCN 2025). Species which are considered provisional, doubtful or unconfirmed, are not included in this checklist.

**Establishing threat and conservation status**

The International Union for Conservation of Nature (IUCN) produces The IUCN Red List of Threatened Species, the world's most comprehensive inventory of species classified based on the level of extinction threat to the species. In this checklist, the species have been classified under different categories as per IUCN Red List of Threatened Species (Version 2024-2) (IUCN 2025) as well as CITES appendices and different schedules of the Indian Wildlife (Protection) Amendment Act, 2022 (Anonymous 2022).

## RESULTS

The current checklist of the mammals of Jammu & Kashmir reports 111 mammal species across eight orders and 28 families representing 24% of the total wild mammal species found in India. Of these, 94 have been examined in hand or deposited in museums across the world and 70 have media records (Table 1). Orders Chiroptera and Rodentia are represented by maximum number of species, 31 and 26 respectively, followed by Carnivora (23) and Artiodactyla (13).

A second list (Appendix A) includes species that have not gained automatic entry into the checklist based on the criteria set in the methodology.

**Conservation Status**

Jammu & Kashmir has 13 species which fall under various categories of the IUCN Red List of Threatened Species. Among these, one species (Hangul) is 'Critically Endangered' (CR), six species (Kashmir Gray Langur, Woolly Flying Squirrel, Indian Pangolin, Himalayan Wolf, Hog Deer, and Kashmir Musk Deer) are 'Endangered' (EN), and six species (Central Kashmir Vole, Asiatic Black Bear, Leopard, Snow Leopard, Himalayan Serow, and Sambar) are 'Vulnerable' (VU). An additional 10 species are listed as 'Near Threatened' (NT) (Table 1). Forty-one species fall under Schedule–I of the Indian Wildlife (Protection) Amendment Act 2022, of which one is CR, six EN, five VU, seven NT, and 22 species 'Least Concern' (LC) (Table 1). Sixteen species fall under CITES Appendix–I, three under Appendix–II and 17 under Appendix–III.

**Data availability**

All the data supporting the checklist is publicly accessible through Supplementary information SD1 and website https://mammalsofjk.in/.

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**Table 1. Checklist of mammals of Jammu & Kashmir, India.**

| | Order/ Family | Common Name | Scientific Name | Authority | Alternate Name | Specimen | Media | IUCN | IWLPA 2022 | CITES |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **Primates** Cercopithecidae | Rhesus Macaque | *Macaca mulatta* | (Zimmermann, 1780) | | G | M | LC | - | - |
| 2 | | Kashmir Gray Langur | *Semnopithecus ajax* | (Pocock, 1928) | Chamba Sacred Langur | | M | EN | I | I |
| 3 | | Nepal Gray Langur | *Semnopithecus schistaceus* | Hodgson, 1841 | | G | M | LC | I | I |
| 4 | **Lagomorpha** Leporidae | Cape Hare | *Lepus capensis* | Linnaeus,1758 | | O | | LC | - | - |
| 5 | | Indian Hare | *Lepus nigricollis* | Cuvier, 1823 | Black-napped Hare | O | M | LC | II | - |
| 6 | Ochotonidae | Large-eared Pika | *Ochotona macrotis* | (Günther, 1875) | | O | M | LC | - | - |
| 7 | | Royle's Pika | *Ochotona roylii* | (Ogilby, 1839) | | G | M | LC | I | - |
| 8 | **Rodentia** Hystricidae | Indian Crested Porcupine | *Hystrix indica* | Kerr, 1792 | | | M | LC | I | - |
| 9 | Sciuridae | Five-striped Palm Squirrel | *Funambulus pennantii* | Wroughton, 1905 | Northern Palm Squirrel | O | M | LC | - | - |
| 10 | | Small Kashmir Flying Squirrel | *Eoglaucomys fimbriatus* | (Gray, 1837) | Kashmir Flying Squirrel | G | M | LC | - | - |
| 11 | | Woolly Flying Squirrel | *Eupetaurus cinereus* | Thomas, 1888 | | O | M | EN | I | - |
| 12 | | White-bellied Giant Flying Squirrel | *Petaurista albiventer* | (Gray, 1834) | | G | M | NE | I | - |
| 13 | | Long-tailed Marmot | *Marmota caudata* | (Geoffroy Saint-Hilaire, 1844) | Golden Marmot | G | M | LC | I | III |
| 14 | | Himalayan Marmot | *Marmota himalayana* | (Hodgson, 1841) | | O | | LC | I | III |
| 15 | Sminthidae | Chinese Birch Mouse | *Sicista concolor* | (Büchner, 1892) | Kashmir Birch Mouse (*S.c. leathemi*) | G | | LC | - | - |
| 16 | Cricetidae | Central Kashmir Vole | *Alticola montosus* | (True, 1894) | Kashmir Mountain Vole | G | M | VU | - | - |
| 17 | | Burrowing Vole | *Hyperacrius fertilis* | (True, 1894) | True's Vole / Subalpine Kashmir Vole | G | M | NT | - | - |
| 18 | | Murree Vole | *Hyperacrius wynnei* | (Blanford, 1881) | Conifer Kashmir Vole | G | | LC | - | - |
| 19 | Muridae | Indian Gerbil | *Tatera indica* | (Hardwicke, 1807) | Antelope Rat | G | | LC | - | - |
| 20 | | Himalayan Field Mouse | *Apodemus pallipes* | (Barrett-Hamilton, 1900) | Ward's Field Mouse/ Wroughton's Wood Mouse | G | M | LC | - | - |
| 21 | | Kashmir Field Mouse | *Apodemus rusiges* | Miller, 1913 | Miller's Wood Mouse | G | M | LC | - | - |
| 22 | | Indian Bush-rat | *Golunda ellioti* | Gray, 1837 | | O | | LC | - | - |
| 23 | | Soft-furred Metad | *Millardia meltada* | (Gray, 1837) | Common Metad / Soft-furred Rat | O | | LC | - | - |
| 24 | | Little Indian Field Mouse | *Mus booduga* | (Gray, 1837) | | O | | LC | - | - |
| 25 | | Fawn-colored Mouse | *Mus cervicolor* | Hodgson, 1845 | | O | | LC | - | - |
| 26 | | House Mouse | *Mus musculus* | Linnaeus, 1758 | | G | M | LC | - | - |
| 27 | | Brown Spiny Mouse | *Mus platythrix* | Bennett, 1832 | Flat-haired Mouse | O | | LC | - | - |
| 28 | | Himalayan White-bellied Rat | *Niviventer niviventer* | (Hodgson, 1836) | | | M | LC | - | - |

| | Order/ Family | Common Name | Scientific Name | Authority | Alternate Name | Specimen | Media | IUCN | IWLPA 2022 | CITES |
|---|---|---|---|---|---|---|---|---|---|---|
| 29 | Muridae | Lesser Bandicoot Rat | *Bandicota bengalensis* | (Gray, 1835) | Indian Mole-rat | G | M | LC | - | - |
| 30 | | Short-tailed Bandicoot Rat | *Nesokia indica* | (Gray, 1830) | Short-tailed Nesokia | O | | LC | - | - |
| 31 | | Himalayan Field Rat | *Rattus nitidus* | (Hodgson, 1845) | White-footed Indochinese Rat | O | M | LC | - | - |
| 32 | | Himalayan Rat | *Rattus pyctoris* | (Hodgson, 1845) | Turkestan rat | G | M | LC | - | - |
| 33 | | House Rat | *Rattus rattus* | (Linnaeus, 1758) | Black Rat / Roof Rat | O | M | LC | - | - |
| 34 | **Eulipotyphla** Erinaceidae | Brandt's Hedgehog | *Paraechinus hypomelas* | (Brandt, 1836) | | | M | LC | - | - |
| 35 | Soricidae | Grey Shrew | *Crocidura attenuata* | Milne-Edwards, 1871 | Asian Grey Shrew | O | | LC | - | - |
| 36 | | Bicolored Shrew | *Crocidura leucodon* | (Hermann, 1780) | Bicoloured White-toothed Shrew | O | | LC | - | - |
| 37 | | Kashmir White-toothed Shrew | *Crocidura pullata* | Miller, 1911 | | G | | DD | - | - |
| 38 | | Zarudny's Rock Shrew | *Crocidura zarudnyi* | Ognev, 1928 | Zarudny's White-toothed Shrew | | M | LC | - | - |
| 39 | | House Shrew | *Suncus murinus* | (Linnaeus, 1766) | Asian House Shrew | G | M | LC | - | - |
| 40 | | Himalayan Water Shrew | *Chimarrogale himalayica* | (Gray, 1842) | | O | | LC | - | - |
| 41 | | Hodgson's Brown-toothed Shrew | *Episoriculus caudatus* | (Horsfield, 1851) | | G | | LC | - | - |
| 42 | | Eurasian Pygmy Shrew | *Sorex minutus* | Linnaeus, 1766 | | G | | LC | - | - |
| 43 | | Kashmir Shrew | *Sorex planiceps* | Miller, 1911 | Flat-headed Kashmir Shrew | G | | LC | - | - |
| 44 | **Chiroptera** Pteropodidae | Greater Shortnosed Fruit Bat | *Cynopterus sphinx* | (Vahl, 1797) | Short-nosed Indian Fruit Bat | O | | LC | - | - |
| 45 | | Indian Flying Fox | *Pteropus medius* | Temminck, 1825 | Greater Indian Fruit Bat | O | M | LC | II | II |
| 46 | | Leschenault's Rousette | *Rousettus leschenaultii* | (Desmarest, 1821) | Fulvous Fruit Bat | O | | NT | - | - |
| 47 | Hipposideridae | Fulvus Leaf-nosed Bat | *Hipposideros fulvus* | Gray, 1838 | | O | | LC | - | - |
| 48 | Megadermatidae | Greater False Vampire | *Lyroderma lyra* | (Geoffroy Saint-Hilaire, 1810) | Greater False Vampire Bat | O | M | LC | - | - |
| 49 | Rhinolophidae | Greater Horseshoe Bat | *Rhinolophus ferrumequinum* | (Schreber, 1774) | | O | M | LC | - | - |
| 50 | | Lesser Horseshoe Bat | *Rhinolophus hipposideros* | (André, 1797) | | O | M | LC | - | - |
| 51 | Rhinopomatidae | Lesser Mouse-tailed Bat | *Rhinopoma hardwickii* | Gray, 1831 | | O | | LC | - | - |
| 52 | Miniopteridae | Asian Long-fingered Bat | *Miniopterus fuliginosus* | (Hodgson, 1835) | | | M | NE | - | - |
| 53 | Vespertilionidae | Hutton's Tube-nosed Bat | *Murina huttoni* | (Peters, 1872) | | O | | LC | - | - |
| 54 | | Scully's Tube-nosed Bat | *Murina tubinaris* | (Scully, 1881) | | | M | DD | - | - |
| 55 | | Lesser Mouse-eared Myotis | *Myotis blythii* | (Tomes, 1857) | Lesser Mouse-eared Bat | O | | LC | - | - |
| 56 | | Hodgson's Bat | *Myotis formosus* | (Hodgson, 1835) | Copper-winged Bat | O | | NT | - | - |
| 57 | | Kashmir Cave Bat | *Myotis longipes* | (Dobson, 1873) | Kashmir Cave Myotis | G | | DD | - | - |

| | Order/ Family | Common Name | Scientific Name | Authority | Alternate Name | Specimen | Media | IUCN | IWLPA 2022 | CITES |
|---|---|---|---|---|---|---|---|---|---|---|
| 58 | Vespertilionidae | Nepalese Whiskered Bat | *Myotis muricola* | (Gray, 1847) | Nepalese Whiskered Myotis | | M | LC | - | - |
| 59 | | Nepal Myotis | *Myotis nipalensis* | (Dobson, 1871) | | O | | LC | - | - |
| 60 | | Himalayan Broad-muzzled Bat | *Submyotodon caliginosus* | (Tomes, 1859) | | O | | NE | - | - |
| 61 | | Oriental Serotine | *Cnephaeus pachyomus* | (Tomes, 1857) | | G | M | LC | - | - |
| 62 | | Leisler's Bat | *Nyctalus leisleri* | (Kuhl, 1817) | Leisler's Noctule | O | | LC | - | - |
| 63 | | Common Noctule | *Nyctalus noctula* | (Schreber, 1774) | | O | | LC | - | - |
| 64 | | Indian Pipistrelle | *Alionoctula coromandra* | (Gray, 1838) | | G | | LC | - | - |
| 65 | | Javan Pipistrelle | *Alionoctula javanicus* | (Gray, 1838) | | | M | LC | - | - |
| 66 | | Kuhl's Pipistrelle | *Pipistrellus kuhlii* | (Kuhl, 1817) | | O | | LC | - | - |
| 67 | | Mount Popa Pipistrelle | *Alionoctula paterculus* | (Thomas, 1915) | | O | | LC | - | - |
| 68 | | Common Pipistrelle | *Pipistrellus pipistrellus* | (Schreber, 1774) | | O | | LC | - | - |
| 69 | | Dormer's Bat | *Scotozous dormeri* | Dobson, 1875 | Dormer's Pipistrelle | O | | LC | - | - |
| 70 | | Eastern Barbastelle | *Barbastella darjelingensis* | (Hodgson, 1855) | Asian Barbastelle | O | M | LC | - | - |
| 71 | | Desert Long-eared Bat | *Otonycteris hemprichii* | Peters, 1859 | Hemprich's Desert Bat | O | | LC | - | - |
| 72 | | Hodgson’s Long-eared Bat | *Plecotus homochrous* | Hodgson, 1847 | Himalayan Long-eared Bat | O | | DD | - | - |
| 73 | | Ward's Long-eared Bat | *Plecotus wardi* | Thomas, 1911 | | O | M | LC | - | - |
| 74 | | Greater Asiatic Yellow House Bat | *Scotophilus heathii* | (Horsfield, 1831) | Greater Asian Yellow Bat | O | | LC | - | - |
| 75 | **Pholidota** Manidae | Indian Pangolin | *Manis crassicaudata* | Geoffroy Saint-Hilaire, 1803 | Scaly Anteater | | M | EN | I | I |
| 76 | **Carnivora** Mustelidae | Yellow-throated Marten | *Martes flavigula* | (Boddaert, 1785 | | G | M | LC | I | III |
| 77 | | Beech Marten | *Martes foina* | (Schreber, 1776) | Stone marten | G | M | LC | I | III |
| 78 | | Eurasian Otter | *Lutra lutra* | (Linnaeus, 1758) | European Otter | O | M | NT | I | I |
| 79 | | Altai Weasel | *Mustela altaica* | Pallas, 1811 | Mountain Weasel / Pale Weasel | | M | NT | I | III |
| 80 | | Stoat | *Mustela erminea* | Linnaeus, 1758 | Himalayan Stoat / Ermine | G | M | LC | I | III |
| 81 | | Siberian Weasel | *Mustela sibirica* | Pallas, 1773 | | G | M | LC | I | III |
| 82 | Ursidae | Himalayan Brown Bear | *Ursus arctos isabellinus* | Horsfield, 1826 | | G | M | LC | I | II |
| 83 | | Asiatic Black Bear | *Ursus thibetanus* | Cuvier, 1823 | Asian Black Bear | G | M | VU | I | I |
| 84 | Canidae | Golden Jackal | *Canis aureus* | Linnaeus, 1758 | Common Jackal | G | M | LC | I | III |
| 85 | | Himalayan Wolf | *Canis lupus chanco* | Gray, 1863 | Grey Wolf | | M | EN | I | I |
| 86 | | Bengal Fox | *Vulpes bengalensis* | (Shaw, 1800) | Indian Fox | G | | LC | I | III |
| 87 | | Red Fox | *Vulpes vulpes* | (Linnaeus, 1758) | | G | M | LC | - | III |

| | Order/ Family | Common Name | Scientific Name | Authority | Alternate Name | Specimen | Media | IUCN | IWLPA 2022 | CITES |
|---|---|---|---|---|---|---|---|---|---|---|
| 88 | Felidae | Jungle Cat | *Felis chaus* | Schreber, 1777 | Reed Cat/ Swamp Cat | G | M | LC | I | II |
| 89 | | Mainland Leopard Cat | *Prionailurus bengalensis* | (Kerr, 1792) | Indian Leopard Cat | G | M | LC | I | I |
| 90 | | Rusty-spotted Cat | *Prionailurus rubiginosus* | (Geoffroy Saint-Hilaire, 1831) | | O | | NT | I | I |
| 91 | | Leopard | *Panthera pardus* | (Linnaeus, 1758) | Common Leopard | G | M | VU | I | I |
| 92 | | Snow Leopard | *Panthera uncia* | (Schreber, 1775) | | G | M | VU | I | I |
| 93 | Herpestidae | Small Indian Mongoose | *Urva auropunctata* | (Hodgson, 1836) | | G | M | LC | I | III |
| 94 | | Indian Gray Mongoose | *Urva edwardsii* | (Geoffroy Saint-Hilaire, 1818) | Indian Grey Mongoose | O | M | LC | I | III |
| 95 | | Ruddy Mongoose | *Urva smithii* | (Gray, 1837) | | O | | LC | I | III |
| 96 | Viverridae | Masked Palm Civet | *Paguma larvata* | (Griffith, 1822) | Himalayan Palm Civet | O | M | LC | I | III |
| 97 | | Common Palm Civet | *Paradoxurus hermaphroditus* | (Pallas, 1777) | Asian Palm Civet, Toddy Cat and Musang | O | M | LC | I | III |
| 98 | | Small Indian Civet | *Viverricula indica* | (Geoffroy Saint-Hilaire, 1803) | | O | M | LC | I | III |
| 99 | **Artiodactyla** | Markhor | *Capra falconeri* | (Wagner, 1839) | Pir Panjal Markhor | G | M | NT | I | I |
| 100 | Bovidae | Siberian Ibex | *Capra sibirica* | (Pallas, 1776) | Himalayan Ibex or Asiatic Ibex | G | M | NT | I | - |
| 101 | | Himalayan Serow | *Capricornis sumatraensis thar* | Hodgson, 1831 | | O | M | VU | I | I |
| 102 | | Himalayan Tahr | *Hemitragus jemlahicus* | (Smith, 1827) | | G | M | NT | I | - |
| 103 | | Himalayan Goral | *Naemorhedus goral* | (Hardwicke, 1825) | Himalayan Grey Goral | O | M | NT | I | I |
| 104 | | Nilgai | *Boselaphus tragocamelus* | (Pallas, 1766) | Blue Bull | | M | LC | II | III |
| 105 | Cervidae | Chital | *Axis axis* | (Erxleben, 1777) | Indian Spotted Deer | | M | LC | II | - |
| 106 | | Hog Deer | *Axis porcinus* | (Zimmermann, 1780) | | | M | EN | I | I |
| 107 | | Hangul | *Cervus hanglu* | Wagner, 1844 | Kashmir Stag/ Kashmir Red Deer | G | M | CR | I | I |
| 108 | | Sambar | *Rusa unicolor* | (Kerr, 1792) | Sambar Deer | G | M | VU | I | - |
| 109 | | Northern Red Muntjac | *Muntiacus vaginalis* | (Boddaert, 1785) | Indian Muntjac or Barking Deer | | M | LC | I | - |
| 110 | Moschidae | Kashmir Musk Deer | *Moschus cupreus* | Grubb, 1982 | | G | M | EN | I | I |
| 111 | Suidae | Wild Boar | *Sus scrofa* | Linnaeus, 1758 | Eurasian Wild Pig | G | M | LC | II | - |

G—GBIF (Global Biodiversity Information Facility) | O—Other Specimen (Supplementary Data SD1) | M—Media record (https://mammalsofjk.in/) | IUCN—International Union for Conservation of Nature, CR—Critically Endangered | E—Endangered, VU—Vulnerable | NT—Near Threatened | LC—Least Concern | NE—Not Evaluated | DD—Data Deficient | IWPA—Indian Wildlife (Protection) Amendment Act 2022 | CITES—Convention on International Trade in Endangered Species of Wild Fauna and Flora.

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## Appendix A. Notes on the species not included in the checklist.

**Desert Hare *Lepus tibetanus*:** Wilson & Reeder (2005) mention Kashmir in its distribution range probably because Ellerman & Morrison-Scott (1955) fixed its type locality to "Baltistan, Kashmir (modern day Ladakh) instead of Tibet. Ahmad et al. (2020) lists this species for both Jammu & Kashmir region but no records of its specimens or photographs till date. Sharma et al. (2024) in their checklist of India have mentioned Jammu & Kashmir under its distribution, but it is important to mention here that their checklist has considered erstwhile Jammu & Kashmir state (which included Ladakh also) for this checklist. Hence, many of the Jammu & Kashmir species in their checklist may refer to present day Ladakh.

**Woolly Hare *Lepus oiostolus*:** Wilson & Reeder (2005), Ahmad et al. (2020) and Menon (2023) list this species for Jammu & Kashmir but no records of its specimens or photographs till date.

**Stoliczka's Mountain Vole *Alticola stoliczkanus*:** Ahmad et al. (2020) mentions both Stoliczka's Mountain Vole *A. stoliczkanus* and Thomas's Short-tailed Vole *A. stracheyi* separately. *A. stracheyi* is a synonym of *A. stoliczkanus*. But the species is listed without any details and hence excluded from the checklist.

**Blyth's (Mountain) Vole *Neodon leucurus*:** Wilson & Reeder (2005) refer Kashmir in its distribution. This actually refers to present day Ladakh as both Ladakh and Jammu & Kashmir were once a united territory. Ahmad et al. (2020) lists the species for Jammu, Kashmir and Ladakh without any details. The species is present in Ladakh but no specimen or media record could be traced for Jammu & Kashmir and hence excluded from the checklist.

**Silver Mountain Vole *Alticola argentatus*:** Agrawal (2000; under *A. blanfordi*) mentions Gulmarg in its distribution along with Gilgit and Nultan Valley (Ladakh) which is the type locality of the species. However, the origin of its occurrence in Gulmarg remains unknown as evinced by Hinton (1926), Ellerman (1947, 1961) and Ellerman & Morrison-Scott (1951). The species is accepted by Menon (2023) and listed under Jammu & Kashmir by Sharma et al. (2024) which again may refer to present day Ladakh. Ahmad et al. (2020) lists both *A. blanfordi* and *A. argentatus* separately but without any details and hence excluded from the checklist.

**Grey Dwarf Hamster *Nothocricetulus migratorius*:** Listed in Ahmad et al. (2020) for Kashmir and Ladakh without any details. The species is present in Ladakh but not in Jammu & Kashmir and hence excluded from the checklist.

**Yellow-necked Field Mouse *Apodemus flavicollis*:** Three specimens in Smithsonian Institution, National Museum of Natural History (NMNH) of this species collected from Jammu & Kashmir (GBIF 2025) are those of *A. rusiges* originally described as *A. f. rusiges* (Mammal Diversity Database 2025).

**Asiatic Long-tailed Climbing Mouse *Vandeleuria oleracea*:** Listed in Mohammad (2019) and Ahmad et al. (2020) for Jammu region without any details and hence excluded from the checklist.

**Indochinese White-bellied Rat (Chestnut Rat) *Niviventer fulvescens*:** Kamalkannan & Venkatraman (2017), Menon (2023), and Sharma et al. (2024) list the species for Jammu & Kashmir. Alfred et al. (2002) and Srinivasulu & Pradhan (2003) mention the distribution up to Himachal Pradesh only excluding the species for Jammu & Kashmir. No specimen or media records were traced for this species from Jammu & Kashmir in the current review and hence excluded from the checklist.

**Brown Rat *Rattus norvegicus*:** Ward (1905) says that all the Kashmir specimens of Brown Rat are in fact Himalayan Rat *Rattus pyctoris*, but is of the opinion that the species occurs in Poonch and many other parts. Sharma & Sharma (1976) reported it from Chammb sector (Jammu), Udhampur and Bhaderwah ranges. No verifiable specimen or media records were found for this species from Jammu & Kashmir and hence not accepted here.

**Long-eared Hedgehog *Hemiechinus auritus* / Indian Long-eared Hedgehog *H. collaris*:** Sharma & Sharma (1976) reported Long-eared Hedgehog *Hemiechinus auritus* from Naushera, Rajouri, however, the status and traceability of this record remain uncertain. Based on this observation, Chakraborty (1983) accepted the species for Jammu & Kashmir. Surprisingly, Alfred et al. (2002) and Chakraborty et al. (2004) instead listed Indian long-eared Hedgehog *H. collaris* for the region, rather than *H. auritus*. Historically, *H. collaris* was considered a subspecies of *H. auritus*, but Roberts (1977) highlighted significant differences in distribution and morphology between the two, leading to their taxonomic separation. *Hemiechinus collaris* is now regarded as being restricted to Pakistan and northwestern India, whereas *H. auritus* has a broader distribution extending from eastern Ukraine to Mongolia in the north and from Libya to western Pakistan in the south (Wilson & Reeder 2005). This taxonomic distinction likely influenced the acceptance of *H. collaris* for Jammu & Kashmir by Alfred et al. (2002) and Chakraborty et al. (2004).

More recently Kamalakannan & Venkatraman (2017) and Sharma et al. (2024) have excluded both species from Jammu & Kashmir, though no specific justification for this decision has been provided. The ambiguity surrounding the identification of the specimen reported by Sharma & Sharma (1976), its subsequent untraceability, and the absence of recent confirmed records from the region may have contributed to this exclusion. Until verifiable evidence emerges, we continue to classify the species under doubtful category.

**Horsfield's Shrew *Crocidura horsfieldi*:** Listed in Ahmad et al. (2020) for Jammu, Kashmir, and Ladakh without any details. The species is present in Ladakh but not in Jammu & Kashmir and hence excluded from the checklist.

**Pale Grey Shrew *Crocidura pergrisea*:** Chakraborty (1983) listed the species for Jammu & Kashmir but mentions the location as Baltistan, which is in modern day Ladakh. Walker (1999) also included it in Kashmir based on Chakraborty (1983).

**Lesser White-toothed Shrew *Crocidura suaveolens*:** Listed in Mohammad (2019) and accepted by Ahmad et al. (2020) for Jammu & Kashmir but without any details. The species is considered extralimital to India and no major Indian authority includes the species for India (Menon 2023; Sharma et al. 2024).

**Hodgsons's Brown-toothed Shrew *Episoriculus caudatus***

Wilson & Reeder (2005) lists Kashmir in the distribution of this species. No specimen or media records were found for this species from Jammu & Kashmir and hence not accepted here.

**Naked-rumped Tomb Bat *Taphozous nudiventris*:** Sharma & Sharma (1976) recorded it from Bhaderwah and Akhnoor who considered it a new record for Jammu & Kashmir. It is not clear whether the authors have collected the specimens or just had recorded its presence in those regions. The species is included in Jammu & Kashmir by Alfred et al. (2002), the basis of which remains unknown. Until strong evidence is reached, we have kept the species out of the checklist.

**Dark (Flat-headed) Woolly Bat *Kerivoula furva*:** Chakraborty (1983) collected a specimen of *Kerivoula hardwickii* from Patnitop on 27 October 1975. Ahmad et al. (2020) accepts the species for Jammu & Kashmir. *Kerivoula hardwickii*, a species complex, traditionally included several taxa listed as subspecies or its synonyms including *K. crypta, K. depressa, K. engana, K. fusca,* and *K. malpasi* (Simmons 2005; Rosell-Ambal et al. 2008). After the taxonomic revision of the *K. hardwickii* complex, it is now *sensu stricto* considered extralimital to India and a new species *K. furva* was described (Kuo et al. 2017). This species was accepted by Menon (2023) and Tu et al. (2018) as the one occurring in Jammu & Kashmir. However, considering the complexities of this group and a lack of recent sample from NW Himalayas, the question of its occurrence in NW Himalayas and particularly in Jammu & Kashmir remains unknown (Uttam Saikia in litt. email dated 25.iii.2025). Hence, we have kept this species under unconfirmed category until strong evidence emerges.

**Steppe Whiskered Bat (David's Myotis) *Myotis davidii*:** Menon (2023) mentions two isolated records from Jammu & Kashmir the origin of which remains unknown.

**Botta's Serotine *Cnephaeus bottae*:** Listed in Ahmad et al. (2020) for Jammu and Kashmir but without any details. The species is considered extralimital to India and no major Indian authority includes the species for India (Menon 2023; Sharma et al. 2024).

**Gobi Big Brown Bat (Bobrinskii's Serotine) *Cnephaeus gobiensis*:** Listed in Ahmad et al. (2020) and Sharma et al. (2024) for Jammu and Kashmir without any details. The species is present in Ladakh but not in Jammu & Kashmir and hence excluded from the checklist.

**Fulvus Leaf-nosed Bat *Hipposideros fulvus*:** Menon (2023) shows one isolated record of this species from Jammu & Kashmir in its distribution map, the origin of which remains unknown.

**Least Pipistrelle *Pipistrellus tenuis*:** Sharma & Sharma (1976) recorded it from Jammu and in Mandi, Poonch but it is not clear whether they have collected the specimen or just had recorded its presence in those regions. Hence not accepted as per the methodology set above.

**Parti-colored Bat *Vespertilio murinus*:** Scully (1881) collected two specimens of this species from Nultar Valley in Gilgit. Blanford (1888-1891) mention about some Kashmir specimens and also that the species has been found in Kashmir by Sir O.B. St. John. Neuhauser. Ghosh (2008) also mention Gilgit (Kashmir) in its distribution. Chakraborty (1983) and Ghosh (2008) reported the two specimens from Gilgit as *Eptesicus nilssoni kashgaricus* (= *E. gobiensis*), which were accepted as *V. murinus* by Bates & Harrison (1997). Saikia & Boro (2013) accept the species for Jammu & Kashmir probably accepting the records from Gilgit, Ladakh whereas Ahmad et al. (2020) lists the species for Jammu & Kashmir but without any reference. Based on this account, we assess that all the records mentioning Kashmir are referring to Gilgit, now in Ladakh.

**Yellow-bellied Weasel *Mustella kathiah*:** Alfred et al. (2002), Kamalkannan & Venkatraman (2017), and Sharma et al. (2024) list Jammu & Kashmir in its distribution range. The basis of the distribution is based on a specimen collected from Baltoro, Karakoram range (Pocock 1941) previously a part of Jammu & Kashmir and now in Ladakh.

**Wild Dog (Dhole) *Cuon alpinus*:** Lydekker (1877) mentions the species to be present in the Chenab and Warwan Valleys based on the tracks, but did not mention about any specimen. Ward (1928) refers Wild Dog as very rare in the Valley of Kashmir. Blanford (1888–1891) in its distribution said that it is found in Gilgit, Ladakh, and other parts of Upper Indus Valley (all outside of Jammu &

Kashmir) and also occurring throughout the Himalayan forests from Kashmir to Assam. Included in Jammu & Kashmir by Sharma et al. (2024). None of the references refer to any specimens collected from the Jammu & Kashmir and hence excluded from the checklist.

**Striped Hyaena *Hyaena hyaena*:** Menon (2023) and Sharma et al. (2024) mention Jammu & Kashmir in its geographic range. Ellerman & Morrison-Scott (1951) also list Striped Hyaena for Kashmir in its distribution. Chakraborty (1983) noticed an individual from a considerable distance on the Jammu-Srinagar National Highway near Ramban but didn't collect the specimen. There is no photographic or specimen evidence from present day Jammu & Kashmir and reason for its inclusion in the literature probably origins from Ward (1928) which says 'very rare in Kashmir but has been found on the Murree road'.

**Caracal *Caracal caracal*:** Ward (1923) mentions about a skin in Srinagar which is said to have come from Ladakh and he later listed the species for Kashmir in '*The Mammals and Birds of Kashmir*' (Ward 1926). Stockley (1928) reported that the Caracal does not occur in Kashmir, finding no evidence of its presence in the Himalayas and noting the absence of skins in the Srinagar skin markets.

**Tiger *Panthera tigris*:** Lydekker (1877) mentions about a friend who told him that an individual was killed in Warwan and Lydekker considered that if the information was true, the species could be considered as an occasional straggler to the region. Ellerman & Morrison-Scott (1951) however couldn't trace any reliable reference to its occurrence in Kashmir. Sharma & Sharma (1976) mentions that this species is found rarely in the jungles of Loran ranges in Poonch but didn't mention about any material or specimen collected. No reliable reference till date and hence excluded from the checklist.

**Cheetah *Acinonyx jubatus*:** Fayrer (1879) mentioned in his memoir about an exhibition of a Cheetah hunting in which one or two antelopes were killed along with other acrobatic performances on 21 January 1876 in Jammu. Based on the context provided, we conclude the cheetah was tamed and not a wild one.

**Waved Cat *Felis torquata*:** Ward (1907, 1926) lists *F. torquata* for Kashmir. This probably refers to the domestic cat and hence excluded from the checklist. Also collected by Dr. Abbott from Lolab Valley, Kashmir who also thought it to be a tame specimen (True 1894).

**Large Indian Civet *Viverra zibetha*:** Ward (1926) mentions to have shot and trapped this species in Kashmir. Pocock (1939) in his Fauna of British India, says that Col. Ward was mistaken in recording it from Kashmir citing that his measurements of head, body, and weight are correct enough; but his remark that Blanford's skull-measurements are far larger than anything in the western Himalayas shows that the skull he had did not belong to this species. Ward's further statement that the animal is found "often living under thatched roofs" suggests confusion with the Kashmir Toddy-Cat (*Paradoxurus*) (= Common Palm Civet), although he cited the latter under a separate heading. Pocock (1939) further added that he is not acquainted with any other record of *V. zibetha* in Kashmir also citing Col. Stockley wherein, he never came across the species in that country or in Kumaon, although all collectors agree that it is one of the easiest mammals to trap. This discussion is convincing enough to exclude Large Indian Civet from Jammu & Kashmir checklist.

**Blackbuck *Antilope cervicapra*:** Ward (1925) lists the species for Jammu & Kashmir mentioning few black bucks are left near Jammu, but doesn't provide any further details whether any of them were shot or collected. The measurements provided are those by Dunbar Brander (1923).

**Himalayan Musk Deer *Moschus leucogaster*:** Ahmad et al. (2020) list Himalayan Musk Deer for the regions of both Jammu as well as Kashmir but without any details. However, Sharief et al. (2023) in their study confirmed the presence of only Kashmir Musk Deer in the Western Himalayas with no other evidence of any other species. We excluded this species from Jammu & Kashmir based on Sharief et al. (2023).

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COMMUNICATION

# Notes on distribution, identification and typification of the Elongated Sweet Grass *Anthoxanthum hookeri* (Aveneae: Poaceae) with comparative notes on *A. borii*

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**Abstract:** *Anthoxanthum hookeri* is reported for the first time from western Himalaya. The present collection from Nanda Devi Biosphere Reserve also represents the westernmost extension of its known global distribution. This finding clarifies the typification of the species through a critical analysis of type elements. Moreover, this study provides additional insights into the taxonomic relationship between *A. hookeri* and its closely related species *A. borii*. The second-step lectotypification of *A. borii* is also proposed. These findings underscore the importance of field-based taxonomy and herbarium studies in resolving complex species delimitations in Himalayan grasses.

**Keywords:** Alpine meadows, biodiversity, flora, Himalaya, India, Nanda Devi Biosphere Reserve, protected areas, recollection, second-step lectotypification, Valley of Flowers.

**Hindi:** *Anthoxanthum hookeri* को पहली बार पश्चिमी हिमालय से दर्ज किया गया है। नंदा देवी बायोस्फीयर रिज़र्व से किया गया यह संग्रह इसके ज्ञात वैश्विक वितरण की पश्चिमतम सीमा का प्रतिनिधित्व करता है। यह अध्ययन प्रकार (टाइप) तत्वों के समालोचनात्मक विश्लेषण के माध्यम से इस प्रजाति के टाइपफिकेशन को स्पष्ट करता है। इसके अतिरिक्त, यह शोध *A. hookeri* और इससे निकट संबंधी प्रजाति *A. borii* के बीच टैक्सोनोमिक संबंधों पर नए दृष्टिकोण प्रदान करता है। *A. borii* का द्वितीय-चरण लेक्टोटाइपफिकेशन भी प्रस्तावित किया गया है। ये निष्कर्ष हिमालयी घासों में जटिल प्रजाति सीमांकन को सुलझाने में क्षेत्र-आधारित वर्गिकी (टैक्सोनॉमी) और हरबेरियम अध्ययनों की महत्ता को रेखांकित करते हैं।

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**Author contributions:** KS—conducted field surveys and drafted the initial version of the manuscript; MC—conducted field surveys and assisted in preparing the final draft of the manuscript; RN—supervised the research; SG—supervised the research.

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## INTRODUCTION

The Himalaya, known as the third pole, supports diverse ecosystems from tropical forests to alpine meadows (Rawat et al. 2023). Poaceae, one of the most diverse plant families, has been the subject of continuous research since *Genera Plantarum* (1753) through to the present (Saha et al. 2024). While molecular methods are now prevalent, field taxonomy remains essential for documenting narrowly distributed grasses (Rouhan & Gaudeul 2021).

In the Valley of Flowers National Park, locally known as "Phoolon ki Ghati" and situated between the Alaknanda and Dhauli Ganga valleys in Chamoli District, Uttarakhand, India, such an occurrence was observed. As part of the Himalayan biodiversity hotspot, this valley holds immense ecological and cultural significance. In Hindu mythology, it is referred to as Nandan Kanan, or the "Garden of Indra in Paradise" (Rawat et al. 2023). During 1999 to 2024, several field explorations were carried out in this region, during which a distinctive grass species—characterized by its long, white, feathery stigmas—was documented. Based on comparisons with various taxonomic references (Bor 1960; Jain & Pal 1975; Wu & Sylvia 2006; Connor 2012; Kandwal 2025), the species was identified as *Anthoxanthum hookeri*.

Macro and micro-morphological study of A. *hookeri* revealed key features, including a lax panicle measuring 6–10 cm, and spikelets 6–10 mm long. The species also has male floret with short awn, a geniculate awn arising near the base of the second floret, along with shiny, awnless, glabrous bisexual 3rd floret (Bor 1960; Jain & Pal 1975; Wu & Sylvia 2006; Connor 2012).

The genus *Anthoxanthum* L. belongs to the subtribe Alopecurinae (Clayton & Renvoize 1986), tribe Aveneae (Bor 1960), subfamily Pooideae, within the family Poaceae. Initially established by Carl Linnaeus (1753) with three taxa the genus now comprises 52 taxa (POWO 2025) with nine taxa reported from India to date (Prasanna et al. 2020). Key characteristics of the genus include panicle inflorescence, lanceolate spikelets with three florets, the two lower staminate or barren and terminal floret is usually bisexual and protogynous, rachilla is not produced beyond the third floret, and lodicules absent (Bor 1960; Schouten & Veldkamp 1985; Connor 2012; de Lange & James 2024).

While herbaria play a crucial role in verifying species records (Zych et al. 2023), misidentified specimens have caused significant confusion. Kellogg et al. (2020) reported several questionable grass occurrences, including *A. hookeri*. One such specimen labelled as *A. hookeri* from the Palni Hills (Kodaikanal), Pondicherry (HIFP022578, digital image!), appeared doubtful due to the clear ecological mismatch between its tropical environment and the known habitat of *A. hookeri*—high-altitude open grassy slopes, rocky ridges, and alpine meadows in temperate and cold desert regions. Detailed taxonomic and ecological studies later determined that the specimen likely represented *Anthoxanthum borii* (Matthew 1996; Kabeer & Nair 2009), highlighting the challenges of habitat misidentification and overlooked records.

Long-term field data are critical for conservation sciences, as they help monitor population stability and persistence over time (Hoffmann et al. 2020). Amid growing concerns about flora reduction and medicinal plant loss, this research confirms the recollection of population of *A. hookeri* on multiple occasions between 1999 to 2024. Specimens were collected in 1999, 2012, 2017, 2018, 2019, and 2024 from the Valley of Flowers, a UNESCO World Heritage Site. The subpopulations were found scattered across various habitats within this protected area, including glacier moraines, open alpine meadows (Bugyal), and in association with other species such as *Meconopsis aculeata* Royle, *Codonopsis rotundifolia* Benth, *Juncus* sp., and *Dactylis glomerata* L. Despite threats such as climate change, biodiversity loss, and over-tourism, the population of *A. hookeri* remains stable and well-conserved in these protected areas. Interestingly, although the genus *Anthoxanthum* is known for its distinct coumarin fragrance (Bor 1960; Schouten & Veldkamp 1985; Kandwal 2025), this feature was not observed in *A. hookeri* during our field survey, consistent with the observations made by Kandwal (2025).

During the present study, seven herbarium specimens of *Anthoxanthum hookeri* were identified, all of which represent type specimens. Due to the absence of a designated holotype, all these specimens are treated as syntypes in accordance with Articles 9.4 and 9.6 of the ICN. Following Article 9.3 of the Shenzhen Code (Turland et al. 2018), a lectotype was designated. To confirm original material, TL-2 (Stafleu & Cowan 1976) was consulted for details on collectors, authors, and herbarium holdings. Specimens were traced and reviewed across several herbaria (BM, CAL, DD, E, GOET, K, L, P, W, and S; Thiers 2024), and each was critically compared with the protologue. The most representative specimen was selected as the lectotype (Image 3), following Articles 9.3 and 9.17 of the Shenzhen Code. While *A. borii* required a second-step lectotype (Image 4) designation according to Art. 9.17 of Turland et al.

(2018), as Jain & Pal (1975) indicated gatherings rather than a single specimen as their type.

Previous studies (Bor 1960; Uniyal et al. 2007; Prasanna et al. 2020; Kandwal 2025; POWO 2025) did not report the occurrence of A. *hookeri* in western Himalaya. The present study provides the first confirmed record of this species from the western Himalaya, northern India, thereby documenting newly identified habitats. To facilitate field identification, field photographs were provided (Image 1), a detailed morphological plate showing key structural features (Image 2), a comprehensive taxonomic description, and a collection site map (Figure 1) created with QGIS version 3.36.2. The herbarium specimen has been deposited at herbarium of Forest Research Institute, Dehradun (DD). Additionally, a comparative discussion highlighting distinguishing characters between *A. hookeri* and *A. borii* is presented, along with the lectotypification of both taxa.

**Taxonomic treatment**

*Anthoxanthum hookeri* (Griseb.) Rendle, J. Linn. Soc., Bot. 36: 380 (1904).

*Ataxia hookeri* Griseb. in Nachr. Königl. Ges. Wiss. Georg-Augusts-Univ. 3: 77 (1868).

**Type:** — INDIA: Sikkim, 9000’-12000’, Regio. Temp, *2 Ataxia*, s.d., Coll. J.D. Hooker lectotype designated here [L0043608 (digital image!)]; isolectotypes: INDIA: Sikkim, 9000’-12000’, Regio. Temp, *2 Ataxia*, s.d., Coll. J.D. Hooker [W0028397 (digital image!)]; INDIA: Sikkim, 9000’-12000’, Regio. Temp, *2 Ataxia*, s.d., Coll. J.D.


**Image 1. *Anthoxanthum hookeri* (Griseb.) Rendle: a—natural habitat | b&c—close-up of inflorescence. © Kuntal Saha.**

Hooker [BM011027783 (digital image!)]; INDIA: Sikkim, 9000′-12000′, Regio. Temp, *2 Ataxia*, s.d., Coll. J.D. Hooker [GOET006527 (digital image!)]; INDIA: Sikkim, 9000′-12000′, Regio. Temp, *2 Ataxia*, s.d., Coll. J.D. Hooker [S1421991 (digital image!)]; INDIA: Sikkim, Regio. alp, *2 Ataxia*, s.d., Coll. J.D. Hooker [K000032286 (digital image!)]; INDIA: Sikkim, 11000′, Regio. alpina, *2 Ataxia*, s.d., Coll. J.D. Hooker [K000032287 (digital image!)].

Perennial, loosely tufted. Culms 45–60 cm, green, erect, nerved, nerves scabrid; 4–5 nodes, brown, short pubescent, no nerved. Leaf sheaths open 2/3 of culms, green, glabrous, nerved, scabrid. Ligule 4–6 mm, membranous-lacerate, apex truncate. Leaf blades 10–24 cm × 3–3.5 mm, green, glabrous, linear, apex subulate, margin serrate, involutely rolled when dry. Panicle 6–14 cm, lax, erect; semi-whorled branched, primary branches (racemes) borne along a central axis; each whorl bearing 1–3 branches, 3–5 spikelets. Spikelets 6–10 mm, solitary, pedicelled, lanceolate, laterally compressed, reddish-green, with up to 1 cm long white feathery stigma. Lower glume 4–6.5 mm, persistent, keeled, membranous, lanceolate, apex acuminate. Upper glume 7–8.5 mm, persistent, keeled, two veined, membranous, ovate, apex acuminate. Floret 3, in cluster, compactly arranged; bearing two sterile florets, one fertile floret, without rhachilla extension; callus glabrous, shinning. 1st floret 5–6 mm, ciliate on back, male; lemma equal to floret, linearly-oblong, apex two-fid, lobes acute, awned; awn median to sub-apical, straight, arising from sinus, up to 4.5 mm; palea 3–3.5 mm, oblong, smooth, transparent, two-nerved,apex two-lobed; anther 3, 2.1–2.3 mm. 2nd floret 7–9 mm, densely long ciliate, golden-brown, shinning, sterile, no palea; lemma equal to floret, oblong, apex shortly two-lobed,awned; awn median, geniculate, 10–12 mm. 3rd floret 3–3.5 mm, glabrous, shiny, bisexual; lemma equal to floret, cartilaginous, keeled, ovate, apex obtuse or boat-shaped, rolled in convolute, covering of entire palea; palea less than 2.5 mm, smooth, membranous, oblong, one-nerved, nerve upwardly scabrid; Stigmas 1; white feathery, bifurcated; ovary 1.3–1.5 mm, glabrous, apex two-lobed; anther 2, 2.3–2.5 mm. Caryopsis 0.5–1 mm, golden-brown, elliptical-lanceolate.

**Flowering and Fruiting:** July–September.

**Habitats:** near glacier moraines, in moist, shaded areas beneath large trees, or on open grassy slopes and dry rocky ridges at elevations of 2000–3500 m.

**Distribution:** INDIA [Sikkim, Arunachal Pradesh, Meghalaya, West Bengal, Uttarakhand (Present report)], South & Central China, Bhutan, Myanmar, Nepal, Tibet.

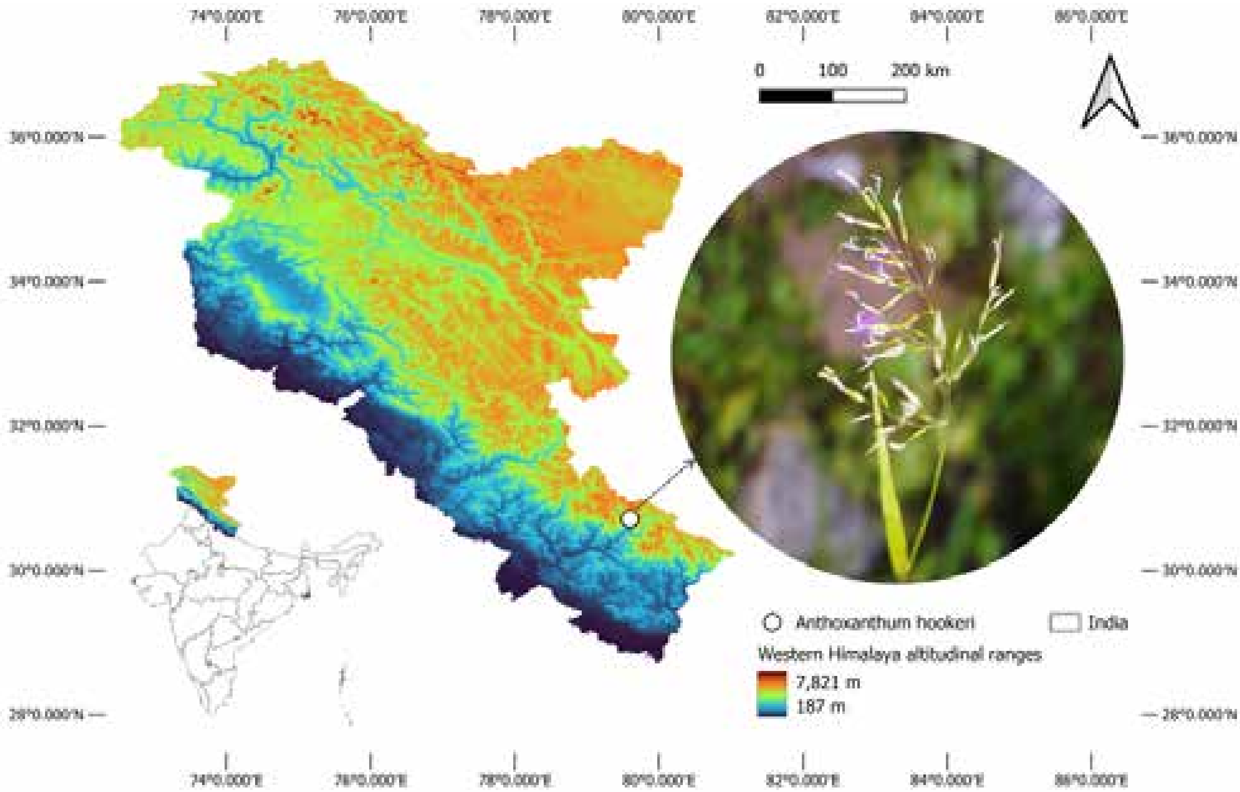


**Figure 1. Map depicting the place of collection of *Anthoxanthum hookeri* (Griseb.) Rendle in northern India. © Kuntal Saha.**

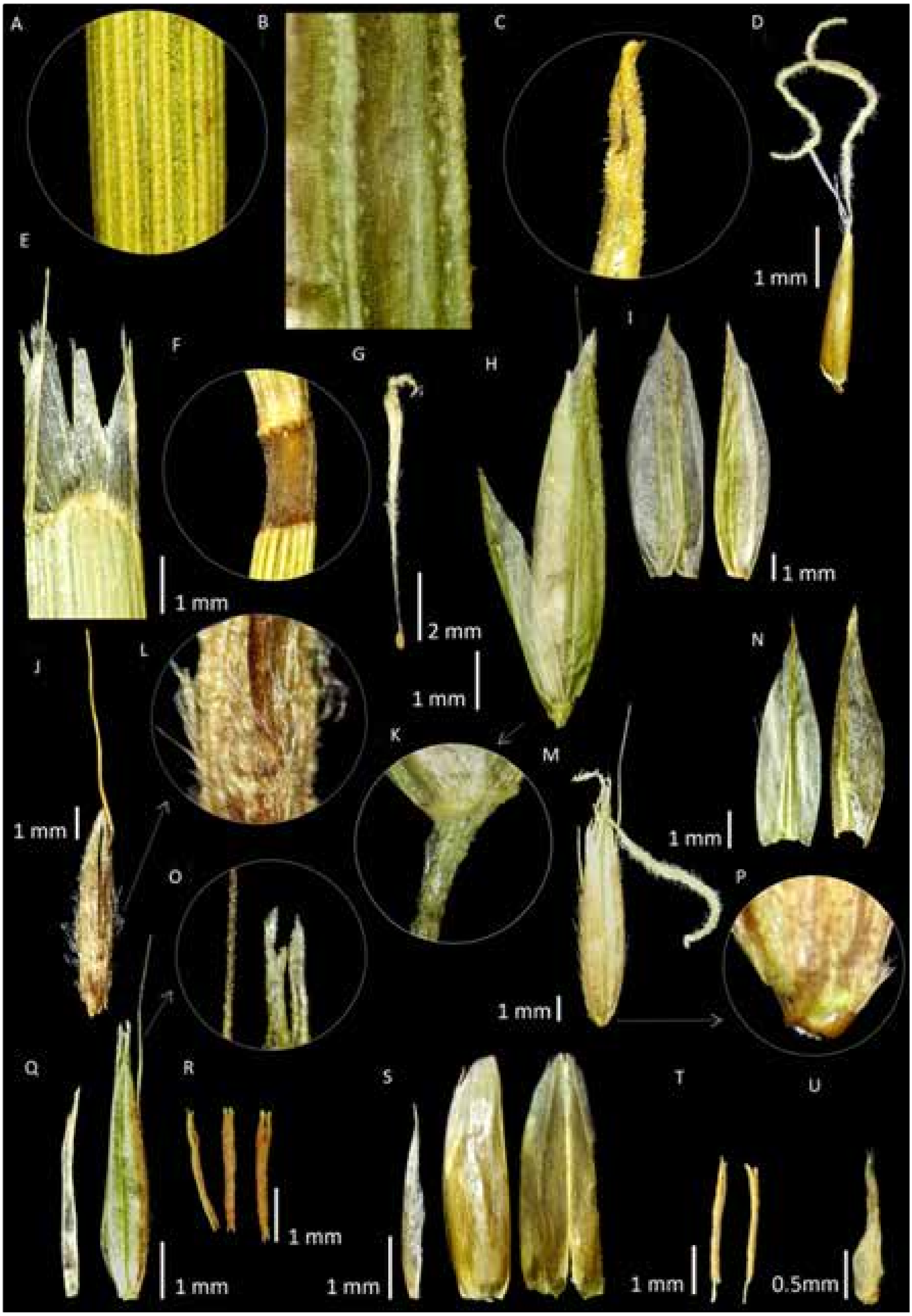


**Image 2.** ***Anthoxanthum hookeri*** **(Griseb.) Rendle: a—internode | b—scabrid leaf surface | c—subulate leaf tip | d—3rd fertile floret | e—ligule | f—node | g—feathery stigma with caryopsis | h—spikelets | i—upper glume (dorsal & lateral view) | j—lemma of 2nd floret | k—awn attachment with lemma of 2nd floret | l—close-up of pedicel | m—three floret in cluster | n—lower glume (dorsal & lateral view) | o—two-lobed apex of lemma of 1st floret | p—callus | q—palea & lemma of 1st floret | p—anther of 1st floret | s—Palea & lemma (lateral & dorsal view) of 3rd floret | t—anther of 3rd floret | u—ovary. © Kuntal Saha.**

**Typification Note:** August Heinrich Rudolf Grisebach originally described *Ataxia hookeri* Griseb. in 1868, based on specimens collected by Sir Joseph Dalton Hooker from Sikkim, India, at elevations ranging 2,727–3,636 m (9,000–12,000 ft). The material was assigned the collection number "two Ataxia" although no specific collection date was mentioned. During this present study, seven herbarium specimens corresponding to this gathering were identified across several major herbaria, including GOET, K, W, BM, L, and S. Specimens such as 2 Ataxia (GOET006527, W0028397, BM011027783, L0043608, & S1421991) consistently mention the collection region as temperate ("Regio: Temp.") and altitude as 2,727–3,636 m (9,000–12,000 ft), all attributed to J.D. Hooker. Two additional specimens housed at Kew herbarium (K000032286 & K000032287) also correspond to the same collection number and locality. Two Ataxia (K000032286) does not specify altitude and labels the region as alpine ("alp"), while two Ataxia (K000032287) notes an altitude of 3,333 m (11,000 ft) and specifies the region as alpine ("alpina"). All these specimens constitute original material and are thus eligible for lectotypification. Another specimen (K000838011), bearing the same collection number but collected from Lachung, Sikkim, includes only a partial date (July 14/44) and lacks the collector's name. Due to these ambiguities, it was excluded from consideration as type element. Among the syntypes described above, two Ataxia (barcode: L0043608) is designated here as the lectotype (Image 3) for *Anthoxanthum hookeri*, as it offers the most complete set of diagnostic features. This includes detailed morphological information along with clearly indicated locality, collector's name, and collection number, ensuring its reliability for accurate identification.

**Tracing the shared traits of *A. borii* and *A. hookeri***

*Anthoxanthum borii* was first mentioned by Bor (1960) and later described by Dr. S.K. Jain & D.C. Pal in 1975. It was named in honour of Dr. N.L. Bor, who first suspected this taxon to be new. During this study we found that *A. borii* and *A. hookeri* share the common characteristic. Both are perennial, 3 florets: 2 sterile or reduced + 1 hermaphrodite, glume are both with persistent, lemma (1$^{st}$ floret) is 2-fid apex with awn arising from sinus, 2$^{nd}$ floret is sterile, with a geniculate awn, 3$^{rd}$ floret is hermaphrodite, small in size, contains ovary. The distinguishing features that separate *A. borii* (BSID0001097, BSID0001098, & BSID0001099) as a new species, rather than a part of *A. hookeri*, are as follows: culm height and habit: *A. borii* is taller and rhizomatous, whereas *A. hookeri* is shorter and lacks rhizomes. Leaf aroma: *A. borii* has aromatic leaf blades, while *A. hookeri* is non-aromatic. Ligule: *A. hookeri* possesses longer (4–6 mm), lacerate ligules. Spikelet coloration and stigma visibility: spikelets of *A. hookeri* are reddish-green with prominently long white feathery stigmas. Floral awns: the second floret of *A. hookeri* features longer geniculate awns (10–12 mm). Stigma number: *A. hookeri* uniquely has a single bifurcate feathery stigma, in contrast to the two found in *A. borii* (Bor 1960; Jain & Pal 1975; Kabeer & Nair 2009; Kandwal 2025).

**Typification**

*Anthoxanthum borii* Jain & Pal, J. Bombay Nat. Hist. Soc. 72(1): 92 (1975).

**Type:** — India: Tamil Nadu, Pulneys, Pambar stream, near Shenthadikanal, 6 December 1898, Bourne 1954, Coll. Alfred Gibbs Bourne lectotype designated here [CAL0000002343 (digital image!)]; isolectotype: INDIA: Tamil Nadu, Pulneys, Pambar stream, near Shenthadikanal, 6 December 1898, *Bourne* 1954, Coll. Alfred Gibbs Bourne [CAL0000002342 (digital image!)].

Typification Note: *A. borii* was described by Dr. S.K. Jain and D.C. Pal based on specimens collected by Alfred Gibbs Bourne in the Pulney Hills, Tamil Nadu, India (Bourne 1954). The authors designated the type specimen in the protologue as "Holotype: CAL". Upon examination, two specimens were located at the CAL herbarium (CAL0000002342 & CAL0000002343), where CAL0000002343 is annotated as "Holo-TYPE" and CAL0000002342 as "Iso-TYPE". CAL0000002343 (digital image!) were designated as the second-step lectotype (Image 4) according to Art. 9.17 of Turland et al. (2018), as it is well-preserved and aligns with the original description.

**Specimens examined**

*Anthoxanthum hookeri*: 175039(DD), India, Uttarakhand, Chamoli District, Valley of Flowers, 30.705 °N 79.595 °E, 3,200 m, 18.viii.1999, coll. Manoj Chandran; 175038(DD), after crossing the Valley of Flowers gate, near the river bridge, 30.708 °N 79.595 °E, 3,267 m, 25.vii.2024, coll. Kuntal Saha; 2 Ataxia, L0043608 (digital image!), Sikkim, 9000′–12000′, Regio. Temp, s.d., Coll. J.D. Hooker; 2 Ataxia, W0028397 (digital image!), Sikkim, 9000′–12000′, Regio. Temp, s.d., Coll. J.D. Hooker; 2 Ataxia, BM011027783 (digital image!), Sikkim, 9000′–12000′, Regio. Temp, s.d., Coll. J.D. Hooker; 2 Ataxia, GOET006527 (digital image!), Sikkim, 9000′-12000′, Regio. Temp, s.d., Coll. J.D. Hooker; 2 Ataxia, S1421991 (digital image!), Sikkim, 9000′-12000′, Regio. Temp, s.d.,

**Image 3. Lectotype of *Anthoxanthum hookeri* L0043608. Digital Image @ L, reproduced with permission (http://data.biodiversitydata.nl/naturalis/specimen/L%20%200043608).**

**Image 4. Second-step lectotype of *Anthoxanthum borii* CAL0000002343. Digital Image @ CAL, reproduced with permission (http://ivh.bsi.gov.in/phanerogams-Details/en?link=CAL0000002343&column=szBarcode).**

Coll. J.D. Hooker; 2 Ataxia, K000032286 (digital image!), Sikkim, Regio. alp, s.d., Coll. J.D. Hooker; 2 Ataxia, K000032287 (digital image!), Sikkim, 11000', Regio. alpina, s.d., Coll. J.D. Hooker; 2 Ataxia, K000838011 (digital image!), Sikkim, Lachung, 11,000'–12,000', 14.vii.1844, Coll. leg. ignot.

*Anthoxanthum borii*: Bourne 1954(CAL), CAL0000002342 (digital image!), India, Tamil Nadu, Pulneys, Pambar stream, near Shenthadikanal, 6.xii.1898, Coll. Alfred Gibbs Bourne; Bourne 1954(CAL), CAL0000002343 (digital image!), Pulneys, Pambar stream, near Shenthadikanal, 6.xii.1898, Coll. Alfred Gibbs Bourne; 69430(CAL), BSID0001097 (digital image!), India, Kerala, Idukki District, Eravikulam National Park, 16.xi.1980, Coll. P.V. Sreekumar; 67795 (CAL), BSID0001098 (digital image!), India, Kerala, Idukki district, Eravikulam National Park, 26.viii.1980, Coll. P.V. Sreekumar; 67786 (CAL), BSID0001099 (digital image!), India, Kerala, Idukki District, Eravikulam National Park, 25.viii.1980, Coll. P.V. Sreekumar.

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COMMUNICATION



# Conservation significance of Yelakundli Sacred Grove: a relic population of the endemic dipterocarp *Vateria indica* L.

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**Abstract:** Yelakundli Sacred Grove, a 4 ha evergreen forest patch in Shivamogga District, Karnataka State, India, harbours a rare and exceptionally large population of the endemic dipterocarp tree *Vateria indica*. A single transect revealed 122 mature individuals of this species, whereas it was virtually absent outside the grove. The grove's unique characteristics, including 100% evergreenness, 87% tree endemism, and a thick leaf litter layer, support the dominance of *Vateria indica* and other climax tree species, such as *Mesua ferrea*. The absence of fire and the non-removal of leaf litter have contributed to the grove's ecological integrity. In contrast, intensive litter collection and forest fires in other forest patches have altered soil properties, impaired seedling establishment, and shifted species composition. Yelakundli sacred grove's conservation significance lies in its role as a biodiversity heritage site, providing a window into the evolutionary history of tropical forests. Its protection by the local community, driven by cultural and religious beliefs, has ensured the persistence of this relic population, highlighting the importance of community-driven conservation efforts.

**Keywords:** Biodiversity heritage site, community-driven conservation, evergreen forest, flowering plant, sacred grove, Western Ghats.

**Kannada:** ಯೆಲಕುಂದ್ಲಿ ದೇವರಕಾಡು, ಕರ್ನಾಟಕದ ಶಿವಮೊಗ್ಗ ಜಿಲ್ಲೆಯಲ್ಲಿರುವ ೪ ಹೆಕ್ಟೇರ್ ವಿಸ್ತೀರ್ಣದ ಹರಿದ್ವರ್ಣ ಕಾಡು. ಇಲ್ಲಿ ಅಪರೂಪದ ಸ್ಥಳೀಯ ಡಿಪ್ಟೆರೋಕಾರ್ಪ್ ಪ್ರಭೇದದ ವೆಟೇರಿಯಾ ಇಂಡಿಕಾ (ಸಾಲ್ಧೂಪ) ಮರಗಳನ್ನು ಅತ್ಯಧಿಕ ಸಂಖ್ಯೆಯಲ್ಲಿ ಹೊಂದಿದೆ. ಒಂದೇ ಟ್ರಾನ್ಸೆಕ್ಟ್‌ನಲ್ಲಿ ಈ ಜಾತಿಯ ೧೨೨ ವೆಟೇರಿಯಾ ಇಂಡಿಕಾ ಮರಗಳು ದಾಖಲು ಮಾಡಲಾಗಿದ್ದು, ದೇವರಕಾಡಿನ ಹೊರಗೆ ಈ ಮರಗಳು ಬಹುತೇಕ ಕಾಣಸಿಗುವುದಿಲ್ಲ . ಈ ದೇವರಕಾಡಿನ ವಿಶಿಷ್ಟ ಲಕ್ಷಣಗಳಾದ 100% ಹರಿದ್ವರ್ಣ ಕಾಡು, 87% ಸ್ಥಳೀಯ ಜಾತೀಯ ಮರಗಳು, ಮತ್ತು ಮಣ್ಣಿನಲ್ಲಿ ಹೇರಳವಾಗಿ ಸಿಗುವ ದರಗೆಲೆಗಳ ಪದರು ವೆಟೇರಿಯಾ ಇಂಡಿಕಾ ಮತ್ತು ಮೆಸುವಾ ಫೆರಿಯಾ (ನಾಗಕೇಸರಿ) ಮುಂತಾದ ಮರ ಪ್ರಭೇದಗಳ ಹೆಚ್ಚಿನ ಸಂಖ್ಯೆಗೆ ಕಾರಣವಾಗಿದೆ. ಕಾಡಿನಲ್ಲಿ ಬೆಂಕಿಯ ಅನುಪಸ್ಥಿತಿ ಮತ್ತು ದರಗೆಲೆಗಳ ಸಂಗ್ರಹಣೆಯಿಲ್ಲದಿರುವುದು ದೇವರಕಾಡಿನ ಪರಿಸರ ಸಮತೋಲನವನ್ನು ಕಾಯ್ದುಕೊಳ್ಳಲು ಸಹಾಯಮಾಡಿದೆ. ಇತರೆ ಕಾಡು ಪ್ರದೇಶಗಳಲ್ಲಿ, ದರಗೆಲೆಗಳ ತೀವ್ರ ಸಂಗ್ರಹಣೆ ಮತ್ತು ಕಾಡಾಗ್ನಿಗಳ ಪರಿಣಾಮವಾಗಿ ಮಣ್ಣಿನ ಗುಣಲಕ್ಷಣಗಳು ಬದಲಾಗಿದ್ದು, ಮರಗಳ ಬೀಜಪುನರುತ್ಪಾದನೆ ಅಸ್ಥಿರಗೊಂಡಿದೆ ಮತ್ತು ಗಿಡಗಳ ಪ್ರಭೇದ ಸಂಯೋಜನೆ ಬದಲಾಗಿದೆ. ಯೆಲಕುಂದ್ಲಿ ದೇವರಕಾಡು ಜೀವ ವೈವಿಧ್ಯ ಪರಂಪರೆ ತಾಣವಾಗಿದ್ದು, ಉಷ್ಣವಲಯದ ಕಾಡುಗಳ ವಿಕಾಸನದ ಇತಿಹಾಸ ಪರಂಪರೆಯನ್ನು ಅರಿಯುವಲ್ಲಿ ಸಹಾಯಕವಾಗಿದೆ. ಸ್ಥಳೀಯ ಜನ ಸಮುದಾಯದ ಧಾರ್ಮಿಕ ಹಾಗು ಸಾಂಸ್ಕೃತಿಕ ನಂಬಿಕೆಗಳಿಂದಾಗಿ, ಈ ಅಪರೂಪದ ವೆಟೇರಿಯಾ ಇಂಡಿಕಾ ಮರಗಳ ಹರಿದ್ವರ್ಣ ಕಾಡು ಇಂದಿಗೂ ಉಳಿದುಕೊಂಡಿರುವುದು ವಿಶೇಷವಾಗಿದೆ.

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## INTRODUCTION

Western Ghats represent one of the best non-equatorial tropical forests and are also considered one of the 36 biodiversity hotspots of the world (Nayar 1996; Myers et al. 2000; Conservation International 2025). These ancient landscapes have nurtured the evolution of several primitive plant families, notably Myristicaceae and Dipterocarpaceae, with the latter forming the dominant canopy component of primary lowland forests (Meijer 1973). The discovery of fossilized ambers (a hardened resin) of dipterocarp origin from the Cambay shale of Gujarat in Western India indicates the antiquity of the family to be over 50 million years ago (Rust et al. 2010). Yelakundli Sacred Grove (Yelakundli SG) of Sagara Taluk, Karnataka, is one such dipterocarp forest patch dominated by the endemic tree *Vateria indica* L., surrounded by paddy fields and other human landscapes. How did such an ancient forest patch survive despite climatic adversities and human disturbances? The answer lies in the genesis of sacred groves. Sacred groves are segments of landscape containing trees and other forms of life and geographical features that are delimited and protected by human societies, believing that preserving such a patch of vegetation in a relatively undisturbed state is necessary for expressing one's relation to nature. So, these remain as isolated patches of forests in the midst of agricultural landscapes (Hughes & Chandran 1998). It is one such sacred grove that escaped human pressures due to its sanctity. Gadgil & Berkes (1991) attributed the traditional practice of most human societies in providing complete protection to certain biological communities by setting aside refugia to a variety of regulatory measures that have been an integral part of the utilization of biological resources. This has kept alive the protection of primaeval relic forest patches as sacred groves. Despite their size limitations, these fragments conserve local biodiversity and offer important ecological services (Ray & Ramachandra 2010). This study investigates the structure and floristic composition of the Yelakundli SG, with a focus on understanding its conservation through the role of community-driven management, rooted in cultural reverence and its significance as a living relic of evolutionary antiquity.

### Study area

This study was conducted in the Yelakundli Sacred Grove (SG), located in Sagara Taluk, Shivamogga District of Karnataka State (Figure 1). The grove is situated within evergreen-to-semi-evergreen forest matrix, surrounded by human-modified landscapes comprising paddy fields and Areca plantations. The Yelakundli SG is a 4-ha evergreen climax forest, harbouring several deities and small sacred places, with Rachamma Devi being the primary worshipped deity (Image 1).

## MATERIALS AND METHODS

Due to strict regulations and restricted access set by the local people community, a transect-based approach was employed to study the Yelakundli Sacred Grove. The work was done barefoot within the grove's boundaries, adhering to local customs. A single belt transect (2,000 $m^2$, 180 m long) was established, comprising five quadrats (20 x 20 m each), following Chandran et al. (2010) (Figure 2). In each tree quadrat, trees with >30 cm GBH and lianas >10 cm GBH were enumerated. Tree height, climbers, and epiphytes were also recorded. Shrubs (GBH <30 cm, height >1 m) were counted in two 5 x 5 m quadrats within each tree quadrat. Herb plots (1 x 1 m) were established within each shrub quadrat to study herbs and woody seedlings.

Data analysis included calculating Shannon-Wiener's diversity index, Simpson dominance (Ludwig & Reynolds 1988), and importance value indices (IVI) for each tree species (Curtis & McIntosh 1951). Basal area per ha was calculated to understand the dominant species in the tree layer. Evergreeness and endemism percentage of the tree layer were calculated following Mesta & Hegde (2018), along with girth class distribution of the dominant tree, *Vateria indica*. Local people and priests were interviewed to gather information on the sacred grove's history, conservation, and community involvement.

## RESULTS

### Vegetation structure and composition

A total of 187 plant species, representing 52 families, were recorded across the tree, shrub, and herb layers during the survey. There were 122 individuals of *Vateria indica* (Dipterocarpaceae) recorded in a single transect within the tree layer, indicating a near-monodominant forest composition. Other notable tree species present in the transect included *Mesua ferrea, Saraca asoca, Holigarna arnottiana, Artocarpus hirsutus,* and *Knema attenuata*. Importance value indices (IVI) revealed *Vateria indica* as the dominant species (IVI = 209), followed by *M. ferrea* (IVI = 30.86) and *S. asoca* (IVI = 19.58) (Table 1). The Shannon diversity index was low (H' = 0.6) and Simpson dominance index was high (D = 0.71) indicating

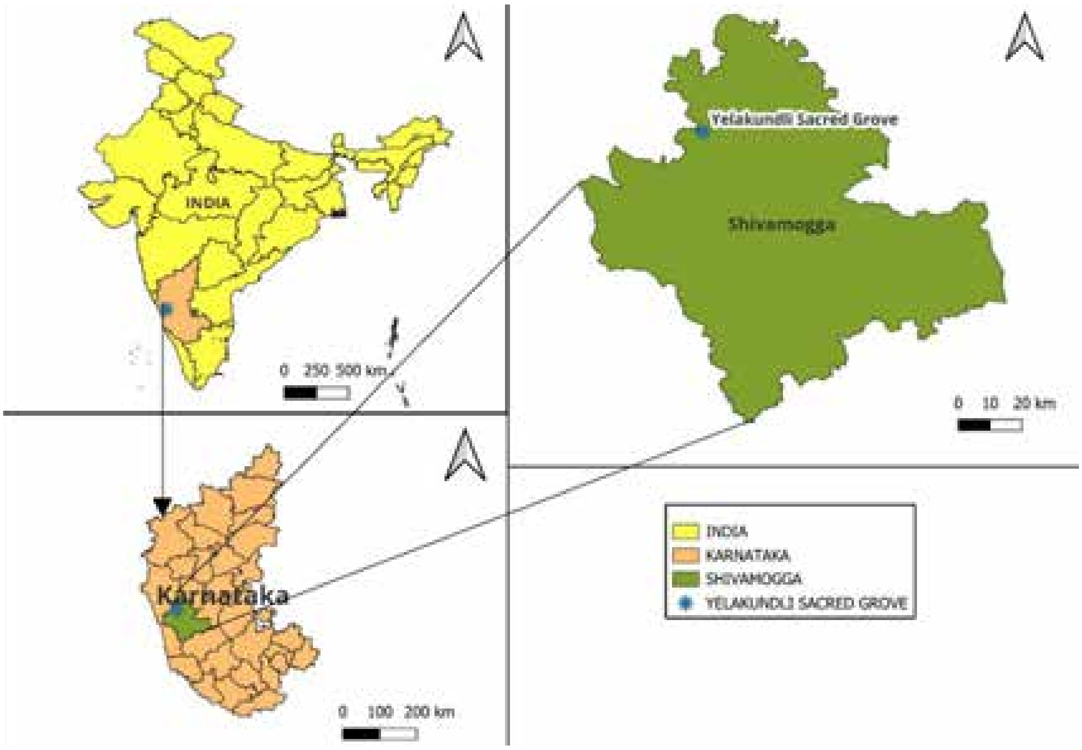


**Figure 1. Map of Yelakundli Sacred Grove, Sagara Taluk, Shivamogga District, Karnataka State.**

**Table 1. IVI of seven tree species (tree layer) in the Yelakundli Sacred Grove.**

| Species | IVI |
|---|---|
| *Vateria indica* | 209.01 |
| *Mesua ferrea* | 30.86 |
| *Saraca asoca* | 19.58 |
| *Artocarpus hirsutus* | 14.13 |
| *Knema attenuata* | 9.05 |
| *Caryota urens* | 8.69 |
| *Holigarna arnottiana* | 8.69 |

the overwhelming dominance of *V. indica*.

The forest exhibited 100% evergreenness, with a remarkably high level (87%) of tree endemism (Figure 3). Transect analysis of the tree layer revealed a basal area of 86.9 $m^2$/ha, primarily attributed to the massive individuals of *V. indica*, which averaged 17 m in height. Other tree species, such as *A. hirsutus* and *K. attenuata* were represented by a few individuals. Girth class distribution analysis of *V. indica* revealed a healthy population structure with individuals ranging 30 cm to over 100 cm GBH, and some trees exceeding 300 cm GBH (Figure 4). In the shrub layer, *V. indica* exhibited the highest number of saplings (148), followed by *M. ferrea* (51), *Syzygium stocksii* (19), and others. Similarly, in the herb layer, *V. indica* had the highest number of individuals (119), followed by *Lagenandra ovata* (81), *Combretum latifolium* (52), and others.

## DISCUSSION

The Yelakundli SG is distinguished by a rare and exceptionally large population of the endemic dipterocarp *V. indica*. Within a single transect, 122 mature individuals of this species were recorded, whereas outside the grove, *V. indica* was virtually absent. This species represents one of the important relic species along with other endangered dipterocarps such as *Dipterocarpus indicus* (Chandran et. al. 2010). Other important trees include *M. ferrea, S. asoca, H. arnottiana,* and *A. hirsutus* , also form some of the important elements of the evergreen forest (Image 2). As the forest area has shrunk to just a few ha the diversity was very low with nearly mono-dominant dipterocarp *V. indica* in overwhelming numbers and just six other tree species sparingly occurring (Table 1). This healthy population of *V. indica* was seen in tree, shrub, and herb layers. The sacred grove was also 100% evergreen climax forest with highest level of tree endemism (87%). One of the important factors contributing to this is the


**Image 1. A glimpse into the sacred grove: A—a dense canopy of lofty *Vateria indica* trees | B—the revered deity Rachamma inside the sacred grove, Yelakundli, Sagara Taluk, Shivamogga District, Karnataka State | C—sacred grove entrance view. © G. Ramachandra Rao.**

presence of heavy leaf litter, which were not collected by the local people. They informed that even a single dry leaf or fallen twig was never collected or taken out from the sacred grove. The leaf litter layer is itself nearly 0.6 m (2 ft.) thick making ideal nursery grounds for large seeded climax trees such as *V. indica* and *M. ferrea*. The absence of fire promotes the luxuriant regeneration of large-seeded evergreen species. In contrast, many other forest patches, including sacred groves practice intensive litter collection for agricultural use, which significantly alters soil structure. Studies have shown that litter removal increases soil bulk density and reduces surface-soil carbon and nitrogen content, thereby impairing seedling establishment and nutrient cycling (Chandran et al. 2010; Ito et al. 2014). When compounded by forest fires, these disturbances further degrade soil properties, volatilize essential nutrients, and kill microbial communities, leading to a shift in species composition toward smaller-seeded, fire-tolerant, and often deciduous taxa (Elakiya et al. 2023). Such changes undermine the ecological integrity and resilience of evergreen forest fragments.

**Yelakundli SG as a biodiversity heritage site**

The Yelakundli SG, dedicated to the mother goddess 'Rachamma', stands as a rare and remarkable remnant of tropical forest heritage (Figure 2B). Its continued existence owes much to the unwavering protection offered by the local village community. Other deities seen include Chowdamma and Rameshwar. Outside the SG, a deity by the name Anegundi Bhutappa was also worshipped during the commencement of early monsoon rains. These gods and bhutas with rigorous religious sanctity have played a pivotal role in maintenance and survival of this ancient primary patch. *Vateria indica* trees, being lofty emergent primary forest species, have large sized fruits and seeds. Seeds dispersal can only be feasible by wild animals and large birds such as Hornbills. In Yelakundli SG the forest size is very less to support larger wild animals and hence are totally absent. Absence of larger dispersal agents and soil having heavy leaf litter with moisture, supported trees such as *V. indica* and *M. ferrea* which have dominated the sacred grove over the years. Other evergreen trees might have slowly got locally extinct from the area due to small grove size. But the very presence of primary tree species, *V. indica*, and *M. ferrea* in this hostile area indicates the past grandeur these areas might have had. What is now seen is just a chunk of that bygone history of tropical luxuriance. Studies indicate

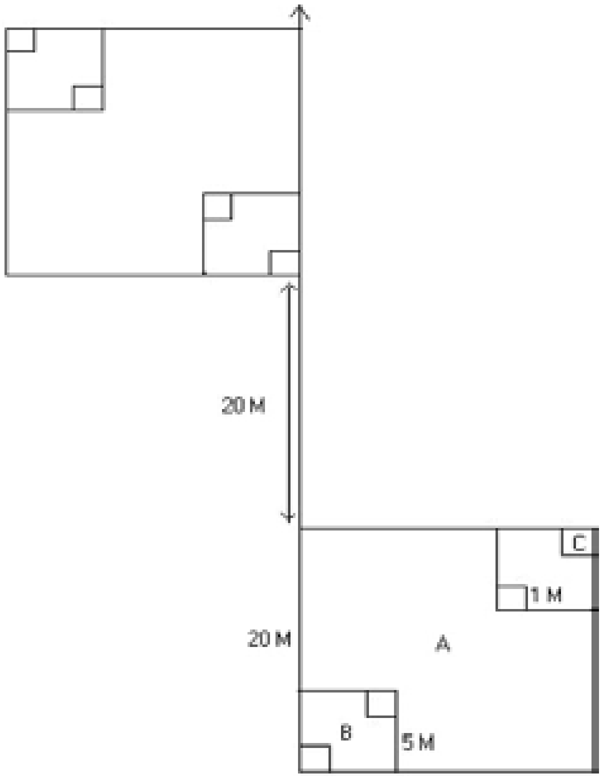


Figure 2. Schematic representation of the modified belt transect design, illustrating two of the five quadrats (20 x 20 m each): A—tree quadrat (20 x 20 m) | B—shrub plot (10 x 10 m) | C—herb plot (5 x 5 m), used for vegetation sampling and analysis.

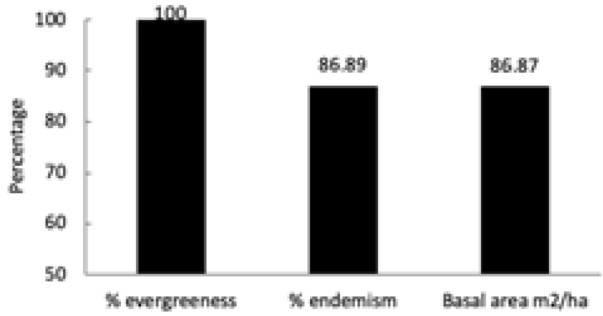


Figure 3. Ecological characteristics of Yelakundli sacred grove: A—percentage evergreenness | B—percentage endemism | C—basal area per ha.

that natural populations of *V. indica* are rare in the central Western Ghats, occurring only in undisturbed primary forest patches or well-preserved sacred groves (Chandran et al. 2010; Gunaga et al. 2015) and more frequent in southern Western Ghats (Jose & Binoy 2018; Singh et al. 2022). Therefore, Yelakundli SG with all its evolutionary significance and cultural importance highly qualifies to be declared as biodiversity heritage site. These are some of the areas where the missing links of tropical forest evolution are discovered, which would have been highly impossible if it had not been protected with such rigorous austerity.

## CONCLUSIONS

The Yelakundli SG represents a unique relic of evergreen forest dominated by the endemic dipterocarp *V. indica*. Its near-monodominant structure, high endemism and ever-greenness underscore both its evolutionary antiquity and its role as a living museum of Dipterocarpaceae heritage. Community-driven protection rooted in sacred grove traditions has safeguarded this fragment against litter removal, fire and land conversion. This fosters seedling establishment for large-seeded climax species. This culturally enforced refuge illustrates how traditional

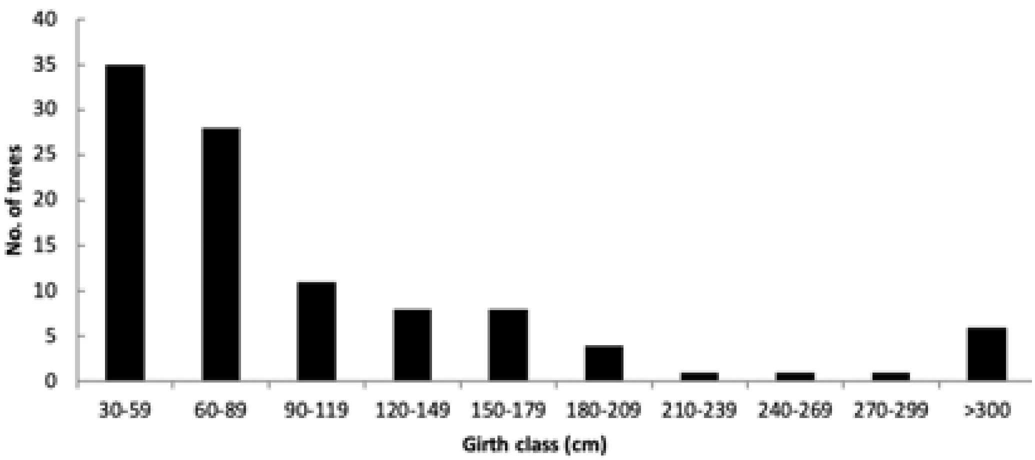


Figure 4. Girth class distribution of the endemic dipterocarp *Vateria indica* in Yelakundli Sacred Grove: a transect-based analysis revealing the population structure and size-class distribution.


**Image 2. Important trees of Yelakundli Sacred Grove: A—*Knema attenuata* | B—*Saraca asoca* | C—*Mesua ferrea* | D—*Vateria indica*. © G. Ramachandra Rao.**

ecological knowledge can sustain primeval forest even within intensively modified agricultural landscapes.

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COMMUNICATION



# A preliminary study of fish diversity in Sirum River of East Siang District, Arunachal Pradesh, India

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**Abstract:** A preliminary study was conducted in the Sirum River, a tributary of the Siang River, located in the easternmost part of Arunachal Pradesh. A review of existing literature indicated a lack of systematic fish assessment in this river, which this study aimed to address. Fish sampling was carried out twice a month from October 2023 to September 2024 at three sites. Fifty four species belonging to four orders, 15 families, and 38 genera were recorded. Cypriniformes comprised 35 species, Siluriformes 14, Anabantiformes seven, and Synbranchiformes one species. Three species were classified as Endangered, two as Near Threatened, four as Vulnerable, 31 as Least Concern, four as Data Deficient, and 10 as Not Evaluated. Representative images of threatened and economically important fish species are included to aid in visual identification and documentation.

**Keywords:** Aquatic ecosystem, biodiversity, conservation, ecotourism, economic, Endangered, fish sampling, threatened, Vulnerable, species.

**Adi abstract: Lé:tom:** Arunachal Pradesh lok Sanggo kenyung lo tokna, Siang asi lo toklík duna Sirum Korong ém rimék kíto. Supak ké kapang dunam kotbum kídí so Sirum Korong sok éngo yena kídíém aipé rimík nam kapang madung, dém rimík domílo émla si ikí namko. October 2023 lokké ila September 2024 lopé, éngo angu-angu ém polo lo lénnyi pé ikol angum lok ladum suto. Íying pilngo kolang appi éngo ko, obak appi lok, íying kolang pilngo érang lok délokké íying angum kolang pínyi ramík ém ladum subom dola rimík toh. Rimík nam éngo kídí sok íying angum kolang pilngo é Cypriniformes é, íying kolang appi é Siluriformes, kínít é Anabantiformes délokké atél é Synbranchiformes pé ido. Délokké íying pilngo kolang appi éngo lokké, angum si nyokdak bong, anyi si nyoknam pé idung délo appi si nyokladung, íying angum kolang atél si padung ada, appi ko aipé kenmang nam é délokké íying ko aipé kangken manam é. Nyokdak bong ina délokké pesi korét pé ipénam engo mimang kídíém kajing-tatjing dopé atkumla lébitung.

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**Author contributions:** OT—conceptualization, data collection, analysis of data set and preparation of the initial draft of the manuscript, images; LW—editing, data validation; DND—species identification, and editing of the final version of the manuscript.

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## INTRODUCTION

Fish biodiversity is crucial for maintaining healthy aquatic ecosystems and supporting human well-being. Fish play an integral role as a source of food, recreation, and livelihood for millions of people globally. Safeguarding and conserving fish biodiversity ensures that future generations continue to benefit from the numerous ecological, nutritional, and economic advantages provided by fish (Lisbeth 2023). Furthermore, the abundance and diversity of species within an ecosystem act as key indicators of its ecological health. The population size and condition of fish are directly correlated to the overall health of water bodies, with changes in fish communities often reflecting shifts in environmental quality (Hamzah 2007). Fish biodiversity is increasingly threatened by various human activities, including overfishing, habitat destruction, and pollution (Lisbeth 2023). Ecotourism represents a promising sector for biodiversity conservation, offering potential to reverse biodiversity loss and assist in enhancing the economy (Buckley 2009).

Arunachal Pradesh, located at coordinates 27.975° N and 94.455° E, occupies a large portion (61%) of the eastern Himalayan region, covering an area of 83,743 km² within the Indo-Burma biodiversity hotspot (Myers et al. 2000). The region is characterized by mountainous terrain, hilly regions, lowland areas, and diverse drainage systems. An extensive network of river systems provides rich habitats for a wide range of fish and other aquatic organisms. The tribal communities in Arunachal Pradesh have a close connection to nature and its resources, and for generations they have practiced community-based fishing. Wild fish from these water bodies are a vital natural resource, providing an essential protein source for rural populations, particularly for growing children and lactating mothers. Consequently, the conservation of fish populations, along with water resources, plays a vital role for present and future generations, especially in light of increasing environmental challenges.

As far as the ichthyofauna of the state is concerned, McClelland (1839) was considered the earliest pioneering worker, who reported four species. This was followed by subsequent contributions from Chaudhuri (1913), Hora (1921), Jayaram (1963), Jayaram & Mazumdar (1964), Srivastava (1966), Dutta & Sen (1977), and Dutta & Barman (1984, 1985). Ghosh (1979) was the first to report on the fish fauna diversity of the East Siang District, documenting 16 species, followed by Sen (1999), who reported 32 species, and Sen (2006) reported 21 species from the same district. Sinha & Tamang (2015) extended the documentation by reporting 121 fish species from the natural water bodies of both lotic and lentic environments in eastern Siang, and Das et al. (2017) listed 82 species from the Siang River. Over the past two decades, several authors have shown significant interest in documenting the fish fauna of the state. Nath & Dey (2000) first compiled the fish fauna of the state in the form of a book, which reported 131 species. Thereafter, Bagra et al. (2009) reported 213 species, and then Darshan et al. (2019) further updated to 218 species. Recently, Tamang & Das (2024) listed an additional 25 species, bringing the total to 233 species. In recent years, Gurumayum & Nath (2022) listed 30 threatened species in Arunachal Pradesh based on museum collections and published literature and suggested a dedicated and intense effort for conservation as well as exploration and documentation. Several studies have also documented the practice of non-conventional fishing methods, habitat degradation, and disturbances to riparian vegetation within the Itanagar Wildlife Sanctuary in Papum Pare District and along the Sille river in East Siang District (Chaudhry & Tamang 2007; Tamang & Chaudhry 2012; Taro et al. 2022). These activities are gradually exerting detrimental effects on the local fish fauna, leading to significant ecological concerns. The gradual decline in fish populations, attributed to these anthropogenic pressures, emphasizes the urgent need for a more comprehensive understanding and management of the aquatic ecosystems. Review of literature revealed no systematic documentation of the ichthyofaunal diversity of the Sirum River. The Sirum River is a socio-culturally integral part of the Adi tribe (Vishwanath 2002) and fishing is a popular recreational activity, with many people enjoying fishing as a way to relax and connect with nature. Documentation of the fish fauna of Sirum River forms the basis of this study, aiming to create a comprehensive database that serves as valuable information for future conservation efforts and management strategies.

## MATERIALS AND METHODS

### Study area

The Sirum River originates from the hilly terrain known as 'Rumdong Kosing' at coordinates approximately 28.544° N and 95.628° E near Adi Pasi Sibuk Village in the Upper Siang District of Arunachal Pradesh. It is an important tributary of the Siang River, that follows a roughly 33 km zigzag course through dense mountain forests, flowing over sedimentary rocks and eventually converging with the Siku River near Mebo Village in the East Siang District, where it is locally known as the 'Sikusirum' River, which finally forms the headwaters of the Brahmaputra River in the south (Image 1). The recorded temperature in this region ranges from 4–8 °C, with altitudes varying 180–2,400 m near Adi Pasi Sibuk Village. The Sirum River is characterized by a prevalence of medium to large boulders, cobbles, and pebbles, particularly in its upper reaches. These conditions, combined with its clear freshwater, create an ideal habitat for true hill stream fish species.

**Fish sampling**

Fish sampling was conducted from October 2023–September 2024 over the period of one year, with samples collected from three study sites (I, II, and III) along the river, each approximately 1 km in length, with a 1 km gap between each site for comparative analysis. Traditional and sustainable fishing methods were employed consistently across all three selected sites—Porang, Edil, and Kotong. These methods included conical-shaped basket traps, which allow fish to enter but prevent their escape, as well as other techniques such as Lipum, Hibok, and cast nets. Lipum, in particular, is a fishing technique commonly used during the winter season. Medium-sized boulders are arranged in a cylindrical pattern with gaps between them, and the spot is left undisturbed for about one month. This setup provides shelter for bottom-feeding fishes. After one month, a large cylindrical bamboo trap, known as 'Edil' (open at both the top and bottom), is used to cover the boulders. The bottom edges are sealed with sand and gravel to prevent the fish from escaping. The boulders are then manually removed, allowing the fish to move into the trap, which is connected to a smaller collection conical trap attached just above the bottom of Edil.

*Hibok* is another traditional fishing method, typically employed in a diverted river course. One side of the watercourse is blocked using various materials such as boulders, banana leaves, ferns, plastic, soil, and sand. As the water level decreases, fish emerge from the gaps between the boulders and are subsequently captured by hand or with a scoop net.

The frequent use of non-conventional methods and indiscriminate fishing practices in various water bodies throughout the state has led to restrictions on fishing activities in many villages, with penalties imposed by village authorities. As a result, fish sampling in the present study was conducted only after obtaining prior authorization from the village head, the Gaon Burah. Additionally, a local guide and several village fishing experts were engaged to ensure the proper investigation and documentation of fish diversity. The collected fish specimens were photographed in the field using a Nikon

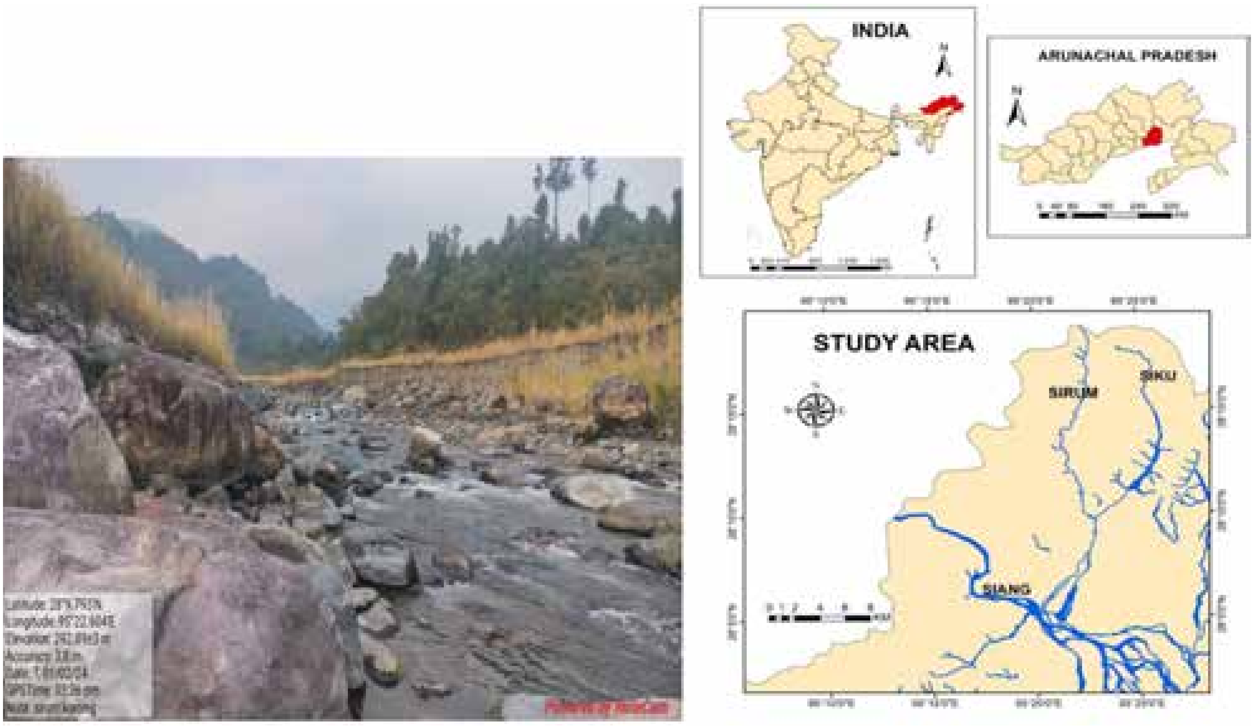


Image 1. The habitat characteristics and study area (Sirum River), East Siang District, Arunachal Pradesh (Maps are not to scale).

D850 DSLR camera with a 24–120 mm lens. Initially, the specimens were preserved in 5% formalin on site and then transported to the laboratory at the Department of Zoology, Jawaharlal Nehru College, Pasighat. In the laboratory, the specimens were sorted and identified using standard literature (Talwar & Jhingran 1991; Nath & Dey 2000; Darshan et al. 2019). The conservation status of the identified species was confirmed from the IUCN Red List of Threatened Species Version 2024-2 (https://www.iucnredlist.org). The scientific names, families, and orders of the identified fish species were confirmed following Eschmeyer's Catalogue of Fishes (Fricke et al. 2025). The identified fish specimens were stored in 10% formalin, labelled, registered, and deposited in the Fish Museum of the Department of Zoology, Jawaharlal Nehru College, Pasighat, for future reference.

**Data analysis**

Diversity indices were calculated as per the standard method (Shannon & Wiener 1963) by the formula: $H = -\Sigma (ni/N) \log2 (ni/N)$, where H = Shannon-Wiener index of diversity, ni = total number of individuals of a species and N = total number of individuals of all the species. Evenness of the species was calculated following Pielou's evenness index (Pielou 1966), i.e., $J = H'max/logS$, where H'max = the maximum value of Shannon-Wiener's index, and S = the total number of species. The value of J falls between 0 and 1. The less variation in the species composition between the communities, the higher the E value. Simpson's diversity index was calculated by the formula: $D = 1-(\Sigma n(n-1)/N(N-1))$, where D = diversity, n = number of individuals of a single species, N = total number of all species. The relative abundance (RA%) of each study site was calculated by dividing the number of species by the total number of individuals of all the species, multiplying by 100. All the diversity indices were performed using PAST software version 4.02.

## RESULTS

A systematic list of fish species collected from three contiguous lotic water bodies (sites I, II, & III) of the Sirum River, along with their local names, abundances, types, and IUCN conservation status, is provided in Table 1. The total ichthyofaunal diversity revealed 54 fish species distributed over four orders, 15 families, and 38 genera, with a total of 1909 individuals captured (Table 1).

The catch composition revealed that Cyprinidae was the dominant family, contributing 35.2% (19 species), followed by Nemacheilidae with 11.1% (6 species), and both Danionidae and Bagridae accounted for 9.3% (5 species) each. Sisoridae represented 5.6% (3 species), while Schilbeidae, Psilorhynchidae, Cobitidae, Channidae, Badidae, and Amblycipitidae each contributed 3.7% (2 species). The families Siluridae, Mastacembelidae, Heteropneustidae, and Botiidae were the least represented, each contributing 1.9% (1 species) (Table 1 & Figure 1).

Quantitative analysis of the three study sites revealed that, among the 54 species, Hill Trout *Opsarius bendelisis* was the most abundant species, with 104 individuals, followed by *Aborichthys kempi* (81), *Garra annandalei* (74), and both *Garra arupi* and *Mustura daral* (65 each) in comparison to others (Table 1 & Figure 2). The majority of species were found in all three sites, except six species: *Schistura scaturigina* and *Psilorhynchus arunachalensis*, *Clupisoma gorua*, *Eutropiichthys vacha*, *Pterocryptis indica*, and *Macrognathus pancalus*, which were absent in Site III (upstream). Fish abundance showed that site I (downstream) has the highest number of individuals (1,088), followed by site II (midstream) (573 individuals), while site III (upstream) has the lowest number of captures (246 individuals). This pattern suggests that fish diversity and abundance are inversely correlated from downstream to upstream.

## DISCUSSION

The IUCN conservation status shows that out of 54 species, majority, i.e., 57% (31 species), belong to the Least Concern category, followed by 19% (10) as Not Evaluated, 7% (4) as Data Deficient, 7% (4) as Vulnerable, 6% (3) as Endangered, and 4% (2) as Near Threatened (Table 1 & Figure 3). The threatened species recorded in the study included three species as Endangered: *Tor putitora, Neolissochilus hexagonolepis,* and *Amblyceps arunachalensis*, and four species as Vulnerable: *Schizothorax richardsonii*, *Semiplotus semiplotus*, *Botia rostrata*, and *Pseudecheneis sirenica* (Table 1).

Regarding the biodiversity indices, the Shannon-Weiner index (H) values were found to be quite similar across three sites: site I (3.831), site II (3.812), and site III (3.678). The values in sites I and II were almost identical, whereas site III exhibited a slightly lower value. This suggests that, despite minor differences in these values, the overall diversity of species throughout the three sites is relatively comparable. Similarly, the Simpson diversity index showed that the values for all three sites were very similar: site I (0.9753), site II (0.9749), and site III (0.9703). This indicates that, despite slight variations

**Table 1. List of fish species, local name, abundance, types, IUCN conservation status collected from the Sirum River, East Siang District, Arunachal Pradesh.**

| Species | Local name | Study sites | | | No. of specimens | Type of fish | Conservation status |
|---|---|---|---|---|---|---|---|
| | | I | II | II | | | |
| **I. Order: Cypriniformes**<br>**i. Family: Cyprinidae** | | | | | | | |
| *1.* *Bangana dero* (Hamilton, 1822) | Ngopy | 15 | 8 | 6 | 29 | Carp | LC |
| *2.* *Barilius vagra* (Hamilton, 1822) | Sepung | 19 | 13 | 5 | 37 | Carp | LC |
| *3.* *Chagunius chagunio* (Hamilton, 1822) | Lingkar/Hara peking | 9 | 5 | 2 | 16 | Carp | LC |
| *4.* *Garra annandalei* (Hora, 1921) | Ngopih | 45 | 20 | 9 | 74 | Carp | LC |
| *5.* *Garra arunachalensis* (Nebeshwar & Vishwanath, 2013) | Ngopih | 25 | 15 | 8 | 48 | Carp | NE |
| *6.* *Garra arupi* (Nebeshwar et al., 2009) | Ngopih | 36 | 20 | 9 | 65 | Carp | NE |
| *7.* *Garra birostris* Nebeshwar & (Vishwanath, 2013) | Ngopih | 18 | 12 | 6 | 36 | Carp | NE |
| *8.* *Garra kempi* (Hora, 1921) | Ngopih | 15 | 3 | 1 | 19 | Carp | LC |
| *9.* *Labeo pangusia* (Hamilton, 1822) | Tengir | 15 | 8 | 4 | 27 | Carp | NT |
| *10.* *Neolissochilus hexagonolepis* (McClelland, 1839) | Taga | 16 | 8 | 6 | 30 | Carp | EN |
| *11.* *Puntius chola* (Hamilton, 1822) | Ngrtak/Metak | 9 | 4 | 1 | 14 | Barb | LC |
| *12.* *Puntius sophore* (Hamilton, 1822) | Ngrtak/Metak | 15 | 7 | 3 | 25 | Barb | LC |
| *13.* *Raiamas bola* (Hamilton, 1822) | Osonggombey | 9 | 5 | 3 | 17 | Trout | LC |
| *14.* *Rasbora daniconius* (Hamilton, 1822) | Jommeng | 16 | 5 | 3 | 24 | Minnows | LC |
| *15.* *Schizothorax richardsonii* (Gray, 1832) | Ngoying | 20 | 14 | 3 | 37 | Common snowtrout | VU |
| *16.* *Schizothorax sikusirumensis* (Jha, 2020) | Ngoying | 18 | 12 | 6 | 36 | Common snowtrout | NE |
| *17.* *Semiplotus semiplotus* (McClelland, 1839) | Orpey | 25 | 15 | 6 | 46 | Carp | VU |
| *18.* *Tariqilabeo latius* (Hamilton, 1822) | Piiyong | 25 | 12 | 4 | 41 | Carp | LC |
| *19.* *Tor putitora* (Hamilton, 1822) | Rulbung | 26 | 12 | 4 | 42 | Carp | EN |
| **ii. Family: Danionidae**<br>*20.* *Danio dangila* (Hamilton, 1822) | Tapong | 24 | 13 | 5 | 42 | Minnows | LC |
| *21.* *Devario aequipinnatus* (McClelland, 1839) | Tapong | 36 | 12 | 5 | 53 | Minnows | LC |
| *22.* *Devario devario* (Hamilton, 1822) | Tapong | 20 | 12 | 6 | 38 | Minnows | LC |
| *23.* *Opsarius bendelisis* (Hamilton, 1807) | Taseng | 56 | 30 | 18 | 104 | Hill trout | LC |
| *24.* *Opsarius barna* (Hamilto, 1822) | Seypar | 32 | 16 | 5 | 53 | Barred hill trout | LC |
| **iii. Family: Nemacheilidae**<br>*25.* *Aborichthys kempi* (Chaudhuri, 1913) | Riibi | 40 | 26 | 15 | 81 | Loach | NT |
| *26.* *Mustura daral* (Rameshori et al., 2022) | DiiteRiibi | 36 | 24 | 5 | 65 | Loach | NE |
| *27.* *Paracanthocobitis mackenziei* (Chaudhuri, 1910) | Riibi | 23 | 12 | 5 | 40 | Loach | LC |
| *28.* *Paraconthocobitis botia* (Hamilton, 1822) | Riibi | 36 | 13 | 6 | 55 | Loach | LC |
| *29.* *Paraconthocobitis hijumensis* Rime et al., 2022 | Riibi | 12 | 5 | 2 | 19 | Loach | NE |
| *30.* *Schistura scaturigina* (McClelland, 1839) | Riibi | 12 | 8 | 0 | 20 | Loach | LC |
| **iv. Family: Psilorhynchidae**<br>*31.* *Psilorhynchus arunachalensis* (Nebeshwar et al., 2007) | Riipi piijep | 9 | 4 | 0 | 13 | Minnow | DD |
| *32.* *Psilorhynchus balitora* (Hamilton, 1822) | Riipi piijep | 16 | 10 | 6 | 32 | Minnow | LC |
| **v. Family: Botiidae** | | | | | | | |
| *33.* *Botia rostrata* (Gunther, 1868) | Riiibi | 40 | 14 | 6 | 60 | Loach | VU |
| **vi. Family: Cobitidae**<br>*34.* *Canthoprys gongota* (Hamilton, 1822) | Riibi | 6 | 3 | 1 | 10 | Loach | LC |
| *35.* *Lepidocephalichthys guntea* (Hamilton, 1822) | Riibi | 8 | 4 | 1 | 13 | Loach | LC |
| **II. Order: Siluriformes**<br>**vii. Family: Amblycipitidae**<br>*36.* *Amblyceps apangi* (Nath & Dey, 1989) | Beyek | 40 | 18 | 12 | 70 | Catfish | LC |

| Species | Local name | Study sites | | | No. of specimens | Type of fish | Conservation status |
|---|---|---|---|---|---|---|---|
| | | I | II | II | | | |
| *37. Amblyceps arunachalensis* (Nath & Dey, 1989) | Beyek | 36 | 20 | 7 | 63 | Catfish | EN |
| **viii. Family: Bagridae**<br>*38. Batasio fasciolatus* (Ng, 2006) | Nareng | 14 | 8 | 6 | 28 | Catfish | LC |
| *39. Batasiomerianiensis* (Chaudhuri, 1913) | Nareng | 16 | 8 | 4 | 28 | Catfish | DD |
| *40. Mystus dibrugarensis* (Chaudhuri, 1913) | Nareng | 18 | 13 | 4 | 35 | Catfish | LC |
| *41. Mystus pulcher* (Chaudhuri, 1911) | Nareng | 10 | 5 | 2 | 17 | Catfish | LC |
| *42. Olyra longicaudata* (McClelland, 1842) | Beyek | 30 | 16 | 8 | 54 | Catfish | LC |
| **ix. Family: Heteropneustidae**<br>*43. Heteropneustes fossilis* (Bloch, 1794) | Beyek | 4 | 2 | 1 | 7 | Catfish | LC |
| **x. Family: Schilbeidae**<br>*44. Clupisoma gorua* (Hamilton, 1822) | Gerek | 6 | 2 | 0 | 8 | Catfish | LC |
| *45. Eutropiichthys vacha* (Hamilton, 1822) | Gerek | 7 | 3 | 0 | 10 | Catfish | LC |
| **xi. Family: Siluridae**<br>*46. Pterocryptis indica* (Datta et al., 1987) | Beyek | 10 | 3 | 0 | 13 | Catfish | DD |
| **xii. Family: Sisoridae**<br>*47. Exostoma dhritae* (Pratima et al., 2022) | Ngorey-rejep | 16 | 13 | 5 | 34 | Catfish | NE |
| *48. Glyptothorax pasighatensis* (Arunkumar, 2016) | Ngokey | 12 | 8 | 3 | 23 | Catfish | NE |
| *49. Pseudecheneis sirenica* (Vishwanath & Darshan, 2007) | Ngorey | 17 | 12 | 3 | 32 | Catfish | VU |
| **III. Order: Anabantiformes**<br>**xiii. Family: Badidae**<br>*50. Badis assamensis* (Ahl, 1937) | Ngotupatang | 20 | 12 | 6 | 38 | Chameleon fish | DD |
| *51. Badis singenensis* (Geetakumari & Kadu, 2011) | Ngotupatang | 25 | 15 | 8 | 48 | Chameleon fish | NE |
| **xiv. Family: Channidae**<br>*52. Channa punctata* (Bloch,1793) | Talum | 10 | 3 | 1 | 14 | Snakehead | LC |
| *53. Channa pomanensis* (Gurumayum & Tamang, 2016) | Talum | 9 | 4 | 3 | 16 | Snakehead | NE |
| **IV. Order: Synbranchiformes**<br>**xv. Family: Mastacembelidae**<br>*54. Macrognathus pancalus* (Hamilton, 1822) | Germey | 6 | 4 | 0 | 10 | Spiny eel | LC |
| | **Total** | **1088** | **573** | **248** | **1909** | | |

DD—Data Deficient | EN—Endangered | LC—Least Concerned | NE—Not Evaluated | NT—Near Threatened | VU—Vulnerable.

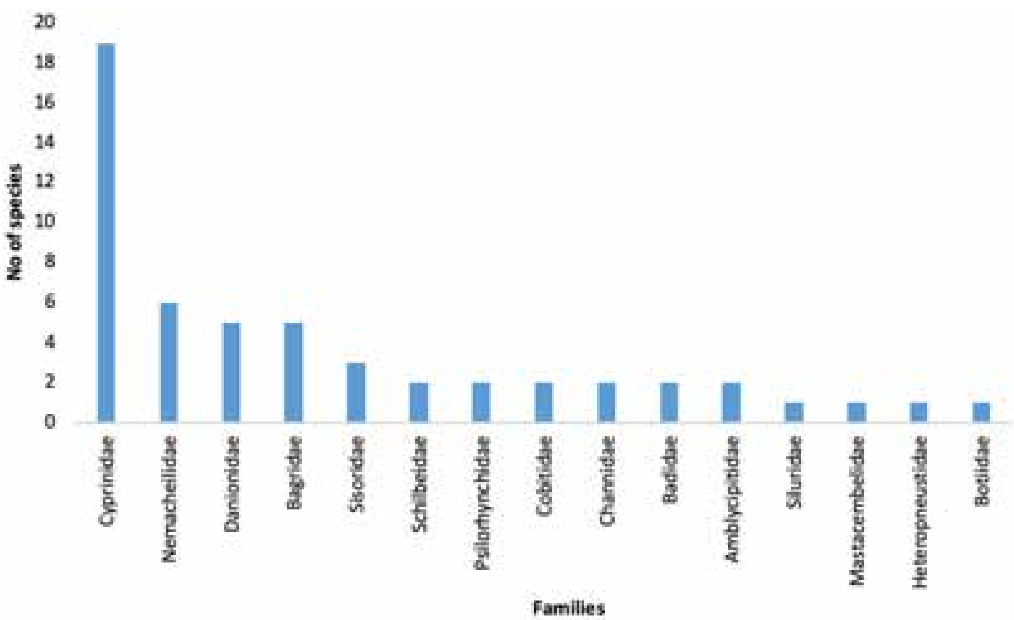


**Figure 1. Distribution of fish species among different families.**

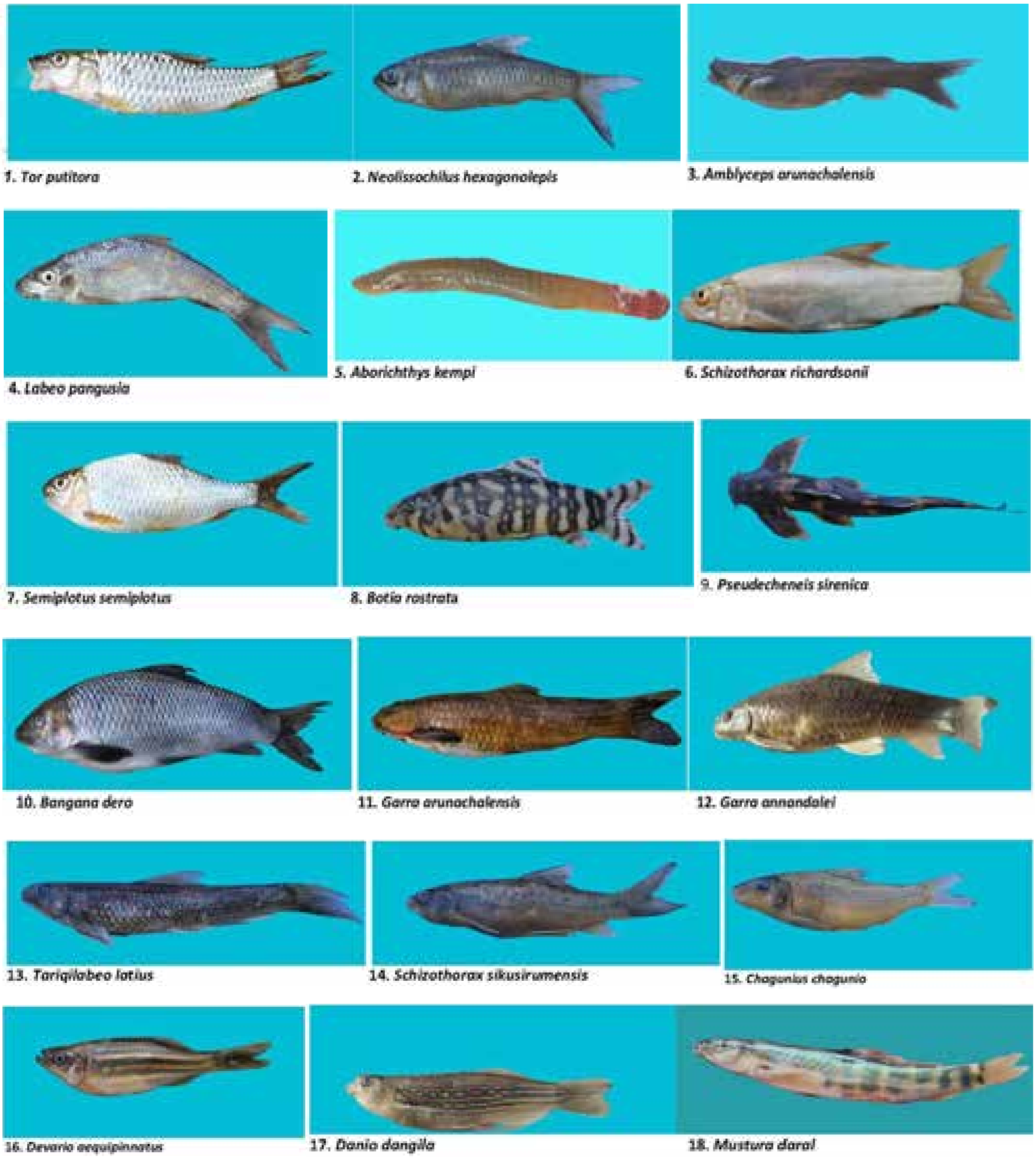


**Image 2. Some threatened and economically important food and ornamental fish species encountered in the Sirum River. © Obinam T.**

in the specific biodiversity measures at each site, the overall community diversity is nearly identical over the three locations. Pielou's evenness indices (J) showed that the values for the three sites were similar: site-I (0.8541), site-II (0.838), and site-III (0.8246), showing only minor variations. These relatively high values suggest that species at all three sites are fairly evenly distributed. The relative abundance (RA%) is inversely correlated, depicting the highest in site-III, i.e., 19.3, whereas lower in site-II, 9.4, and lowest in site-I, 4.9 (Table 2). The taxonomic enumeration of 54 species, with the majority falling under the Least Concern category, indicates a healthy level of species diversity and stability.

Aquatic environments worldwide are facing serious

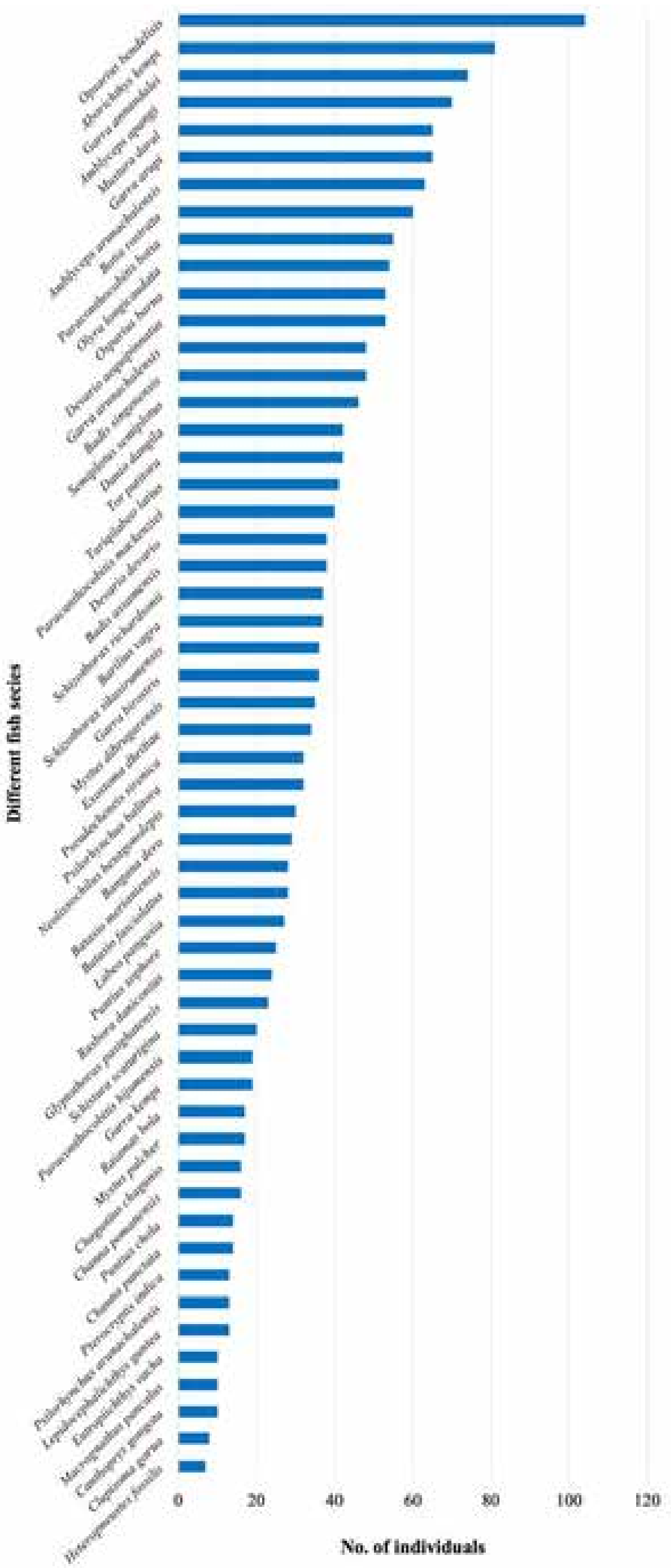


**Figure 2. Different fish species and its abundance collected from the Sirum River, East Siang District, Arunachal Pradesh.**

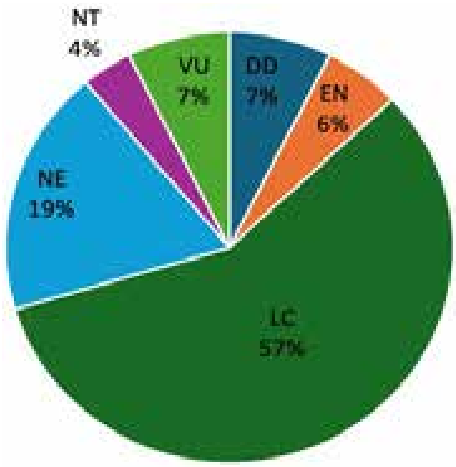


**Figure 3. IUCN Red List status of fish species recorded from the Sirum River, East Siang District, Arunachal Pradesh.**

**Table 2. Diversity indices of three study sites of Sirum River.**

| | Study Sites | | |
|---|---|---|---|
| | I | II | III |
| Species richness | 54 | 54 | 48 |
| Species abundance | 1088 | 573 | 248 |
| Simpson_1-D | 0.9753 | 0.9749 | 0.9703 |
| Shannon_H | 3.83 | 3.81 | 3.68 |
| Evenness_e^H/S | 0.85 | 0.84 | 0.82 |
| Relative abundance (%) | 4.9 | 9.4 | 19.3 |

threats to both their biodiversity and ecosystem stability, suggesting ongoing research aimed at developing systematic conservation planning to protect freshwater biodiversity (Margules & Pressey 2000; Saunders et al. 2002). The frequent degradation of stream and riverine ecosystems ultimately leads to the destruction of the structure and function of stream biota, which is a critical concern for the health of these ecosystems (Stoddard et al. 2006). On the other hand, faunal documentation from various regions has become an important aspect of understanding the current status of biodiversity, especially in light of the rapidly declining global environmental conditions.

During the study period, it was observed that the rural populations of the adjacent villages depend on the fish fauna of the Sirum River for their subsistence needs. Besides serving as a critical dietary component, fish also becomes a primary source of income for local households. They engage in the sale of fish in various forms, like fresh, dried, smoked, and processed varieties, all of which are sold in local markets. Some fish species observed in the market were *Garra annandalei*, *Garra arunachalensis*, *Tor putitora*, *Neolissochilus hexagonolepis*, *Schizothorax sikusirumensis*, *Semiplotus semiplotus*, and *Bangana dero*. These fish are not only ecologically significant but also commercially valuable. The market price of fish ranges Rs. 500–1000/- per kg in Pasighat Town.

While conducting interviews with nearby villagers and the head Goan Burah, it was revealed that, over the past two decades, anthropogenic pressures such as illegal fishing practices have gradually led to a decline in the fish fauna of the Sirum River. In response to these ongoing threats, the local governing authority of Sibuk Village in Upper Siang District, in the upstream and Mebo block, along with Mebo and Ayeng villages in East Siang District, in the downstream, respectively, has taken proactive measures by imposing a ban on unauthorized fishing in the Sirum River. The village community has imposed a penalty of Rs. 25,000 for illegal fishing. However, the community allows for sustainable community fishing occasionally, but only with prior permission from the village head. If the fish fauna of the Sirum River is well managed and sustainably used, the region could attract both national and international tourists for angling, which provides a significant source of income for both the state, and the local communities.

Cleaning drives were organized by the local community along the banks of the Sirum River, particularly women's groups, students, and youth organizations as, part of the Swachh Bharat Abhiyan. The Sirum River is not only a vital natural resource but also fulfills the cultural and spiritual significance of the tribal community. Moreover, the river also possesses the majority of fish that belong to the Least Concern category and some threatened species. Therefore, this study allows consideration of a long-term conservation strategy for ichthyofauna in the Sirum River.

## CONCLUSION

This study represents the first comprehensive documentation of the ichthyofauna of the Sirum River, comprising 54 fish species belonging to four orders, 15 families, and 38 genera, which is valuable data for government agencies, non-governmental organizations (NGOs), ichthyologists, and research scholars in relation to future conservation efforts and sustainable utilization of aquatic resources.

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COMMUNICATION

# Preliminary investigation on morphometrics and habitat of the Indian Flapshell Turtle *Lissemys punctata* (Bonnaterre, 1789) (Reptilia: Trionychidae) in rural wetlands of Alappuzha, Kerala, India

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**Abstract:** Turtles require significant conservation attention due to their low reproductive output and delayed maturity. We analysed the morphometry of Flap-shell Turtle *Lissemys punctata* from selected wetland sites in Alappuzha District, Kerala, India, to address the problem of suboptimal habitats for the species outside protected areas. Information was collected through surveys of local inhabitants, and live specimens. From our surveys in 11 sites that were identified as the habitats for Black Pond Terrapin *Melanochelys trijuga* and *L. punctata*, *M. trijuga* was predominantly found in Mannarassala (Haripad) and *L. punctata* in Karthikappally. Our preliminary morphometric analysis revealed potential links between shell dimensions and the wetland's water quality, contributing to habitat assessment and species management. Our questionnaire study indicated a decline in *L. punctata* population, primarily due to their exploitation for food and medicinal purposes, emphasizing the urgent need for targeted conservation efforts to ensure the species' survival outside protected areas.

**Keywords:** Conservation, environmental stressors, field surveys, human exploitation, late maturity, protected areas, population decline, reproductive output, species management, water quality.

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**Competing interests:** The authors declare no competing interests.

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**Author contributions:** SWE: Research Conceptualization, Methodology and manuscript editing. NTP: Reviewing and manuscript editing. SS: Conducted field surveys, carried out photographic documentation, prepared the draft manuscript and editing. VAS: Acquired necessary permissions for the field surveys, Supervision and reviewing of manuscript editing.

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## INTRODUCTION

The Indian Flapshell Turtle *Lissemys punctata* (Bonnaterre, 1789) is a freshwater turtle found in tropical South Asian countries such as India, Sri Lanka, Bangladesh, Nepal, Myanmar, and Pakistan. The femoral flaps that stretch from the shell to envelop the limbs are its distinctive features. A flapshell turtle can grow up to 370 mm long and survive for roughly 20 years (Das 1995, 2011). While adults have oval shells, young ones have round shells. They live in freshwater bodies like shallow lentic waters of lakes, rivers, streams, ponds, and marshes as well as artificial storage tanks, and canals dug for irrigation. They prefer sandy or muddy water bottoms because they may easily burrow into them. Monitoring health of the body and the habitat of *L. punctata*, a vulnerable freshwater turtle species, is crucial for effective in situ conservation efforts (Rashid & Swingland 1997; Das 2011). The morphometrical characteristics of *L. punctata* and water quality of the lake they inhabit are intricately linked with the turtles' health and survival, being directly influenced by the physicochemical properties and pollution levels of their aquatic environment (Baruah et al. 2016).

The physicochemical parameters of lake inhabited by *L. punctata*, including pH, dissolved oxygen, temperature, and nutrient levels can help to assess the suitability of the habitat for its long-term survival (Bhupathy & Vijayan 1989; Dutta et al. 2022). Morphometric measurements, such as carapace length, width, and height, as well as limb & head dimensions, can provide insights into the species' growth, development, and adaptations to their environment (Hossain et al. 2013). Integrating the findings from morphometrical analysis and water quality assessment can contribute to a comprehensive understanding of the species' ecology and the pressures it faces in its natural environment (Moll & Moll 2004). A lack of comprehensive conservation work will cause many species of turtles and tortoises to go extinct in the next few decades (Turtle Conservation Fund 2003). The current study aims to do a thorough morphometric examination of *L. punctata* (Image 1), encompassing measures of body weight, plastron length, carapace width, and carapace length, so that the health of *L. punctata* and its environment may be tracked with the use of this data to develop management plans and targeted conservation initiatives (Rhodin et al. 2018).

Image 1. Indian Flapshell Turtle *Lissemys punctata*. © Sajan Sunny.

## METHODS

Visits were made to upper Kuttanad Taluk and Karthikapally of Alappuzha District (Image 2). In the study areas, based on their habitats, both the species of turtles *M. trijuga* (called Karayaama or land turtle/tortoise) and *L. punctata* (called Vella aama or water turtle/tortoise) were observed respectively. Data about the flapshell turtles was compiled using the questionnaire survey approach. Random inquiries were posed to the villagers who lived close to the wetlands. A total of 15 *L. punctata* turtles, (female = 10, male = 4 and one juvenile) were measured and weighed in the least invasive way possible. In adults, sexes were distinguished by differences in length of limbs, tail, and configurations (Das 1995). Morphological parameters were measured using flexible meter tape and ruler scale nearest to 0.1 cm, and weight was loaded on electronic weighing balance nearest to 0.1 g. The data of the present study was undertaken with 20 associations comprising of each turtle morphometrics. Based on mean values of males and females, the percentage of 14 morphometric characteristics were calculated (Table 1). The statistical analysis was done using statistiXL 2.0 for Microsoft Excel 2016. Regression test was used to analyze data pertaining to the different morphometric measurements of *L. punctata* and deduce the importance of the correlation coefficient at the two-tailed level.

## RESULTS

### Questionnaire & Field Surveys

A total of 150 people, representing a range of ages (14–80), participated in the survey. Ninety percent of respondents were interested in providing information about turtles, whereas 10% showed little interest in gathering data about them. The fishing community in the Alappuzha District is well known, and they were crucial in aiding in the turtle capture utilizing different kinds of nets.

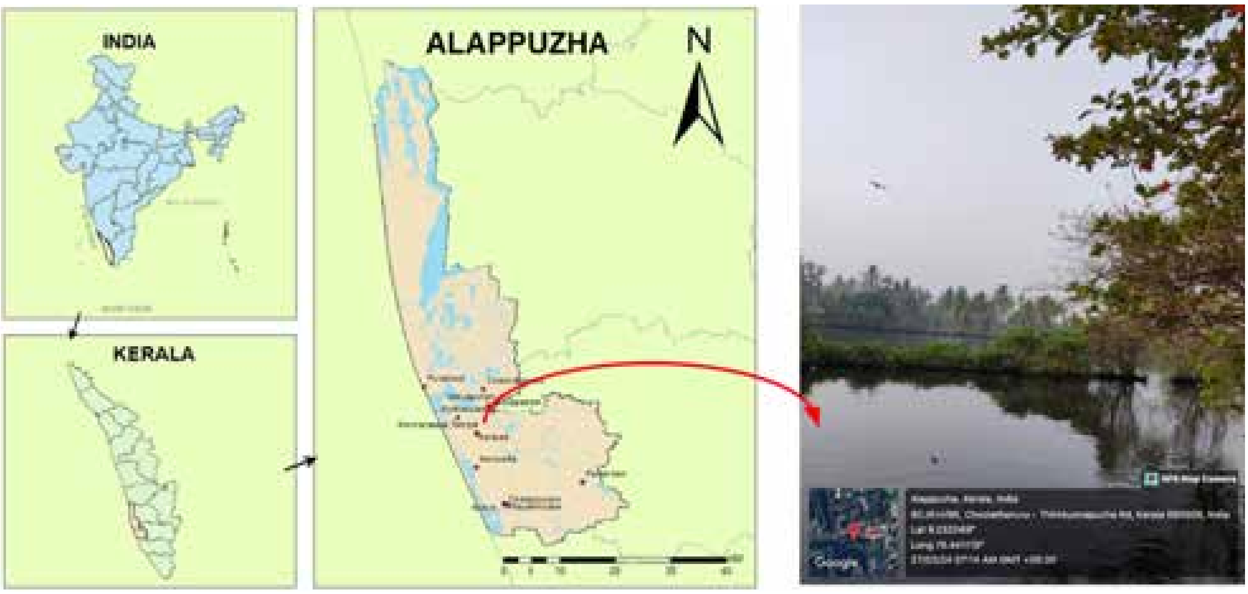


**Image 2. Map depicting the study area.**

According to the results of the survey, Mannarassala has higher *M. trijuga* population while Karthikapally has higher *L. punctata* population. The local people are unaware of the species' endangered status. *Melanochelys trijuga* was observed to be intensively utilized for medicinal and commercial purposes whereas *L. punctata* are hunted and traded for meat consumption. A good number of turtles (*M. trijuga*) are protected with the belief of sanctity in the temple pond of Mannarassala, Ambalappuzha of Alappuzha district. The illegal collection of turtle eggs for consumption and traditional medicine was observed to pose a threat to the survival of turtles, as it can significantly reduce reproductive success and contribute to a population decline. In some locations of Karthikapally, turtles were seen to be hunted for food and for traditional medicines.

**Morphometrics**

The shell height of males varied from 11.0 –13.5 cm (mean 11.8 ± 1.1 cm) and that of females varied from 13.0–17.0 cm (mean 14.8 ± 1.4 cm). The mean length of males and females were 17.8 cm and 22.0 cm, respectively. It was observed that the mean length of females were 1.2 times greater than the males. The weight of male turtles varied 0.42–0.78 kg with a mean value of 0.56 ± 0.16 kg and that of females varied from 0.7 kg to 1.53 kg with a mean value of 1.08 ± 0.31 kg. The mean weight of females were approximately two times greater than the males (Table 1). From the regression analysis, it was evident that all the correlation coefficients had positive values (Table 2), and when the size or length increases, the associated covariate, i.e., weight also increases.

The correlation coefficient between straight carapace length (SCL) & curved carapace length (CCL) was 0.961. The F-value from ANOVA was 155.4 indicating that CCL increases with increase in SCL. The correlation coefficient between SCL & straight carapace width (SCW) was 0.96. The F-value of 150.98 showed that SCW increases with increase in SCL. The correlation coefficient between SCL & straight plastron length (SPL) was 0.938. The F-value of 95.63 showed that when SCL increases SPL also increases. The correlation coefficient between SCL & straight plastron width (SPW) was 0.951. The F-value from ANOVA of 124.201 showed that SCL increases with increase in SPW. The correlation coefficient was found significant in all the above cases. The correlation coefficient between CCL & curved carapace width (CCW) was 0.952. The F-value from ANOVA was 124.590. So, it showed CCW increases as CCL increases. The correlation coefficient was significant. Similarly, all the parameters are correlated and are significant because $p < 0.01$. The shell height of male *L. punctata* was 24.29% whereas that of females was 75.71%. The carapace lengths (SCL and CCL) of males and females were 24.8% and 75.20%, respectively. Carapace width (SCW and CCW) of the males was 25% and females was 75%, plastron length (SPL and CPL) of males was 23.5% and females was 76.5%. Plastron width (SPW and CPW) of males was 25.06% and females 74.94% and the body weight of males was 17.30% and females 82.7%. It was found that all the regression equations related to the morphometric analysis are correlated and their values are significant (Tables 2, 3, & 4).

**Table 1. Measurements of adult male and female Flapshell Turtle *Lissemys punctata*.**

| Parameters | Males (n = 4) | | Females (n = 10) | |
|---|---|---|---|---|
| | Range | Mean ± SD | Range | Mean ± SD |
| Straight Carapace Length SCL (cm) | 14.5–17 | 16.25 ± 1.32 | 17.5–23 | 19.7 ± 2.05 |
| Curved Carapace Length CCL (cm) | 16.5–19 | 17.87 ± 1.31 | 19–26 | 22 ± 2.8 |
| Straight Carapace Width SCW (cm) | 11.5–15 | 13.25 ± 1.55 | 14–18.7 | 15.68 ± 1.5 |
| Curved Carapace Width CCW (cm) | 15.2–18.5 | 16.55 ± 1.51 | 17.5–22.5 | 19.85 ± 1.82 |
| Straight Plastron Length SPL (cm) | 13.5–16 | 14.5 ± 1.08 | 15.5–22.3 | 18.88 ± 2.22 |
| Curved Plastron Length CPL (cm) | 14.7–17 | 15.67 ± 0.96 | 17–23 | 19.9 ± 2.25 |
| Straight Plastron Width SPW (cm) | 12–13.5 | 12.62 ± 0.75 | 12.5–17.5 | 15.1 ± 1.79 |
| Curved Plastron Width CPW (cm) | 12.5–14 | 13.37 ± 0.75 | 13.5–19 | 16.05 ± 1.97 |
| Head Length HL (cm) | 8–15 | 12.37 ± 2.13 | 16–18 | 15.9 ± 1.1 |
| Head Width HW (cm) | 2–3.5 | 2.75 ± 0.64 | 2.3–4.5 | 3.63 ± 0.66 |
| Head Circumference H.CIR (cm) | 8–10 | 9.25 ± 0.95 | 8–14 | 11.5 ± 2.01 |
| Body Circumference (cm) | 29–31.5 | 29.5 ± 1.68 | 30.5–39.5 | 35.4 ± 3.53 |
| Shell Height (cm) | 11–13.5 | 11.87 ± 1.1 | 13–17 | 14.8 ± 1.47 |
| Body Weight (kg) | 0.42–0.78 | 0.56 ± 0.16 | 0.7–1.53 | 1.08 ± 0.31 |

**Table 2. Relationship based on carapace data.**

| Parameters | Correlation coefficient | F | Regression (y = bx + a) |
|---|---|---|---|
| SCL – CCL | 0.961* | 155.4* | CCL = SCL*1.04 + 1.51 |
| SCL – SCW | 0.96* | 150.98* | SCW = SCL* 0.774 + 0.46 |
| SCL – SPL | 0.938* | 95.63* | SPL = SCL*0.886 + 1.535 |
| SCL – SPW | 0.951* | 124.201* | SPW = SCL*0.673 + 1.811 |
| CCL– CCW | 0.952* | 124.59* | CCW = CCL*0.797 + 2.209 |
| CCL – CPL | 0.954* | 131.774* | CPL = CCL*0.87 + 0.540 |
| CCL – CPW | 0.957* | 140.279* | CPW = CCL* 0.683 + 1.003 |
| SCL – HL | 0.76* | 17.797* | HL = SCL*0.508 + 5.42 |
| CCL – HL | 0.709* | 13.13* | HL = CCL*0.439 + 5.711 |

* denotes significance [$p < 0.01$]

**Table 3. Relationship based on head data.**

| Parameters | Correlation Coefficient | F | Regression Equation (y = bx + a) |
|---|---|---|---|
| HL – HW | 0.553* | 5.726* | HW = HL*0.174 + 0.779 |
| HL – HC | 0.729* | 14.772* | HC = HL*0.66 + 0.987 |

* denotes significance [$p < 0.01$]

**Table 4. Relationship based on body data.**

| Parameters | Correlation Coefficient | F | Regression Equation (y = bx + a) |
|---|---|---|---|
| BH – BW | 0.882* | 41.851* | Log weight = Log height*2.648 – 0.086 |
| BH – Circumference | 0.94* | 98.291* | Cicumference = BH*2.128 + 3.885 |

* denotes significance [$p < 0.01$]

### Habitat Assessment

The average values of physicochemical parameters in Muthukulam Lake of Karthikapally area (Alappuzha district) are listed in Table 5. The water quality test yielded a pH value of 7.35. It demonstrated the lake's rather alkaline composition. This alkalinity may be caused by the local population's usage of detergents. These bodies of water might potentially become eutrophic. There would be a possibility of eutrophication in these water bodies. The dissolved oxygen (DO) was found to be 4.7 mg/L, showing anticipated microbial activities. Hardness of the water proclaimed the extremely high levels of calcium and magnesium in the lake. High levels of chloride (> 5,000 mg/L), fluoride (1.39 mg/L), and sulphate (348.67 mg/L) was detected in the water during the present study indicating high levels of freshwater pollution. The high values on electrical conductivity showed maximum ionic concentration of the lake. Low values of iron were detected (0.39 mg/L) and nitrate (4.75 mg/L) showed a moderate value. The high amount of total dissolved solids (TDS) (> 10,000 mg/L) indicated the concentration of dissolved ions in water. The presence of harmful organisms was demonstrated by the massive amounts of *Escherichia coli* and total coliforms in lake water.

**Table 5. Water quality parameters of the studied lakes (Muthukulam, Karthikapally).**

| | Characteristics | Unit | Maximum acceptable limits (Freshwater) | Result |
|---|---|---|---|---|
| **Chemical Parameters** | | | | |
| 1 | Turbidity | NTU | 70 | 6.5 |
| 2 | pH at 25˚C | | 6.0 – 9.0 | 7.35 |
| 3 | Total dissolved solids | mg/L | 1000 | >10000 |
| 4 | Total Hardness | mg/L | 200 – 600 | >5000 |
| 5 | Calcium | mg/L | 75 | 561 |
| 6 | Magnesium | mg/L | 150 | 923 |
| 7 | Chloride | mg/L | 250 | >5000 |
| 8 | Electrical conductivity | micro mhos/cm | 2000 | 39160 |
| 9 | Sulphate | mg/L | 250 | 348.67 |
| 10 | Fluoride | mg/L | 1.5 | 1.39 |
| 11 | Iron | mg/L | 1 | 0.39 |
| 12 | Nitrate | mg/L | 10 | 4.75 |
| 13 | Dissolved Oxygen | mg/L | 4.5 – 10.3 | 4.7 |
| **Biological Parameters** | | | | |
| 14 | Total coliforms | | Shall not be detected/100 ml | Present |
| 15 | E. Coli/100 ml | | Shall not be detected/100 ml | Present |

## DISCUSSION

The present preliminary study provides the first step in understanding the morphometric characteristics and habitat conditions of the Indian flap-shelled turtle, *L. punctata*, in the Muthukulam (Alappuzha) Kerala, India. The results of the present study showed maximum CCL and CW by the males and females of *L. punctata*, was in accordance with published findings (Yadava & Prasad 1982; Bhupathy & Vijayan 1991). The length of head, forelimbs, hindlimbs, and body circumference of males and females revealed in the present investigation agreed with literature (Auffenberg 1981; Agarwal 1987; Shrestha 1997). The juvenile turtle noted by us, had dark striped pattern which tend to reduce with growth (Smith 1931; Das 1995).

The present study found that the female turtles were twice as large in carapace length, carapace width, plastron length, plastron width, and body weight compared to males, consistent with literature (Moll 1984; Bhupathy & Choudhury 1995). The higher body size and weight of females are likely adaptations to accommodate the energy requirements for egg production and brooding, which is an essential reproductive strategy in turtles (Gibbons 1990; Janzen & Paukstis 1991). Our preliminary regression analysis yielded a positive correlation of shell dimensions, which agrees with the literature (Ling & Palaniappan 2011; Hossain et al. 2013; Talukdar et al. 2021). These significant associations indicate that the growth and development of different body parts in *L. punctata* are closely linked, and the measurement of one parameter can be used to reliably predict the value of another (Kuchling & Kuchling 1999; Zuffi et al. 1999). The data represented here has a rather higher number of variables than turtle sample size, which may generate chances for overfitting issue (p>N). The randomness of chances might produce pseudo correlations. Future attempts of improving the current preliminary study must aim to overcome these caveats, as postulated here.

The unsuitable water quality values revealed by us in the Muthukulam (Kayamkulam) lake, with high levels of dissolved solids, hardness, chloride, fluoride, sulfate, *E. coli,* and total coliforms, mirror previous studies on freshwater bodies in Kerala (Das & Jain 2017; Kumar et al. 2015). The alkaline pH, low dissolved oxygen, and high electrical conductivity of the lake water indicate eutrophication, which is a common issue in many water bodies due to human activities, like the detergents use and agricultural runoff (Sharpley et al. 1994; Carpenter et al. 1998; Smith 1998). The high levels of nitrates in the lake water also suggest the presence of organic pollutants, which can have detrimental effects on the aquatic flora and fauna, including the *L. punctata* population (Camargo et al. 2005; Camargo & Alonso 2006). The implications of the poor water quality in the *L. punctata* habitat are significant, as turtles are known to be sensitive to environmental changes and pollution (Davenport & Wrench 1990; van Dijk et al. 2014; Benn et al. 2021). Krishnakumar et al. (2009) studied the distribution, habitat preferences, and conservation status of *L. punctata* in Kerala and reported that the species is widely distributed across the state, but its populations are threatened by habitat degradation, pollution, and illegal harvesting.

In a global context, the challenges faced by freshwater turtles, including *L. punctata*, are not limited to India and its neighboring regions. A review by Buhlmann et al. (2009) on the conservation status of freshwater turtles worldwide revealed that more than 50% of these species are threatened with extinction, primarily due to habitat loss, pollution, and overexploitation. To secure the long-term survival of these endangered species, the authors emphasized the necessity of all-encompassing conservation initiatives that include habitat restoration, pollution prevention, and sustainable resource management. To sum up, this work offers important new information about the morphometric traits and environmental circumstances of the Flap-shelled Turtle of southern Kerala. Future studies and conservation plans targeting *L. punctata* and other freshwater turtle species in the area can be built upon the data and analysis provided here.

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COMMUNICATION

# A preliminary assessment of avifaunal diversity in Parwati Arga Bird Sanctuary, Uttar Pradesh, India

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**Abstract:** Birds are important for the proper functioning of an ecosystem. In this study, the avifaunal diversity of the Important Bird and Biodiversity Area, Parwati Arga Bird Sanctuary situated in Gonda District, Uttar Pradesh was assessed using point count method from March 2024 to February 2025. A total of 140 bird species (53 families and 19 orders) were recorded, of which 110 species (78%) were resident, 29 species (21%) were winter visitors and one species (1%) was a summer visitor. One 'Endangered' species, four 'Vulnerable' species, and six 'Near Threatened' species were recorded as per the IUCN Red List. According to the global population trend, 49 species (35%) were decreasing, 39 species (27%) were stable, 26 species (19%) were increasing, and 26 species (19%) were unknown. This scientific documentation is essential for the forest department to ensure better management and conservation in the sanctuary area.

**Keywords:** Bird survey, global population trend, Gonda District, Important Bird Area, IUCN Red List status, oxbow lake, point count method, Ramsar site, residential status, wetland.

पक्षी किसी भी पारिस्थितिकी तंत्र के समुचित कार्यन्वयन में महत्वपूर्ण भूमिका निभाते हैं। इस अध्ययन में उत्तर प्रदेश के गोंडा जनपद स्थित "पार्वती अर्गा पक्षी अभयारण्य" जो कि एक महत्वपूर्ण पक्षी एवं जैव विविधता क्षेत्र है, की पक्षी विविधता का मूल्यांकन मार्च 2024 से फरवरी 2025 तक पॉइंट काउंट पद्धति के माध्यम से किया गया। कुल 140 प्रजातियों की पहचान की गई जो 53 कुलों (families) और 19 गणों (orders) से संबंधित थीं। इनमें से 110 प्रजातियाँ (78%) निवासी थीं, 29 प्रजातियाँ (21%) शीतकालीन आगंतुक तथा 1 प्रजाति (1%) ग्रीष्मकालीन आगंतुक के रूप में दर्ज की गई। अंतर्राष्ट्रीय प्रकृति संरक्षण संघ (IUCN) की रेड लिस्ट के अनुसार, 1 प्रजाति 'संकटग्रस्त' (Endangered), 4 प्रजातियाँ 'असुरक्षित' (Vulnerable) तथा 6 प्रजातियाँ 'निकट संकटग्रस्त' (Near Threatened) श्रेणियों में रखी गई। वैश्विक जनसंख्या प्रवृत्ति के अनुसार, 49 प्रजातियाँ (35%) घटाव की स्थिति में, 39 प्रजातियाँ (27%) स्थिर, 26 प्रजातियाँ (19%) वृद्धि पर तथा 26 प्रजातियों (19%) की प्रवृत्ति अज्ञात पाई गई। यह वैज्ञानिक अभिलेख वन विभाग के लिए संरक्षण और अभयारण्य क्षेत्र के प्रभावी प्रबंधन हेतु अत्यंत आवश्यक है।

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**Author contributions:** Y-U conceived and designed the study, conducted the fieldwork and finalized the manuscript. MS compiled the data, analyzed the data and prepared the draft manuscript. Both the authors read and approved the final manuscript.

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KALINGA UNIVERSITY

## INTRODUCTION

Avifauna represent highly reliable bio-indicators and serve as effective model organisms for addressing a wide spectrum of environmental concerns due to their pronounced sensitivity to even subtle ecological alterations. They provide critical insights into the health status and functional productivity of ecosystems (Newton 1995; Desai & Shanbhag 2007; Li & Mundkur 2007). Within the Indian subcontinent, the extensive diversity of wetland habitats contributes to a rich avian assemblage, simultaneously functioning as significant wintering refuges for numerous migratory waterbird species. The state of Uttar Pradesh has 31 Important Bird and Biodiversity Areas (IBAs) and 25 protected areas (Rahmani et al. 2016). In the past, studies have been conducted on bird diversity in rural-urban gradients (Siddiqui et al. 2019), agricultural landscapes (Yashmita-Ulman & Singh 2021), unprotected wetlands (Yashmita-Ulman & Singh 2022), riverine systems (Varghese et al. 2007; Yashmita-Ulman 2022) and university campus (Yashmita-Ulman 2023) in Uttar Pradesh. Bird diversity of protected areas in Uttar Pradesh, such as Hastinapur Wildlife Sanctuary (Khan et al. 2013), Okhla Bird Sanctuary (Upadhyay et al. 2019), and Sandi Bird Sanctuary (Khan & Khalid 2024) have been assessed. Previous studies in Parwati Arga Bird Sanctuary have been conducted on biodiversity (Verma et al. 2023), and floristic composition (Khanna 2015; Singh et al. 2016; Singh & Srivastava 2023). But to date, the bird diversity studies are unreported, making this study a pioneering attempt in preparing an inventory of birds in Parwati Arga Bird Sanctuary.

## MATERIALS AND METHODS

### Study Area

The present investigation was undertaken at the Parwati Arga Bird Sanctuary, situated in Tarabganj Tehsil of Gonda District, Uttar Pradesh, encompassing an area of approximately 1,084.47 ha (Rahmani et al. 2016). The site was officially designated as a Bird Sanctuary on 23 May 1990. The sanctuary is characterized by extensive vegetation interspersed with oxbow lakes, namely, Parwati (a deep-water lake) and Arga (a shallow-water lake), both originating from natural depressions and forming a hoof-shaped configuration (Rahmani et al. 2011) (Figure 1).

Geomorphologically, the area represents a part of the paleochannel of the Ghaghara River, which, during its southward course, left behind several minor streams (Agarwal & Mishra 1987). These lakes maintain hydrological connectivity with the Terhi River via the Gulriha Nala. Geographically, the Parwati and Arga lakes are located between 26.955° N, 82.174° E, having an elevation of approximately 93 m. The prevailing climate can be classified as moist mid-latitude, with moderately cold winters and intensely hot summers. The region receives an average annual rainfall of about 1,240 mm, while the temperature ranges from a minimum of 4°C in winter to a maximum of 48°C in summer (Rahmani et al. 2016). Importantly, the Parwati Arga Wetland holds international conservation significance as it has been designated a Ramsar site on 2 December 2019, having fulfilled criteria 2, 3, 4, 5, and 8 under the Ramsar Convention framework (Ramsar Convention 1971; Site Management Plan 2011). The sanctuary also has been accorded IBA status in criteria A1, A4iii (Rahmani et al. 2016).

### Method

Bird surveys were conducted monthly using the point-count method (Bibby et al. 2000) from March 2024–February 2025. On the perimeter of each wetland (Parwati and Arga), two points were fixed, making a total of four points, each of which was 250 m apart from each other (Figure 1). Each point was surveyed four times in a month, making a total of 48 replicates of each point during the one-year duration. Observations were made from 0600–1000 h during clear weather for 15 min at each point count. The species name and number of individuals of the species detected within 150 m of the observer were noted down. A Nikon 7 x 35 binocular was used to aid the sighting of species. Bird identification and residential status classification for each species were done using the standard field guide (Grimmett et al. 2011). Both the conservation status and global population trend of each bird species recorded were updated using the Red List of IUCN (2025).

## RESULTS

In the present study, a total of 140 species of birds belonging to 53 families and 19 orders were recorded in the Parwati Arga Bird Sanctuary (Table 1). The order Passeriformes recorded the highest number of bird species (45) (Table 1). Out of recorded bird species, resident bird species were 110 (78%), winter visitors were 29 (21%) and summer visitor was 1 (1%) (Table 1 & Figure 2). One 'Endangered' species (Egyptian

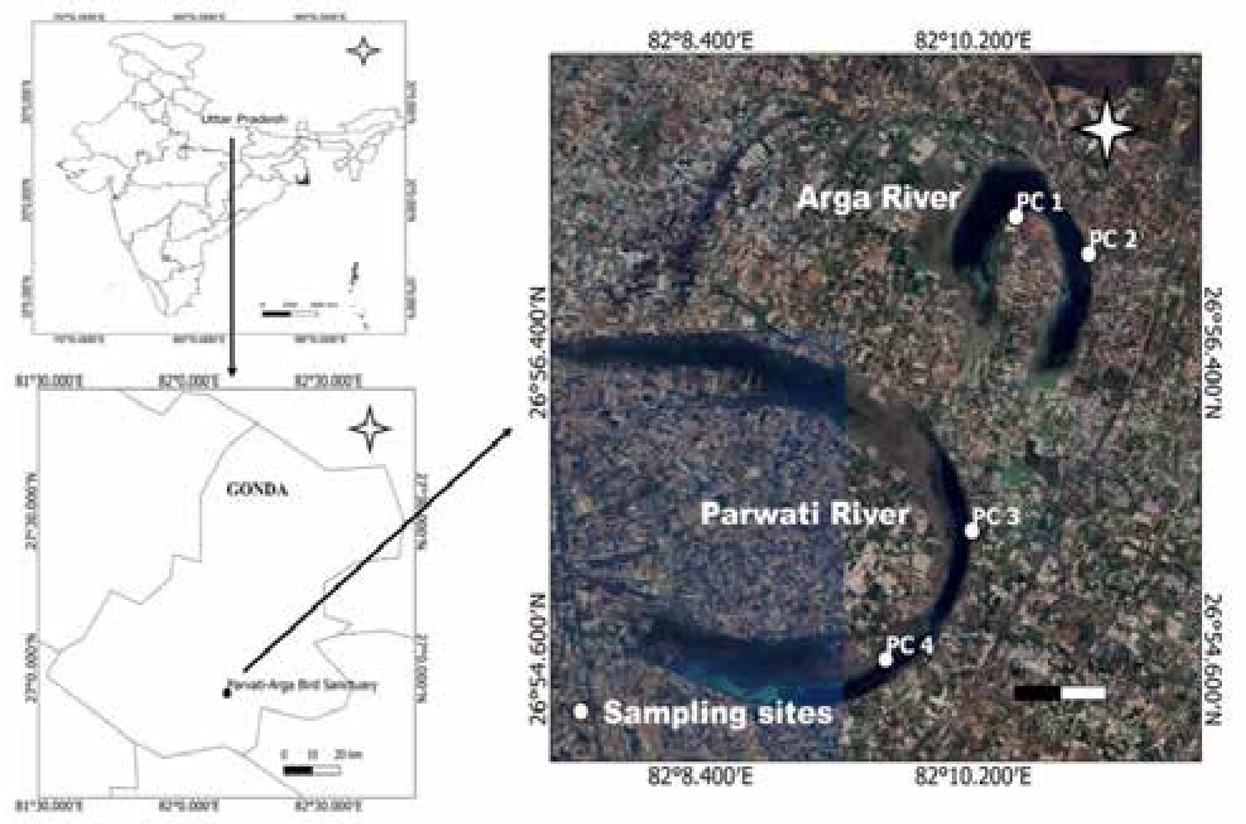


**Figure 1. The study area and sampling locations.** PC—Point count.

Vulture *Neophron percnopterus*), four 'Vulnerable' species (Sarus Crane *Grus antigone*, Common Pochard *Aythya ferina*, Indian Spotted Eagle *Clanga hastata,* and River Tern *Sterna aurantia*), and six 'Near Threatened' species (Great Thick-knee *Esacus recurvirostris*, River Lapwing *Vanellus duvaucelii*, Black-necked Stork *Ephippiorhynchus asiaticus*, Lesser Adjutant *Leptoptilos javanicus*, Asian Woollyneck *Ciconia episcopus*, and Oriental Darter *Anhinga melanogaster*) were recorded (Table 1 & Figure 3). According to the global population trend of IUCN (2025), 49 species (35%) were decreasing, 39 species (27%) were stable, 26 species (19%) were increasing, and 26 species (19%) were unknown (Table 1 & Figure 4). Overall, 29 families recorded single species each and five families recorded two species each (Table 1).

The family Anatidae recorded the highest species richness (14 species), followed by the families Accipitridae (9 species) and Ardeidae (8 species) (Table 1). Families Anatidae and Scolopacidae comprised mostly of all winter migrants, exceptions being Knob-billed Duck *Sarkidiornis melanotos*, Cotton Pygmy-goose *Nettapus coromandelianus*, Lesser Whistling-duck *Dendrocygna javanica*, and Indian Spot-billed Duck *Anas poecilorhyncha*, which are resident (Table 1). Families Ardeidae, Strigidae, Columbidae, Cisticolidae, and Sturnidae comprised of all resident birds. The Blue-tailed Bee-eater *Merops philippinus* was the only summer visitor (Table 1).

## DISCUSSION

The current study records 140 species of birds, which is higher than the number of species recorded in other bird sanctuaries of Uttar Pradesh, e.g., Hastinapur Wildlife Sanctuary (117 species) (Khan et al. 2013), but lesser than the species recorded at Okhla Bird Sanctuary (302 species) (Upadhyay et al. 2019). Other studies from different bird sanctuaries in Tamil Nadu such as Therthangal (96) (Byju et al. 2024), Chitrankudi (122), Melsevanoor-Kelselvanoor (117), Sakkarakottai (116) (Byju et al. 2025) and Pakhibitan Bird and Wildlife Sanctuary, West Bengal (124) (Roy et al. 2024) reported lower bird species than the current study, whereas Manjeera Wildlife Sanctuary, Andhra Pradesh (164) (Prasad et al. 2014) and Samanatham Bird Sanctuary, Tamil Nadu (150) (Byju et al. 2023) reported higher bird

**Table 1. Avian diversity recorded in Parwati Arga Bird Sanctuary.**

| | Scientific name | Common name | IUCN Red List status | GPT | RS |
|---|---|---|---|---|---|
| | **Accipitriformes Accipitridae (9)** | | | | |
| 1 | *Accipiter badius* | Shikra | LC | → | R |
| 2 | *Circaetus gallicus* | Short-toed Eagle | LC | → | R |
| 3 | *Circus melanoleucos* | Pied Harrier | LC | ↓ | WV |
| 4 | *Clanga hastata* | Indian Spotted Eagle | VU | ↓ | R |
| 5 | *Elanus caeruleus* | Black-winged Kite | LC | → | R |
| 6 | *Milvus migrans* | Black Kite | LC | → | R |
| 7 | *Neophron percnopterus* | Egyptian Vulture | EN | ↓ | R |
| 8 | *Pernis ptilorhynchus* | Oriental Honey-buzzard | LC | ↓ | R |
| 9 | *Spilornis cheela* | Crested Serpent-eagle | LC | → | R |
| | **Anseriformes Anatidae (14)** | | | | |
| 10 | *Anas crecca* | Common Teal | LC | ? | WV |
| 11 | *Anas platyrhynchos* | Mallard | LC | ↑ | WV |
| 12 | *Anas poecilorhyncha* | Indian Spot-billed Duck | LC | ↓ | R |
| 13 | *Anser anser* | Greylag Goose | LC | ↑ | WV |
| 14 | *Anser indicus* | Bar-headed Goose | LC | ↓ | WV |
| 15 | *Aythya ferina* | Common Pochard | VU | ↓ | WV |
| 16 | *Dendrocygna javanica* | Lesser Whistling-duck | LC | ↓ | R |
| 17 | *Mareca strepera* | Gadwall | LC | ↑ | WV |
| 18 | *Nettapus coromandelianus* | Cotton Pygmy-goose | LC | ? | R |
| 19 | *Sarkidiornis melanotos* | Knob-billed Duck | LC | ↓ | R |
| 20 | *Spatula clypeata* | Northern Shoveler | LC | ↓ | WV |
| 21 | *Spatula querquedula* | Garganey | LC | ↓ | WV |
| 22 | *Tadorna ferruginea* | Ruddy Shelduck | LC | ? | WV |
| 23 | *Tadorna tadorna* | Common Shelduck | LC | ↑ | WV |
| | **Apodiformes Apodidae (1)** | | | | |
| 24 | *Cypsiurus balasiensis* | Asian Palm Swift | LC | → | R |
| | **Bucerotiformes Bucerotidae (1)** | | | | |
| 25 | *Ocyceros birostris* | Indian Grey Hornbill | LC | → | R |
| | **Bucerotiformes Upupidae (1)** | | | | |
| 26 | *Upupa epops* | Common Hoopoe | LC | ↓ | R |
| | **Charadriiformes Burhinidae (2)** | | | | |
| 27 | *Burhinus indicus* | Indian Thick-knee | LC | ? | R |
| 28 | *Esacus recurvirostris* | Great Thick-knee | NT | ↓ | R |
| | **Charadriiformes Charadriidae (4)** | | | | |
| 29 | *Charadrius dubius* | Little Ringed Plover | LC | → | R |
| 30 | *Vanellus duvaucelii* | River Lapwing | NT | ↓ | R |
| 31 | *Vanellus indicus* | Red-wattled Lapwing | LC | ? | R |
| 32 | *Vanellus malabaricus* | Yellow-wattled Lapwing | LC | → | R |
| | **Charadriiformes Glareolidae (1)** | | | | |
| 33 | *Glareola lactea* | Little Pratincole | LC | ? | R |
| | **Charadriiformes Jacanidae (2)** | | | | |
| 34 | *Hydrophasianus chirurgus* | Pheasant-tailed Jacana | LC | ? | R |
| 35 | *Metopidius indicus* | Bronze-winged Jacana | LC | ? | R |
| | **Charadriiformes Laridae (1)** | | | | |
| 36 | *Sterna aurantia* | River Tern | VU | ↓ | R |
| | **Charadriiformes Recurvirostridae (1)** | | | | |
| 37 | *Himantopus himantopus* | Black-winged Stilt | LC | ↑ | WV |
| | **Charadriiformes Scolopacidae (4)** | | | | |
| 38 | *Actitis hypoleucos* | Common Sandpiper | LC | ↓ | WV |
| 39 | *Calidris minuta* | Little Stint | LC | ↑ | WV |
| 40 | *Gallinago gallinago* | Common Snipe | LC | ↓ | WV |
| 41 | *Tringa nebularia* | Common Greenshank | LC | → | WV |
| | **Ciconiiformes Ciconiidae (7)** | | | | |
| 42 | *Anastomus oscitans* | Asian Openbill | LC | ? | R |
| 43 | *Ciconia ciconia* | White Stork | LC | ↑ | WV |
| 44 | *Ciconia episcopus* | Asian Woollyneck | NT | ↓ | R |
| 45 | *Ciconia nigra* | Black Stork | LC | ? | WV |
| 46 | *Ephippiorhynchus asiaticus* | Black-necked Stork | NT | ↓ | R |
| 47 | *Leptoptilos javanicus* | Lesser Adjutant | NT | ? | R |
| 48 | *Mycteria leucocephala* | Painted Stork | LC | ↑ | WV |
| | **Columbiformes Columbidae (5)** | | | | |
| 49 | *Columba livia* | Blue Rock Pigeon | LC | ↓ | R |
| 50 | *Spilopelia chinensis* | Spotted Dove | LC | ↑ | R |
| 51 | *Streptopelia decaocto* | Eurasian Collared-dove | LC | ↑ | R |
| 52 | *Streptopelia orientalis* | Oriental Turtle-dove | LC | ↓ | R |
| 53 | *Treron phoenicopterus* | Yellow-footed Green-pigeon | LC | ↑ | R |
| | **Coraciiformes Alcedinidae (3)** | | | | |
| 54 | *Alcedo atthis* | Common Kingfisher | LC | ↓ | R |
| 55 | *Halcyon smyrnensis* | White-throated Kingfisher | LC | ↑ | R |

| | Scientific name | Common name | IUCN Red List status | GPT | RS |
|---|---|---|---|---|---|
| 56 | *Pelargopsis capensis* | Stork-billed Kingfisher | LC | ↓ | R |
| | **Coraciiformes Coraciidae (1)** | | | | |
| 57 | *Coracias benghalensis* | Indian Roller | LC | ↑ | R |
| | **Coraciiformes Meropidae (1)** | | | | |
| 58 | *Merops philippinus* | Blue-tailed Bee-eater | LC | → | SV |
| | **Cuculiformes Cuculidae (1)** | | | | |
| 59 | *Centropus sinensis* | Greater Coucal | LC | → | R |
| | **Falconiformes Falconidae (1)** | | | | |
| 60 | *Falco tinnunculus* | Common Kestrel | LC | ↓ | R |
| | **Galliformes Phasianidae (3)** | | | | |
| 61 | *Francolinus pondicerianus* | Grey Francolin | LC | → | R |
| 62 | *Gallus gallus* | Red Junglefowl | LC | ↓ | R |
| 63 | *Pavo cristatus* | Indian Peafowl | LC | → | R |
| | **Gruiformes Gruidae (1)** | | | | |
| 64 | *Grus antigone* | Sarus Crane | VU | ↓ | R |
| | **Gruiformes Rallidae (5)** | | | | |
| 65 | *Amaurornis phoenicurus* | White-breasted Waterhen | LC | ? | R |
| 66 | *Fulica atra* | Eurasian Coot | LC | ↑ | WV |
| 67 | *Gallicrex cinerea* | Watercock | LC | ↓ | R |
| 68 | *Gallinula chloropus* | Common Moorhen | LC | → | R |
| 69 | *Porphyrio poliocephalus* | Grey-headed Swamphen | LC | ? | R |
| | **Passeriformes Aegithinidae (1)** | | | | |
| 70 | *Aegithina tiphia* | Common Iora | LC | ? | R |
| | **Passeriformes Cisticolidae (5)** | | | | |
| 71 | *Cisticola juncidis* | Zitting Cisticola | LC | ? | R |
| 72 | *Orthotomus sutorius* | Common Tailorbird | LC | → | R |
| 73 | *Prinia hodgsonii* | Grey-breasted Prinia | LC | ↓ | R |
| 74 | *Prinia inornata* | Plain Prinia | LC | → | R |
| 75 | *Prinia socialis* | Ashy Prinia | LC | → | R |
| | **Passeriformes Corvidae (3)** | | | | |
| 76 | *Corvus macrorhynchos* | Large-billed Crow | LC | ↓ | R |
| 77 | *Corvus splendens* | House Crow | LC | → | R |
| 78 | *Dendrocitta vagabunda* | Rufous Treepie | LC | ↓ | R |
| | **Passeriformes Dicruridae (3)** | | | | |
| 79 | *Dicrurus caerulescens* | White-bellied Drongo | LC | ↓ | R |
| 80 | *Dicrurus leucophaeus* | Ashy Drongo | LC | ? | R |
| 81 | *Dicrurus macrocercus* | Black Drongo | LC | ? | R |
| | **Passeriformes Estrildidae (4)** | | | | |
| 82 | *Amandava amandava* | Red Avadavat | LC | → | R |
| 83 | *Euodice malabarica* | Indian Silverbill | LC | → | R |
| 84 | *Lonchura malacca* | Tricoloured Munia | LC | → | R |
| 85 | *Lonchura punctulata* | Scaly-breasted Munia | LC | → | R |
| | **Passeriformes Hirundinidae (1)** | | | | |
| 86 | *Hirundo rustica* | Barn Swallow | LC | ↓ | WV |
| | **Passeriformes Laniidae (1)** | | | | |
| 87 | *Lanius schach* | Long-tailed Shrike | LC | ? | R |
| | **Passeriformes Leiothrichidae (1)** | | | | |
| 88 | *Turdoides striata* | Jungle Babbler | LC | → | R |
| | **Passeriformes Monarchidae (1)** | | | | |
| 89 | *Terpsiphone paradisi* | Asian Paradise Flycatcher | LC | → | R |
| | **Passeriformes Motacillidae (4)** | | | | |
| 90 | *Anthus rufulus* | Paddyfield Pipit | LC | → | R |
| 91 | *Motacilla alba* | White Wagtail | LC | → | WV |
| 92 | *Motacilla cinerea* | Grey Wagtail | LC | → | WV |
| 93 | *Motacilla citreola* | Citrine Wagtail | LC | ↑ | WV |
| | **Passeriformes Muscicapidae (6)** | | | | |
| 94 | *Copsychus malabaricus* | White-rumped Shama | LC | ↓ | R |
| 95 | *Copsychus saularis* | Oriental Magpie-robin | LC | → | R |
| 96 | *Eumyias thalassinus* | Verditer Flycatcher | LC | ↓ | WV |
| 97 | *Luscinia svecica* | Bluethroat | LC | → | WV |
| 98 | *Oenanthe fusca* | Brown Rockchat | LC | → | R |
| 99 | *Saxicola ferrea* | Grey Bushchat | LC | → | WV |
| | **Passeriformes Nectariniidae (1)** | | | | |
| 100 | *Cinnyris asiaticus* | Purple Sunbird | LC | → | R |
| | **Passeriformes Oriolidae (1)** | | | | |
| 101 | *Oriolus xanthornus* | Black-hooded Oriole | LC | → | R |
| | **Passeriformes Paridae (1)** | | | | |
| 102 | *Parus cinereus* | Cinereous Tit | LC | → | R |
| | **Passeriformes Passeridae (1)** | | | | |
| 103 | *Passer domesticus* | House Sparrow | LC | ↓ | R |
| | **Passeriformes Ploceidae (1)** | | | | |
| 104 | *Ploceus philippinus* | Baya Weaver | LC | → | R |
| | **Passeriformes Pycnonotidae (1)** | | | | |
| 105 | *Pycnonotus cafer* | Red-vented Bulbul | LC | ↑ | R |
| | **Passeriformes Rhipiduridae (1)** | | | | |
| 106 | *Rhipidura albicollis* | White-throated Fantail | LC | ↓ | R |

| | Scientific name | Common name | IUCN Red List status | GPT | RS |
|---|---|---|---|---|---|
| | **Passeriformes Sittidae (1)** | | | | |
| 107 | *Sitta castanea* | Indian Nuthatch | LC | ↑ | R |
| | **Passeriformes Stenostiridae (1)** | | | | |
| 108 | *Culicicapa ceylonensis* | Grey-headed Canary-flycatcher | LC | ↓ | WV |
| | **Passeriformes Strunidae (5)** | | | | |
| 109 | *Acridotheres fuscus* | Jungle Myna | LC | ↓ | R |
| 110 | *Acridotheres ginginianus* | Bank Myna | LC | ↑ | R |
| 111 | *Acridotheres tristis* | Common Myna | LC | ↑ | R |
| 112 | *Gracupica contra* | Asian Pied Starling | LC | ↑ | R |
| 113 | *Sturnia pagodarum* | Brahminy Starling | LC | ? | R |
| | **Passeriformes Zosteropidae (1)** | | | | |
| 114 | *Zosterops palpebrosus* | Indian White-eye | LC | ↓ | R |
| | **Pelecaniformes Ardeidae (8)** | | | | |
| 115 | *Ardea cinerea* | Grey Heron | LC | ? | R |
| 116 | *Ardea purpurea* | Purple Heron | LC | ↓ | R |
| 117 | *Ardeola grayii* | Indian Pond-heron | LC | ? | R |
| 118 | *Dupetor flavicollis* | Black Bittern | LC | ? | R |
| 119 | *Egretta alba* | Great White Egret | LC | ? | R |
| 120 | *Egretta garzetta* | Little Egret | LC | ↑ | R |
| 121 | *Egretta intermedia* | Intermediate Egret | LC | ↓ | R |
| 122 | *Nycticorax nycticorax* | Black-crowned Night-heron | LC | ↓ | R |
| | **Pelecaniformes Threskiornithidae (2)** | | | | |
| 123 | *Pseudibis papillosa* | Red-naped Ibis | LC | ↓ | R |
| 124 | *Threskiornis melanocephalus* | Black-headed Ibis | LC | ↑ | R |
| | **Piciformes Megalaimidae (1)** | | | | |
| 125 | *Psilopogon haemacephalus* | Coppersmith Barbet | LC | ↑ | R |
| | **Podicipediformes Podicipedidae (2)** | | | | |
| 126 | *Podiceps cristatus* | Great Crested Grebe | LC | ? | WV |
| 127 | *Tachybaptus ruficollis* | Little Grebe | LC | ↓ | R |
| | **Psittaciformes Psittaculidae (2)** | | | | |
| 128 | *Alexandrinus krameri* | Rose-ringed Parakeet | LC | ↑ | R |
| 129 | *Himalayapsitta cyanocephala* | Plum-headed Parakeet | LC | ↓ | R |
| | **Strigiformes Strigidae (6)** | | | | |
| 130 | *Athene brama* | Spotted Owlet | LC | → | R |
| 131 | *Bubo bengalensis* | Indian Eagle-owl | LC | ↓ | R |
| 132 | *Glaucidium radiatum* | Jungle Owlet | LC | ↓ | R |
| 133 | *Ketupa zeylonensis* | Brown Fish-owl | LC | ↓ | R |
| 134 | *Ninox scutulata* | Brown Hawk-owl | LC | ↓ | R |
| 135 | *Otus bakkamoena* | Indian Scops-owl | LC | → | R |
| | **Strigiformes Tytonidae (1)** | | | | |
| 136 | *Tyto alba* | Common Barn-owl | LC | → | R |
| | **Suliformes Anhingidae (1)** | | | | |
| 137 | *Anhinga melanogaster* | Oriental Darter | NT | ↑ | R |
| | **Suliformes Phalacrocoracidae (3)** | | | | |
| 138 | *Microcarbo niger* | Little Cormorant | LC | ? | R |
| 139 | *Phalacrocorax carbo* | Great Cormorant | LC | ↑ | R |
| 140 | *Phalacrocorax fuscicollis* | Indian Cormorant | LC | ? | R |

IUCN Red List status (IUCN 2025): LC—Least concern | NT—Near Threatened | VU—Vulnerable | EN—Endangered. GPT (Global Population Trend) (IUCN 2025): →—Stable | ↓—Decreasing | ↑—Increasing | ?—Unknown. RS (Residential Status): R – Resident, WV – Winter Visitor, SV – Summer Visitor

species than the current study. The number of winter migrants (n = 29) recorded in this study is higher than that recorded in Hastinapur Wildlife Sanctuary, Uttar Pradesh (19 species; Joshi et al. 2021) and lower than that recorded in Okhla Bird Sanctuary, Uttar Pradesh (40 species; Mazumdar 2019). The current study recorded 11 threatened bird species, which is similar to the results obtained in Hastinapur Wildlife Sanctuary, Uttar Pradesh (11 species; Joshi et al. 2021) and higher than the species recorded in Bhimbandh Wildlife Sanctuary, Bihar (five species; Khan & Pant 2017) and Okhla Bird Sanctuary, Uttar Pradesh (10 species; Mazumdar 2019).

Parwati Arga Bird Sanctuary hosts diverse flora and fauna, including many resident, rare, and migratory species due to its diverse habitats consisting of two oxbow lakes having freshwater ecosystems, along with marshes, swamps, interspersed with agricultural fields and adjoining Tikri Reserve Forest (Image 1). These habitats support the foraging, nesting, and roosting activities of waterbirds and terrestrial birds (Hattori & Mae 2001). The availability of fish in lakes, grains, and insects in the adjacent agricultural fields & grasslands provides good foraging ground for the birds (Prasad et al. 2014; Anand et al. 2023), whereas the aquatic vegetation and adjoining forests provide shelter, escape routes, cover, and nesting sites, attracting diverse birds

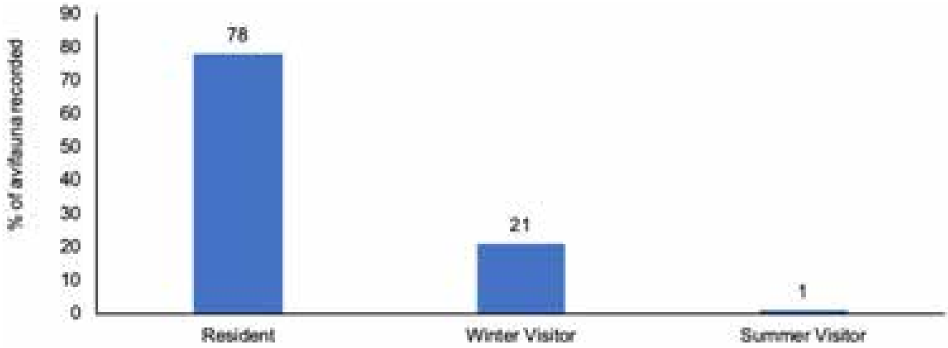


Figure 2. Residential status of the avifaunal species recorded in Parwati Arga Bird Sanctuary.

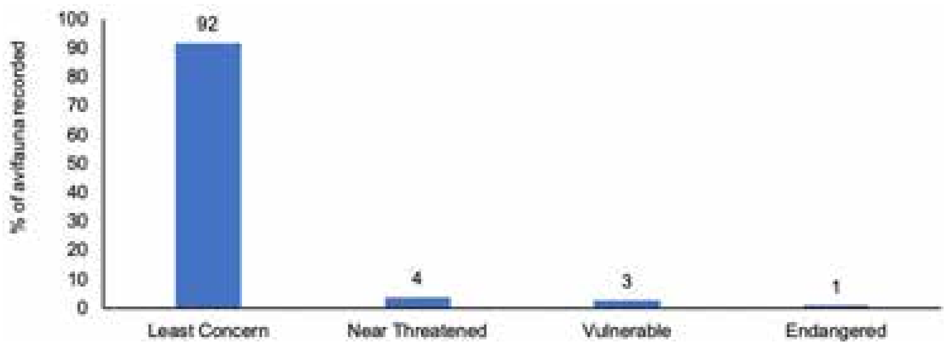


Figure 3. IUCN Red List status of the avifaunal species recorded in Parwati Arga Bird Sanctuary.

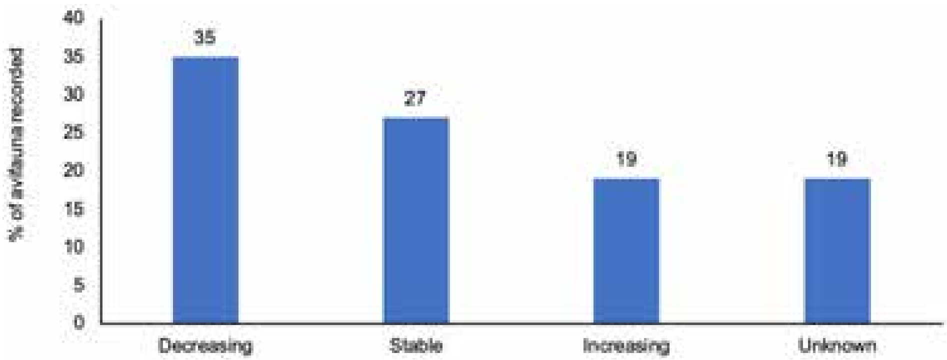


Figure 4. Global population trend of the avifaunal species recorded in Parwati Arga Bird Sanctuary.

(Yashmita-Ulman & Singh 2022). The shallow water bodies with variable depths (Colwell & Taft 2000) might also be a factor attracting birds in the Sanctuary. In the current study, the family Anatidae recorded the highest species richness. This is similar to the findings of Kumar & Gupta (2013) in Chhilchhila Wildlife Sanctuary, Haryana and Prasad et al. (2014) in Manjeera Wildlife Sanctuary, Andhra Pradesh. Families Anatidae and Scolopacidae comprised most of the winter migratory birds, and only one summer visitor was found, which is similar to the results obtained by Prasad et al. (2014) in Manjeera Wildlife Sanctuary, Andhra Pradesh.

The study results highlight the importance of the Sanctuary for the resident and migratory birds. Therefore, long-term monitoring of birds and threat assessment is required to assess the impact of the changing environment and surrounding landscapes on the birds of the Sanctuary. This scientific database is a prerequisite for scientific management and conservation of the sanctuary by the forest department.

Aquatic vegetation in Parwati Arga Bird Sanctuary.

Agricultural fields and forests adjacent Parwati Arga Bird Sanctuary

**Image 1. Diverse habitats of Parwati Arga Bird Sanctuary. © Rajesh Kumar.**

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COMMUNICATION

Small Wild Cats Special Series

# Sightings of the Rusty-spotted Cat *Prionailurus rubiginosus* (I. Geoffroy Saint-Hilaire, 1831) (Mammalia: Carnivora: Felidae) in Saurashtra Peninsula, Gujarat, India

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**Abstract:** We document 31 sightings of the Rusty-spotted Cat *Prionailurus rubiginosus* in the Asiatic Lion Landscape in Gujarat, India, in the period 2016–2024. Twenty-seven sightings occurred in Junagadh District, three in Amreli District and one in Gir Somnath District. Live individuals were observed in 21 incidents and dead ones in 10 incidents, including nine road kills. A total of 17 sightings (54.84%) occurred in revenue land, agricultural land and unclassified forest areas; 14 sightings (45.16%) occurred in protected areas, including seven in Gir Wildlife Sanctuary, six in Girnar Wildlife Sanctuary, and one in Paniya Wildlife Sanctuary. We observed Rusty-spotted Cats in trees on nine occasions. We discuss general distribution within Gujarat, and the negative impact of road networks being a threat to the species.

**Keywords:** Asiatic Lion Landscape, distribution, Gir, natural history, protected ares, roadkills, small wild cat, threats.

**લેખ-ટૂંકસાર (=Gujarati Abstract)**: અભ્યાસ ના ૨૦૧૬ થી ૨૦૨૪ સમયગાળા માં, કુલ ૩૧ વખત કાટવર્ણી ટપકાંવાળી બિલાડી /તામ્રવર્ણી ટપકાંવાળી બિલાડી (*Prionailurus rubiginosus*) ના અવલોકન ગુજરાતમાં ગીર-સિંહ ના વ્યાપ વિસ્તાર માં થયેલ. જેમાં, ૨૭ વખત જુનાગઢ, ૩ વખત અમરેલી અને એક માત્ર ગીર-સોમનાથ જિલ્લામાં અવલોકન નોંધાયા. એમાંથી ૨૧ કિસ્સામાં જીવતી અને ૧૦ મોત પામેલી કાટવર્ણી ટપકાંવાળી બિલાડી /તામ્રવર્ણી ટપકાંવાળી બિલાડીના અવલોકન થયેલ , જેમાં થી નવ કિસ્સામાં તે રસ્તા ઉપર અકસ્માતમાં મોત થયેલી મળેલી . આ બાબતે ૧૭ (૫૪.૮૪%) અવલોકન રેવન્યુ, ખેતીવાડી, અને અન્ય જંગલ વિસ્તારમાં, અને ૧૪ (૪૫.૧૬%) જેટલા અવલોકન પ્રતિબંધિત જંગલ વિસ્તારના છે, જેમાં થી સાત ગીરમાં, છ ગિરનારમાં અને એક પાણિયા જંગલ વિસ્તાર માં નોંધાયેલ હતા. નવ કિસ્સામાં આ કાટવર્ણી ટપકાંવાળી બિલાડી /તામ્રવર્ણી ટપકાંવાળી બિલાડી વૃક્ષ ઉપર વિહરતી-ફરતી જોવા મળેલ. આ સંશોધન લેખ માં આ પ્રજાતિ નો વ્યાપ-વિસ્તાર, રોડ-રસ્તા ઉપરના મરણ બાબતના સંભવિત જોખમો અંગે વિગતે ચર્ચા કરેલ છે.

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**Author details:** Dr. Raju Vyas is now retired after 30+ years of service as a zoo inspector at the Sayaji Baug Zoo, Vadodara, India. Based in Vadodara City, he has conducted long-term research on the natural history of birds, mammals, and reptiles of Gujarat, especially crocodiles and their habitats, as well as on human-crocodile interactions, for more than 25 years. Presently, he is the regional vice chair of the IUCN/SSC Crocodile Specialist Group (South Asia and Iran), and a member of various IUCN/SSC Specialist Groups. Pranav Vaghashiya is a naturalist, by profession an educationist, and the founder and president of Vasundhara Nature Club, Junagadh, and runs education and awareness programs in the Saurashtra region. Being a member of the IUCN/SSC Crocodile Specialist Group (South Asia and Iran), monitoring mugger crocodiles of the Girnar Wildlife Sanctuary, and rescuing wildlife with the assistance of the staff of the local forest department, Gujarat Forest Department, Gujarat. Devendra Chauhan is a naturalist and wildlife photographer. By profession, a medical doctor, and as a member of the Vasundhara Nature Club, he has handled various education and awareness programs in the Saurashtra region and documented the wildlife of Gujarat, India. He is also assisting with a small-mammal survey using camera traps with the forest department.

**Author contributions:** Raju Vyas—design, development of concept, and manuscript writing. Pranav Vaghashiya—design, work-Coordination, field work. Devendra Chauhan—field work, Data analysis, manuscript writing

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## INTRODUCTION

The Rusty-spotted Cat *Prionailurus rubiginosus* is distributed from the western Terai in India and Nepal to southern India and Sri Lanka (Mukherjee et al. 2016). In India, it is afforded the highest legal protection status under Schedule I of the Wildlife Protection Act (1972) (Ministry of Law and Justice 2022). Globally, it is categorised as 'Near Threatened' on the IUCN Red List (Mukherjee et al. 2016).

In India, the Rusty-spotted Cat occurs in the states of Jammu & Kashmir, Uttarakhand, Uttar Pradesh, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, and Odisha (Mukherjee et al. 2016). It has also been recorded in protected areas of Haryana, Chhattisgarh, Telangana, Bihar, and Punjab (Ghaskadbi et al. 2016; Basak et al. 2018; Kanwar & Lomis 2020; Jhala et al. 2021). Records in tiger reserves indicate that it is associated with mixed deciduous forests in low-lying and dry habitats (Habib et al. 2025). Observations by researchers and camera trap records also revealed its presence outside protected areas and in diverse habitats (Manchi et al. 2024; Mukherjee & Nandini 2024; Pawar et al. 2024).

In Gujarat, the Rusty-spotted Cat has been recorded in the arid landscape of Kutch (Mukherjee & Nandini 2024). Sightings have been reported in the dry deciduous forests of central and northern Gujarat and in the moist deciduous forests of Dang District (Digveerendrasinh 1987; Singh 2013; Patel et al. 2024). Since 1986, it has been sighted in Vansda National Park, Purna Wildlife Sanctuary, Shoolpaneshwar Wildlife Sanctuary, Jambughoda Wildlife Sanctuary, Ratanmahal Wildlife Sanctuary, Gir National Park and Wildlife Sanctuary (Digveerendrasinh 1987; Pathak 1990; Chavan et al. 1991; Patel 2006; Vyas & Upadhyay 2014; Vyas et al. 2018; Chaudhary et al. 2022; Patel et al. 2024).

We report sighting records of the Rusty-spotted Cat in the Saurashtra Peninsula between January 2016 and December 2024, along with information on habitat, predation, threats, and natural history.

### Study Area

Our study area was located in the districts of Junagadh, Amreli, and Gir Somnath in the Saurashtra Peninsula of southwestern Gujarat (Figure 1). These three districts are part of the Asiatic Lion Landscape (ALL), which encompasses five protected areas, several protected, reserved and unclassed forests, scrublands, grasslands, croplands, and settlements (Ram et al. 2023). The five protected areas within the ALL are Gir National Park, Gir Wildlife Sanctuary, Paniya Wildlife Sanctuary, Mitiyala Wildlife Sanctuary, and Girnar Wildlife Sanctuary (Ram et al. 2023). The main forest type in the Saurashtra Peninsula is dry deciduous thorn forest (Rodgers & Panwar 1988). As of 2016, the forested area in Saurashtra and Kutch totalled 10,822 km$^2$, equivalent to about 5.5% of Gujarat, whereas 41,370 km$^2$ (21.1%) was under agriculture (Dehingia & Surendra 2020).

Apart from the Rusty-spotted Cat, the Lion *Panthera leo*, Leopard *P. pardus* and Jungle Cat *Felis chaus* also occur in the ALL (Ram et al. 2023).

The Saurashtra Peninsula experiences a temperature range of 8–42 $^{0}$C; it receives 100–865 mm of rain during the rainy season from June to September (Parmar et al. 2025).

## MATERIAL AND METHODS

We initially designed 1.5 km long stretches with five transects in Gir and Girnar Wildlife Sanctuaries within a zone that we considered to represent potential habitat of the Rusty-spotted Cat. During the first three months, all transects were surveyed once a week in the mornings (0530–0630 h) and again in the late evenings (1800–2000 h). However, we did not encounter any cats during these walks. Therefore, we conducted random visits to potential habitat areas. The current results are based on opportunistic sightings during irregular visits and excursions in and around the study area.

Behavioural observations were conducted using Nikon Monarch 8 x 42 and Nature Trek 12 x 50 binoculars. Photographs were taken with Sony Point Shoot, Canon EOS 7d and Sony Alpha a7III digital cameras. The latter two models were equipped with a 100–400 mm Canon and a Sony 200–600 mm camera lens, respectively. Coordinates were recorded using Garmin e-Trex 10 and E-Trex 20 GPS devices set to WGS 84. For each sighting, we collected information on habitat type, activity, and time of sighting.

In addition to our own sightings, we gathered photographic records and associated relevant information from forest department staff, nature club volunteers, wildlife observers and photographers. We revisited the locations of these secondary sightings and determined their coordinates using the mobile phone application GPS Coord Camera.

All data were compiled in Microsoft Excel 2011 and analysed to determine spatial-temporal patterns of sightings, roadkill incidents and preparation of maps. Simple statistical analyses were performed to calculate averages and percentages of sightings.

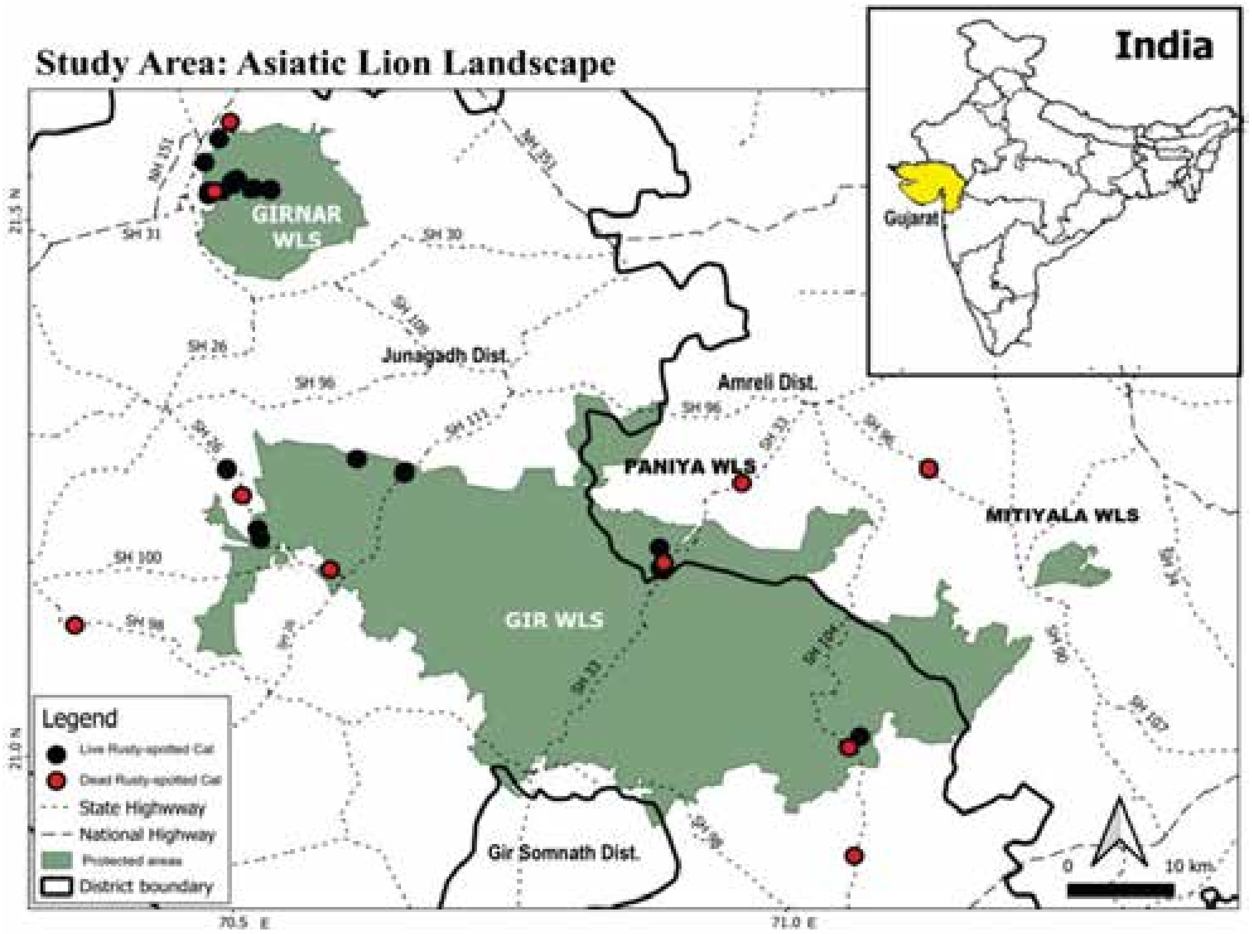


Figure 1. Map of the study area in Saurashtra Peninsula, Gujarat.

## RESULTS

We collated 31 sightings of the Rusty-spotted Cat made from January 2016 to December 2024 (Table 1; Figure 1). Sightings ranged from one each in 2017 and 2019 to seven (22.58%) in 2023, with an average of 3.4 sightings per year (Figure 2). These include 13 sightings by the authors and 18 by secondary sources. Sightings encompass 27 (87.1% of all) in Junagadh District, three (9.68%) in Amreli District, and one (3.22%) in Gir Somnath District. Of these total sightings, 17 (54.84%) occurred outside protected areas (PAs), and 14 (45.16%) inside PAs, comprising seven in Gir Wildlife Sanctuary, six in Girnar Wildlife Sanctuary, and one in Paniya Wildlife Sanctuary.

Live individuals were observed in 21 incidents (67.75% of all sightings), including eight (38.10%) inside forests and 13 (61.90%) at the edges of forested areas and near settlements. Three sightings (14.29%) of live individuals occurred during the day, and 18 (85.71%) between dusk and dawn. Nine individuals were observed in trees that we identified as Manila Tamarind *Pithecellobium dulce* (Image 4A), Wild Almond *Sterculia foetida*, Teak *Tectona grandis*, Cluster Fig *Ficus racemosa,* and Oval-leaved Wheel Creeper *Combretum ovalifolium* (Image 4C).

Dead Rusty-spotted Cats were found in 10 incidents (32.26% of all sightings), including nine road kills, of which

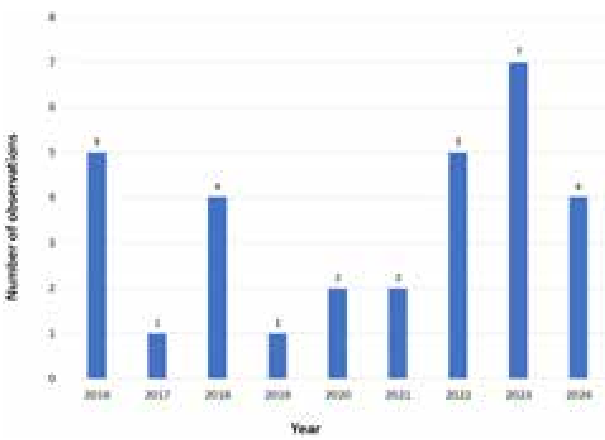


Figure 2. Graph showing the years of sightings of the Rusty-spotted Cat in Saurashtra Peninsula, Gujarat.

**Table 1. Details of sightings of the Rusty-spotted Cat in the Asiatic Lion Landscape, Saurashtra Peninsula, Gujarat, India.**

| Date and time | Location | Coordinates | Habitat | Remarks | Observers |
|---|---|---|---|---|---|
| Live individuals in Gir Wildlife Sanctuary (WS) | | | | | |
| 10.i.2016, 1812 h | Near Sapnes, Jamvada-Dhari Road | 21.176° N, 70.886° E | On a tree at edge of scrubland | Image 1A | D. Chauhan, Amit Vaghashiya |
| 29.i.2021, 0325 h | Near Vaniya Vav | 21.211° N, 70.521° E | Teak forest | Image 1B | Urmil Jhaveri |
| 16.i.2023, 0237 h | Near Chika Kuva Camp, Jasadhar | 21.018° N, 71.066° E | On a tree in a cropland | | K. Sharma, M. Sondarva |
| Live individuals in Girnar Wildlife Sanctuary | | | | | |
| 3.iii.2016, 1830 h | Near 1000 Stairs | 21.528° N, 70.517° E | Rocky scrub | Image 1C | Munir Jikani |
| 9.viii.2016, 2200 h | Near Narayandhara | 21.526° N, 70.491° E | Beside road | Image 2A | Ravi Patel |
| 29.iii.2017, 0925 h | Girnar Top | 21.527° N, 70.533° E | Rocky terrain | Image 2B | Kanbhai Jadav |
| 16.xi.2022, 2328 h | Vagheswari Temple complex | 21.522° N, 70.477° E | At forest edge | | Vishvajitsinh Solanki |
| 6.vi.2023, 0121 h | Girnar Top | 21.528° N, 70.533° E | Rocky big boulders | | Piyush Hirapara |
| Live individual in Paniya Wildlife Sanctuary | | | | | |
| 7.iv.2024, 0113 h | Amreli | 21.194° N, 70.885° E | Mixed dry deciduous forest | Image 2C | Rajdeep Jhala |
| Live individuals in non-protected areas and revenue land | | | | | |
| 27.x.2018, 2300 h | Lal Dhori, Junagadh, edge of Girnar WS | 21.537° N, 70.503° E | Near water body | Image 3A | P. Vaghashiya |
| 15.v. 2019, 2357 h | Lal Dhori, Junagadh, edge of Girnar WS | 21.536° N, 70.503° E | On a tree in a plantation | | D. Chauhan, P. Vaghashiya |
| 31.i.2020, 2304 h | Rupayatan, Junagadh, edge of Girnar WS | 21.535° N, 70.499° E | On a tree in a forest | Image 3B | P. Vaghashiya |
| 29.ix.2020, 0354 h | Ashok Shilalekh, Junagadh, edge of Girnar WS | 21.525° N, 70.479° E | Outside a building at edge of scrub | | Ankit Shukla |
| 7.ii. 2021, 1730 h | Bamangaam Revenue, Junagadh | 21.575° N, 70.487° E | In a bushland | Image 3C | Dipak Vadher |
| 16.xi.2022, 2114 h | Anbabhagat-ni-Jagaya, Bhavnadh, Junagadh | 21.531° N, 70.498° E | On a tree inside a settlement | Image 3D | D. Chauhan |
| 11.ii.2023, 2034 h | Liliya-Haripura Road, Visavadar, Junagadh | 21.276° N, 70.611° E | Near water body | | D. Chauhan |
| 16.xii.2023, 2345 h | Rupayatan Road, Junagadh, edge of Girnar WS | 21.535° N, 70.499° E | On a tree | | P. Vaghasiya |
| 17.xii.2023, 0005 h | Khambha-Visavadar Road, Junagadh | 21.264° N, 70.654° E | On a tree | Image 4A | D. Chauhan, A. Vaghashiya |
| 4.i.2024, 1300 h | Dolatpura Revenue, Junagadh, edge of Girnar WS | 21.553° N, 70.473° E | In a hedgerow at edge of a cropfield | Image 4B | Dipak Vadher |
| 25.vi.2024, 2354 h | Lal Dhori, Junagadh, edge of Girnar WS | 21.536° N, 70.503° E | On a creeper in a forest | Image 4C | D. Chauhan, P. Vaghashiya |
| 2.ix.2024, 1955 h | Lal Dhori, Junagadh, edge of Girnar WS | 21.536° N, 70.500° E | On a tree in a forest | Image 4D | P. Vaghashiya |
| Dead individuals | | | | | |
| 23.xii.2016, 0945 h | Near Jasadhar Naka, Gir WS | 21.008° N, 71.056° E | State highway | Image 5A | Bhavesh Trivedi |
| 6.i.2018, 0622 h | Sasan Tourism Zone, Gir WS | 21.121° N, 70.356° E | In a Lion's mouth | Image 5B | Indranil Ghosh |
| 6.iii.2022, 1842 h | Sapnes-Dhakaniya Road, Gir WS | 21.180° N, 70.889° E | Village road | Image 5C | D. Chauhan, B. Dudhatra |
| 10.iv.2022, 0422 h | Near Sasan Town, Gir WS | 21.174° N, 70.587° E | Village road | Image 6A | Parth Aghera |
| 18.i.2023, 0537 h | Near Panjaka, Bhavnadh, Girnar WS | 21.526° N, 70.483° E | Village road | | Ajay Sonimar |
| 6.viii.2016, 1100 h | Nobel College, Bhesan Road, Junagadh | 21.590° N, 70.497° E | Village road | Image 6B | A. & P. Vaghashiya |
| 11.viii.2018, 1711 h | Dhari-Khambha Road, Khambha, Amreli | 21.267° N, 71.129° E | State highway | Image 6C | Gaurang Bagda |
| 5.xi.2018, 0952 h | Malanka Road, Mendarda, Junagadh | 21.243° N, 70.508° E | State highway | | P. Vaghashiya |
| 9.iii.2022, 2035 h | Dhari-Dhakaniya Road, Dhari, Amreli | 21.2550° N, 70.960° E | State highway | | Rajdeep Jhala |
| 4.i.2023, 0924 h | Dhokadava-Una Road, Gir Gadhada, Gir Somnath | 20.907° N, 71.061° E | State highway | Image 6D | Kaushal Sharma |


**Image 1. Rusty-spotted Cats: A—in Gir Wildlife Sanctuary, 10 January 2016 © D. Chauhan & Amit Vaghashiya | B—in a Teak forest, 29 January 2021 © Urmil Jhaveri | C—in Girnar Wildlife Sanctuary, 3 March 2016 © Munir Jikani.**

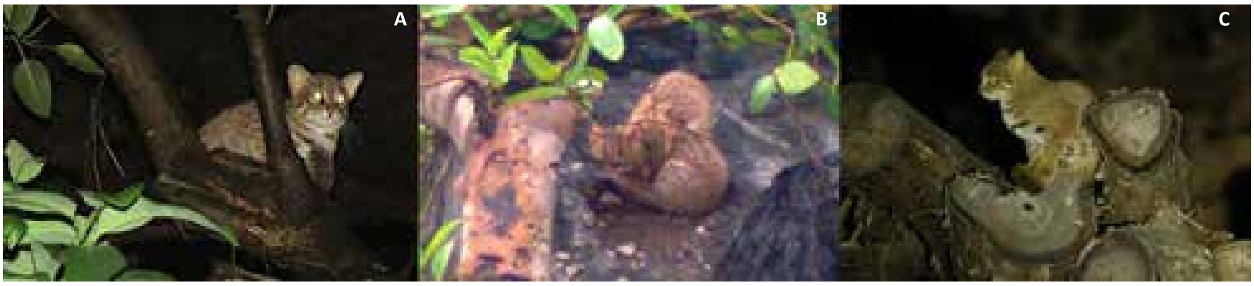


**Image 2. Rusty-spotted Cats: A—in Girnar Wildlife Sanctuary, 9 August 2016 © Ravi Patel | B—Two kittens, 29 March 2017 © Kanbhai Jadav | C—in Paniya Wildlife Sanctuary, 7 April 2024 © Rajdeep Jhala.**

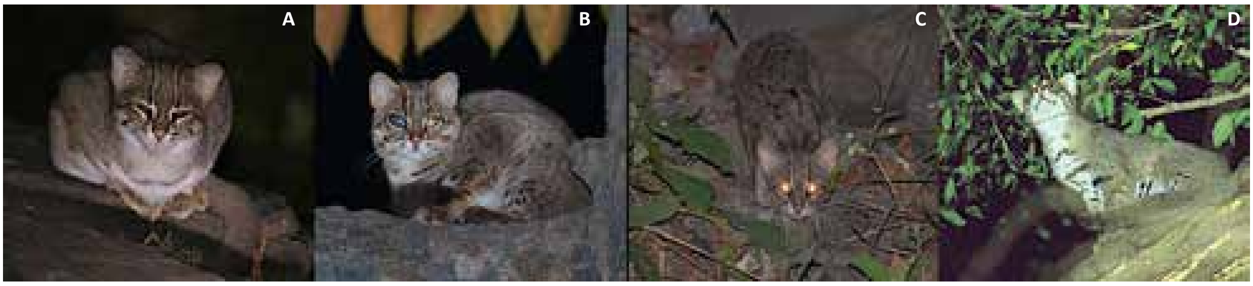


**Image 3. Rusty-spotted Cats outside protected areas: A—near a water body, 27 September 2018 © Pranav Vaghashiya | B—near Rupayatan, 31 January 2020 © P. Vaghashiya | C—in a bushland, 7 February 2021 © Dipak Vadher | D—on a tree near a settlement, 16 Dec 2022 © D. Chauhan.**


**Image 4. Rusty-spotted Cats on trees: A—in a Manila Tamarind tree, 17 December 2023 © P. Vaghashiya | B—in wood stack, 4 January 2024 © Dipak Vadher | C—in Oval-leaved Wheel Creeper, 25 April 2024 © P. Vaghashiya |D—in a Manila Tamarind tree, 2 September 2024 © Pranav Vaghashiya.**


**Image 5. Dead Rusty-spotted Cats in Gir Wildlife Sanctuary: A—on a state highway, 23 December 2016 © Bhavesh Trivedi | B—in a Lion's mouth, 6 January 2018 © Indranil Ghosh | C—on a village road, 6 March 2022 © D. Chauhan.**

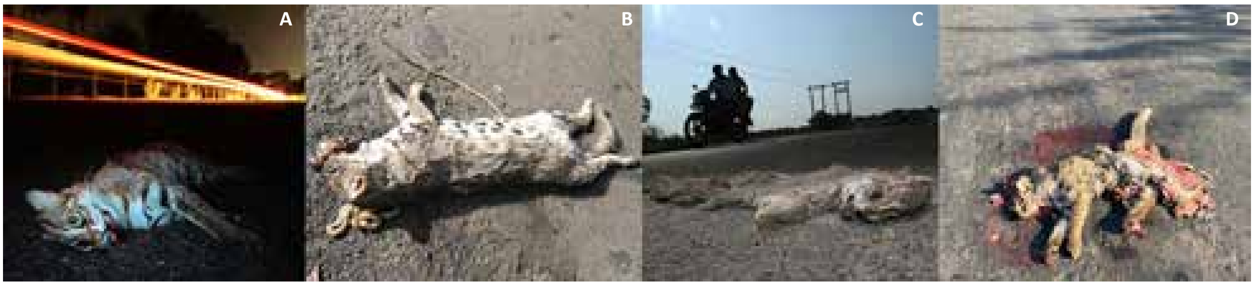


**Image 6. Rusty-spotted Cat roadkills outside protected areas: A—on a village road, 10 April 2022 © Parth Aghera | B—on a village road, 6 August 2016 © Amit Vaghasiya | C—on a state highway, 11 August 2018 © P. Vaghashiya | D—on a state highway, 4 January 2023 © Kaushal Sharma.**

five occurred inside wildlife sanctuaries. Four road kills were found on village roads, and five on state highways. One dead individual was observed in the mouth of an adult Lion (Image 5B).

## DISCUSSION

Our sightings document the presence of the Rusty-spotted Cat in Girnar, Paniya, and Gir Wildlife Sanctuaries and the adjacent unprotected forests. They also show that some individuals venture into plantations and crop fields adjacent to forest edges. Similar observations of Rusty-spotted Cats at forest edges have also been reported in other study areas (Patel & Jackson 2004; Patel 2006 2011; Vasava et al. 2012; Lele & Chunekar 2013; Mukherjee & Koparde 2014; Vyas & Upadhyay 2014; Sharma & Dhakad 2020; Roy & Makwana 2023).

The majority of live individuals were sighted after dusk, corroborating the nocturnal activity pattern of the Rusty-spotted Cat (Bora et al. 2020; Jhala et al. 2021).

The individual with the non-reflecting right eye sighted by night at the edge of Girnar Wildlife Sanctuary (Image 3B) resembles a similar case encountered in eastern Gujarat (Vyas & Upadhayay 2014). The Lion carrying a Rusty-spotted Cat in its mouth is an unusual incident, as the Lion typically preys on large ungulates (Ram et al. 2023).

Our roadkill records corroborate and underline that the road networks have a direct negative impact on the Rusty-spotted Cat's movement between forest patches (Tehsin 1994; Rao et al. 1999; Nayak et al. 2017; Sharma & Dhakad 2020; Patel et al. 2024; Pawar et al. 2024). The existing road and railway networks and recent developments of expanding this linear infrastructure in Gujarat are significant emerging threats to wildlife (Vyas et al. 2023). Roads and railway tracks cutting through natural habitats form barriers to wildlife movements and thus disrupt populations of many species (Rajvanshi et al. 2001; Forman et al. 2003; Benítez-López et al. 2010; Barrientos & Borda-de-Água 2017; Thatte et al. 2020; Vyas et al. 2023). Therefore, we recommend giving special attention to maintaining and improving habitat connectivity between forest patches that are vital for the Rusty-spotted Cat and other species reliant on forests.

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SHORT COMMUNICATION

# Abundance and distribution of the Critically Endangered Giant Staghorn Fern *Platycerium grande* (A.Cunn. ex Hook.) J.Sm. in Maguindanao del Sur, BARMM, Philippines

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**Abstract:** *Platycerium grande*, commonly known as the Giant Staghorn Fern, is a notable species of the Pteridophyte family, Polypodiaceae – confined to the tropical forests of the Malay Archipelago, especially in Mindanao, part of the Philippines. This study assessed the abundance and distribution of *P. grande* in Maguindanao del Sur, as a baseline for future conservation efforts. Using purposive sampling, individuals were counted and georeferenced across multiple sites. A total of 186 individuals were recorded, predominantly thriving on large trees such as *Mangifera indica* (Mango), *Pterocarpus indicus* forma *indicus* (Narra), and *Samanea saman* (commonly called as Acacia in the Philippines), within an elevation range of approximately 672–754 m. A notable observation was the occurrence of the endangered fern, *Ophioderma pendulum,* attached to the basal fronds of *P. grande.* The findings provide valuable insights into the current status of this Critically Endangered fern in the Philippines and fill existing gaps in botanical knowledge of the Bangsamoro Autonomous Region in Muslim Mindanao (BARMM), and support future conservation plans and strategies in compliance with Republic Act No. 9147 (2001), the Wildlife Resources Conservation and Protection Act of the Philippines.

**Keywords:** BARMM, biodiversity, conservation, epiphytic fern, phorophyte, polypodiaceae, *Ophioderma pendulum*, staghorn fern.

*Platycerium* Desv., commonly known as staghorn ferns, is a genus of epiphytic ferns within the family Polypodiaceae. Members of this genus are commonly grown as ornamental plants and are of high value in horticulture due to their unique morphology (Hoshizaki & Moran 2001; Poremski & Biedinger 2001; Darnaedi & Praptosuwiryo 2003). It consists of about 18 species and is predominantly found in subtropical and tropical lowland forests of Africa, Madagascar, Australia, and Asia (Kreier & Schneider 2006). One notable species is the *Platycerium grande*, commonly known as the giant staghorn, which was once tagged as endemic to the Philippines, but is currently confined also to the Sulawesi in Indonesia and is occurring in the Malay Archipelago (Darnaedi & Clayton 2020; POWO 2025). This species can be distinguished from the other *Platycerium* species by its distinctive morphology, which consists of dimorphic fronds, with broad and shield-like sterile fronds, and antler-like fertile fronds which can grow to a considerable size while attaching to its phorophytes without harming or damaging them (Hoshizaki 1972; Hennipman & Roos 1982; Lee 1989; Hoshizaki & Price 1990; Hoshizaki & Moran 2001).

Although *P. grande* was recognized for its high economic value, this species is categorized in the DENR Administrative Order (DAO) No. 2017-11 as a

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critically endangered fern in the Philippines. *P. grande* is reported to be progressively vulnerable due to habitat loss, deforestation, and climate change (Amoroso & Aspiras 2011; DENR 2017). Moreover, due to its high demand for its attractive appearance and majestic size (Madulid 1985), the overharvesting of this species by plant enthusiasts has raised concerns regarding its potential impact (Baker 2018), especially since its spores are difficult to germinate in nature (Amoroso 1992; Amoroso & Amoroso 1998; 2003).

Studying its abundance and distribution can contribute knowledge to the currently limited data about this species, especially in less surveyed regions like Maguindanao in the Bangsamoro Autonomous Region in Muslim Mindanao (BARMM) (Ong et al. 2002; MENRE-BARMM 2021). In this regard, this study aimed to determine the abundance and distribution of *P. grande* in Maguindanao del Sur and provided a baseline for the conservation strategies in compliance with Republic Act No. 9147 (2001), otherwise known as the Wildlife Resources Conservation and Protection Act of the Philippines, 2001.

## Materials and Methods

The study was conducted in South Upi, located in the province of Maguindanao del Sur, Philippines (Image 1). The area is characterized by mixed land use, including residential home lots, farm lots, and roadside vegetation, with open but shaded microhabitats receiving patchy sunlight. Purposive sampling was conducted without a fixed transect, following the methodology of Mangaoang & Gumban (2020). Fieldwork was conducted on 1–3 May 2025. The actual number of individual plants and the positions where *P. grande* is attached were counted and documented. Species identification was based on morphological characteristics, including the structure of the basal, vegetative fronds and the presence & form of the soral patch. Identification was further validated using references such as Copeland (1958), Hovenkamp et al. (1998), and Pelser et al., (2011). Additionally, a distribution map was created using the QGIS application. No specimens were collected during the study, in compliance with Republic Act No. 9147 (2001; Wildlife Resources Conservation and Protection Act).

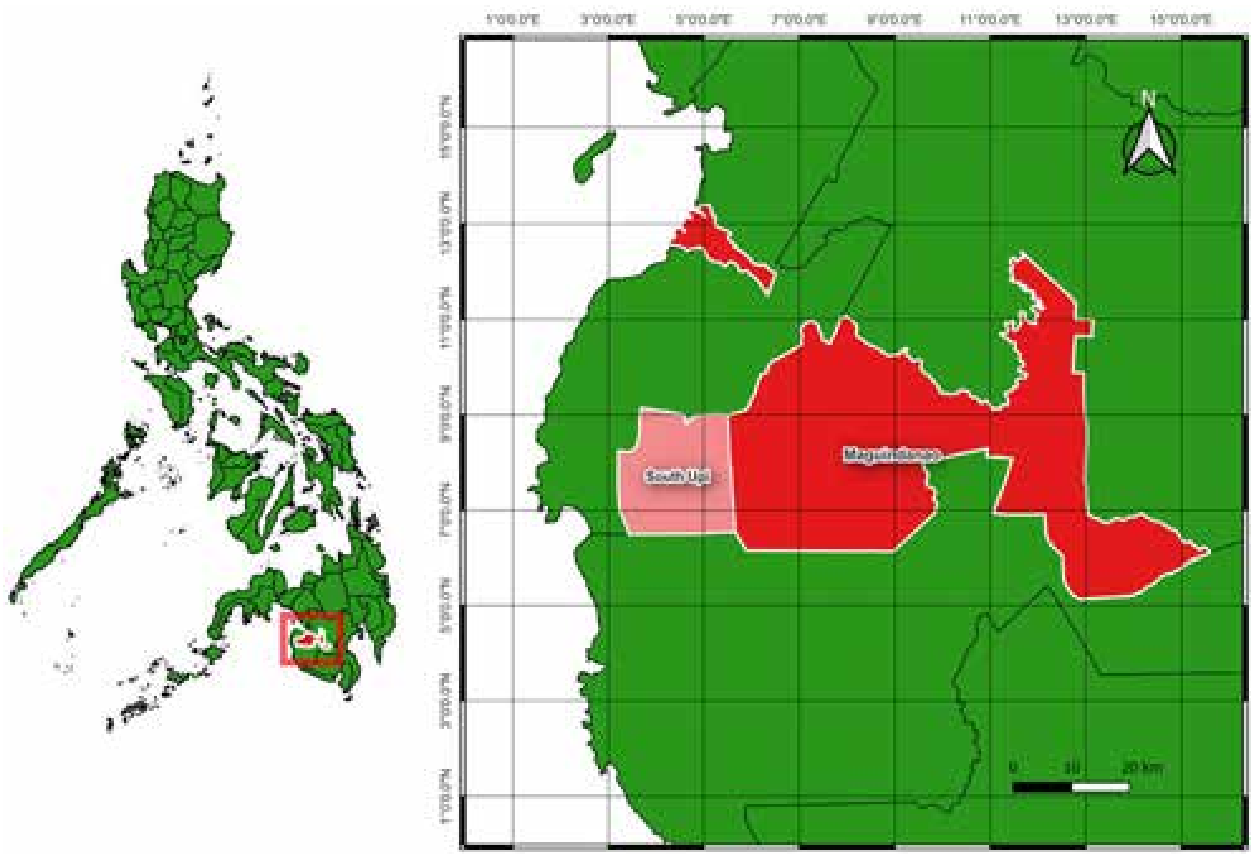


**Image 1. Sampling site location in South Upi, Maguindanao del Sur, Philippines: (Green) Philippine Boundary. (Red) Province of Maguindanao del Sur. (Pink) Municipality of South Upi.**

## Results and Discussions

*Platycerium grande* was mostly observed at approximately 672–754 m, thriving in open but shaded areas with patchy sunlight. Individuals were commonly found along roadsides, in residential home lots, and on farm lots in selected areas of Maguindanao del Sur. A total of 186 individuals of *P. grande* were recorded, often attached to large trees and coconut palms. Notably, a great abundance was observed on trees such as *Samanea saman* (commonly called as Acacia in the Philippines), *Pterocarpus indicus* forma *indicus* (Narra), and *Mangifera indica* (Mango), consistent with previous records of host tree associations for this species (Mangaoang & Gumban 2020).

As shown in Image 2, most *P. grande* individuals were located on trees at the following elevations: *Mangifera indica* at 682 m, *Pterocarpus indicus* forma *indicus* at 687 m, and *Samanea saman* at 686 m, and 733 m. While *P. grande* was often abundant on a single tree, particularly in *S. saman*, where a single tree had up to 16 individuals, it was sparse or even absent on adjacent trees. This pattern may indicate a localized microhabitat preference or limitations in spore dispersal, although such ecological factors are beyond the scope of the current study. It was also observed that two individuals were attached to a coconut tree approximately 1.5 km away from the main cluster, suggesting possible long-distance wind dispersal. Similar mechanisms have been reported in related species (Bhatia & Uniyal 2022).

*Platycerium grande*'s presence in various areas, including human-modified habitats such as roadsides, residential areas, and farm lots, indicates a certain degree of ecological tolerance. Nevertheless, the distance-dependent decline in individual counts suggests that suitable habitat features are not uniformly distributed across the study site (Ong et al. 2002). Although there are fewer *P. grande* individuals in some specific trees, as shown in Image 3, the overall findings indicate that *P. grande* is relatively abundant within the study area, with specific elevation ranges and host tree associations.

The documentation of *P. grande* across multiple areas in Maguindanao del Sur provides valuable insights into its current abundance and distribution. These baseline data strengthen our understanding of its localized population status and underscore the need for continued field studies in the Bangsamoro region (Ong et al. 2002; MENRE-BARMM 2021). Although species interactions were not a primary focus of this study,

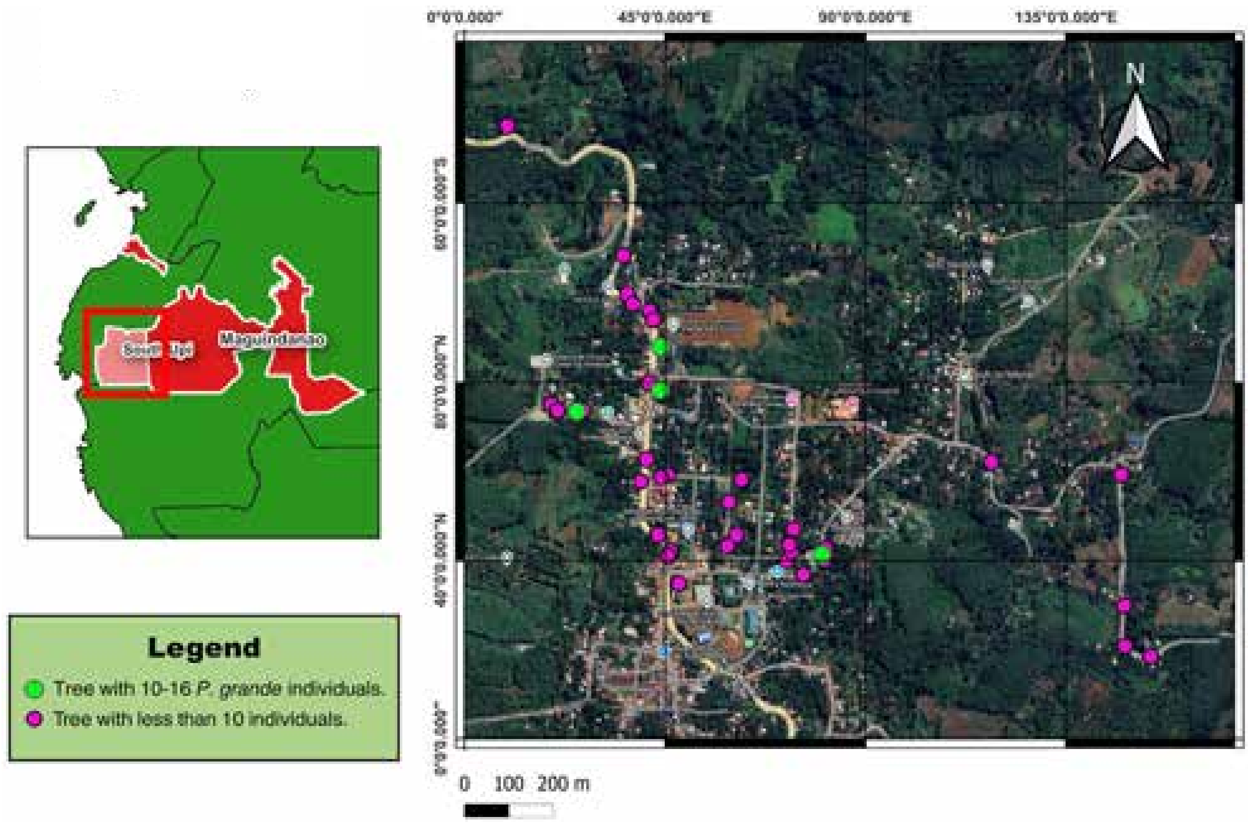


**Image 2. Distribution of *Platycerium grande* in Maguindanao del Sur, Philippines.**


**Image 3. Observed *Platycerium grande* in Maguindanao del Sur, Philippines: A–B—Trees with abundant *P. grande* individuals | C—Tree with fewer abundant *P. grande* individuals | D—*P. grande* with *Ophioderma pendulum* growing on the sterile frond. © Authors.**

the incidental observation of *Ophioderma pendulum* at the same sites highlights the ecological relevance of these habitats and their potential role in conservation of multiple threatened fern species (Amoroso & Aspiras 2011).

Furthermore, it was also observed that some *P. grande* individuals are attached to dead trees, which are at risk of collapsing at any time. Nevertheless, according to personal communication with the Ministry of Environment, Natural Resources and Energy (MENRE), these individuals are planned to be carefully pruned and will then be transferred to more suitable and stable phorophytes to ensure their continued survival.

## Conclusions and Recommendations

This study offers baseline data on the current abundance and distribution of *P. grande*, a critically endangered fern species in the Philippines. A total of 186 individuals were recorded, predominantly growing in open but shaded environments along roadsides, residential areas, and farm lots in Maguindanao del Sur, BARMM. The localized clustering of individuals and limited presence in surrounding areas indicate a fragmented distribution pattern across the region. Additionally, the results of this study contribute valuable information on the current abundance and distribution of *P. grande*, an endemic species in the Malay Archipelago, and provide insights that serve as useful reference for future research. Furthermore, the findings of this study can aid in crafting and implementing local conservation strategies for *Platycerium* species, especially *P. grande*. To support its conservation, further research focusing on its ecology, reproduction, dispersal mechanisms, and microhabitat preferences are strongly recommended. These efforts will support the protection and sustainable management of *P. grande* populations in Bangsamoro

Autonomous Region and ensure compliance with Republic Act No. 9147 (2001) of the Philippines.

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SHORT COMMUNICATION

# *Bonnaya gracilis* a novel find for the flora of Uttarakhand, India

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**Abstract:** *Bonnaya gracilis* was transferred from the genus *Torenia* to the genus *Bonnaya* in 2021. The species resembles *B. antipoda* but can be distinguished by the presence of dense yellow hairy staminodes and long vertical fruiting pedicels. This species only occurs in Nepal, Myanmar, Bangladesh, and India. In India distribution of this species is not very cleear hence this paper reports *Bonnaya gracilis* from Uttarakhand along with their description, images and location map.

**Keywords:** Doon valley, forest ecosystems, Linderniaceae, new record, semi-aquatic, shallow water, staminodes, swamps, torenia.

The word valley refers to low-laying area between two mountain ranges formed by the movement of tectonic plates. Valleys harbour high biological diversity and act as drainage systems for all water sources originated in hills. Doon valley, Uttarakhand is a longitudinal expansion of 75 km in length (east to west) and 22–25 km wide (north to south). Geographically Doon Valley lies at 30.362° N, 77.991° E and covers an area of more than 2000 km$^2$. Valley harbours two main perennial rivers of India, i.e., Yamuna in the west & Ganga in the east (including their tributaries and subtributaries) forming a watershed, creating moist habitat all along the valley. Wetlands of Doon Valley are extensively studied since 1901, recognizing their unique ecosystems, species structure, composition, lifeform diversity, and fragile nature (Kanjilal 1901; Dakshini (1960a,b); Deva & Aswal 1974; Sharma & Joshi 2008; Mir et al. 2018).

The taxonomic complexities within family Linderniaceae Borsch, Kai Müll. & Eb. Fisch. had garnered global attention. However, recent advancements have solidified its taxonomy, defining diagnostic features for every genus. One such complexity has recently been solved where Pal et al. (2021) had transferred *Torenia gracilis* Benth. to the genus *Bonnaya* Link & Otto as *Bonnaya gracilis* as a new species. *B. gracilis* shows prominent characteristic features of genus *Bonnaya*, i.e., deeply-lobed calyx, two clavate staminodes, linear cylindrical capsules twice as long as calyx, hence, this transfer was very justified. Genus *Bonnaya* Link & Otto is among the four largest genera within the family, which was previously suggested to be circumscribed under the genus *Lindernia* sensu lato, currently consisting of 17 species globally and in India represented by nine species (POWO 2024; Garg et al. 2020). The genus is divided into two sections, i.e., section *Bonnaya* noted by Lax racemes and section *Aculeata* noted by capitate inflorescences (Liang & Wang 2014).

In India, three similar looking species—Bonnaya antipoda (L.) Druce, *Bonnaya gracilis* A.Pal, Sardesai &

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M.Chowdhury, and *Bonnaya sanpabloensis* Y.S.Liang & J.C.Wang are found. All these three species can be identified on field by observing staminodes which are either subglabrous or densely hairy with yellow/red/purple hairs or with densely white pilose hairs respectively. *B. antipoda* has wide distribution in country (present in most of the states), *B. gracilis* is reported from parts of southern, central, northern, and northeastern India and *B. sanpabloensis* is so far only reported from the Western Ghats of Maharashtra by Sardesai et al. (2019).

## Materials & Methods

During a local field around the fringe areas of Ashkrodi Range Forest Dehradun, Uttarakhand authors spotted an interesting plant belonging to family Linderniaceae, growing in shallow water pools formed during monsoon season. For further identification some specimens were collected, and after consultation of literature (Hooker 1884; Gaur 1999; Pennell 1943; Liang & Wang 2014; Pal et al. 2021) the specimen was identified as *Bonnaya gracilis*, a species described in 2021. This paper marks the first distributional record of this species from northern India (Uttarakhand). A few specimens were dried following the standard methods of herbarium preparations (Rao & Sharma 1990) and been deposited in the Herbarium of Wildlife Institute of India (WII) Dehradun.

## Taxonomic Description

***Bonnaya gracilis*** A.Pal, Sardesai & M.Chowdhury in Nordic Journal of Botany 39(8) 1–7. 2021.
(Image I)

Erect annual herbs, 25–30 cm long. Stem four angled, with lax branches, ascending or diffused, glabrous occasionally, rooting at lower nodes. Leaves simple, opposite decussate, sessile, oblong obovate to elliptical, acute, glabrous on both surfaces, margins serrate with 6–15 pairs of teeth, pinnately veined; secondary veins 9–12 pairs. Inflorescence terminal or axillary lax racemes. Flower about 8–10 in racemes**,** each with a subtending linear bract about 3–5mm long, pedicels ascending in flowers 5–14 mm and almost vertical in fruits 12–22 mm. Calyx is five-lobed, persistent,5–8 mm long with apex acuminate-acute. Corolla, bilipped, 10–12mm long, ventral lip of the corolla has three rounded lobes (3–3.8 x 3.1–3.9 mm) while the dorsal lip has an obtuse apex or is bilobed (4.1–5.1 x 2–3 mm); pale blue to pale purple coloured, white specks at the base of the central lobe. Stamens 2, epipetalous, pale blue to pale purple,

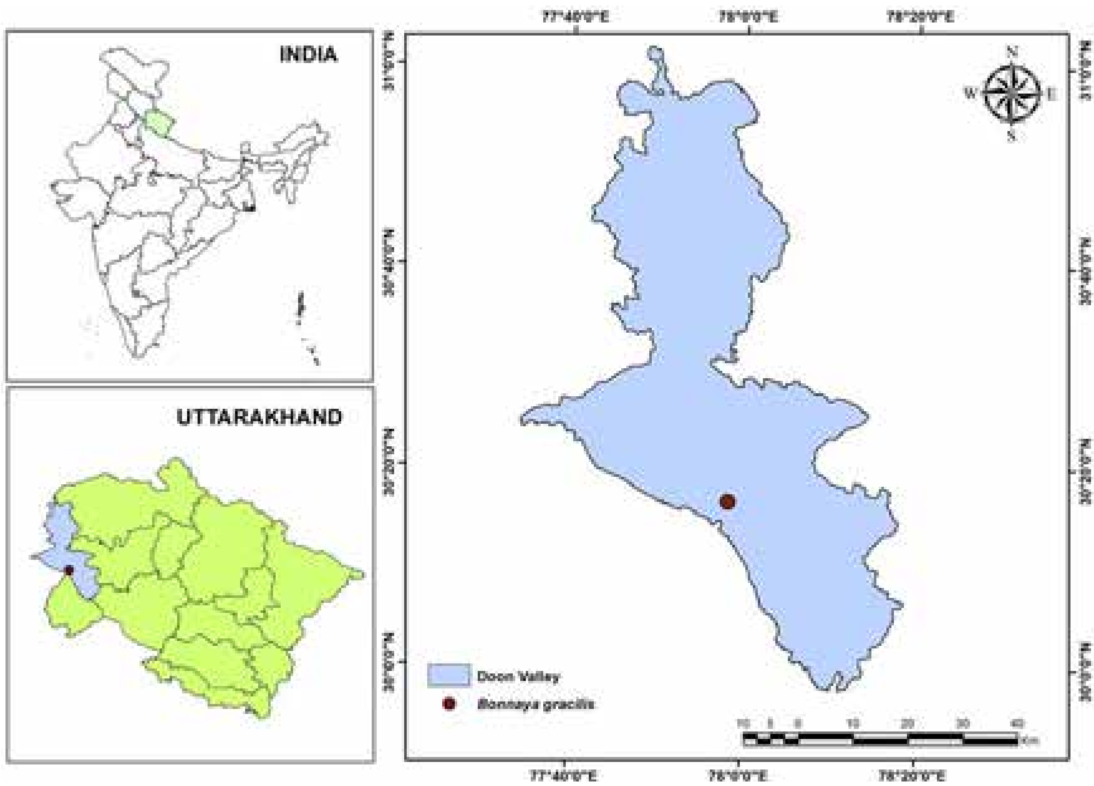


Figure 1. *Bonnaya gracilis* A.Pal, Sardesai & M.Chowdhury in Uttarakhand.

**Table 1. A comparative analysis of *Bonnaya gracilis* A.Pal, Sardesai & M.Chowdhury with other closely related species *Bonnaya antipoda* (L.) Druce.**

| Diagnostic characters | *Bonnaya gracilis* | *Bonnaya antipoda* |
|---|---|---|
| Leaves | Margin serrate with 6–15 pairs of teeth. | Margin serrate with 5–12 pairs of teeth |
| Inflorescence | Always axillary or terminal lax racemes with 4–12 flowers. | Solitary axillary and terminal racemes with 5–10 flowers |
| Staminodes | Staminodes covered with dense yellow, red hairs | Staminodes, glabrous |
| Pedicel | 12–20 mm in fruiting, almost vertical. | 5–12 mm almost half the size of *B. gracilis* in fruiting, ascending. |
| Distribution | Found in Nepal, Bangladesh, Myanmar and India only. | Found across Asia and Africa to the New World including Venezuela, Hawaii, Louisiana, Mauritius. |

1.3–2.1 mm long, anthers 1.3–1.7 mm long; Staminodes 2, filaments 1.5–2 mm long light blue to pale purple, anther 1.1–1.7 mm long, Staminodes 2 about 6 mm long clavate with upper half brightly yellow coloured, lower half white coloured covered with dense pilose hairs. Ovary cylindrical about 2.3 X 0.5, with 5.1–5.5 mm long style. Yellow disc is adherent to ovary on ventral side. Fruit capsule about 2 mm long slightly shorter than pedicels and 2–3 times longer than the calyx. Seeds numerous tiny angular, brownish scrobiculate, with stellate projections and scattered mesh about 0.2–0.5 X 0.2–0.3 mm.

**Flowering and Fruiting:** June to December.

**Habitat and Ecology:** Semi-aquatic plant in shallow water pools formed during the monsoon season found with *Acorus calamus* L., *Bonnaya ciliata* (Colsm.) Spreng., *Bonnaya antipoda* (L.) Druce, *Lobelia alsinoides* Lam., *Paspalum scrobiculatum* L., *Torenia anagallis* (Burm.f.) Wannan, W.R.Barker & Y.S.Liang, *Torenia crustacea* (L.) Cham. & Schltdl.

**Distribution:** Nepal, Bangladesh, Myanmar and India (Kerala, Karnataka, Maharashtra, Puducherry, West Bengal; Pal et al. 2021, and Assam; Roy et al. 2024) now from Uttarakhand.

**Specimens examined:** India: Uttarakhand, Dehradun, Elevation 610m, 13.vii.2024, 30.275° N & 77.972° E, Revan Yogesh Chaudhari 14967. India: Uttarakhand, Dehradun, Elevation 610m, 13.vii.2024, 30.275° N & 77.972° E, Monal Rajendra Jadhav.

## Discussion

Uttarakhand has been extensively explored for its botanical diversity. During our field visits in the Doon Valley, we frequently observed *B. antipoda* and *B. gracilis* growing together. This close association may explain why earlier researchers found it difficult to distinguish between the two species in the field. Without careful and detailed observation, it is challenging to recognize them, indicating a sympatric relationship between the two. Swampy habitats of valley are also home to this species, but these landscapes are under continuous threat of habitat degradation and encroachment posing potential threat to this species. Family Linderniaceae Borsch, Kai Müll. & Eb.Fisch in the state is represented by six genera and 17 species [*Bonnaya* Link & Otto (03 spp.), *Craterostigma* Hochst. (02 spp.), *Lindernia* All. (03 spp.), *Torenia* L. (07 spp.), *Vandellia* L. (01 spp.), and *Yamazakia* W.R.Barker, Y.S.Liang & Wannan (01 sp.)] (Uniyal et al. 2007), with an addition of one species to the list.

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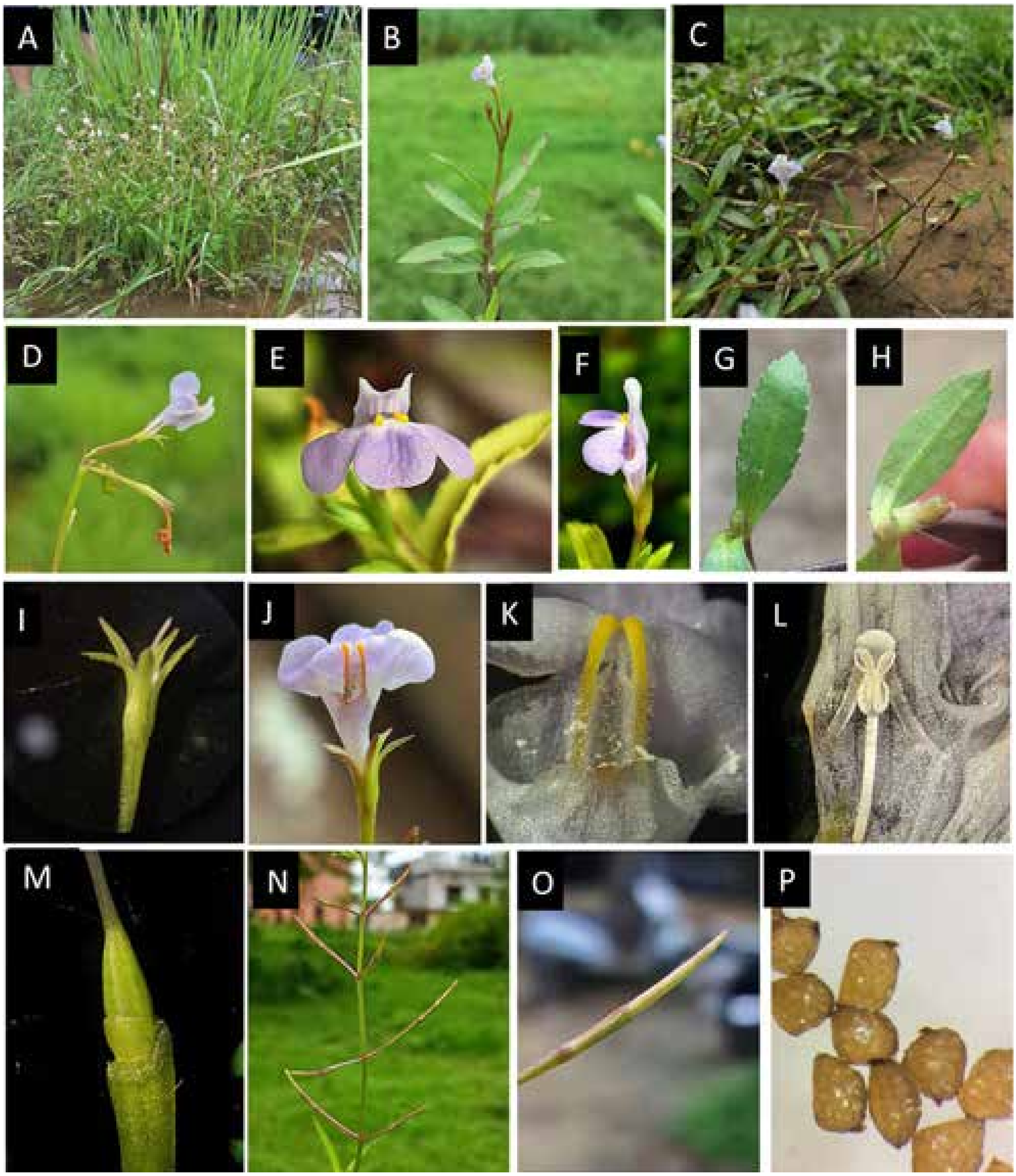


**Image 1. *Bonnaya gracilis* A.Pal, Sardesai & M.Chowdhury: A—Habit | B&C—Flowering twig | D–F—Flower | G&H—Leaf | I—Clayx | J&K—Staminodes with pilose hairs | L—Fertile stamens | M—Ovary with disk | N—Vertical fruiting pedicels | O—Capsule closeup | P—Seeds. © Revan Chaudhari.**

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NOTE

# Crab eating crab: first record of the Horn-eyed Ghost Crab *Ocypode brevicornis* preying on the Mottled Light-footed Crab *Grapsus albolineatus* in Visakhapatnam, India

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One of the classic studies by Paine (1966) demonstrated how the keystone predator, the Ochre Sea Star *Pisaster ochraceus*, regulates species composition and maintains diversity in rocky intertidal communities. Similarly, in sandy intertidal zones, ghost crabs (genus *Ocypode*, family Ocypodidae) act as important keystone predators by influencing benthic invertebrate populations and sediment dynamics, thereby shaping the ecological structure of these habitats. These sand burrowing crabs are called 'ghosts' for their pale sand blending colour, their swift movement to escape threat, and their predominant nocturnal activity (Lucrezi & Schlacher 2014). All ghost crabs are morphologically characterised by their box-shaped carapace, long eye stalk, and unequally sized claws. They are distributed all across the tropics and temperate zones, from the coast of the Atlantic Ocean and the Mediterranean Sea to the eastern Pacific Ocean and the Indo-west Pacific Ocean (Sakai & Türkay 2013). Along the Indian coast, there are at least six recorded species of ghost crabs – *O. brevicornis*, *O. ceratophthalmus*, *O. cordimana*, *O. macrocera*, *O. pallidula*, and *O. rotundata* (Sakai & Türkay 2013; Lucrezi & Schlacher 2014). Of the six, we have observed at least three species in Rushikonda Beach, Visakhapatnam – *O. brevicornis* (Image 1), *O. macrocera*, and *O. cordimanus*.

Ghost crabs play a key role in the intertidal ecosystem. The burrowing activity of crabs on the sandy shores causes bioturbation, mixing sediments and thereby influencing nutrient cycling and overall ecosystem functioning (Dubey et al. 2013; An et al. 2021). Moreover, ghost crabs serve as a key link in intertidal food webs, functioning as apex invertebrate consumers and scavengers while also serving as prey for vertebrates. Their diet ranges from the microscopic organic materials, to macroscopic dendrites of seaweeds and seagrass, animal carcasses beached on the shore, and live invertebrate & vertebrate prey that the crabs can catch and handle (Lucrezi & Schlacher 2014; Vale et al. 2022). Initially, assumed to be predominantly scavengers, there is increasing evidence that ghost crabs are significant apex predators that hunt and feed in the intertidal zone (Wolcott 1978; Kwon et al. 2018; Yong & Lim 2019). They are known to actively prey on clams, gastropods, annelid worms, isopods, shrimps, various kinds of insects, and eggs & young ones of nesting birds and turtles (Lucrezi & Schlacher 2014). They are also known to prey on other crabs such as hermit crabs

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Image 1. Horn-eyed Ghost Crab *Ocypode brevicornis* at the sandy section of Rushikonda Beach, Visakhapatnam, Andhra Pradesh. © Harish Prakash.

Image 2. Mottled Light-footed Crab *Grapsus albolineatus* at rocky section of Rushikonda Beach, Visakhapatnam, Andhra Pradesh. © Harish Prakash.

Image 3. *Ocypode brevicornis* handling *Grapsus albolineatus* (side view) at Rushikonda Beach, Visakhapatnam, Andhra Pradesh. © Harish Prakash.

(family Paguroidea), mole crabs (Hippidae), fiddler crabs (Ocypodidae), box crabs (Calappidae), portunid crabs (Portunidae), sentinel crabs (Macrophthalmidae), and ghost crabs (Branco et al. 2010; Chartosia et al. 2010).

To the best of our knowledge, this is the first documented observation of the *O. brevicornis* actively handling a *G. albolineatus* (family: Grapsidae) (Image 3 & 4). This observation made at Rushikonda Beach, Visakhapatnam, on April 2025 is unique since the *O. brevicornis* is usually found only on the sandy section of the beach, while the *G. albolineatus* is found in the rocky section (Image 2). This natural history observation highlights the sand-dwelling ghost crabs' possible foray into the rocky sections of the intertidal zone as a part of their nocturnal foraging activity. Such predator-prey interaction might be restricted to areas of the beach where rocky and sandy habitats co-occur within the intertidal zone.

Ghost crabs are generalists and opportunistic feeders, with their diet depends on local prey availability and seasonal variation (Vale et al. 2022). Given the wide geographical distribution of *O. brevicornis* along the Indian coast, dietary patterns likely vary spatially. Such differences in marine predator-prey interactions might also arise from the impact of disturbance to the intertidal ecosystem in the form of pollution (Johnston & Roberts 2009) and climate change (Harley 2011). Studies in the future, should systematically examine the diet of apex invertebrate predators like ghost crabs. Such studies will improve our understanding of predator-prey interactions and their spatio-temporal variation along the coast. It also helps infer the impact of such interactions on intertidal community dynamics and broader marine ecosystem functioning.

**Ethical statement:** This observation was based solely on animals in their natural habitat. No manipulation or disturbance was caused to them during the observation except for the brief headlamp light and flash from the camera. Therefore, no ethical approval was required.

**Image 4. *Ocypode brevicornis* handling *Grapsus albolineatus* (top view) at Rushikonda Beach, Visakhapatnam, Andhra Pradesh. © Harish Prakash.**

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# First record of Greater Scaup *Aythya marila* in Farakka IBA near West Bengal & Jharkhand border, India

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West Bengal has a very rich avifaunal diversity with 929 species, including 11 'Critically Endangered' species (Manna et al. 2024). Large numbers of migrants are attracted, especially during winter, by the extensive areas of water bodies of West Bengal. River Ganga enters into West Bengal through Malda District. Due to presence of Farakka Barrage on the river Ganga in Malda District, the river appears to be huge but near stagnant in nature. The river's water level begins to drop as winter approaches, and several `chaurs` or riverine islets are formed and birds utilize these `chaurs` for foraging and roosting. Farakka barrage and the surrounding area is recognized as an IBA (Important Bird and Biodiversity Area) that extends from Farakka Barrage to Manikchak Ghat of Malda District, West Bengal (Rahmani et al. 2016). Due to its diversity, this area attracts a significant number of both terrestrial and aquatic birds. Some are Greater Spotted Eagle *Aquila clanga,* Baer's Pochard *Aythya baeri*, Indian Skimmer *Rynchops albicollis*, and Ferruginous Pochard *Aythya nyroca* (Jha 2006). The 'Endangered' Gangetic Dolphin *Platanista gangetica* also has a strong population in this area.

On 01 December 2024 morning, a Greater Scaup *Aythya marila* was observed near the West Bengal and Jharkhand state borders. The authors recorded this during a four-month-long avifaunal survey (December 2024 to March 2025) in the river Ganga conducted once a month. Figure 1 shows the location of the bird sighting area (24.970° N, 87.938° E). This is the first record of Greater Scaup in Farakka IBA. At first the authors misunderstood it as a Tufted Duck *Aythya fuligula*, as it was floating along with them. The authors took some pictures and later identified it as a female Greater Scaup using a field guide (Grimmett et al. 2016). Image 2 shows a clear picture of a female Greater Scaup floating with a female Tufted Duck. Greater Scaup females often have a rounder head, a wider bill with a whiter base (Kessel et al. 2020). In contrast, female Tufted Ducks may have a smaller white patch at the base of their bill, a flatter-topped head, and a small tuft (Carboneras & Kirwan 2020). The authors recorded a total of nine riverine bird species on that location, including Greater Scaup and

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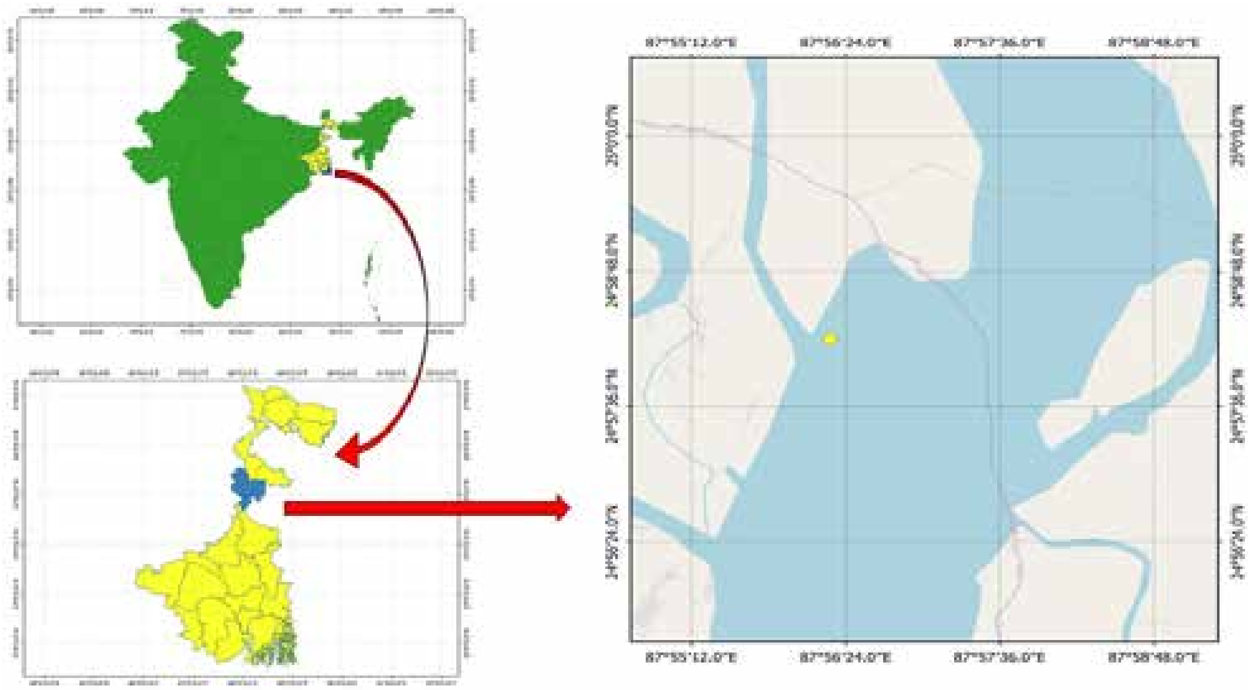


**Figure 1. Location of the sighting area.**

**Image 1. Female Greater Scaup *Aythya marila* (in the right) floating with a Tufted Duck Aythya fuligula (on the left). © Sudip Ghosh.**

Tufted Duck. Other sighted bird species were Common Pochard *Aythya ferina*, Kentish Plover *Anarhynchus alexandrinus*, Brown-headed Gull *Chroicocephalus brunnicephalus*, Black-headed Gull *Chroicocephalus ridibundus*, Great Crested Grebe *Podiceps cristatus*, Great Cormorant *Phalacrocorax carbo*, Black-headed Ibis *Threskiornis melanocephalus*, and Eastern Cattle Egret *Ardea coromandra*.

The Greater Scaup is a rare migratory bird to India (Rasmussen & Anderton 2012; Grimmett et al. 2016). This round-headed diving duck migrates through the Central Asian Flyway (CAF) (Narwade et al. 2021). Though

Greater Scaup has some unique distinguishing features, it is easy to get confused with other *Aythya* ducks. Male Greater Scaup have black breast, medium gray back, white sides, yellow eyes, and a glossy blackish-tinted green head, although head color can vary and is not a reliable distinguishing feature. Females have a white patch on their face and are dull in colour. Their belly is white, and they have a dark brown head and neck with lighter molting (Deviche 2019). Typically, flocks of this species are seen with other *Aythya* ducks. Although Greater Scaup can be found in freshwater, these birds often choose bays and coves with saltwater. As they can dive to hunt for aquatic invertebrates including mollusks, crustaceans, and insects, these ducks favour shallow freshwater lakes, ponds, and rivers. They also consume aquatic plant stems, leaves, and seeds. They are mostly seen in Siberia, Alaska, and northern Canada during the breeding season and winters in south to avoid the severe Arctic weather. Their wintering sites are found around the coasts of North America, Europe, and Asia, as well as other temperate locations (Bellrose 1980; Cannings et al. 1987; American Ornithologists' Union 1998; Trost & Drut 2001). Some individuals occasionally stray further south and are seen in southern Asia, including India (American Ornithologists' Union 1998; Ali et al. 2015).

In recent years, Greater Scaup has been recorded in northeastern India, mostly in Assam, West Bengal, and Sikkim. It is noticed that most of the observations were made in the Brahmaputra and Ganga Rivers. By analyzing secondary literature, it is found in Gajolboba Barrage, West Bengal at the same month of the authors` observation in Farakka IBA; Piyali River, South 24 Parganas, and Gajoldoba in Jalpaiguri (eBird 2025). Few other winter sightings of this species in India recorded are from Bombay Deccan (Aspinall 1950); Corbett National Park, Uttarakhand (Kumar & Lamba 1985); Dihaila Jheel, Karera Bustard Sanctuary, Madhya Pradesh (Natarajan & Sugathan 1987); Nelapattu Bird Sanctuary, Andhra Pradesh (Prashant et al. 1994); Pohara-Malkhed Reserve Forest, Maharashtra (Wadatkar & Kasambe 2002); Pong Dam, Himachal Pradesh (den Besten 2004); Bhindawar Bird Sanctuary, Haryana (Harvey et al. 2006). This present sighting is a reminder for birdwatchers that they should always look for the presence of uncommon birds that may get overlooked due to similarities with their more common congeners.

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NOTE

# Filling the gap: first regional record of the Little Owl *Athene noctua ludlowi* (Strigiformes: Strigidae) from Uttarakhand, India

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High-altitude regions often support species that remain poorly documented due to harsh terrain and limited accessibility, resulting in substantial gaps in biodiversity knowledge (Shrestha et al. 2020). The Little Owl *Athene noctua* is widely distributed across the Palearctic region, with multiple subspecies distinguished primarily by plumage coloration and body size. Vaurie's (1960) comprehensive taxonomic revision recognized 13 subspecies of the Little Owl, including *A. n. ludlowi*, which occurs in the Himalayan region (Koelz 1939). Recent synthesis on the Little Owl confirms that the subspecies *Athene noctua ludlowi* occupies the Himalayan arc and adjoining Tibetan Plateau, with records supporting its occurrence across this region. These records, categorized into distinct geographical clusters, contributed to the delineation of 13 regions within the overall distribution range of the species (Nieuwenhuyse et al. 2023). Although globally assessed as 'Least Concern' by the IUCN Red List with a stable population trend, *A. n. ludlowi* remains one of the least studied subspecies in the Himalaya (BirdLife International 2019). In India, the species is not listed separately but, as a member of the family Strigidae, is included under Schedule II of the Wildlife (Protection) Act, 1972.

The distribution of the species in the Himalaya has been documented only sporadically over the past century, reflecting a consistent lack of focused research. The earliest records appear in The Fauna of British India (Baker 1922, 1927), with observations from the Mishmi Hills, Arunachal Pradesh, from the Lahaul-Spiti landscape of Himachal Pradesh (Marshall 1984), followed by trans-Himalayan records from Ladakh (Ludlow & Kinnear 1937). After several decades with little new information, modern confirmations emerged, including breeding records from Upper Mustang, Nepal (Acharya 2002). Pfister (2001) noted potential interbreeding between *A. n. ludlowi* and *A. n. bactriana* in the southern part of Tso Kar. Additional evidence has come from high-altitude locations such as Sela Pass, Arunachal Pradesh (Limparungpatthanakij et al. 2017), and northern Sikkim (Ganguli-Lachungpa et al. 2011). Taxonomic and distributional treatment in Rasmussen & Anderton

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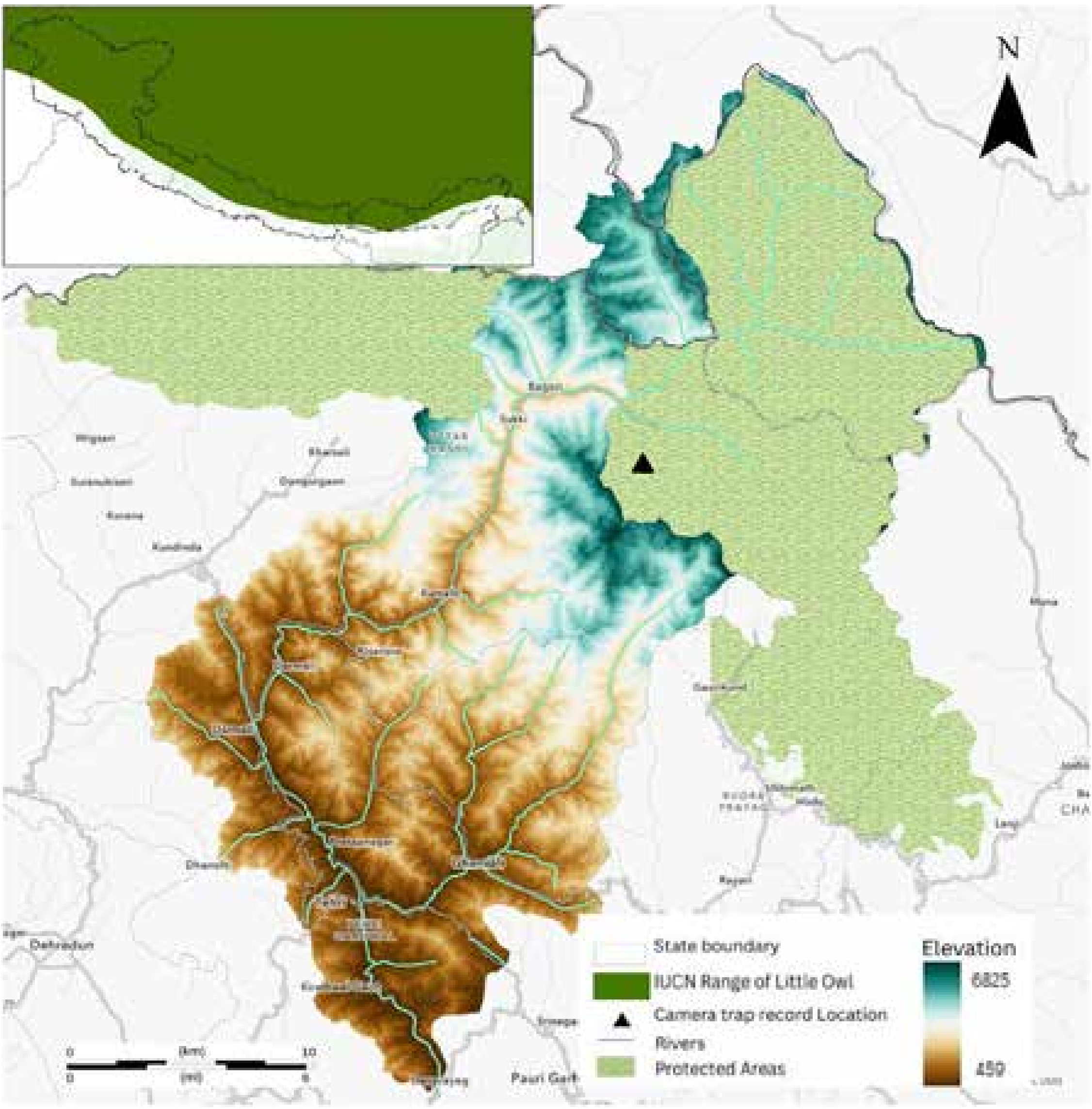


**Image 1. An inset showing IUCN range of Little Owl *Athene noctua* (Scopoli, 1769) in the Indian Himalayan region with camera trap location (in black triangle) where the species has been captured in the Bhagirathi basin, Uttarakhand.**

(2012) consolidated its status, while more recent work added the first national record in Bhutan (Wangdi 2015) and its inclusion in regional checklists (Bhutan Ecological Society 2018; NTNC 2018)

Here, we report a photographic record of the Little Owl from the high-altitude alpine habitat of the Upper Bhagirathi River Basin, Uttarakhand (30.943° N, 78.906° E) (Image 1). The identification was independently verified by multiple experienced birders, with key features including white spectacles, a white throat, and bold white spotting on the underparts (Image 2; Grimmett et al. 2011). The record is particularly noteworthy as it significantly exceeds the typical upper elevation range of the Spotted Owlet *Athene brama*, which rarely occurs above 2,800 m, thereby supporting the validity of the identification. This study forms part of a long-term monitoring program titled 'Assessment and Monitoring of Climate Change Effects on Wildlife Species and Ecosystems for Developing Adaptation Strategies in the Indian Himalayan Region-DST NMSHE', aimed at understanding the responses of medium-sized mammals and ground-dwelling birds to changing climatic conditions in the region. The basin encompasses diverse habitats: subtropical broad-leaved and Chir Pine *Pinus roxburghii* forests at lower elevations (500–1,500 m); montane mixed broad-leaved forests and oak woodlands (*Quercus semecarpifolia*, *Q. floribunda*), and subalpine mixed coniferous forests (*Abies pindrow*,


**Image 2. Camera-trap image of a Little Owl *Athene noctua* (Scopoli, 1769) from the Rudragaira Valley, Gangotri National Park. The inset highlights key identification features, including white spectacles, a white throat, and bold white spotting on the underparts.**

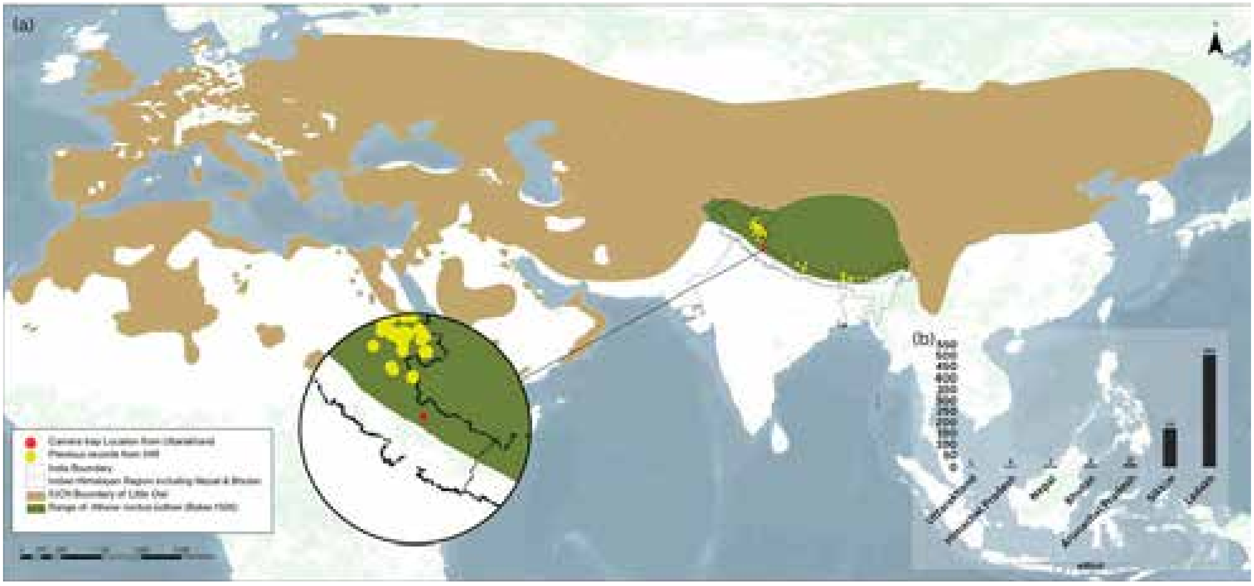


**Image 3. a—IUCN range of little Owl *Athene noctua* (Scopoli, 1769) with the range of subspecies *Athene noctua ludlowi* (Baker, 1926), in green colour | b—Number of observations based on citizen science data in the Himalayan arc of *Athene noctua ludlowi* range. Sourced from eBird.**

*Cedrus deodara*, *Pinus wallichiana*) at mid-elevations (2,000–3,800 m); high-altitude alpine and subalpine vegetation (3,500–5,000 m) with *Rhododendron* spp., *Betula utilis,* and alpine herbs and forbs; and a Trans-Himalayan landscape (3,500–5,200 m) represented in Nelong Valley with alpine desert steppe plants such as *Caragana versicolor*, *Acantholimon lycopodioides*, *Thylacospermum caespitosum*, *Rhamnus prostrata*, and *Artemisia brevifolia*. The alpine habitat surrounding the camera trap site supports a mosaic of herbaceous cover and shrub thickets, which are known to harbour small mammal populations. Although direct rodent surveys were not conducted, the presence of burrow systems and frequent sightings of murid species during concurrent fieldwork suggest adequate prey availability for *A. n. ludlowi*. This aligns with the species' known dietary preference for small mammals, reinforcing the ecological plausibility of its occurrence in this region. Previous studies (e.g., König & Weick 2008; BirdLife International 2019) have emphasised the Little Owl's reliance on rodent-rich habitats, particularly in montane and semi-open landscapes.

Despite its broad occurrence across the Himalayan arc, it remains one of the least studied subspecies of the Little Owl, with research largely restricted to scattered presence-only records. Citizen-science platforms such as eBird now provide important supplementary data, revealing that records are concentrated in Ladakh, followed by Sikkim, with Arunachal Pradesh, particularly the Sela Pass region, showing regular observations. In contrast, Bhutan, Nepal, and Himachal Pradesh report only a handful of sightings, though suitable habitats suggest a potentially wider distribution. A single record from Kalimpong, West Bengal, further indicates its occurrence in the eastern Himalaya (Image 3b).

This first photographic evidence of *Athene noctua ludlowi* from Uttarakhand addresses a key distributional gap within the Himalaya. Despite the subspecies remaining poorly studied, recent contributions from citizen-science initiatives have provided valuable supplementary data, particularly by involving local observers in remote landscapes. Ongoing integration of such participatory records with systematic field surveys offers a practical way forward for refining knowledge of its range and informing conservation planning.

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