

Study on
**DEVELOPMENT OF
BIOACOUSTICS TOOLS
FOR MONITORING OF
AMPHIBIAN DIVERSITY IN
MUNNAR LANDSCAPE,
WESTERN GHATS, INDIA**

FINAL REPORT



Funded by:
Centre for Wildlife Studies, Bengaluru



Project Partners:
Cornell Lab of Ornithology, USA
biometrio.earth, Germany



Implemented by:
Tropical Institute of Ecological Sciences (TIES),
Kottayam

November, 2025



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Affiliated Research Centre of Mahatma Gandhi University, Kottayam

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Funded by:

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Project Partners:

Dr. Vijay Ramesh, Cornell Lab of Ornithology, USA

Dr. Namitha Suresh, biometrio.earth, Germany

Implemented by:

Tropical Institute of Ecological Sciences (TIES), Kottayam

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Preface

The Western Ghats, a global biodiversity hotspot, serves as a critical refuge for amphibian life. However, this fragile ecosystem faces mounting pressures from climate change, habitat fragmentation, and anthropogenic interference. The genesis of this project, "Development of Bioacoustics Tools for Monitoring of Amphibian Diversity in Munnar Landscape, Western Ghats, India," lies in the findings of an earlier IUCN Freshwater Study conducted by the Tropical Institute of Ecological Sciences (TIES). That assessment starkly highlighted that the degradation of freshwater habitats poses an existential threat to local frog communities, particularly those that are highly endemic to the region.

Recognizing that traditional, invasive survey methods are often insufficient for monitoring cryptic and nocturnal species, we identified an urgent need for innovative, technology-driven solutions. This project was conceived to bridge that gap by developing an automated, non-invasive bioacoustic tool capable of identifying species through their unique vocalizations.

This initiative was realized through the generous funding and support of the Centre for Wildlife Studies (CWS), Bengaluru, under their Wild Incubator Tech Program 2024. The project's success is also deeply rooted in a robust scientific collaboration with Dr. Vijay Ramesh of the Cornell Lab of Ornithology (USA) and Dr. Namitha Suresh of Biometrio.earth (Germany), as well as Mr. Vijay Karthik of the Nature Conservation Foundation. Their technical expertise in bioacoustics, machine learning, and data annotation was instrumental in transforming raw field recordings into a functional precision model.

We also extend our gratitude to the Kerala Forest and Wildlife Department and Kannan Devan Hills Plantations for granting essential field access and logistical support. Finally, I commend the dedicated project team at TIES for their rigorous fieldwork and commitment to conservation science.

This report documents our journey in developing this open-source acoustic tool. It is our hope that this work will not only strengthen ecological monitoring in Munnar but also serve as a scalable model for amphibian conservation across the Western Ghats.

Dr. Punnen Kurian
Project Head
Tropical Institute of Ecological Sciences (TIES)

Acknowledgements

This project was implemented by the Tropical Institute of Ecological Sciences (TIES) under the leadership of Dr. Punnen Kurian, with funding support from the Centre for Wildlife Studies (CWS) under the Wild Incubator Tech Project 2024.

TIES gratefully acknowledges the contributions of its research collaborators, whose expertise and technical support were central to the success of the bioacoustic component of the study. Dr. Namitha Suresh (Biometrio.earth, Germany) and Dr. Vijay Ramesh (Cornell Lab of Ornithology, USA) provided advanced analytical support after the completion of field annotations. Using tools such as BirdNET Analyser and associated workflows, they led the development, processing, and refinement of the machine learning classifier used for species-level audio identification. In addition, Dr. Namitha Suresh and Dr. Vijay Ramesh conducted training sessions for the project team on data collection protocols, data management, and especially detailed call annotation, ensuring that the acoustic datasets generated from the field met high scientific and analytical standards.

A special note of appreciation is extended to Dr. Namitha Suresh, whose dedicated work on classifier development and model building formed the core analytical engine of the project, transforming field recordings into a functional acoustic identification framework. Their contribution formed the core of the technological advancement of the project, transforming raw field recordings into a functional framework for automated acoustic monitoring. TIES also deeply appreciates the guidance of Mr. Vijay Karthik (Nature Conservation Foundation, Mysore), whose expertise in the bioacoustics of bush frogs greatly strengthened the scientific foundation of the study. His research insights provided valuable direction on species call characteristics, survey optimisation, and challenges specific to analyzing the calls of endemic Western Ghats amphibians.

The Project Team comprised Project Officer- Nidhichand K. P., Project Assistant- Cimila Sibichen, and Intern- Rohit Gupta, and Project Coordinator- Mr Sarath Babu N.B., whose combined efforts enabled successful field implementation, data collection, and community engagement throughout the project duration. The project experts' team are Dr. Sujith V. Gopalan and Dr. Sandeep Das.

We also acknowledge the Kerala Forest and Wildlife Department and Kannan Devan Hills Plantations for granting field access, logistical support, and cooperation during surveys. Special thanks are extended to Mr. Rajju Joseph for transportation assistance, which ensured the smooth execution of repeated field visits across remote locations in Munnar.

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INTRODUCTION

Rhacophorus pseudomalabaricus (Juvenile)



1. INTRODUCTION

Amphibians are currently experiencing some of the most dramatic declines recorded for any vertebrate group. Over several decades, population collapses have been documented across continents, and the first Global Amphibian Assessment revealed that more than one-third of all amphibian species are threatened with extinction—making them the most imperiled major vertebrate class (Stuart *et al.*, 2004). Recent reassessments by the IUCN show that these negative trends are continuing, now intensified by the combined pressures of habitat transformation, climate change, invasive species, pollution, and emerging infectious diseases (IUCN, 2023). Amphibians play central roles in ecosystem functioning—regulating insects, cycling nutrients, and linking trophic levels—and their sensitivity to environmental change makes them valuable indicators of ecological and climatic health (Gerhardt & Huber, 2002; Hocking & Babbitt, 2014). Long-term studies further demonstrate that declines are occurring even in protected and relatively undisturbed landscapes, underscoring the global scale and urgency of the crisis (Blaustein & Wake, 1990).

Despite their ecological importance, many amphibian lineages remain poorly studied, particularly in tropical regions where species richness is highest. Taxonomic challenges—including high morphological similarity, hidden genetic diversity, and a shortage of trained taxonomists—continue to obscure accurate species identification (Biju *et al.*, 2014; Gowande *et al.*, 2020). In India, major revisions using integrative approaches have revealed deep evolutionary divergence and widespread historical misidentifications, indicating that amphibian diversity has been systematically underestimated (Bossuyt & Biju, 2003). Conservation genetics work similarly shows that a large proportion of Indian amphibians are highly range-restricted, genetically unique, and remain insufficiently sampled or monitored (Hebbar *et al.*, 2019). The Western Ghats—one of the world’s biodiversity hotspots—exemplifies this scenario, with ongoing discoveries of new species and updated distributions across multiple genera (Chandramouli & Ganesh, 2010). Species such as *Philautus ochlandrae* (now known as *Raorchestes ochlandrae*) have been described from previously overlooked microhabitats, highlighting both the richness of the region and the gaps in existing knowledge (Gururaja *et al.*, 2007).

Within this hotspot, the Munnar highlands stand out for their exceptional ecological heterogeneity—shola forests, montane grasslands, high-altitude wetlands, and perennial streams collectively support numerous localized and threatened amphibian species. Recent discoveries within genera such as *Raorchestes*, *Micrixalus*, *Indirana*, and *Uperodon* illustrate the region’s evolutionary significance (Gowande *et al.*, 2020; Biju *et al.*, 2014). However, this landscape is increasingly vulnerable to land-use transitions, expanding agroforestry systems, invasive species, hydrological alterations, and rising tourism pressure. Studies show that such changes can drastically affect amphibian populations, influencing their abundance, microhabitat selection, and demographic structure (Lad *et al.*, 2024).

Global policy frameworks reinforce the urgency of conserving amphibians. The Convention on Biological Diversity’s Post-2020 Global Biodiversity Framework calls for improved monitoring of threatened and endemic species, supported by better assessment tools (CBD, 2022). The IUCN Red List consistently identifies the Western Ghats as a global priority for amphibian conservation (IUCN, 2023), and amphibian declines threaten progress on several UN Sustainable Development Goals, including those related to climate, freshwater ecosystems, and terrestrial biodiversity. Research further warns that the loss of amphibians could destabilize ecosystem services that human societies rely on (Hocking & Babbitt, 2014).

However, reliably monitoring amphibians in the Western Ghats remains challenging. Traditional survey methods such as visual encounter surveys often miss cryptic, nocturnal, or microhabitat-specialist species, resulting in underestimates of true diversity (Chandramouli & Ganesh, 2010). Detection probabilities can vary widely across habitats—particularly in modified landscapes—compromising the reliability of abundance and trend data (Lad *et al.*, 2024). Handling animals during surveys also risks spreading pathogens such as chytridiomycosis, a fungal disease responsible for some of the most severe vertebrate die-offs ever documented (Fisher *et al.*, 2012).

Given these constraints, bioacoustics has emerged as a powerful, non-invasive tool for amphibian research. Species-specific advertisement calls play fundamental roles in communication and reproduction, providing reliable markers for species identification and ecological monitoring (Gerhardt & Huber, 2002). Numerous studies

demonstrate that acoustic surveys—both manual and automated—can substantially increase detection rates, particularly in dense forests or during nocturnal activity peaks (Dorcas *et al.*, 2009). Passive Acoustic Monitoring (PAM) allows long-term, large-scale biodiversity assessments, reduces observer bias, and enables temporal analyses of breeding behavior and species presence (Teixeira *et al.*, 2024). Conservation practitioners worldwide are increasingly adopting these technologies because they are cost-effective, scalable, and suitable for multi-species monitoring (Browning *et al.*, 2017).

Given the taxonomic uncertainties, ecological sensitivity, and high conservation value of the Munnar region, there is a clear need for a robust, scalable amphibian monitoring approach. By integrating structured acoustic surveys with automated analytical tools, this project aims to improve the detection of cryptic species, establish long-term monitoring baselines, and generate essential data for informed conservation planning in one of India's most fragile and biologically significant mountain ecosystems. For the first phase, we focused on five key species to build and test our model. After establishing a strong baseline, the system will be scaled up to cover many more species in the future.

1.1. Aim and Objective

To develop an effective taxonomical tool based on the vocalizations (calls) of frogs in the Munnar landscape. This tool will integrate bioacoustics call features to enhance species detection, monitoring, and conservation efforts in the region

- Conduct field surveys on frog diversity in Munnar;
 - Preliminary survey for frog diversity studies
 - visual encounter survey for 60 mins across different habitats.
- Prepare training data on frog calls (especially advertisement calls);
 - Recording of frog calls, using active and passive recorders placed in the specific location for a period of 5-minute duration and 48 hours respectively.
- Develop a bioacoustics tool for taxonomical identification;
 - Annotation of recorded calls using Raven Pro1.6, model development using Training and Testing data, data validation and uploading to GitHub.



Raorchestes beddomii

METHODOLOGY



Rhacophorus malabaricus (Juvenile)

2. METHODOLOGY

2.1 Study Area and Site Identification

The study was conducted in Munnar (10°04'50"N, 77°03'51"E), situated above 1200 m MSL in the Idukki district of Kerala. This region forms part of the Western Ghats, a UNESCO World Heritage Site (41.COM.8B.37, 2017), and is globally recognized for its ecological significance. Munnar hosts a heterogeneous landscape comprising montane shola forests, grasslands, tea plantations, and diverse freshwater systems, making it an important refuge for several endemic and threatened amphibian species.

To identify sampling sites and target species in Munnar landscape, an initial exploratory survey was carried out across 42 locations (Table 2.1 & Fig. 2.1.) in and around Munnar. Site selection was guided by amphibian experts in the known amphibian habitats-including shola forest patches, perennial and seasonal streams, rivulets and high-elevation wetlands. Secondary data from platforms such as iNaturalist and published literature were also referred. These preliminary assessments enabled the identification of areas with high amphibian richness, particularly those likely to support endemic and threatened taxa.

Sl. No.	Location Name	Site Id	MSL	Latitude	Longitude	Habitat type
1	Anachal	ANCL001	857	10.02741	77.05109	Degraded forest
2	Anakkulam-1st Block	ANKL001	561	10.1657	76.92906	Forest fragment
3	Anakkulam-1st Block	ANKL002	582	10.1727	76.9237	Forest fragment
4	Anakkulam-1st Block	ANKL003	557	10.16571	76.92906	Forest fragment
5	Anakkulam-50th mile	ANKL005	457	10.13045	76.94432	Secondary forest
6	Anakkulam-Mangapara	ANKL004	505	10.17441	76.92272	Degraded forest
7	Devikulam	DEVI003	1660	10.07778	77.09271	Secondary forest
8	Devikulam	DEVI001	1665	10.07501	77.09786	Secondary forest
9	Devikulam	DEVI002	1680	10.06957	77.1067	Secondary forest
10	Eravikulam	ERAV003	1537	10.12462	77.05344	Secondary forest
11	Eravikulam	ERAV001	1532	10.09968	77.05738	Degraded forest
12	Eravikulam	ERAV002	1497	10.11651	77.05736	Forest fragment
13	Eravikulam	ERAV004	1876	10.14926	77.08326	Forest fragment
14	Kallar-Kottappara	KTPR001	1069	10.02641	76.96998	Degraded forest
15	Lekshmi Estate	LEKS001	1306	10.07274	76.96952	Degraded forest
16	Lekshmi Estate	LEKS003	1508	10.05907	77.02222	Degraded forest
17	Lekshmi Estate	LEKS005	1496	10.06507	77.04299	Degraded forest
18	Lekshmi Estate	LEKS006	1402	10.06462	76.985	Degraded forest
19	Lekshmi estate	LEKS002	1469	10.06867	76.98366	Degraded forest
20	Lekshmi estate	LEKS004	1483	10.05846	77.0282	Secondary forest
21	Mankulam	MNKL001	1001	10.08364	76.95132	Forest fragment
22	Mankulam	MNKL002	1027	10.08311	76.9498	Forest fragment
23	Mankulam	MNKL003	968	10.0891	76.948	Degraded forest
24	Mattupetty	MTPY003	1598	10.10055	77.12027	Secondary forest
25	Mattupetty	MTPY004	1588	10.10084	77.12012	Degraded forest
26	Mattupetty	MTPY001	1673	10.0944	77.09531	Degraded forest
27	Mattupetty	MTPY002	1643	10.09887	77.10332	Forest fragment

28	Munnar	MUNR002	1630	10.09386	77.06834	Degraded forest
29	Munnar	MUNR003	1474	10.07939	77.06104	Degraded forest
30	Munnar	MUNR004	1530	10.08437	77.08661	Degraded forest
31	Munnar	MUNR005	1496	10.09337	77.05328	Degraded forest
32	Munnar	MUNR006	1538	10.08763	77.08819	Degraded forest
33	Munnar	MUNR001	1537	10.09033	77.06998	Degraded forest
34	Pallivasal	PASL002	1245	10.04406	77.04633	Degraded forest
35	Passivasal-Attukadu	PASL001	1233	10.05358	77.05663	Degraded forest
36	Pothamedu	PTMD001	1524	10.055	77.07117	Degraded forest
37	Pothamedu	PTMD002	1503	10.06243	77.06535	Degraded forest
38	Pothamedu	PTMD003	1370	10.04768	77.0786	Degraded forest
39	Pothamedu	PTMD004	1458	10.06906	77.06912	Degraded forest
40	Pothamedu	PTMD005	1463	10.07124	77.06797	Degraded forest
41	Pothamedu	PTMD006	1488	10.07392	77.06587	Degraded forest
42	Thalikam- Kallar	TLKM001	1082	10.06208	76.95819	Secondary forest

Table 2.1.: Data of all the 42 sites identified as a part of the study.

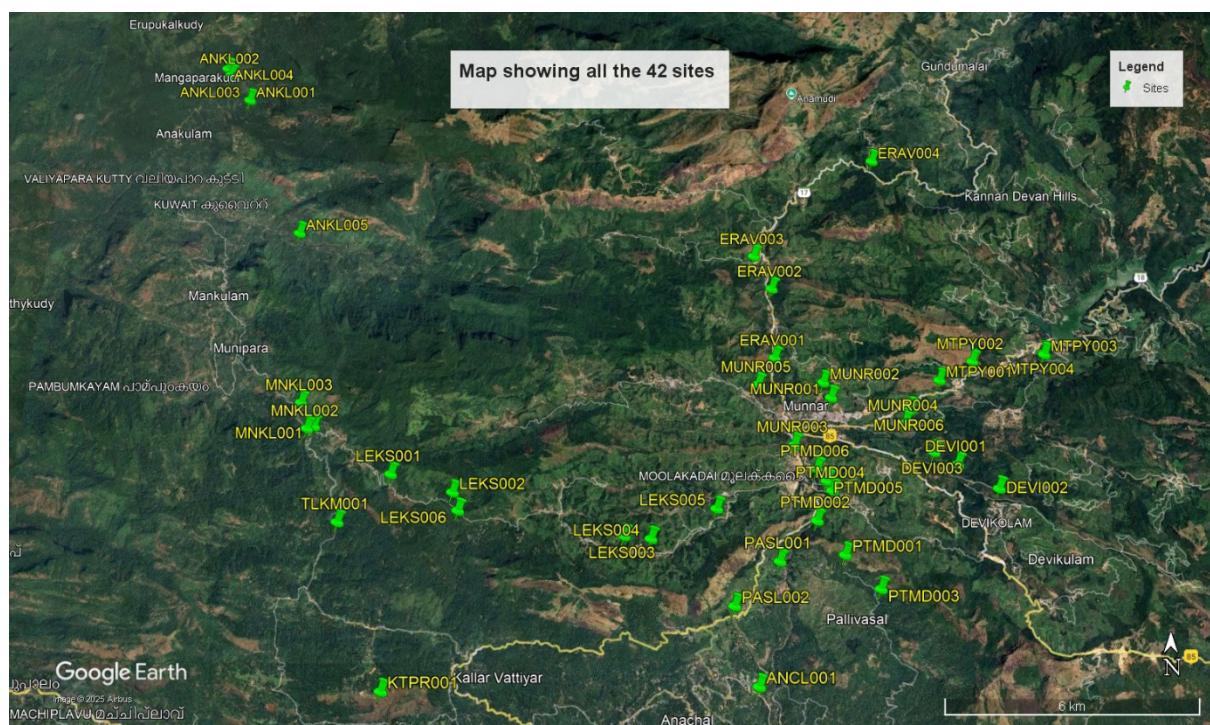


Fig. 2.1.: Map of all identified sites

from the 42 sites surveyed, 20 (Table 2.2, Fig 2.2 & Fig.2.3) were shortlisted for recording audio using criteria such as confirmed presence of priority species, representation of high-elevation habitat diversity, suitability for acoustic recordings with minimal anthropogenic noise, and overall

field safety. Logistical considerations—including accessibility, risk of encounters with wild animals, and distance from the base location- were also incorporated to ensure efficiency and safety during repeated visits.

Sl. No	Location Name	Site Id	MSL	Latitude	Longitude	Habitat type
1	Devikulam	DEVI003	1660	10.07778	77.09271	Secondary forest
2	Eravikulam	ERAV003	1537	10.12462	77.05344	Secondary forest
3	Lekshmi Estate	LEKS001	1306	10.07274	76.96952	Degraded forest
4	Lekshmi Estate	LEKS003	1508	10.05907	77.02222	Degraded forest
5	Lekshmi Estate	LEKS005	1496	10.06507	77.04299	Degraded forest
6	Lekshmi Estate	LEKS006	1402	10.06462	76.98500	Degraded forest
7	Mattupetty	MTPY003	1598	10.10055	77.12027	Secondary forest
8	Mattupetty	MTPY004	1588	10.10084	77.12012	Degraded forest
9	Munnar	MUNR002	1630	10.09386	77.06834	Degraded forest
10.	Munnar	MUNR003	1474	10.07939	77.06104	Degraded forest
11.	Munnar	MUNR004	1530	10.08437	77.08661	Degraded forest
12.	Munnar	MUNR005	1496	10.09337	77.05328	Degraded forest
13.	Munnar	MUNR006	1538	10.08763	77.08819	Degraded forest
14.	Pothamedu	PTMD001	1524	10.0550	77.07117	Degraded forest
15.	Pothamedu	PTMD002	1503	10.06243	77.06535	Degraded forest
16.	Pothamedu	PTMD003	1370	10.04768	77.0786	Degraded forest
17.	Pothamedu	PTMD004	1458	10.06906	77.06912	Degraded forest
18.	Pothamedu	PTMD005	1463	10.07124	77.06797	Degraded forest
19.	Pothamedu	PTMD006	1488	10.07392	77.06587	Degraded forest
20.	Thalikam- Kallar	TLKM001	1082	10.06208	76.95819	Secondary forest

Table 2.2.: Data of all the sites from where recordings were collected



Fig. 2.2. : Map of study area and sites

Images of study sites



Lekshmi Estate (LEKS003); N10.05907, E77.02222



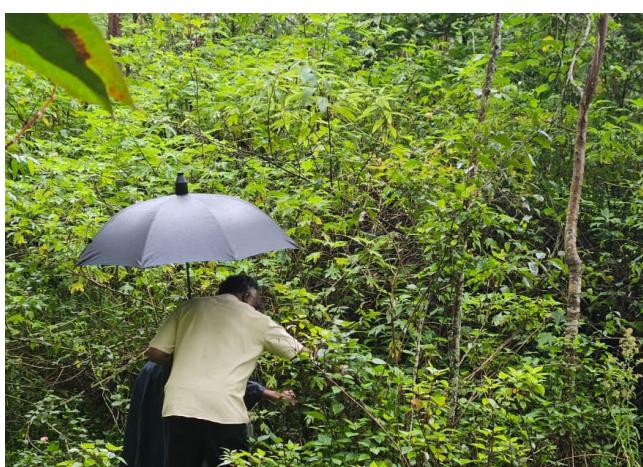
Pothamedu (PTMD001); N10.0550, E77.07117



Lekshmi Estate (LEKS005); N10.06507, E77.04299



Eravikulam (ERAV003); N10.12462, E77.05344



Mattupetty (MTPY003); N10.10055, E77.12027



Lekshmi Estate (LEKS006); N10.06462, E76.98500

Images of study sites



Munnar (MUNR006); N10.0876, E77.08819



Lekshmi Estate (LEKS001); N10.07274, E76.96952



Devikulam (DEVI003); N10.07778, E77.09271



Pothamedu (PTMD003); N10.04768, E77.0786



Mattupetty (MTPY003); N10.10055, E77.12027



Munnar (MUNR002); N10.09386, E77.06834

Images of study sites



Munnar (MUNR005); N10.09337, E77.05328



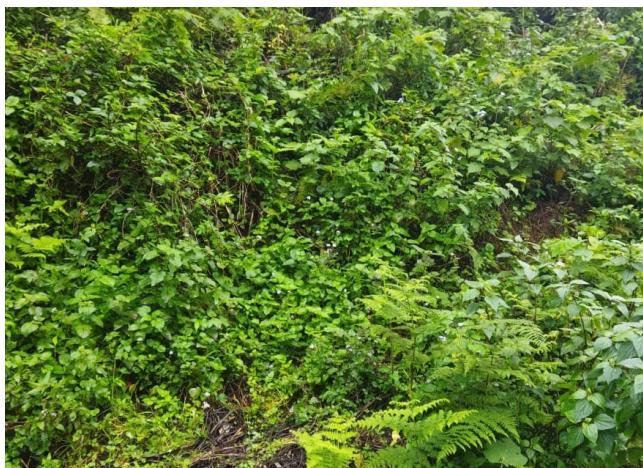
Munnar (MUNR003); N10.07939, E77.06104



Munnar (MUNR004); N10.08437, E77.08661



Thalikam- Kallar (TLKM001); N10.06208, E76.95819



Mattupetty (MTPY004), N 10.10084, E 77.12012



Pothamedu (PTMD004), N10.06906, E77.06912

Fig. 2.3.: images of selected study sites



Each survey and site conditions were systematically documented using a standardized assessment framework to ensure consistency and ecological relevance. Target species detection was carried out after 6:00 PM, and their relative abundance was estimated through call intensity and encounter rates. Additional amphibian species observed during daytime surveys were recorded along with their relative abundance to capture broader community composition. Dominant species at each site were identified based on overall vocal activity. Environmental factors such as natural ambient sounds (e.g., wind, insect activity) and anthropogenic disturbances were documented due to their influence on call detectability and recording quality. Habitat parameters- including vegetation cover, habitat type, and character-

istics of nearby water sources such as seasonal pools, rivulets, or quarry depressions- were also assessed. Each site was finally evaluated for its suitability for deploying Passive Acoustic Monitoring (PAM) units to support long-term acoustic data collection.

Following site verification, call recordings were collected between June and October 2024 using both active and passive acoustic monitoring methods. Active recordings were conducted during peak calling hours (6:00–10:00 PM) using ZOOM H6 and Tascam DR-05 recorders paired with Sennheiser MKH416 microphones. Passive recording used Song Meter Micro 2 devices deployed for 48-hour periods at selected sites.



ZOOM H6



Tascam DR-05



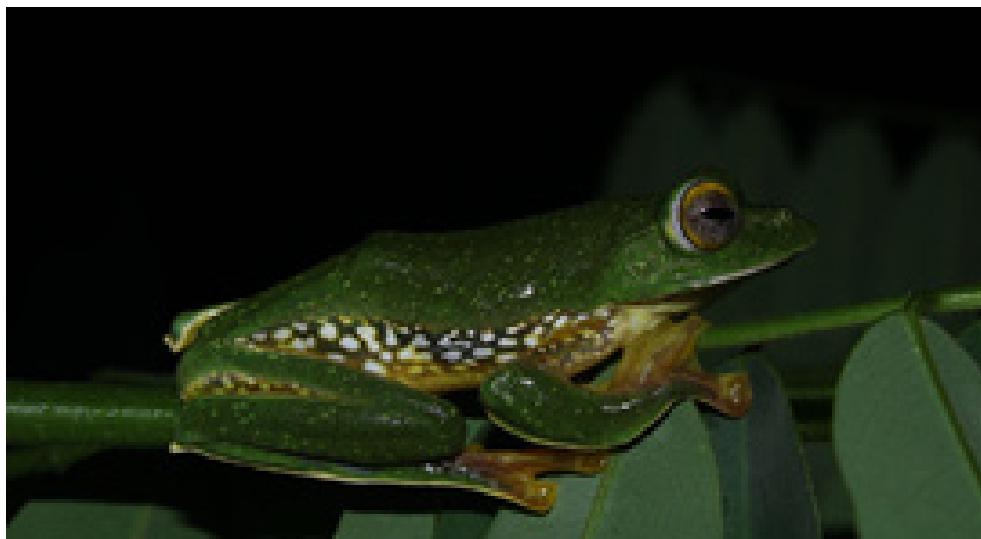
Song Meter Micro 2

Fig. 2.4.: Photograph showing the recording devices

2.2 Target Species

Five species were selected for detailed acoustic analysis and model development based on a combination of endemism to the Western Ghats, IUCN threat categories, ecological representation, and bioacoustic suitability: *Raorchestes beddomii* (LC), *Raorchestes jayarami* (EN), *Raorchestes chlorosomma* (EN), *Raorchestes blandus* (EN), and *Rhacophorus pseudomalabaricus* (VU). These species were prioritized for their high conservation priority, with four classified as Endangered or Vulnerable due to habitat loss, climate sensitivity, and restricted distributions in Munnar's high-elevation shola-grassland ecosystems.

Raorchestes beddomii (LC) was specifically selected to represent a common frog species in Munnar, providing baseline vocal activity patterns and abundant recordings for robust classifier training across varying abundance gradients. *Rhacophorus pseudomalabaricus* (VU) complemented the selection, adding phylogenetic diversity within Rhacophoridae. Additional criteria included distinct call signatures for reliable machine learning differentiation, and sensitivity to artificial light—many *Raorchestes* cease calling under headlamps, necessitating passive methods and low-disturbance protocols. This targeted approach ensured feasible data collection while maximizing conservation impact for Munnar's amphibian hotspot.



Rhacophorus pseudomalabaricus

Common name: Anaimalai Flying Frog

IUCN Red list category: Vulnerable (VU)

Description: The fingers and toes are webbed, thin dark vein-like markings present. A canopy dwelling species inhabiting moist, wet evergreen forests of higher elevations, typically between 1,000 and 1,600 meters above sea level.



Raorchestes blandus

Common name: Pleasant Bush Frog/ Anamalai Bush Frog

IUCN Red list category: Endangered (EN)

Description: Present on small bushes above the ground. Dorsum is rufous or brownish in colour. Seen at an elevation of 45 to more than 806 meters above sea level.



Raorchestes beddomii

Common name: Beddome's Bush Frog

IUCN Red list category: Least Concern (LC)

Description: The eyes are prominent, red in colour and a bluish tinge on the side of the belly/groin. Seen at an elevation of 1200 to 1780 meters above sea level.



Raorchestes jayarami

Common name: Jayaram's Bush Frog

IUCN Red list category: Endangered (EN)

Description: A green frog with eyes ranging from yellow to brownish-red and toes and fingers yellow in colour. Seen at an elevation of 600 to 1800 meters above sea level.



Raorchestes chlorosomma

Common name: Green Eyed Bush Frog

IUCN Red list category: Endangered (EN)

Description: Characterized by a striking greenish iris patterned with dark brown reticulations and a clearly visible tympanum. Seen at an elevation of 1400 to 1500 meters above sea level.

Fig.2.5. : Images of five target species:

2.3 Data Processing and Annotation

Recordings were visualized and annotated using Raven Pro 1.6 software (Fig. 2.7. - Fig. 2.12.). Each call was annotated with metadata, including start and end times, frequency range, species name, and annotator confidence level (1–5). In total, 4,873 active and 1,515 passive calls were processed. For each species, 400 calls were used 200 for training and 200 for testing. The curated dataset was used for machine-learning model training in collaboration with Biometrio.earth, and the Cornell Lab of Ornithology.

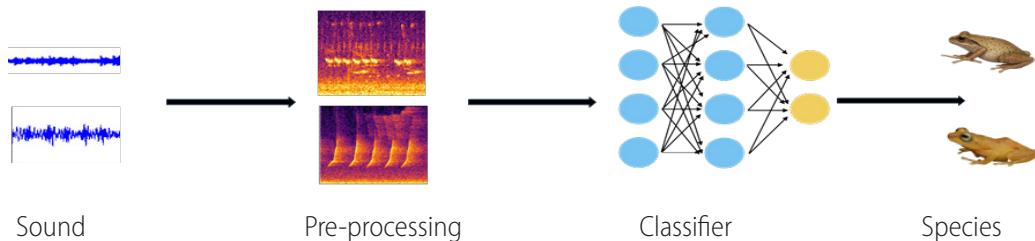


Fig.2.6. : Image of the steps in training the model

BirdNet embeddings were used to train the custom classifier. For training, the audio files were split into 3 second segments that contain at least one annotation. Around 200 of these segments spanning the different sites and different levels of background noise for each species were selected for training. The number of training samples (3 second audio chunks) used for each species are as follows:

1. *Rhacophorus pseudomalabaricus*: 190
2. *Ranocheates jayarami*: 194
3. *Ranocheates chlorosomma*: 183
4. *Ranocheates blandus*: 192
5. *Ranocheates beddomii*: 198

Feature extraction and validation steps were performed to enable accurate automatic detection and classification of frog calls.

The methodological framework for bioacoustics sampling, data handling, and call interpretation was developed with the guidance of the external research collabora-

2.4 Model Training

Using annotated datasets, a supervised classifier model was trained for species-level call identification. The model was developed as an open-source framework integrating signal preprocessing, feature extraction, and classification modules.

tors. Dr. Namitha Suresh (biometrio.earth), Dr. Vijay Ramesh (Cornell Lab of Ornithology), and Mr. Vijay Karthik (NCF) conducted structured training sessions for the project team on standardised field data collection techniques, file management, and high-precision call annotation. These sessions ensured that all recordings from focal and passive surveys were labelled systematically, following species-specific call characteristics and metadata standards. The collaborators also provided methodological direction on annotation workflows, spectrogram interpretation, and quality control, forming the foundation on which the subsequent acoustic analysis, model training, and automated recognition pipeline were built. This collaborative methodological input significantly strengthened the scientific rigour and reproducibility of the study.

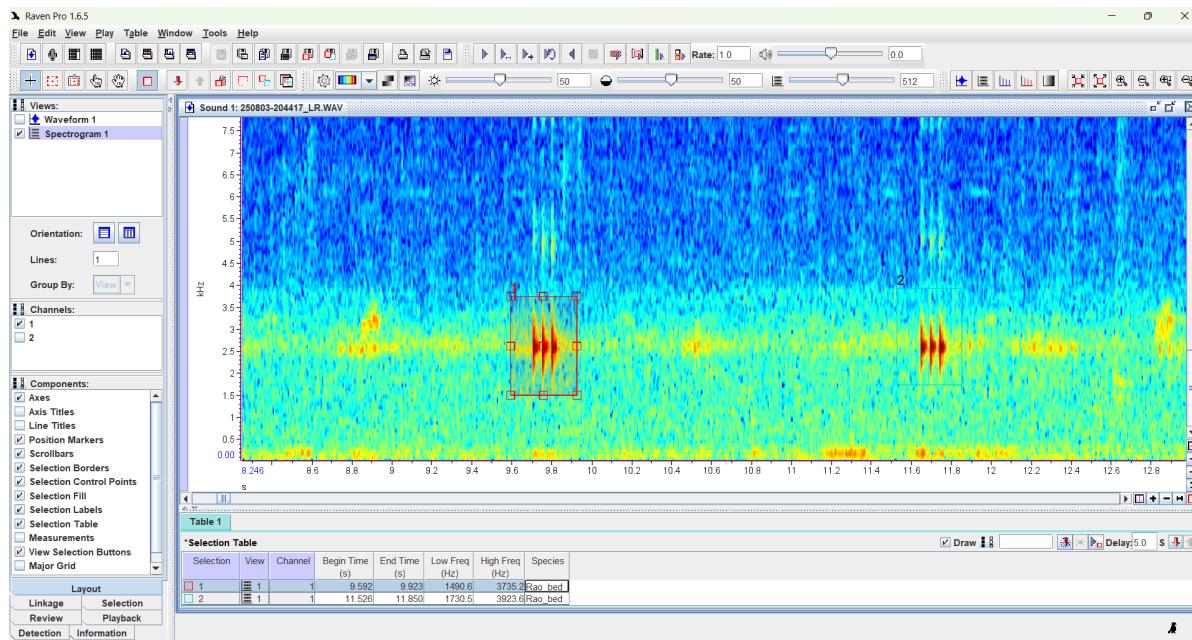


Fig.2.7. Raven Pro 1.6 interphase with spectrogram and selection table

Raorchestes beddomii

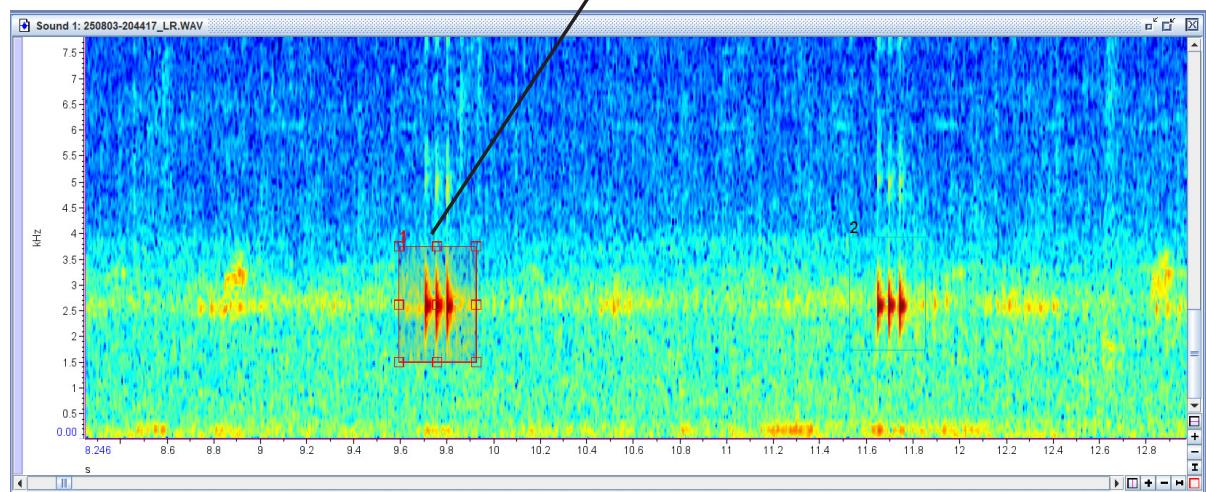


Fig.2.8. Spectrogram of *Raorchestes beddomii*

Raorchestes blandus

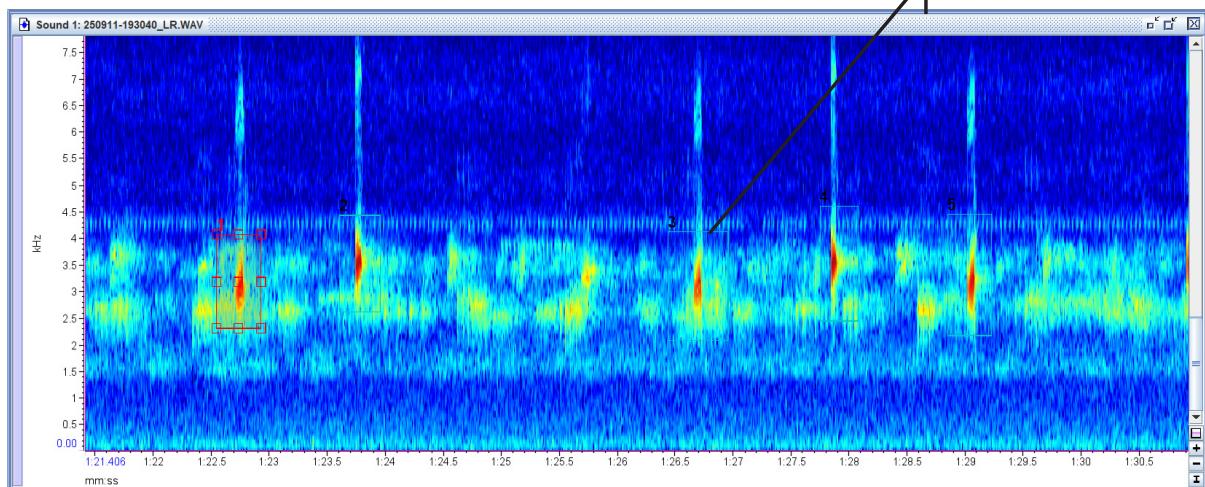


Fig.2.9. Spectrogram of *Raorchestes blandus*

Raorchestes chlorosomma

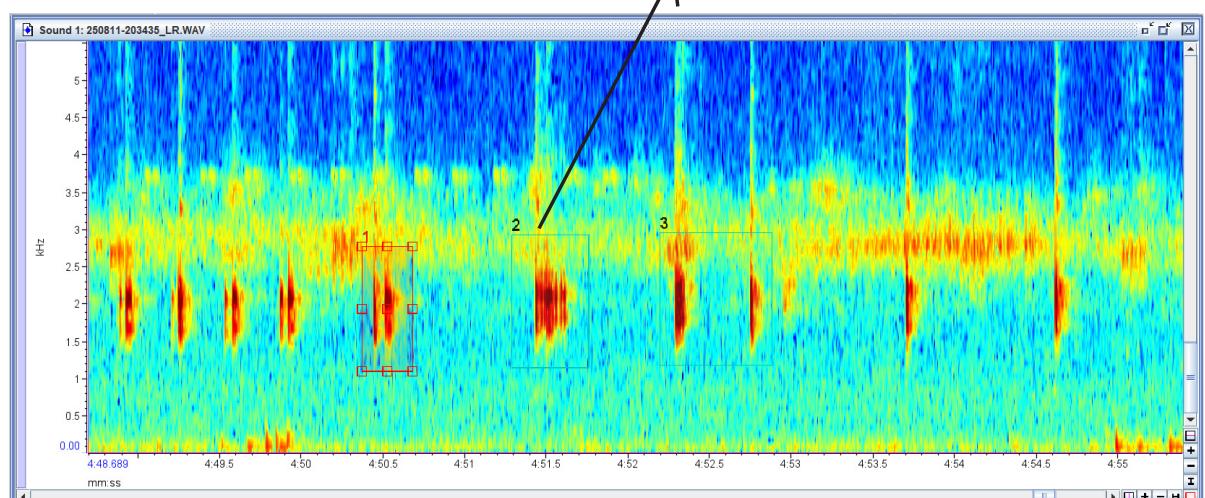


Fig.2.10. Spectrogram of *Raorchestes chlorosomma*

Ranocheates jayarami

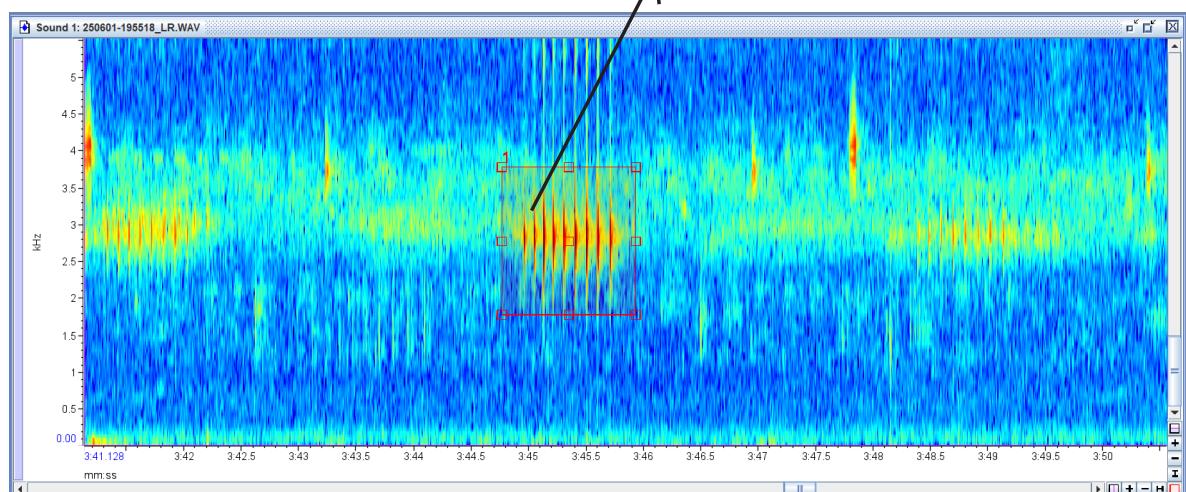


Fig.2.11. Spectrogram of *Ranocheates jayarami*

Rhacophorus pseudomalabaricus

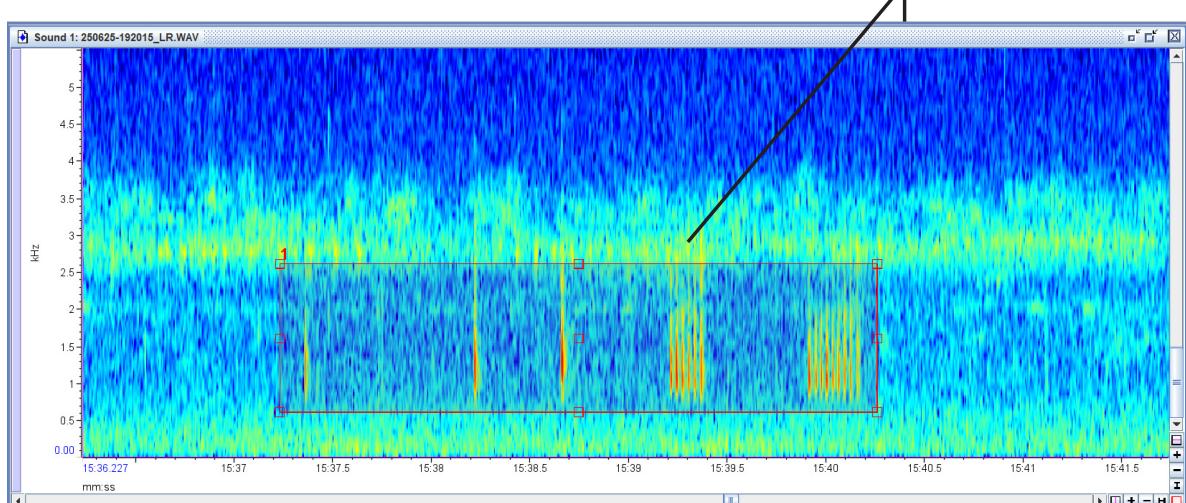


Fig.2.12. Spectrogram of *Rhacophorus pseudomalabaricus*

3

RESULTS AND DISCUSSION



Rhacophorus pseudomalabaricus

3. RESULTS AND DISCUSSION

3.1 Site Identification

A total of 20 sites representing five selected species were identified through presence–absence surveys. The surveys were done at night as well as late evening hours (Fig.3.1.). For each species, a minimum of seven sites were included. The dataset was then divided for model development, allocating more sites for training—at least four per species—and the remaining three sites for testing. The given figure shows the sites from which the recordings were collected for the study.



Fig.3.1.: Images from the field work

3.2 Species Diversity

A total of 62 frog species (Appendix 1) were identified within the Munnar landscape based on secondary data sources. Of these, 32 species were recorded during field surveys, representing diverse ecological guilds including arboreal, terrestrial, aquatic, and fossorial frogs. Notably,

27 of the 32 species documented during fieldwork fall under threatened categories of the IUCN Red List, underscoring the conservation significance of the region. The table below shows the number of sites from where the selected species were identified.

Sl. No.	Targeted Species	No. of sites
1	<i>Rhacophorus pseudomalabaricus</i>	15
2	<i>Raorchestes beddomii</i>	27
3	<i>Raorchestes blandus</i>	32
4	<i>Raorchestes chlorosomma</i>	19
5	<i>Raorchestes jayarami</i>	27

Table 3.1.. Number of Targeted species observed across all sites.

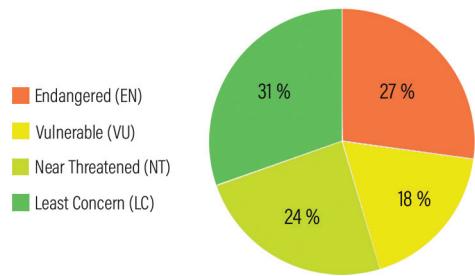


Fig.3.2..: Percentage of species documented

3.2.1 The checklist of species with IUCN status

The Images and names of all the species identified during the study period is given below as a checklist with common name, scientific name, IUCN status and photograph.

Sl. No.	Common name	Scientific name	IUCN Status	Photo
1.	Malabar Flying Frog	<i>Rhacophorus malabaricus</i>	LC	
2.	Kalakad Tree Frog	<i>Rhacophorus calcadensis</i>	VU	
3.	Griet Bush Frog	<i>Raorchestes griet</i>	VU	

4.	Dark-eared Bush Frog/Wayanad Bush Frog	<i>Pseudophilautus wynaadensis</i>	LC	
5.	Munnar Bush Frog	<i>Raorchestes munnarensis</i>	EN	
6.	Ponmudi Bush Frog	<i>Raorchestes ponmudi</i>	LC	
7.	Sushil's Bush Frog	<i>Raorchestes sushili</i>	EN	
8.	Anil's Bush Frog	<i>Raorchestes anili</i>	LC	

9.	Kodaikanal Bush Frog	<i>Raorchestes dubois</i>	VU	
10.	Kadalar Bush Frog	<i>Raorchestes kadalarensis</i>	NT	
11.	Uthaman's Bush Frog	<i>Raorchestes uthamani</i>	NT	
12.	Variable Bush Frog	<i>Raorchestes akroparallagi</i>	LC	
13.	Ochlandrae Reed Frog	<i>Raorchestes ochlandrae</i>	LC	

14.	Star-eyed Tree Frog/Ghat Tree Frog	<i>Ghatixalus asterops</i>	NT	
15.	Western Tree Frog/ Charpa Tree Frog	<i>Polypedates occidentalis</i>	LC	
16.	Don's Gold-en-backed Frog	<i>Indosylvirana doni</i>	NT	
17.	Sreeni's Gold-en-backed Frog	<i>Indosylvirana sreeni</i>	LC	
18.	Yadera Leaping Frog	<i>Indirana yadera</i>	VU	

19.	Gunther's Leaping Frog	<i>Indirana brachytarsus</i>	LC	
20.	Kerala Warty Frog	<i>Minervarya keralensis</i>	VU	
21.	Beautiful Dancing Frog	<i>Micrixalus adonis</i>	EN	
22.	Spinular Night Frog	<i>Nyctibatrachus acanthodermis</i>	EN	
23.	Meowing Night Frog	<i>Nyctibatrachus poocha</i>	NT	

24.	Anamallai Night Frog	<i>Nyctibatrachus anamallaiensis</i>	EN	
25.	Kadalar Swamp Frog	<i>Beddomixalus bijui</i>	EN	
26.	Jerdon's Rama-nella	<i>Uperodon montanus</i>	NT	
27.	Purple Frog	<i>Nasikabatrachus sahyadrensis</i>	NT	
28.	Anamalai Flying Frog	<i>Rhacophorus psedomala</i>	VU	

29.	Anamalai Bush Frog/Pleasant Bush Frog	<i>Raorchestes blandus</i>	EN	
30.	Green Eyed Bush Frog	<i>Raorchestes chlorosomma</i>	EN	
31.	Jayaram's Bush Frog	<i>Raorchestes jayarami</i>	EN	
32.	Beddom's Bush Frog	<i>Raorchestes beddomii</i>	LC	
33.	Common Toad	<i>Duttaphrynus melanostictus</i>	NT	

Fig.3.3. Checklist of all the species identified throughout the study sites

Sl. No	Sites (columns)			
	Species (rows)	1	2	3
1	<i>Beddomixalus bijui</i>			
2	<i>Ghatixalus astylops</i>			
3	<i>Indiranra brachytarsus</i>			
4	<i>Indiranra yadera</i>			
5	<i>Indosylvirana doni</i>			
6	<i>Indosylvirana sreeni</i>			
7	<i>Mierixalus adonis</i>			
8	<i>Minervarya keralensis</i>			
9	<i>Nasikabatrachus sahyadrensis</i>			
10	<i>Nyctibatrachus acanthodermis</i>			
11	<i>Nyctibatrachus anamallaiensis</i>			
12	<i>Nyctibatrachus poocha</i>			
13	<i>Polypedates occidentalis</i>			
14	<i>Pseudophilautus wynaudensis</i>			
15	<i>Raorchestes akropallagi</i>			
16	<i>Raorchestes anili</i>			
17	<i>Raorchestes beddomii</i>			
18	<i>Raorchestes blandus</i>			
19	<i>Raorchestes chlorosomma</i>			
20	<i>Raorchestes dubois</i>			
21	<i>Raorchestes griet</i>			
22	<i>Raorchestes jayarami</i>			
23	<i>Raorchestes kadalarensis</i>			
24	<i>Raorchestes munarensis</i>			
25	<i>Raorchestes ochlandrae</i>			
26	<i>Raorchestes ponnudi</i>			
27	<i>Raorchestes sushili</i>			
28	<i>Raorchestes uttamani</i>			
29	<i>Rhaeophorus calcadensis</i>			
30	<i>Rhaeophorus malabaricus</i>			
31	<i>Rhaeophorus pseudomalabaricus</i>			
32	<i>Uperodon montanus</i>			
	Total	4	4	5
		4	5	5
		5	5	3
		3	5	5
		16	4	9
		4	7	6
		4	15	8
		10	6	8
		5	13	10
		11	5	11
		7	9	9
		6	6	7
		9	9	7
		2	5	328

Fig.3.4. List of all species identified from 42 sites

3.3 Data Processing and Annotation

A total of 472 focal recordings and 8,090 passive recordings were collected during the study. From these, 4,873 calls were manually annotated from 121 active recordings (5–35 minutes each), and 1,515 calls were annotated from 31 passive recordings (10 minutes each) by selectively choosing maximum site diversity for training and testing data per species. A comprehensive dataset was compiled summarizing the number of active recordings for target species, other amphibian species, and back-

ground noise, along with the corresponding annotated calls and the division of data into training and testing sets for model development. A detailed visual summary showing the total active (Table 3.2.) and passive recordings (Table 3.3.) from each site, site code expansions, and the distribution of training and testing datasets was also produced. A heatmap was generated to illustrate the distribution of active recordings of target species across all sampled sites (Fig.3.5.).

ACTIVE RECORDINGS DATA					
	Sl. No	Species	Total call recordings	Annotated	No. of Testing & Training data
Target species	1	<i>Rhacophorus pseudomalabaricus</i>	87	19	15
	2	<i>Raorchestes jayarami</i>	89	32	31
	3	<i>Raorchestes chlorosomma</i>	99	24	24
	4	<i>Raorchestes blandus</i>	102	22	18
	5	<i>Raorchestes beddomii</i>	97	22	17
Other species	1	<i>Raorchestes munnarensis</i>	3		
	2	<i>Rhacophorus calcadensis</i>	6		
	3	<i>Raorchestes anili</i>	3	1	
	4	<i>Raorchestes uthamani</i>	1		
	5	<i>Upredon montanus</i>	1		
	6	<i>Raorchestes kadalorensis</i>	2		
	7	Unknown	11		
	8	Background	6	3	3
Total			507	123	108

Table 3.2.: List of the number of active recordings of target species, other species and background noise taken from the field, number of annotated recordings and the number of testing and training datasets

PASSIVE RECORDINGS DATA					
	No.	Species	Total call recordings	Annotated	No. of Testing & Training data
Target species	1	<i>Rhacophorus pseudomalabaricus</i>	2602	8	8
	2	<i>Raorchestes jayarami</i>	1486	5	5
	3	<i>Raorchestes chlorosomma</i>	1987	4	4
	4	<i>Raorchestes blandus</i>	471	4	4
	5	<i>Raorchestes beddomii</i>	1678	5	5
Other species	1	<i>Rhacophorus calcadensis</i>	303		
	2	<i>Upredon montanus</i>	208		
	3	<i>Raorchestes kadalorensis</i>	4		
	4	Unknown	824		
	5	Background	8	5	5
Total			9571	31	31

Table 3.3.: List of the number of passive recordings of target species, other species and background noise taken from the field, number of annotated recordings and the number of testing and training datasets

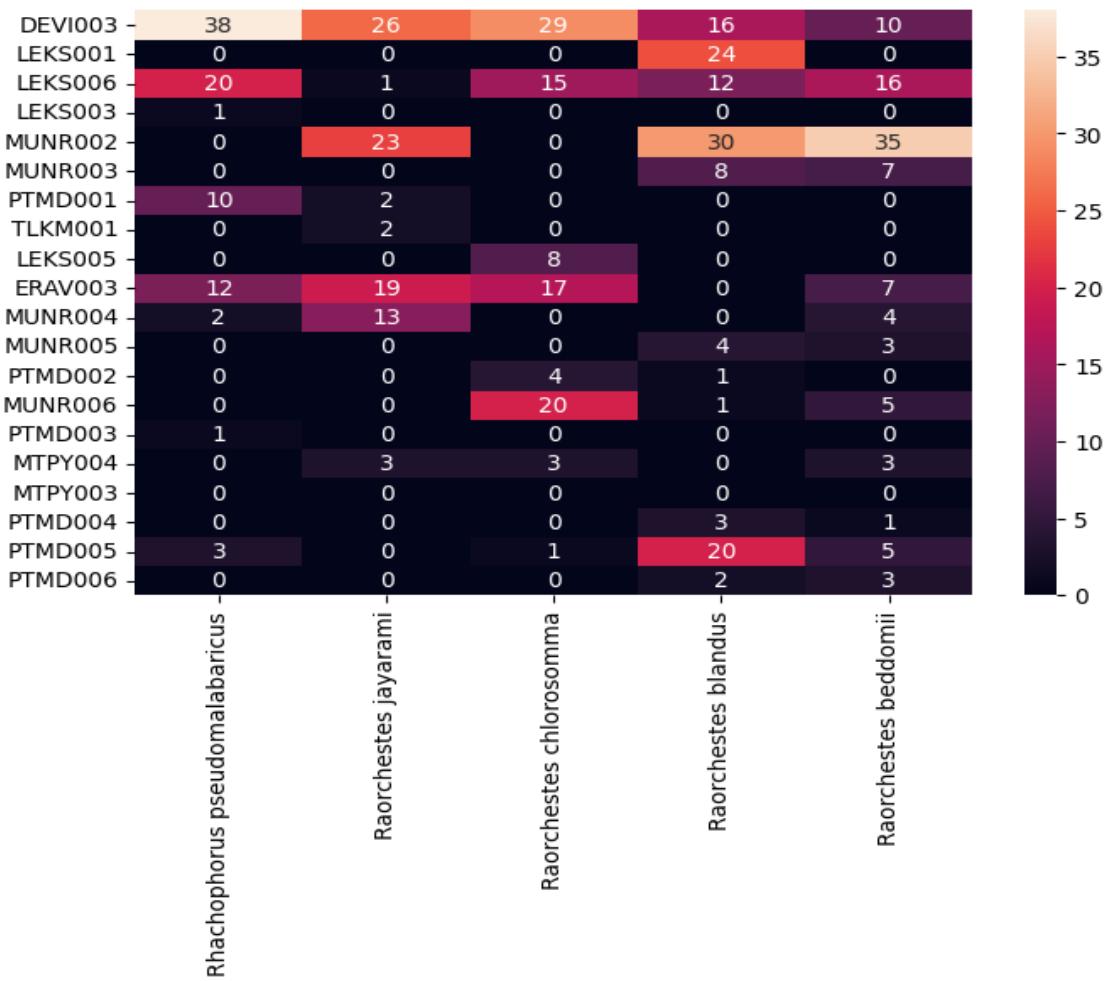


Fig. 3.5.: Heatmap of the number of active recordings of target species taken from each site



ACTIVE		PASSIVE		Total	
Species	Count	Species	Count	Species	Count
<i>Rhacophorus pseudomalabaricus</i>	38	nil	20	1	nil
<i>Raorchestes jayarami</i>	26	nil	1	nil	23
<i>Raorchestes chlorosomma</i>	29	nil	15	nil	nil
<i>Raorchestes blandus</i>	16	nil	24	8	nil
<i>Raorchestes beddomi</i>	10	nil	16	nil	35
				474	
PTMD006		MUNR006		Total	
<i>Rhacophorus pseudomalabaricus</i>	nil	nil	12	2	nil
<i>Raorchestes jayarami</i>	nil	nil	19	13	nil
<i>Raorchestes chlorosomma</i>	nil	nil	8	17	nil
<i>Raorchestes blandus</i>	nil	nil	4	20	nil
<i>Raorchestes beddomi</i>	nil	nil	3	nil	3
				87	
PTMD005		MUNR005		Total	
<i>Rhacophorus pseudomalabaricus</i>	nil	nil	3	nil	3
<i>Raorchestes jayarami</i>	nil	nil	3	nil	3
<i>Raorchestes chlorosomma</i>	nil	nil	1	nil	1
<i>Raorchestes blandus</i>	nil	nil	3	nil	3
<i>Raorchestes beddomi</i>	nil	nil	1	nil	1
				89	
PTMD004		MTPY004		Total	
<i>Rhacophorus pseudomalabaricus</i>	nil	nil	1	nil	1
<i>Raorchestes jayarami</i>	nil	nil	3	nil	3
<i>Raorchestes chlorosomma</i>	nil	nil	3	nil	3
<i>Raorchestes blandus</i>	nil	nil	3	nil	3
<i>Raorchestes beddomi</i>	nil	nil	1	nil	1
				97	
PTMD003		MUNR006		Total	
<i>Rhacophorus pseudomalabaricus</i>	nil	nil	1	nil	1
<i>Raorchestes jayarami</i>	nil	nil	3	nil	3
<i>Raorchestes chlorosomma</i>	nil	nil	3	nil	3
<i>Raorchestes blandus</i>	nil	nil	3	nil	3
<i>Raorchestes beddomi</i>	nil	nil	1	nil	1
				102	
PTMD002		MUNR002		Total	
<i>Rhacophorus pseudomalabaricus</i>	nil	nil	10	nil	10
<i>Raorchestes jayarami</i>	nil	nil	2	nil	2
<i>Raorchestes chlorosomma</i>	nil	nil	19	13	nil
<i>Raorchestes blandus</i>	nil	nil	4	20	nil
<i>Raorchestes beddomi</i>	nil	nil	3	nil	3
				474	
PTMD001		MUNR001		Total	
<i>Rhacophorus pseudomalabaricus</i>	nil	nil	nil	nil	nil
<i>Raorchestes jayarami</i>	nil	nil	nil	nil	nil
<i>Raorchestes chlorosomma</i>	nil	nil	nil	nil	nil
<i>Raorchestes blandus</i>	nil	nil	nil	nil	nil
<i>Raorchestes beddomi</i>	nil	nil	nil	nil	nil
				102	
ERAV003		MUNR003		Total	
<i>Rhacophorus pseudomalabaricus</i>	nil	nil	nil	nil	nil
<i>Raorchestes jayarami</i>	nil	nil	nil	nil	nil
<i>Raorchestes chlorosomma</i>	nil	nil	nil	nil	nil
<i>Raorchestes blandus</i>	nil	nil	nil	nil	nil
<i>Raorchestes beddomi</i>	nil	nil	nil	nil	nil
				89	
ERAV004		MUNR004		Total	
<i>Rhacophorus pseudomalabaricus</i>	nil	nil	nil	nil	nil
<i>Raorchestes jayarami</i>	nil	nil	nil	nil	nil
<i>Raorchestes chlorosomma</i>	nil	nil	nil	nil	nil
<i>Raorchestes blandus</i>	nil	nil	nil	nil	nil
<i>Raorchestes beddomi</i>	nil	nil	nil	nil	nil
				1987	
ERAV005		MUNR005		Total	
<i>Rhacophorus pseudomalabaricus</i>	nil	nil	nil	nil	nil
<i>Raorchestes jayarami</i>	nil	nil	nil	nil	nil
<i>Raorchestes chlorosomma</i>	nil	nil	nil	nil	nil
<i>Raorchestes blandus</i>	nil	nil	nil	nil	nil
<i>Raorchestes beddomi</i>	nil	nil	nil	nil	nil
				471	
ERAV006		MUNR006		Total	
<i>Rhacophorus pseudomalabaricus</i>	nil	nil	nil	nil	nil
<i>Raorchestes jayarami</i>	nil	nil	nil	nil	nil
<i>Raorchestes chlorosomma</i>	nil	nil	nil	nil	nil
<i>Raorchestes blandus</i>	nil	nil	nil	nil	nil
<i>Raorchestes beddomi</i>	nil	nil	nil	nil	nil
				8090	

Location names	Codes
Devikulam	DEVI
Eravikulam	ERAV
Munnar	MUNR
Mattupetty	MTPY
Pothamedu	PTMD
Lekshmi Estate	LEKS
Thalikam	TLKM

Fig.3.6.: Image of the number of active and passive recordings taken from all the sites, site code expansions and a representation of the distribution of testing and training datasets

3.4 Model Development

For model development, 123 annotated segments from active recordings and 31 annotated segments from passive recordings were done and a subset of those were used for training the model. Out of the total annotations, a portion was reserved for model validation.

3.4.1 Precision Recall (PR) Curve of all Species

Precision is the ratio of true positive detections to all detections predicted as positive, reflecting how accu-

rate the positive predictions are. Recall (also called true positive rate) is the ratio of true positive detections to all actual positive instances, representing how many of the true species detections the model found. AUPRC (Area Under the Precision-Recall Curve), a performance metric used to evaluate classification models, measures how well the model identifies true positive examples without including many false positives. An AUPRC value closer to 1 indicates better performance.

The AUPRC for all the species combined is 0.774.(Fig.3.7.)

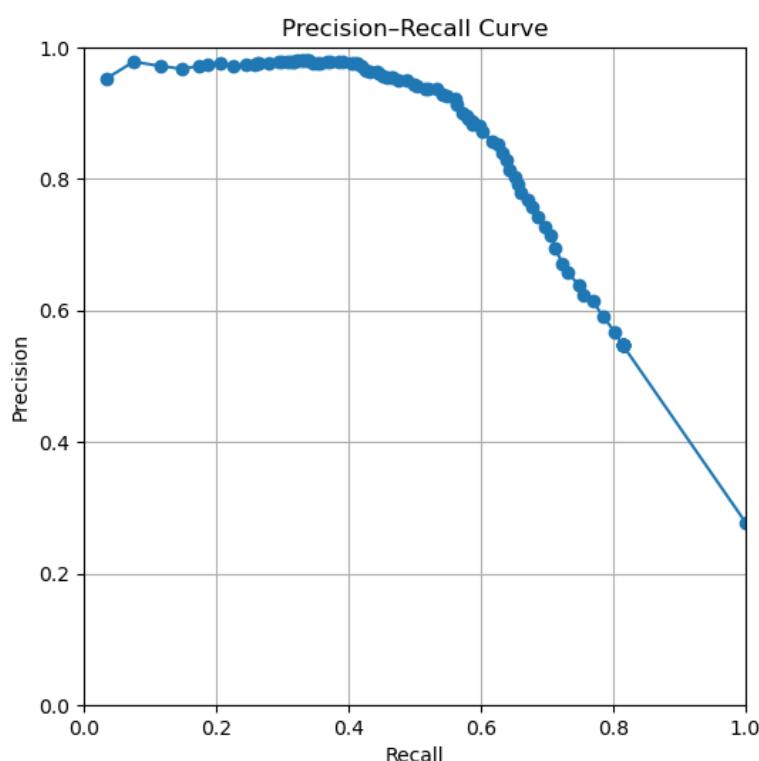


Fig.3.7.: AUPRC Curve of all five target species

3.4.2 Species-wise Precision Recall (PR) Curve

The species-wise Precision-Recall (PR) curves highlight clear differences in model performance across the five frog species examined (Fig.3.8.). The AUPRC values are:

Raorchestes beddomii: 0.717

Raorchestes blandus: 0.816

Raorchestes chlorosomma: 0.804

Raorchestes jayarami: 0.826

Rhacophorus pseudomalabaricus: 0.882

Raorchestes beddomii achieved the lowest at 0.717,

indicating moderate detection reliability likely due to acoustic overlaps causing more false positives or misses, yet exceeding typical baselines for sparse positives (e.g., 0.1-0.2 prevalence). Stronger performers included *Raorchestes blandus* (0.816) and *Raorchestes chlorosomma* (0.804) for robust precision and recall balance suitable for field monitoring; *Raorchestes jayarami* (0.826) showed excellent discrimination; and *Rhacophorus pseudomalabaricus* topped at 0.882, leveraging distinct call features for superior identification even at varied thresholds.

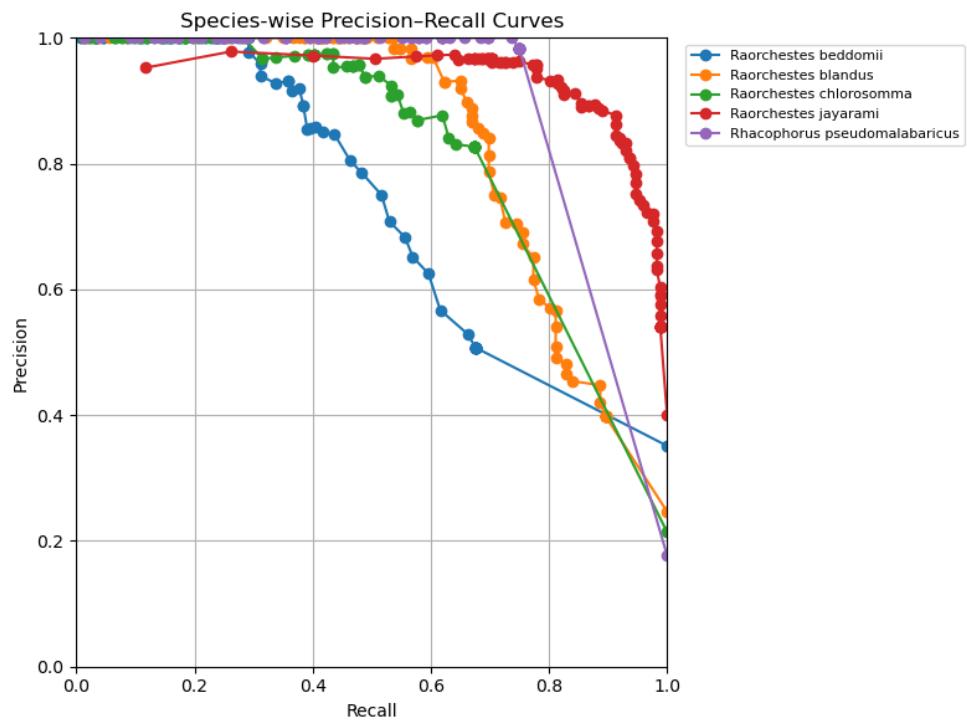


Fig.3.8. : Species-wise Precision-Recall Curves

3.4.3 Species specific logistic regression curves

Logistic regression curves were fitted to a subset of detection data to establish threshold confidence scores corresponding to 90% prediction accuracy. The model's probability output was used in a logistic function to find the cutoff point at which predictions are 90% correct, helping to decide a meaningful confidence score threshold for reliable species presence detection. Species-wise logistic regression plots are as follows.

- ***Raorchestes beddomii*:** The logistic regression model showed a gradual rise in accuracy with increasing confidence, with most false detections occurring at low scores (<0.30). BirdNET reached 90% accuracy at 0.364 and 95% accuracy at 0.421, demonstrating good performance at moderate confidence. Nearly perfect accuracy was achieved at 0.548 (Fig.3.9).

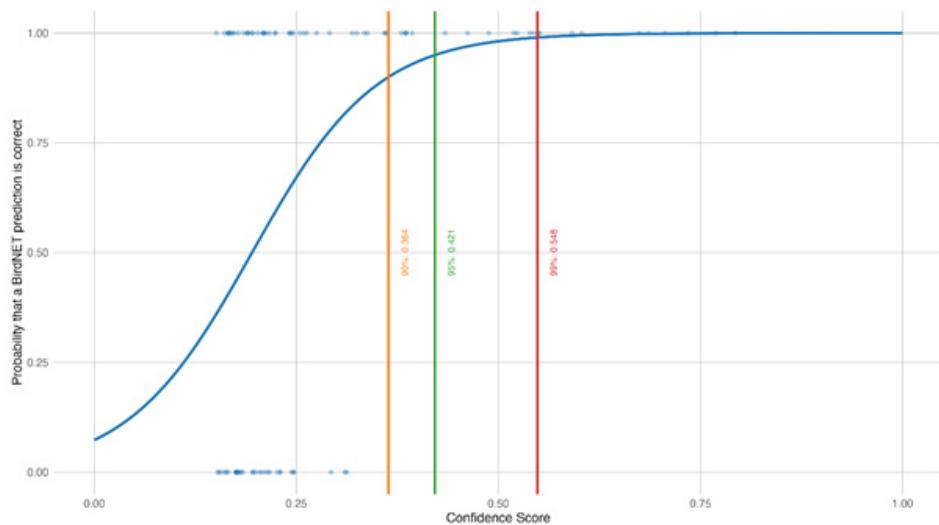


Fig.3.9. : Logistic regression curve of *Raorchestes beddomii*

- ***Raorchestes jayarami*:** BirdNET predictions were reliable from mid-level confidence values onward, with incorrect detections clustering below 0.40. The model achieved 90% accuracy at 0.666 and 95% accuracy at 0.781, indicating a relatively high threshold compared to other species. Perfect reliability was obtained only at a confidence of 1.0. *R. jayarami* required relatively higher confidence scores to ensure high prediction accuracy, suggesting a more conservative threshold is needed to minimize false positives (Fig.3.10).

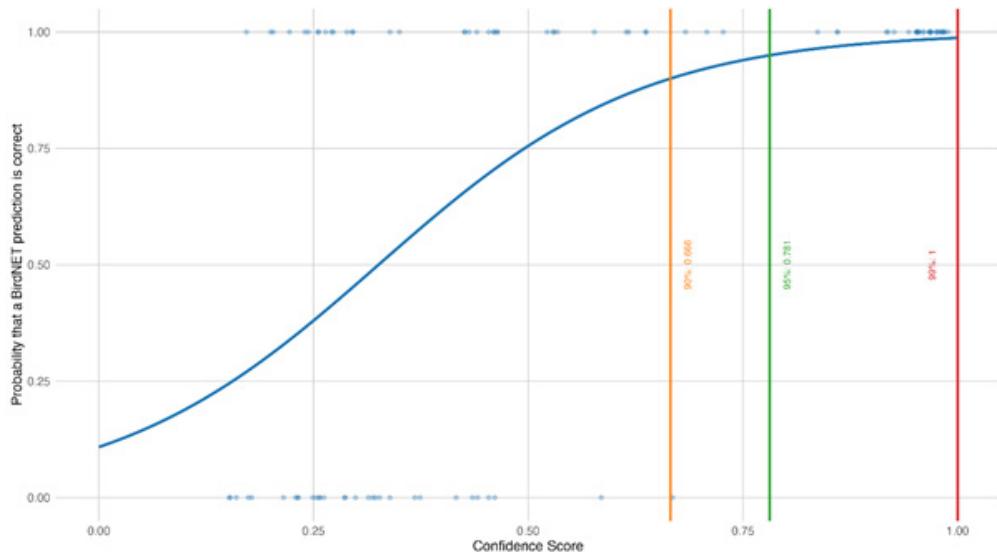


Fig.3.10. : Logistic regression curve of *Raorchestes jayarami*

- ***Raorchestes blandus*:** BirdNET displayed a smoother transition from low to high accuracy across the confidence range. Most misclassifications occurred below 0.30, while predictions above 0.50 were predominantly correct. The model reached 90%, 95%, and 99% accuracy at confidence values of 0.639, 0.720 and 0.898 respectively (Fig.3.11).

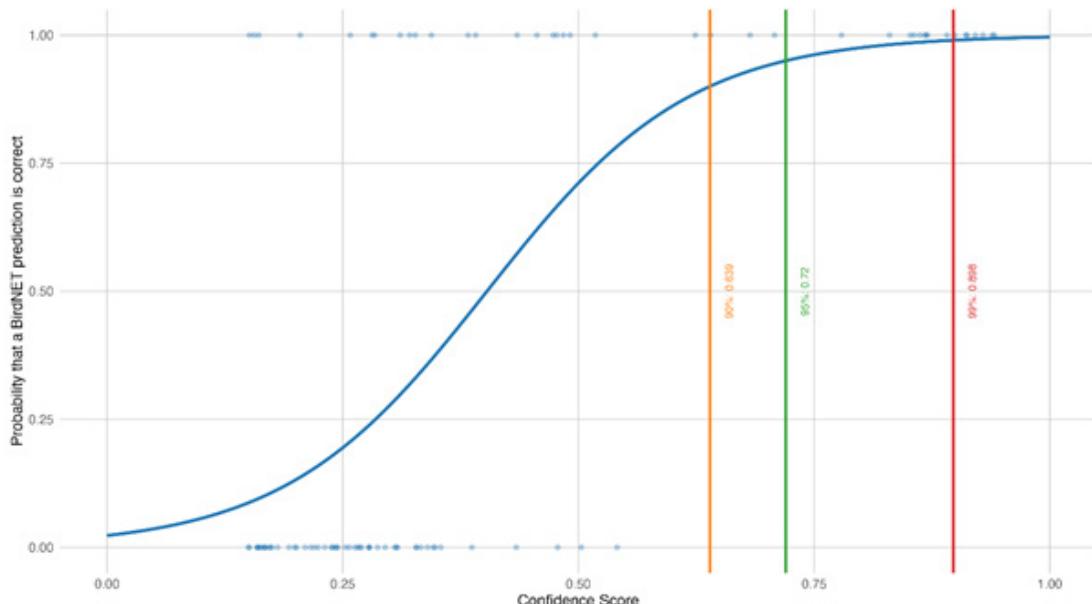


Fig.3.11. : Logistic regression curve of *Raorchestes blandus*

- ***Raorchestes chlorosomma***: Prediction accuracy increased steadily with confidence, with most false positives occurring below 0.40. The thresholds for 90% and 95% accuracy were 0.458 and 0.570 respectively, suggesting strong detectability by BirdNET. A high confidence level of 0.818 was required to reach 99% accuracy (Fig. 3.12).

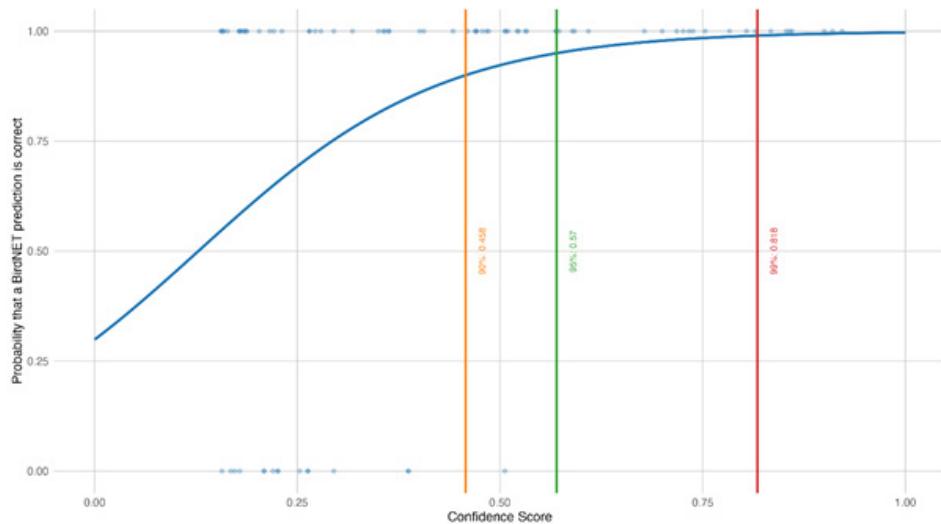


Fig.3.12. : Logistic regression curve of *Raorchestes chlorosomma*

- ***Rhacophorus pseudomalabaricus***: BirdNET predictions showed a strong relationship between confidence score and identification accuracy. The logistic curve rose steeply at low confidence values and reached high accuracy levels even at moderate scores. The model estimated that a BirdNET confidence score of 0.276 corresponds to 90% probability of being correct, while 0.41 and 0.704 correspond to 95% and 99% correctness, respectively. This indicates that *R. pseudomalabaricus* has a highly distinctive call signature in the dataset, allowing BirdNET to perform reliably even at relatively low confidence thresholds (Fig.3.13).

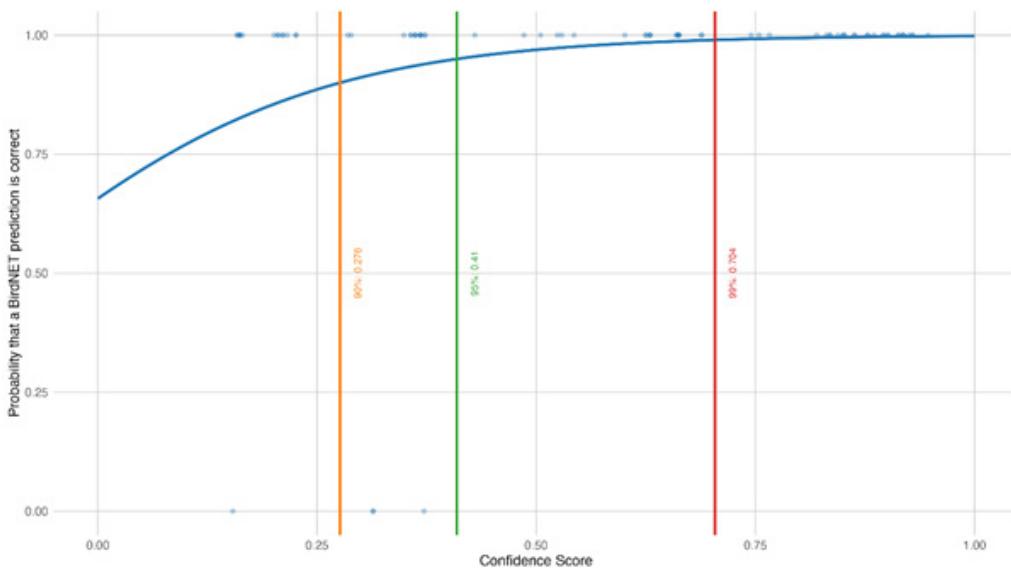


Fig.3.13. : Logistic regression curve of *Raorchestes chlorosomma*

The first stage of the open-source bioacoustics identification tool was successfully developed, with the classifier demonstrating reliable accuracy in distinguishing the calls of the five target species. Following successful performance evaluation, the model has been uploaded to GitHub. The tool, after thorough testing and validation, is now being publicly released as an open-access resource on GitHub.

3.5 Ecological and Conservation Insights

The 32 documented species highlight the exceptional amphibian richness of Munnar, reinforcing the need for long-term monitoring programs. Continuous acoustic data can provide valuable insights into species distribution, breeding seasonality, and responses to environmental change.

3.5.1 Threats to Frog Populations in Munnar

Frog populations in Munnar face multiple anthropogenic pressures that contribute to population decline and habitat degradation.

- **Habitat Loss and Fragmentation:** Large tracts of natural forest have been converted to tea, cardamom, and eucalyptus plantations, along with roads and resorts. These activities destroy breeding habitats and isolate frog populations, affecting dispersal and gene flow.
- **Climate Change:** Irregular rainfall and rising temperatures disrupt breeding cycles and reduce the availability of moist microhabitats vital for amphibian survival.

- **Pollution:** Pesticide and fertilizer runoff from plantations, combined with detergents and sewage from hotels, contaminate freshwater systems and breeding pools.
- **Invasive Species:** Non-native fish prey on frog eggs and tadpoles, while invasive plants such as Lantana camara alter habitat structure and microclimate.
- **Diseases:** The chytrid fungus (*Batrachochytrium dendrobatidis*) poses an emerging threat to amphibians, with pollution and stress potentially increasing disease susceptibility.
- **Light and Noise Pollution:** Artificial lighting and traffic noise interfere with frogs' acoustic communication, reducing calling activity and mating success.
- **Impact of Tourism:** Unregulated tourism, littering, resort construction, and wetland trampling by visitors degrade habitats and increase freshwater pollution.
- **Illegal Collection:** Rare and brightly coloured frogs are occasionally collected for the pet trade and, in some regions, for consumption, further threatening vulnerable populations.



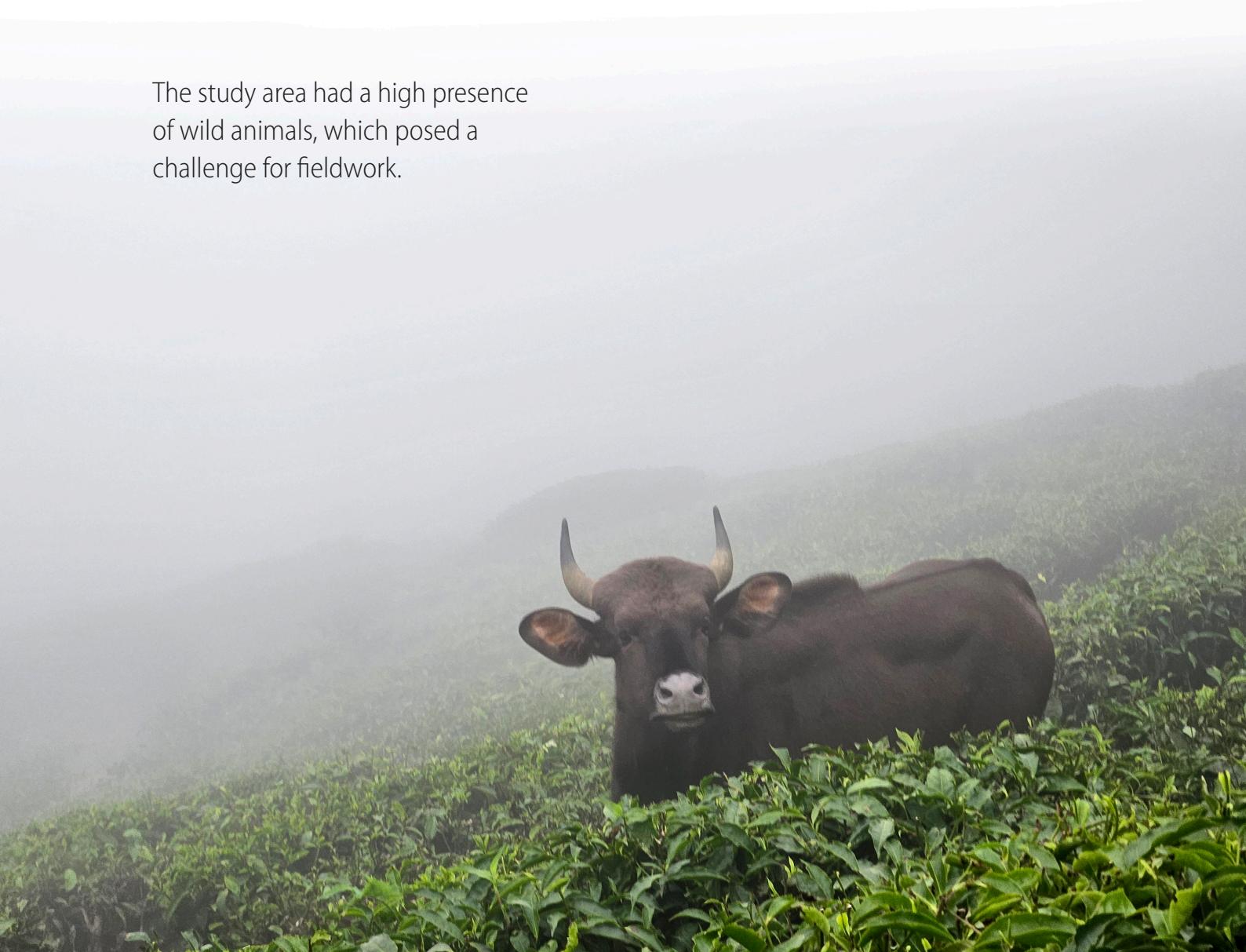
3.5.2 Technological Relevance

By integrating acoustic data with machine learning, the project sets a framework for AI-assisted biodiversity assessment. Such tools can eventually be adapted for mobile or web-based applications, enabling citizen scientists, researchers, and forest departments to participate in real-time monitoring.

3.5.3 Challenges

Challenges included high background noise, overlapping calls, frequent wild animal movement, and weather-related limitations that affected recording quality. Future phases should incorporate advanced noise-reduction algorithms, expand the diversity frog call datasets, and apply model fine-tuning to enhance detection accuracy and overall performance of the bioacoustics tool.

The study area had a high presence of wild animals, which posed a challenge for fieldwork.



4

OUTREACH AND AWARENESS



Uperodon mondanus (Juvenile)

4. OUTREACH AND COMMUNITY ENGAGEMENT

4.1 Introduction

As part of the project "Development of Bioacoustics Tools for Monitoring Amphibian Diversity in the Munnar Landscape", a series of community-based awareness programmes were conducted to promote environmental literacy and to familiarise students with the ecological importance of amphibians. These initiatives were designed to complement the scientific components of the project by fostering public engagement, encouraging stewardship among young learners, and strengthening local support for amphibian conservation.

Recognising that children play a crucial role in shaping future conservation values, the project team conducted structured awareness classes in two government schools in Munnar—Government U.P. School, Thokkupara and Government Anglo Tamil Primary (ATP) School, Munnar. These activities not only served as educational interventions but also acted as platforms to introduce the concept of bioacoustics monitoring, an emerging method for wildlife research in India.

4.2 Awareness Programme at Government U.P. School, Thokkupara

The program began with a beautiful prayer song followed by a warm welcome from Head Master Mr. Mahesh Kumar. Dr. Punnen Kurian, Director of TIES, presided over the event, stressing the vital role amphibians play in our ecosystem. Mr. Nidhichand K.P. (Project Officer, TIES) led the main session, introducing students to frog life cycles, habitats, and the unique amphibian diversity of Munnar—especially its endemic and threatened species. A big shout-out to teachers Ms. Beena Peter and Ms. Zanudeen for their wonderful support, and to TIES team members Mr. Sarath Babu N B (Nature Education Officer) and Ms. Cimila Sibichen (Project Assistant) for their active involvement. Senior Assistant Ms. Suja Varghese closed the event with a heartfelt vote of thanks. The day ended with a fun colouring competition, sparking creativity while reinforcing conservation learning. Winners of the 1st and 2nd prizes were awarded for their impressive work!

TIES extends sincere gratitude to the school for its warm hospitality. Programmes like this nurture young ambassadors of nature and help protect Munnar's rich amphibian diversity



4.3 Awareness Programme at Government Anglo Tamil Primary School, Munnar

The session was led by Dr. Punnen Kurian (Director, TIES) and Ms. Cimila Sibichen (Project Assistant – Munnar Bioacoustics Study), with wonderful support from the school's teacher coordinators. The program began with a soulful prayer by the school choir, followed by a warm welcome from Head Master Mr. Shanmugavel, who stressed the importance of connecting children with nature early in life. Dr. Punnen Kurian inaugurated the session, opening a window into the fascinating world of frogs and the need for conservation. Students enjoyed an engaging presentation on frog lifecycles, Munnar's endemic and endangered species, their habitats, and the threats these little amphibians face.

They were especially thrilled to learn about the Munnar Bioacoustics Study—how scientists use frog calls to

identify and monitor species in the Western Ghats! The learning continued with a colourful twist—an exciting colouring competition featuring one of the target species from the study. This creative activity helped students better recognise and appreciate local amphibians. Teachers including Ms. Mahalakshmi, Ms. Beena Begum, Ms. Shobhana, Mr. Vinu, Ms. Chithra Devi, Ms. Saranya, and Ms. Devibala actively coordinated the event, also translating the session into Tamil to ensure every child connected with the message.

The day wrapped up with a prize distribution ceremony, motivating students to keep exploring and protecting the biodiversity around them. Smt. Mahalakshmi delivered the vote of thanks, appreciating the Head Master, staff, and the TIES Team for making the event truly memorable.



4.4 Development and Distribution of Amphibian Awareness Brochures

To ensure that the knowledge shared during the sessions reached beyond the classroom and remained accessible to students even after the programme, the project team designed and distributed dedicated amphibian awareness brochures. These brochures were created as part of the outreach strategy to reinforce learning, promote amphibian-friendly practices, and introduce the concept of bioacoustics monitoring to a wider audience.

MEET MUNNAR'S THREATENED VOICES

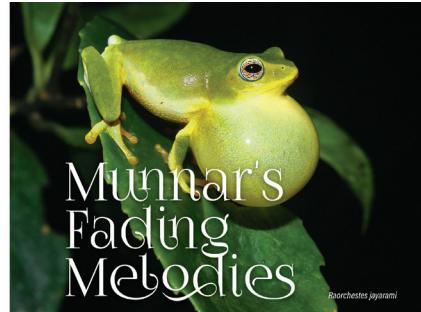
Our study focuses on five key endemic and threatened species, each with its own unique call.



Join the Chorus

TIES
CENTRE FOR WILDLIFE STUDIES
1984

biometrio.
earth



WHY WE MUST LISTEN TO AND CONSERVE OUR FROGS..?

Based on the Bioacoustics Study of Threatened Frogs in Munnar

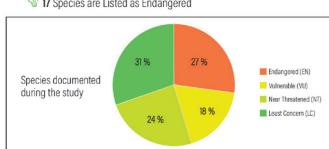


The Barometers of Our Planet

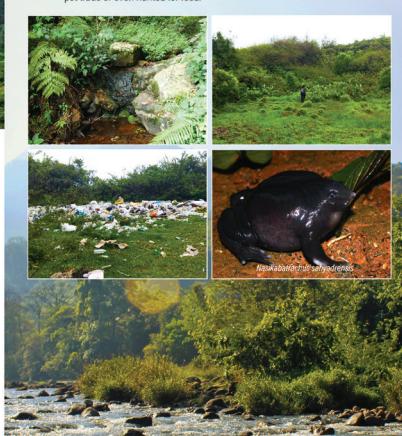
A World of Diversity



Munnar: A Fragile Hotspot



An Ecosystem Under Threat



LISTENING FOR ANSWERS

We listen

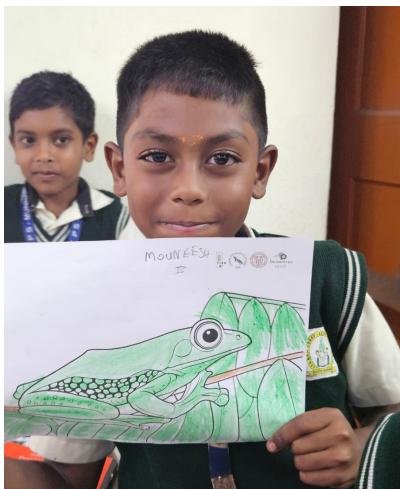
Our Goal



4.5 Conclusion

The outreach programmes, combined with the development of visually engaging awareness brochures, reflect the project's commitment to linking scientific research with community education. By integrating classroom-based learning, interactive activities, creativity-driven competitions, and take-home educational materials, the project ensured a lasting impact on young conservationists.

The distribution of brochures significantly strengthened community engagement by extending conservation messages beyond the school and into the students' families and neighbourhoods. Together, these efforts—awareness sessions, brochures, and the introduction of bioacoustics—support long-term amphibian conservation and promote a scientifically informed, environmentally responsible society.



5

CONCLUSION

Raorchestes ochlandrae (Juvenile)

5.1 Conclusion and Recommendations

The project successfully combined field ecology, technology, and data science to establish a foundation for bioacoustics-based amphibian monitoring in the Munnar landscape. This initial effort represents a significant step toward advancing conservation through novel acoustic tools and public engagement.

5.1.1 Key findings

- Conducted a comprehensive biodiversity survey, identifying 32 frog species in the Munnar region.
- Collected and catalogued audio recordings (both active and passive) of five target species, all endemic and most threatened.
- Collected acoustic data were organised hierarchically by site and species, following established bioacoustic practices for structured datasets.
- High-quality recordings were selectively annotated using Raven Pro software to create balanced training and test datasets, enabling effective machine learning workflows.
- Classifier building and model development were conducted by project partners using machine learning techniques tailored for bioacoustic classification.
- The final validated model was uploaded publicly to the project's GitHub repository, promoting open access and collaborative advancements in amphibian monitoring.

Species-specific acoustic classifier was built and rigorously validated using annotated datasets, achieving promising preliminary accuracy levels. This pilot bioacoustic tool development, focused on the five endemic and endangered frog species, successfully demonstrated feasibility for automated monitoring in Munnar's diverse habitats, laying the groundwork for scalable conservation applications. Complementing the technical advancements, awareness sessions were organized for schools in Munnar

to highlight frog conservation needs, while school engagements—such as interactive activities where students spelt frog species names—fostered ecological literacy and long-term sensitivity among young learners.

5.2 Future Aspects

- Expand acoustic monitoring to include a larger number of species across broader habitats to improve understanding of amphibian diversity and distribution.
- Refine and enhance bioacoustic classifiers using more extensive datasets to improve accuracy and reliability.
- Integrate long-term passive acoustic monitoring to detect temporal changes and potential impacts of environmental factors.
- Collaborate with local conservation agencies, researchers, and policymakers to leverage bioacoustics data for actionable conservation planning.
- Increase public outreach by incorporating schools and community groups as regular stakeholders in monitoring and conservation education.
- Explore the use of automated real-time acoustic detection systems for continuous monitoring in remote areas.
- Develop multilingual educational materials tailored to local communities to foster ongoing conservation awareness.
- Share open-access datasets and tools on public platforms to encourage further research, validation, and innovation in amphibian bioacoustics.

This study forms a foundational framework for amphibian bioacoustics monitoring in the Western Ghats and offers a model for combining scientific research with community engagement to support endangered species conservation.

6

EXECUTIVE SUMMARY



Beddomixalus bijui

Executive summary

Project Overview

This report details the outcomes of a pioneering bioacoustic initiative implemented by the Tropical Institute of Ecological Sciences (TIES) to monitor amphibian diversity in the Munnar landscape of the Western Ghats. Funded by the Centre for Wildlife Studies (CWS) and supported by technical partners from the Cornell Lab of Ornithology and Biometrio.earth, the project aimed to develop an automated, open-source taxonomic tool to identify endemic frog species using their vocalizations.

Methodology and Data Collection

Spanning the 2024–2025 period, the study utilized a combination of active and passive acoustic monitoring (PAM) techniques. Following preliminary surveys across 42 potential sites, 20 high-priority locations were shortlisted based on endemism, threat status, and acoustic feasibility.

The project focused on five distinct, threatened, and endemic focal species: *Raorchestes beddomii*, *Raorchestes jayarami*, *Raorchestes chlorosomma*, *Raorchestes blandus*, and *Rhacophorus pseudomalabaricus*.

Data collection yielded a robust acoustic library:

- **Active Monitoring:** Over 4,873 calls were annotated from 121 active recording sessions conducted during peak breeding hours.
- **Passive Monitoring:** 1,515 calls were processed from long-duration deployments using Song Meter Micro 2 devices.
- **Biodiversity Documentation:** In total, 33 amphibian species were documented during the field surveys, significantly updating the understanding of species richness in the region

Technical Development

High-quality recordings were annotated using Raven Pro 1.6 software to create balanced training and testing datasets (200 calls per species). These datasets were used to train a supervised machine-learning classifier using the BirdNET framework. The resulting model demonstrated reliable accuracy in distinguishing the complex calls of the target species, establishing the feasibility of AI-assisted monitoring for Western Ghats amphibians.

Key Outcomes and Impact

- **Open-Source Tool:** The validated model and associated documentation are being made accessible through a public GitHub repository, promoting transparency and future collaboration.
- **Community Outreach:** The project integrated a strong educational component, conducting awareness sessions and competitions in local schools to foster environmental stewardship among the younger generation.
- **Conservation Implications:** This study validates bioacoustics as a scalable, cost-effective, and non-invasive alternative to traditional visual surveys.

Recommendations

The report concludes with recommendations to expand acoustic datasets to cover additional species and elevations, develop multilingual outreach materials, and deploy a wider network of passive monitors to track long-term population trends against climate change and habitat loss.

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Nasikabatrachus sahyadrensis (Tadpole)

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• Appendix I

SI No	Species name with Author	Common Name	IUCN Threat status
1	<i>Beddomixalus bijui</i> (Zachariah, Dinesh, Radhakrishnan, Kunhikrishnan, Palot & Vishnudas, 2011)	Montane Foam-nest Tree Frog/ Kadalar Swamp Frog	EN
2	<i>Duttaphrynus melanostictus</i> (Schneider, 1799)	Common Indian Toad	LC
3	<i>Duttaphrynus microtympanum</i> (Boulenger, 1882)	Small-eared Toad	LC
4	<i>Duttaphrynus scaber</i> (Schneider, 1799)	Schneider's Toad	LC
5	<i>Euphlyctis cyanophlyctis</i> (Schneider, 1799)	Common skittering Frog/Skipper Frog	LC
6	<i>Ghatixalus asterops</i> (Biju Roelants & Bossuyt, 2008)	Star-eyed Tree Frog/Ghat Tree Frog	NT
7	<i>Ghatixalus magnus</i> (Abraham, Mathew, Cyriac, Zachariah, Raju & Zachariah, 2015)	Large-sized Ghat Tree Frog/Green Tree Frog	VU
8	<i>Hoplobatrachus tigerinus</i> (Daudin, 1802)	Indian Bullfrog	LC
9	<i>Hoplobatrachus crassus</i> (Jerdon, 1853)	Jerdon's Bullfrog	LC
10	<i>Hylarana doni</i> (Biju, Garg, Mahony, Wijayathilaka, Senevirathne, and Meegaskumbura, 2014)	Don's Golden-backed Frog	NT
11	<i>Hylarana sreeni</i> (Biju, Garg, Mahony, Wijayathilaka, Senevirathne, and Meegaskumbura, 2014)	Sreen's Golden-backed Frog	LC
12	<i>Indirana brachytarsus</i> (Günther, 1876)	Günther's Leaping Frog	LC
13	<i>Indirana semipalmata</i> (Boulenger, 1882)	Brown Leaping Frog	LC
14	<i>Melanobatrachus indicus</i> (Beddome, 1878 - Black Microhylid Frog)	Orange Black Tuberclad Indian Microhylid/Galaxy Frog	VU
15	<i>Micrixalus frigidus</i> (Biju, Garg, Gururaja, Shouche, and Walujkar, 2014)	Cold Stream Torrent Frog	EN
16	<i>Micrixalus adonis</i> (Biju, Garg, Gururaja, Shouche, and Walujkar, 2014)	Beautiful Dancing Frog	EN
17	<i>Micrixalus nigraventris</i> (Biju, Garg, Gururaja, Souche & Walujkar, 2014 - Black-bellied Dancing Frog)	Black-bellied Dancing Frog	EN
18	<i>Micrixalus silvaticus</i> (Boulenger, 1882)	Forest Dancing Frog	EN
19	<i>Microhyla ornata</i> (Duméril & Bibron, 1841)	Ant Frog/Ornamented Pygmy Frog	LC
20	<i>Microhyla rubra</i> (Jerdon, 1853)	Guandong Rice Frog	LC
21	<i>Minervarya agricola</i> (Jerdon, 1853)	Jerdon's Cricket Frog	LC
22	<i>Minervarya brevipalmata</i> (Peters, 1871)	Short-webbed Frog	DD
23	<i>Minervarya keralensis</i> (Dubois, 1981)	Kerala Warty Frog	VU
24	<i>Minervarya syhadrensis</i> (Annandale, 1919)	Long-legged Cricket Frog	LC

25	<i>Nasikabatrachus sahyadrensis</i> (Biju & Bossuyt, 2003)	Purple Frog	NT
26	<i>Nyctibatrachus acanthodermis</i> (Biju, Van Bocxlaer, Mahony, Dinesh, Radhakrishnan, Zachariah, Giri & Bossuyt, 2011)	Spinular Night Frog	EN
27	<i>Nyctibatrachus anamallaiensis</i> (Myers, 1942)	Anamalai Night Frog	EN
28	<i>Nyctibatrachus deccanensis</i> (Dubois, 1984)	Deccan Night Frog	EN
29	<i>Nyctibatrachus poocha</i> (Biju, Van Bocxlaer, Mahony, Dinesh, Radhakrishnan, Zachariah, Giri, and Bossuyt, 2011)	Meowing Night Frog	NT
30	<i>Nyctibatrachus webilla</i> (Garg, Suyesh, Sukesan & Biju, 2017)	Kadalar Night Frog	EN
31	<i>Polypedates maculatus</i> (Gray, 1830)	Spotted Tree Frog	LC
32	<i>Polypedates occidentalis</i> (Das & Dutta, 2006)	Western Tree Frog/ Charpa Tree Frog	LC
33	<i>Pseudophilautus wynaadensis</i> (Jerdon, 1853)	Munnar Bush Frog	LC
34	<i>Raorchestes akroparallagi</i> (Biju & Bossuyt, 2009)	Variable Bush Frog	LC
35	<i>Raorchestes blandus</i> (Vijayakumar, Dinesh, Prabhu & Shanker, 2014)	Pleasant Bush Frog/ Anamalai Bush Frog	EN
36	<i>Raorchestes anili</i> (Biju & Bossuyt, 2006)	Anil's Bush Frog	LC
37	<i>Raorchestes beddomii</i> (Günther, 1876)	Beddome's Bush Frog	LC
38	Raorchestes chlorosomma (Biju & Bossuyt, 2009)	Green-eyed Bush Frog	EN
39	<i>Raorchestes drutaahu</i> (Garg, Suyesh, Das, Bee, and Biju, 2021)	Fast-calling Shrub Frog	DD
40	<i>Raorchestes dubois</i> (Biju & Bossuyt, 2006)	Kodaikanal Bush Frog	VU
41	<i>Raorchestes flaviventris</i> (Boulenger, 1882)	Yellow-bellied Bush Frog/Malabar bubble nest frog	VU
42	<i>Raorchestes griet</i> (Bossuyt, 2002)	Griet's Bush Frog	VU
43	<i>Raorchestes jayarami</i> (Biju & Bossuyt, 2009)	Jayaram's Bush Frog	EN
44	<i>Raorchestes kadalorensis</i> (Zachariah, Dinesh, Kunhikrishnan, Das, Raju, Radhakrishnan, Palot & Kalesh, 2011)	Kadalar Bush Frog	NT
45	<i>Raorchestes munnarensis</i> (Biju & Bossuyt, 2009)	Munnar Bush Frog	EN
46	<i>Raorchestes ochlandrae</i> (Gururaja, Dinesh, Palot, Radhakrishnan & Ramachandra, 2007)	Ochlandra Shrub Frog	LC
47	<i>Raorchestes ponmudi</i> (Biju & Bossuyt, 2005)	Large Ponmudi Bush Frog	LC
48	<i>Raorchestes resplendens</i> (Biju, Shouche, Dubois, Dutta & Bossuyt, 2010)	Resplendent's Bush Frog	EN
49	<i>Raorchestes sushili</i> (Biju & Bossuyt, 2009)	Sushil's Bush Frog	EN

50	<i>Raorchestes travancoricus</i> (Boulenger, 1891)	Travancore Bush frog	EN
51	<i>Raorchestes uthamani</i> (Zachariah, Dinesh, Kunhikrishnan, Das, Raju, Radhakrishnan, Palot & Kalesh, 2011)	Uthaman's Bush Frog	NT
52	<i>Rhacophorus calcadensis</i> (Ahl, 1927)	Kalakad Tree Frog	VU
53	<i>Rhacophorus malabaricus</i> (Jerdon, 1870)	Malabar Gliding Frog	LC
54	<i>Rhacophorus pseudomalabaricus</i> (Vasudevan & Dutta, 2000)	Anamali Flying Frog	VU
55	<i>Uperodon anamalaiensis</i> (Rao, 1937)	Anamalai Globular Frog	LC
56	<i>Uperodon globulosus</i> (Gunther, 1864)	Indian Globular Frog	LC
57	<i>Uperodon systoma</i> (Schneider, 1799)	Marbled Globular Frog	LC
58	<i>Uperodon montanus</i> (Jerdon, 1853)	Jerdon's Narrow-mouthed Frog	NT
59	<i>Uperodon taprobanicus</i> (Parker, 1934)	Sri Lankan Bull Frog	LC
60	<i>Uperodon variegatus</i> (Stoliczka, 1872)	Eluru Dot Frog	LC
61	<i>Walkerana leptodactyla</i> (Boulenger, 1882)	Boulenger's Indian Frog	VU
62	<i>Walkerana phrynoderma</i> (Boulenger, 1882)	Kerala Indian Frog/Toad-skinned Frog	EN



Rhacophorus calcadensis (Juvenile)

Amphibians and Reptiles
are sometimes thought of as
primitive, dull and
dim-witted. In fact, of course,
they can be lethally fast,
spectacularly beautiful,
surprisingly affectionate and
very sophisticated.

David Attenborough



Raorchestes munnarensis



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