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Vandalur, Chennai, Tamil Nadu

PROCEEDINGS

**Udhayan, A., Senbagapriya, S., Eswaran, D., Manimozhi, A.,
Sankar, K., Vasanthakumari, D., Siva Ranjani, S. and Gabriel
Paulraj, M.**

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PREFACE

The importance and need for biodiversity conservation has never been greater than at present times, where human development and resultant climate change have been unprecedented. Habitat loss and degradation, fragmentation, climate change and proliferation of alien invasive species are some of the key factors leading to severe biodiversity loss and human-wildlife conflicts. Poaching and the illegal trade of wildlife articles are further exacerbating the situation. There is a clear need for various stakeholders in conservation to get together more often and come up with solutions to prevent and halt the depletion of wildlife.

Tamil Nadu is a state well-known for its rich biological diversity and the various conservation initiatives implemented by the state to protect this natural heritage. The State has actively encouraged wildlife research studies by various entities, as research findings have been critical for the scientific management of habitats and ecosystems. The results of such research have been incorporated at multiple levels of planning and implementation. Several Protected Areas have been established based on key research inputs.

The Advanced Institute for Wildlife Conservation (AIWC) of the Tamil Nadu Forest Department, by holding the Annual Research Conference (ARC), provides a platform for wildlife researchers to showcase their findings, which are then discussed with field managers and other stakeholders. The fourth ARC was conducted on February 13th and 14th, 2025, in the institute's premises. Thirty-six abstracts were received from the researchers, and 34 were presented by scientists, professors, NGOs, research scholars, and in-house researchers at the conference. This proceeding contains 19 research papers. I am confident that the insights provided in these research articles will be highly beneficial for field managers and wildlife researchers.

The diligent work of Dr. K. Sankar, Former Director of SACON, in revising and editing all the abstracts and full-length manuscripts is sincerely appreciated. The contribution of Dr. A. Manimozhi, Scientist 'C' (Retd) and Dr. M. Gabriel Paulraj, Project Scientist at AIWC, in coordinating all activities related to the Conference is deeply acknowledged. We express our gratitude for the assistance and direction offered by the senior officials of the Tamil Nadu Forest Department in organising the conference and preparing this proceeding. We also thank the researchers who submitted the manuscripts and the field managers who enhanced the research papers with their contributions. The planning and implementation of the ARC and preparation of these proceedings by the research team, range team and office staff are greatly acknowledged.

**A. Udhayan, IFS, PCCF & Director,
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CONTENT

		Page
1	Study on the impact of ocean acidification on the aragonite saturation state (Ω_{ar}) in the coral reef ecosystem of the Gulf of Mannar and Palk Bay and mapping blue carbon hotspots for harnessing ecosystem-based services as well as climate change mitigation Anand, M., Rangesh, K., Pandiya Rajan, R.S. and Panda, U.S.	1
2	Conservation of Tropical Dry Evergreen Forest (TDEF) within Tamil Nadu Glenn Baldwin, Paul Blanchflower and Sivasankaran, A.	16
3	Comprehensive analysis of road kills in Tamil Nadu highway network: Identifying hotspots and suggesting mitigation measures Sowjanya, V.L., Sathishkumar, S., Udhayan, A., Manimozhi, A., Ganesan, M.G. and Senbagapriya, S.	34
4	Spatial patterns of sea urchin diversity and their relationship to ecosystem health in the Gulf of Mannar Radhika Rajasree, S. R., Anagha Biju, Praisya M. Shaju, Vishnu, P. and Anugrah Jayesh	54
5	Distribution and habitat use by shola birds of the Nilgiris Nisha Bhakat, Vivek Ramachandran, Ashwin Vishwanathan and Jayashree Ratnam	62
6	Seasonal diversity of the finfish community in a tropical estuary, south-east coast of India, Tamil Nadu Kanishkar, A., Santhoshkumar, S., Abinaya, R., Pavinkumar, P., Aruna, S. and Ranjithkumar, V.	74
7	Checklist of Ichthyofaunal diversity in the Muthupet coastal ecosystem: Biodiversity insights and conservation implications Abinaya, R. and Sajeewan, M.K.	95
8	First synchronized population estimation and social organization of Nilgiri tahr <i>Nilgiritragus hylocrius</i> in Tamil Nadu, south India Ganesan, M.G, Ganesh Ram, K., Priyanka, S., Subbaiyan, B., Manigandan, K., Rajeshkumar, N., Nesan, T., Ashokkumar, M	113
9	Understanding the ecology of lesser-known mammals in Sathyamangalam Tiger Reserve, Tamil Nadu Vandana Kannan, Mathesan, R., Vijay Ramesh, Anita Varghese and Pratim Roy	127
10	Assessing the wildlife-domestic dog interface in Mudumalai Tiger Reserve, Tamil Nadu Sanjana Vadakke Kuruppath, Varun Kher and K. Ramesh	142

11	Effect of land-use change on the abundance of grizzled giant squirrel (<i>Ratufa macroura</i>), around the protected area of Srivilliputhur-Meghamalai Tiger Reserve, Srivilliputhur division, Tamil Nadu	158
	Shilpa Bevoor, Gopi, G.V., Goyal, S.P. and Varun Kher	
12	Age and sex influence seed dispersal of native and non-native plants by lion-tailed macaques <i>Macaca silenus</i>	170
	Bindu K, Honnavalli N. Kumara and Rohit Naniwadekar	
13	Development of normal thermography data for Asian Elephants at Anamalai and Mudumalai Elephant Camps, Tamil Nadu	190
	Madeswaran, R., Kumar, K., Siva Ranjani, S., Eswaran, D., Senbagapriya, S. and Udhayan, A.	
14	Babesiosis: A thread for captive wild felids – A case report of captive lion (<i>Panthera leo</i>) at Arignar Anna Zoological Park, Chennai, India	207
	Sandhya, P., Divya, D., Sridhar, K., Vasanthakumari, D., Siva Ranjani, S. and Udhayan, A.	
15	Light microscopic studies of some pollen morphotypes of the upper montane Nilgiri flora	214
	Lazar, J., Prasad, S. and Anupama, K.	
16	An inventory of grass species in the Nilgiri tahr (<i>Nilgiritragus hylocrius</i>) habitat of the Anamalai Tiger Reserve, Tamil Nadu, India	230
	Ganesan, M.G., Ganesh Ram, K., Subbaiyan, B., Manigandan, K., Rajeshkumar, N. and Nesan, T.	
17	Four elusive Indian mosses discovered in the Western Ghats	239
	Williams, Z.H., Daniels, D.T.T., Ben, C.P. and Daniels, A.E.D.	
18	Illegal cannabis cultivation in Tamil Nadu: An analysis of patterns and spatial distribution	249
	Arulraj Rajappa, Srinivasan Murugesan and Jose Benjamin Thomas	
19	Identification and characterization of south Indian mammal hair using Tricho-taxonomic analysis	261
	Rajasivam, M. and Nazia, A.	
	Author Index	273

1 STUDY ON THE IMPACT OF OCEAN ACIDIFICATION ON THE ARAGONITE SATURATION STATE (Ω_{Ar}) IN THE CORAL REEF ECOSYSTEM OF THE GULF OF MANNAR AND PALK BAY AND MAPPING BLUE CARBON HOTSPOTS FOR HARNESSING ECOSYSTEM-BASED SERVICES AS WELL AS CLIMATE CHANGE MITIGATION

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ABSTRACT

Ocean acidification (OA), driven by atmospheric Carbon dioxide (CO₂) absorption, poses significant risks to coral reef ecosystems and calcifying organisms worldwide. OA reduces the availability of aragonite, which is essential for coral calcification and ultimately weakens coral structures and reduces reef growth. The Gulf of Mannar (GoM) and Palk Bay (PB), located on the southeast coast of India, are vital marine regions providing critical ecosystem services, including biodiversity support, carbon sequestration, and fisheries production. Between January 2023 and September 2024, we conducted a pilot study to assess the aragonite saturation state (Ω_{Ar}) across 24 stations in these coastal waters, alongside measurements of pH, temperature, salinity, nutrients, and carbonate parameters following the Global Ocean Acidification Observing Network (GOA-ON) protocol. The results revealed PB exhibited higher pH (mean $\pm$ SD of pH 8.33 $\pm$ 0.06) compared to GoM (mean $\pm$ SD of pH 8.08 $\pm$ 0.02), with Ω_{Ar} values ranging from 2.64 in GoM - indicative of marginal calcification conditions to 6.71 in PB, signifying optimal conditions for calcifiers. The findings highlighted lower Ω_{Ar} values in GoM, suggesting an alarming trend towards marginal calcification conditions, which could compromise coral reef growth and resilience. This aligns with observed global trends where increased anthropogenic CO₂ emissions exacerbate acidification in nearshore environments. This study underscores the importance of regular monitoring of OA parameters in these regions and highlights the need for community-based conservation strategies to protect these critical ecosystems and their associated services.

Keywords: Aragonite saturation state, ocean acidification, coral reef ecosystem, Gulf of Mannar, Palk Bay

INTRODUCTION

Gulf of Mannar (GoM) and Palk Bay (PB) region are situated off the southeastern coast of India. GoM, spanning approximately 15,000 sq. km along the Indian coastline from Tuticorin to Mandapam, over a distance of about 190 km, has significant biodiversity and acts as a distinct Marine Biosphere Reserve. There are 21 Islands situated in the GoM between the Southern Sea of Rameswaram and Tuticorin, with a total area of 623 hectares. These 21 Islands are categorized into four groups such as a) Mandapam group of Islands (7 Islands), b) Keelakarai group of Islands (7 Islands), c) Vembar group of Islands (3 Islands), and d) Tuticorin group of Islands (4 Islands). Each island has fringing and patchy coral reefs, most commonly *Acropora* sp., *Montipora* sp., and *Porites* sp., as well as diversified floral and faunal occurrences. Notably, Kurusadai Island, among the 21 small islands dotting the GoM's vicinity, is renowned as a marine biologist's paradise. Recent biodiversity assessments have identified approximately 4,000 faunal species in the GoM, including 1,147 fish species, 856 mollusk species, 451 tunicate species, 262 coelenterate species (117 of which are corals), 158 arthropod species, 153 echinoderm species and 77 sponge species (ENVIS, 2015). Many of these species are protected under India's Wildlife Protection Act (1972), highlighting the imperative to safeguard this ecologically sensitive area.

Despite its status as a marine biosphere reserve, the GoM faces threats from increasing human settlement and livelihood activities, which could jeopardize its environmental integrity. Nevertheless, the GoM remains a key hub for fish landing in India, underscoring its potential as a source of rich bioresources. The GoM is globally renowned for its pearl oyster (*Pinctada fucata*) and molluscan resources, particularly the sacred chank (*Xancus pyrum*). Notably, the presence of *Ptychodera flava*, a living fossil, and *Balanoglossus*, which bridges invertebrates and vertebrates, is exclusive to this region in India (Kannapiran *et al.*, 2008; Retnamma *et al.*, 2021).

The GoM and Palk Bay experience distinct wind and tide patterns influenced by various meteorological and oceanographic factors. The wind patterns in the GoM are primarily influenced by the seasonal monsoon winds that prevail in the region. During the southwest monsoon (June to September), winds blow from the southwest, bringing moisture-laden air from the Indian Ocean. These winds are generally strong and consistent, contributing to rough seas and high waves in the GoM. Conversely, during

the northeast monsoon (October to December), winds shift direction and blow from the northeast. These winds are typically drier and less intense than southwest monsoon winds but still significantly impact the GoM region. Similar wind pattern is found in Palk Bay (Suresh *et al.*, 2014; Rajendran *et al.*, 2012). Apart from the monsoon winds, local sea breezes also influence the wind patterns in the GoM. During the day, as land heats up faster than the sea, warm air rises over the land, creating a low-pressure area. Cooler air from the sea then moves inland to fill this void, resulting in a sea breeze. In the evening, the reverse occurs, with cooler air from the land moving towards the sea, creating a land breeze (Thangaradjou & Balasubramanian, 2005; Balachandran & Rajamanickam, 2000).

During the early 2000s, the environmental parameters showed significant variations compared to the earlier survey, which indicates an increase in temperature. In the late 2010s, GoM mean annual pH, depth, salinity, dissolved oxygen (DO), and temperature were pH 7.81, 1.42 m, 34.71 PSU, 6.32 mg/l and 30.23 °C, respectively, and seasonally varied algal dynamics are a potential threat to coral reefs (Ramesh *et al.*, 2020). Temperature values annually increased with a warming SST trend of 0.04 °C in the GoM (Mondal & Lee, 2023). The dissolved oxygen in GoM depends on temperature, salinity, oxygen solubility, consumption and production. Maximum DO of 6.2 mg/l was observed in April-May. In the Tuticorin harbour area, 0.5 ppm of DO was reported due to the influence of municipal sewage. In surface and sea bottom waters, high ammonia levels and low dissolved oxygen levels were also observed (Kumaraguru *et al.*, 2006).

Ocean acidification, driven by the absorption of carbon dioxide (CO₂) from the atmosphere, poses a long-term threat to coral reef ecosystems worldwide. Acidification reduces the availability of carbonate ions, essential for coral calcification, leading to weakened coral skeletons and decreased reef growth rates. Sadhukan *et al.* (2022) investigated the impacts of ocean acidification on coral bleaching in the GoM, highlighting the vulnerability of reef-building corals to changing seawater chemistry. Panchang and Ambokar (2021) outlined the interactive effects of ocean acidification and temperature stress on coral bleaching susceptibility in Palk Bay, emphasizing the need for adaptive management strategies to enhance reef resilience.

The main objective of the present study is to evaluate the aragonite saturation (Ω_{ar}) state in the critical ecosystems of the GoM and Palk Bay region.

MATERIALS AND METHODS

Study area

GoM and Palk Bay stations were chosen to monitor the seawater's physicochemical parameters. Eight sampling sites comprising 24 stations of the GoM and Palk Bay regions were selected (Fig.1). The study site was chosen based on the prevalence of corals, seagrass and mangrove areas, and they are considered ecologically sensitive areas. Water samples collection was carried out between 2023 and 2024.

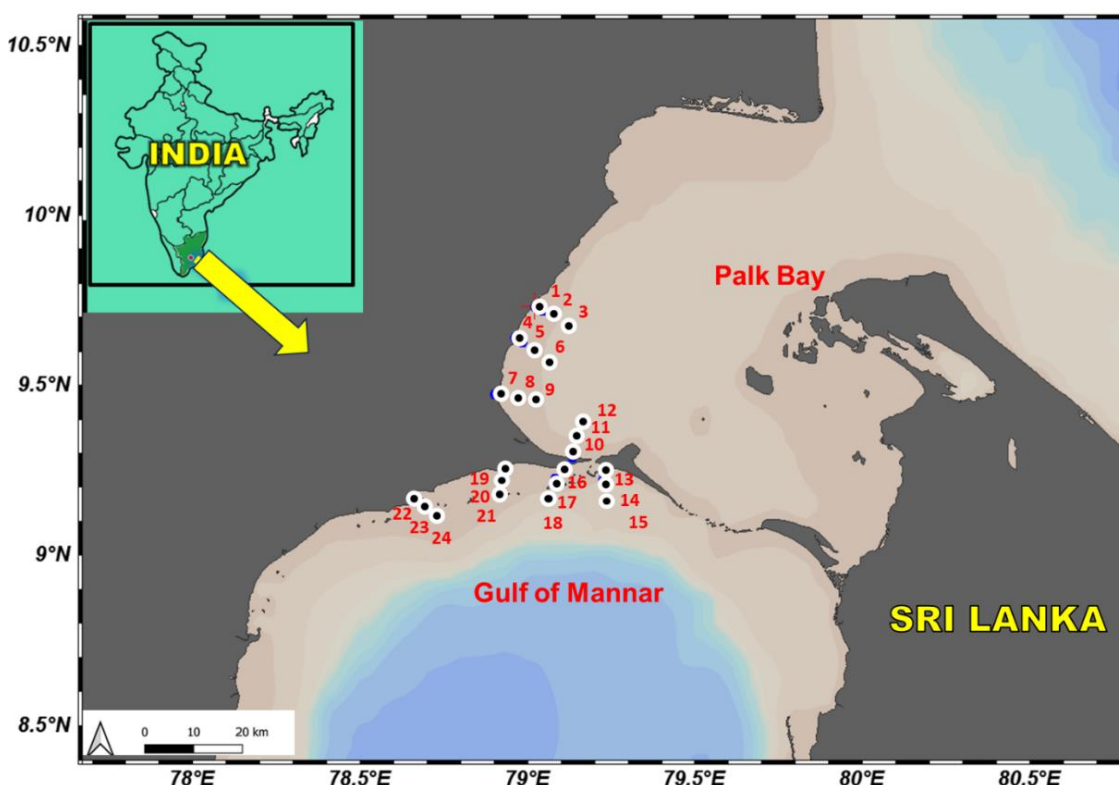


Figure 1. Study area map showing Gulf of Mannar (Kurusadai, Vedalai, Periyapattinam and Valinokkam) and Palk Bay (Munaikadu, Devipattinam, Karankadu and Thondi)

Seawater sample collection

The weather parameters such as environmental state, weather condition, tide, air temperature, humidity, wind speed, wind direction, and light intensity were recorded during sampling. Seawater was collected at morning time between 07:00 h and 11:00 h local time (GMT+5:30). Niskin water sampler (5 litres capacity) was deployed from mechanized boat at each station. The Niskin water sampler used the metallic messenger to shut the bottle at the proper depth while being controlled by a nylon rope. Subsurface water samples were taken to measure dissolved oxygen and

biochemical oxygen demand (DO/BOD). At the collection site, Winkler 'A' and 'B' solution were added in 125 ml flask DO bottles for dissolved oxygen. Further water samples were collected for salinity and total alkalinity (with 50 μ l of mercuric chloride). *In-situ*, temperature was measured using a Microprobe pH meter (Model: Waterproof Pester 30). Salinity was measured using argentometric titration. Total alkalinity was determined using APHA method. The pH levels were measured using Aquamater 8100 spectrophotometer.

Aragonite saturation state

Results of pH, temperature, salinity and total alkalinity were subjected to get the associated seawater carbonate parameters such as partial pressure of carbon dioxide ($p\text{CO}_2$), Revelle factor, calcite saturation state (Ω_{Ca}) and aragonite saturation state (Ω_{Ar}). CO2SYS Excel sheet was set for an algorithm towards the equation for the dissociation constants of K1 and K2 from Mehrbach *et al.* (1973) refit by Dickson and Millero (1987) and the pH scale was set for the total scale.

RESULTS

pH

During the study period, there was fluctuation in water pH across seasons, ranging from pH 8.08 to pH 8.24 in the GoM and pH 8.14 to 8.33 in PB (Fig. 2). At GoM seawater, a minimum pH of 8.08 was recorded, while at PB, a maximum pH of 8.33 was observed. These findings suggest that GoM pose high vulnerability to ocean acidification. A pH >8.0 was observed throughout the study period at both GoM and PB stations. During 2023, there was an observation of low pH levels, whereas during the summer season, higher pH levels were noticed. Several key factors characterize the seasonal fluctuations of pH. These include the removal of CO_2 , dilution of seawater by freshwater influx, and upwelling (Retnamma *et al.*, 2021).

Temperature

The lowest seawater temperature was 26.4 $^{\circ}\text{C}$ in Palk Bay, whereas the highest temperature was 29.8 $^{\circ}\text{C}$ in GoM. In 2024, there was a noticeable decrease in temperature compared to 2023, with a recorded temperature of 24.6 $^{\circ}\text{C}$ (Fig. 2).

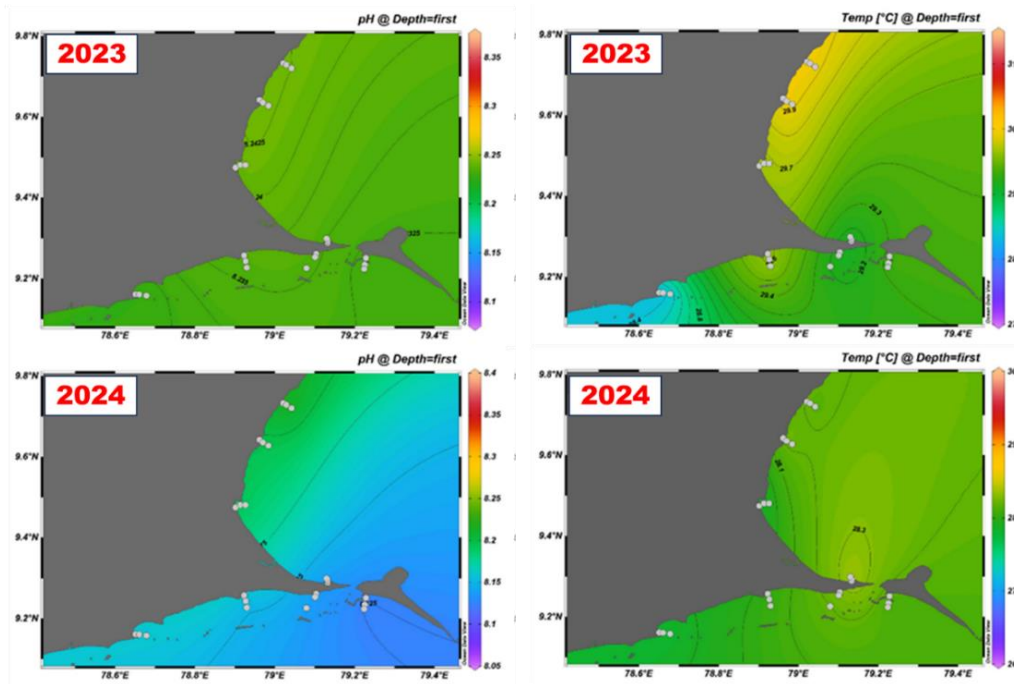


Figure 2. pH and temperature levels in the GoM and PB between 2023 and 2024

The water temperature in most parts of the GoM is influenced by the atmospheric temperature. Thus, the temperature gradually increases from January to April, reaching its highest point in May with a summer temperature of 32 °C. There was a steady decline in temperature up to August. Surface temperature exhibited a recurring pattern with a notable increase in 2023, followed by a subsequent decrease in 2024. This specific oscillation pattern in water temperature is highly unique in the GoM. In the shallow regions of the GoM, closer to the land, the water temperature occasionally exceeds the atmospheric temperature in the summer months.

Salinity

Both the GoM and PB experienced a significant increase in salinity during the late summer in 2023, with measurements reaching 36 PSU in these regions (Fig. 3). It is interesting to note that the salinity in PB decreased to 31.24 PSU in 2024 due to rainfall and increased freshwater input during the Northeast monsoon. In contrast, the salinity in the GoM was recorded at 35.5 PSU, which can be attributed to the low rainfall and reduced freshwater input in that region. These rainfall events occurred due to a trough, is aka a narrow depression (as in the earth or between ocean waves or in the ocean bed), in easterlies that runs from south Sri Lanka to North Coastal Tamil Nadu in the lower tropospheric levels during 2024. Under its influence, light to moderate rainfall

occurred at many places over Tamil Nadu, with heavy to very heavy rain at a few places over North Coastal Tamil Nadu.

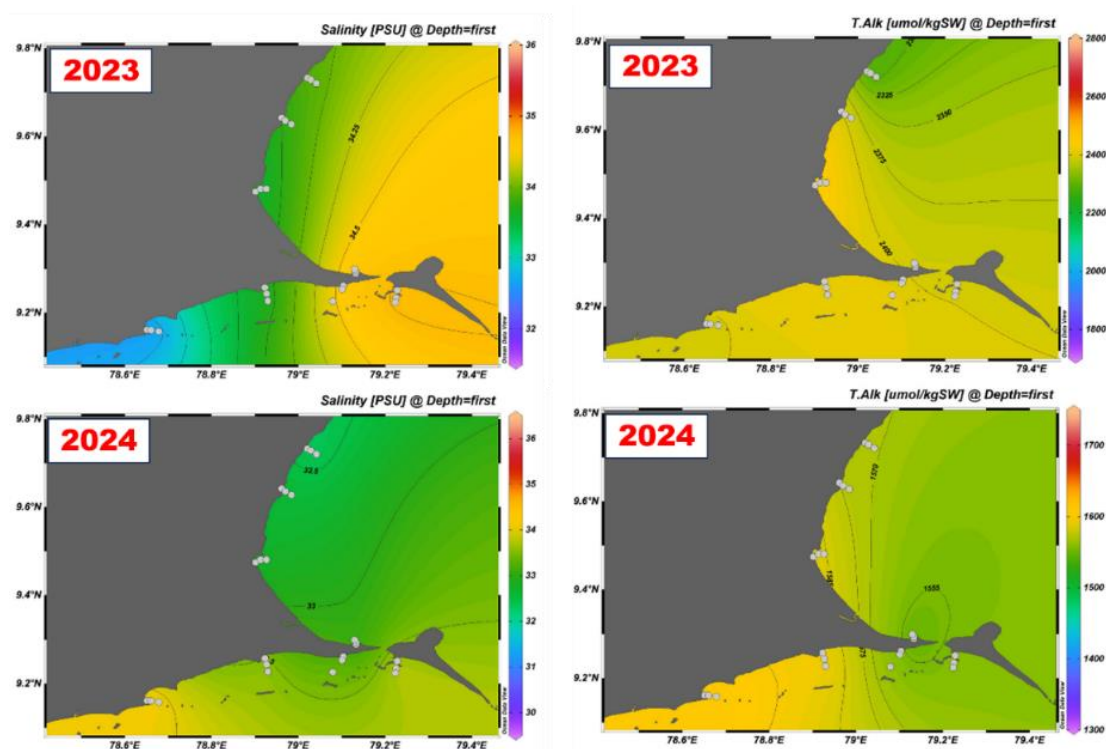


Figure 3. Salinity and Total alkalinity levels in the GoM and PB between 2023 and 2024

Total Alkalinity

The total alkalinity (TA) measurements revealed a significant difference between PB and GoM, with a low value of 1417 $\mu\text{mol/kgSW}$ in GoM and PB has recorded the highest value of 2875 $\mu\text{mol/kgSW}$ (Fig. 3). Season wise, huge changes in total alkalinity were observed in 2024 samples. The high total alkalinity associated with high salinity and low aragonite saturation state in all sampling months.

Dissolved oxygen and Biochemical Oxygen Demand (DO/BOD)

Based on the data collected, PB had an observed dissolved oxygen (DO) level of 6.54 mg/l, while GoM had the lowest DO level of 3.92 mg/l (Fig. 4). In 2023, a significant decline in dissolved oxygen levels was observed in both the GoM and PB. Typically, the summer showed higher dissolved oxygen (DO) levels, whereas the northeast monsoon exhibited lower levels. This can be attributed to the decrease in oxygen solubility caused by the increase in temperature and salinity. of the water column. The highest recorded BOD level was 3.69 mg/l in GoM, while the lowest BOD level was 0.6 ± 0.26 (mean $\pm$ SD) mg/l in PB.

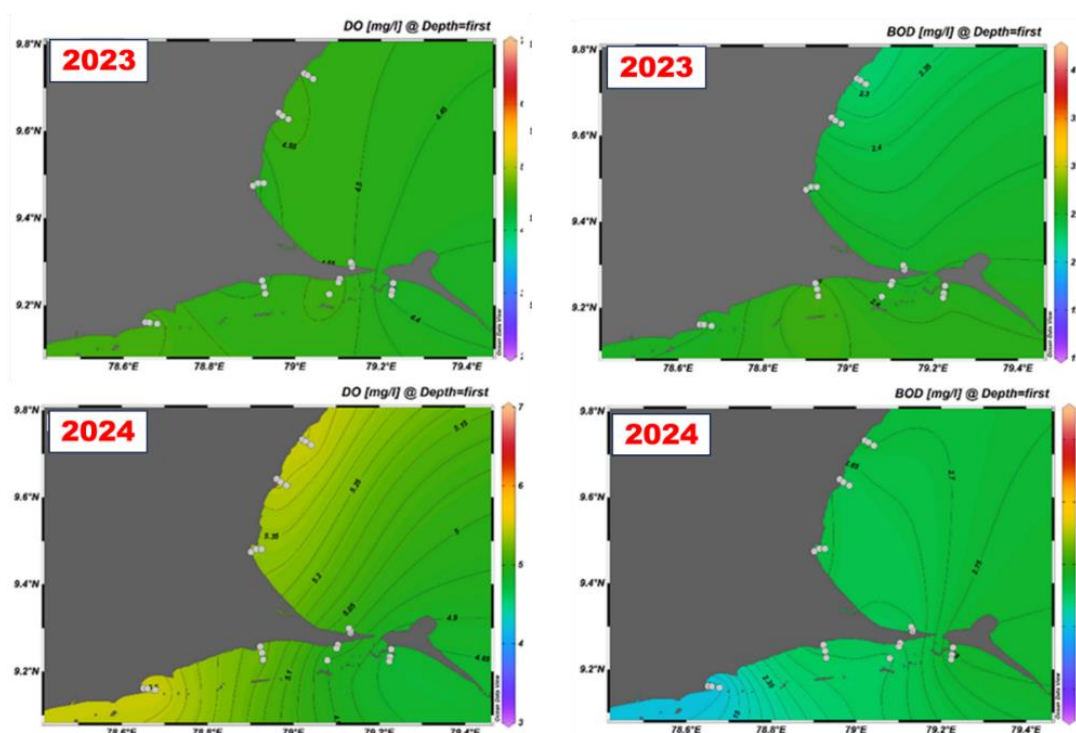


Figure 4. DO and BOD levels in the GoM and PB between 2023 and 2024

pCO₂

GoM and Palk Bay has high variability in pCO₂ ranging from 174 μ atm (PB) to 361 μ atm (GoM) due to various factors, including the absorption or emission of CO₂ by different oceanic regions, environmental conditions like temperature and salinity, storms, input from rivers, and biological processes such as photosynthesis and respiration, influence the proportion of carbon molecules (Fig. 5).

Revelle Factor

GoM has highest revelle factor (8.4) in 2024 (Fig. 5). The Revelle factor can be used to represent the link between changes in dissolved inorganic carbon (DIC) system and changes in atmospheric CO₂. The Revelle factor, also known as the buffer factor, is a measure used to describe the sensitivity of the ocean's DIC system to changes in atmospheric carbon dioxide (CO₂) levels. It quantifies how much the concentration of CO₂ in the atmosphere influences the concentration of CO₂ in seawater (Revelle & Suess, 1957). The lowest revelle factor 6.9 was found in Palk Bay during 2023, which represents the highest uptake of atmospheric CO₂.

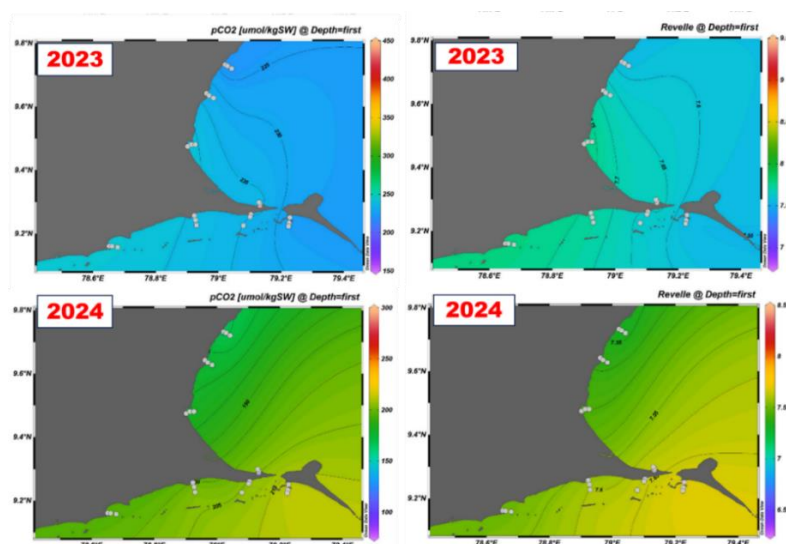


Figure 5. pCO₂ and Revelle factor in the GoM and PB between 2023 and 2024

Calcite / Aragonite saturation state

Aragonite saturation state at GoM was recorded at below adequate level (2.64) in 2024, whereas in Palk Bay, optimal level of aragonite saturation state 6.71 was recorded in 2023 (Fig. 6). Similarly, calcite saturation state (Ω_{Ca} 4.36) was high in 2023 and subsequent decrease in 2024. Aragonite (Ω_{Ar}) value greater than 1 indicates supersaturation, which is favourable for forming aragonite shells and skeletons. Values less than 1 indicate undersaturation, leading to conditions where aragonite can dissolve. The pH of seawater is a critical component of the carbonate system, influencing the concentrations of carbonate and bicarbonate ions, which are essential for forming aragonite type of calcium carbonate.

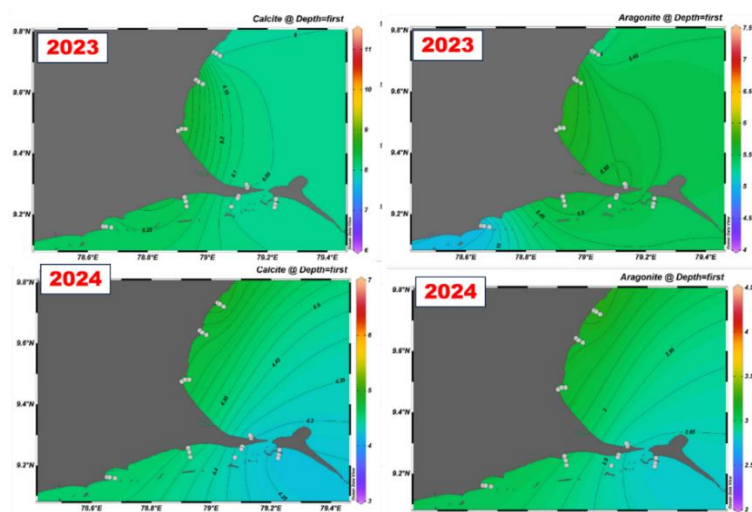


Figure 6. Calcite and Aragonite saturation state in the GoM and PB between 2023 and 2024

DISCUSSION

The study highlights significant spatial variability in the aragonite saturation state (Ω_{Ar}) between the GoM and Palk Bay PB, which has profound implications for the resilience of coral reef ecosystems in these regions. The recorded Ω_{Ar} value of 2.64 in the GoM suggests a marginally adequate environment for calcifying organisms. While this value is above the undersaturation threshold, it indicates suboptimal conditions that could stress coral reefs and other carbonate-dependent organisms (Feely *et al.*, 2009). In contrast, PB exhibited a markedly higher Ω_{Ar} of 6.71, signifying a more favourable environment for calcification and suggesting a robust buffering capacity that enhances carbonate ion availability (Anthony *et al.*, 2011). Coastal upwelling is happening in Indian coasts during Southwest monsoon (Retnamma *et al.*, 2021) is one of the reasons for depletion of the aragonite saturation state in the Gulf of Mannar (Harris *et al.*, 2013). The GoM experience periodic upwelling events driven by monsoonal winds, which bring nutrient-rich but carbon dioxide (CO_2) laden waters from deeper Indian Ocean layers to the surface. This process enhances primary productivity and increases dissolved inorganic carbon (DIC) concentrations, reducing Ω_{arag} and making waters more corrosive to carbonate structures (Feely *et al.*, 2009).

Seagrass distribution pattern in the GoM is very low compared to Palk Bay (Kaladharan *et al.*, 2021). Seagrass meadows act as natural buffers against ocean acidification by sequestering CO_2 through photosynthesis and increasing local Ω_{arag} . In PB, extensive seagrass meadows facilitate higher carbonate saturation states by reducing DIC concentrations and promoting calcium carbonate precipitation (Job *et al.*, 2023). In contrast, GoM had a relatively lower seagrass cover due to habitat degradation and increased sedimentation, leading to less effective CO_2 sequestration (Mathews *et al.*, 2010). This difference in seagrass-mediated buffering capacity contributes to the observed lower Ω_{arag} in GoM compared to PB, making GoM corals more vulnerable to ocean acidification.

The depth profile of GoM, which extends to greater depths compared to PB, also influences Ω_{arag} and coral health. Deeper waters in GoM are subject to greater temperature variations, particularly during thermal anomalies, leading to frequent coral bleaching (Retnamma *et al.*, 2021). High-temperature stress exacerbates the metabolic demand of corals, increasing their sensitivity to lowered Ω_{arag} and reducing their

ability to calcify (Fabricius *et al.*, 2011). PB, being shallower, experiences more stable thermal conditions, which, coupled with higher Ω_{Ar} , supports better coral resilience (Sadhukhan *et al.*, 2022). This suggests that the combination of depth-driven temperature fluctuations and low Ω_{Ar} in GoM contributes to higher coral mortality rates compared to PB.

Marginalized Ocean Acidification in the Gulf of Mannar

The relatively low Ω_{Ar} in the GoM indicates a phenomenon known as marginalized ocean acidification, where saturation levels approach critical thresholds that can compromise biological and ecological integrity (Andersson & Gledhill, 2013). This condition may be driven by multiple factors, including elevated atmospheric CO₂ absorption, increased organic matter decomposition, and localized anthropogenic influences such as coastal runoff and industrial discharges (Gattuso & Hansson, 2011). These factors can collectively reduce carbonate ion concentrations, thereby limiting the ability of coral reefs to maintain their skeletal structures and exacerbating their vulnerability to additional stressors like warming and eutrophication (Kleypas *et al.*, 2006).

The marginal Ω_{Ar} observed in the GoM directly affects coral resilience and reef accretion rates. Corals and other calcifiers require an Ω_{Ar} above 3.0 for optimal growth and skeletal deposition (Comeau *et al.*, 2014). The recorded value of 2.64 suggests reef-building corals in the GoM may experience reduced calcification rates, weakening skeletal structures and increased susceptibility to bioerosion and disease (Fabricius *et al.*, 2011). Moreover, persistent exposure to near-threshold conditions could result in shifts in reef composition, favouring non-calcifying organisms over traditional reef builders (Albright *et al.*, 2018).

Favourable Conditions for Calcification in Palk Bay

The significantly higher Ω_{Ar} value of 6.71 in PB suggests an environment with ample carbonate ion availability, fostering robust coral growth and reef resilience (Guinotte & Fabry, 2008). This high saturation state may be attributed to favourable hydrodynamic conditions, including limited freshwater influx, high primary productivity, and efficient carbon cycling mechanisms that sustain elevated carbonate ion concentrations (Duarte *et al.*, 2013). The enhanced buffering capacity in PB ensures

that even with fluctuating CO₂ levels, the system remains conducive to calcification processes, thereby supporting a thriving reef ecosystem.

Implications for Blue Carbon and Climate Change Mitigation

Mapping Blue Carbon hotspots in the GoM and PB is critical for harnessing ecosystem-based services and formulating climate change mitigation strategies. Seagrass meadows and mangrove ecosystems within these regions serve as crucial carbon sinks, mitigating ocean acidification impacts by sequestering CO₂ and enhancing local alkalinity (Fourqurean *et al.*, 2012). Protecting and restoring these ecosystems can enhance the resilience of marine calcifiers by stabilizing Ω_{Ar} levels and buffering against localized acidification stress (Howard *et al.*, 2017). The contrasting Ω_{Ar} values between GoM and PB underscore the need for targeted conservation efforts, emphasizing habitat restoration, pollution control, and sustainable coastal management practices to safeguard reef ecosystems from the progressing threats of ocean acidification and climate change.

CONCLUSION

This study highlights the critical influence of ocean acidification on the aragonite saturation state (Ω_{Ar}) in the coral reef ecosystems of the GoM (GoM) and Palk Bay (PB). The findings indicate that GoM exhibits a lower Ω_{Ar} (2.64), suggesting marginal calcification conditions, whereas PB maintains a significantly higher Ω_{Ar} (6.71), conducive to coral resilience and reef growth. This disparity can be attributed to differences in hydrodynamic conditions, freshwater input, seagrass coverage, and upwelling processes. The periodic upwelling in GoM introduces CO₂-enriched waters, exacerbating acidification and potentially increasing coral vulnerability. In contrast, PB's extensive seagrass meadows are crucial in CO₂ sequestration, mitigating acidification impacts and promoting a stable carbonate system. With the increasing threats posed by climate change and anthropogenic influences, monitoring OA parameters is imperative to track long-term shifts in coral reef health. Additionally, conservation strategies should be prioritised to enhance reef resilience, including habitat restoration, pollution control, and blue carbon ecosystem management. Future research should expand towards spatial mapping of blue carbon hotspots and long-term modelling of OA trends to inform adaptive management strategies and policy interventions to mitigate ocean acidification impacts.

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2 CONSERVATION OF TROPICAL DRY EVERGREEN FOREST (TDEF) WITHIN TAMIL NADU

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ABSTRACT

Sacred groves, remnants of the Tropical Dry Evergreen Forest (TDEF), are ecologically and culturally significant, serving as biodiversity reservoirs and spiritual sites. This study was conducted from 2021 to 2022. We examined 58 sacred groves through an integrated methodology, including field surveys, GIS mapping, and historical satellite imagery analysis, to assess their size, canopy cover, species diversity, and ecological health. The findings revealed a steady decline in vegetative cover, with 58% of groves experiencing canopy loss over the past two decades. Key drivers of degradation include temple expansion, deforestation, understory clearing, and waste accumulation. Despite these challenges, the groves continue to support rare and vulnerable plant species, highlighting their role as biodiversity banks. The study emphasizes the urgent need for conservation efforts, awareness initiatives, and sustainable management strategies to protect these fragile ecosystems and preserve their ecological and cultural value.

Keywords: Tropical dry evergreen forest, sacred groves, ecological status, biodiversity conservation, rapid assessment survey, conservation strategies.

INTRODUCTION

Within the coastal region of south-eastern peninsular India, there is a vegetation type defined as Tropical Dry Evergreen Forest – TDEF (Champion & Seth, 1968). It is a narrow range, approximately 500 km long running north to south, and with a width no wider than 50 km. This range experiences both of India's monsoon systems, the summer South West monsoon and the North East monsoon in the winter. The annual rainfall for the zone varies between 1000 and 1500 mm, with the majority experienced at the latter part of the year (Meher-Homji, 1974). In 1992, it was estimated that only 5% of the TDEF zone was under forest cover (Meher-Homji, 1992). In 2002, this estimate was revised to only 4% (Wikramanayake *et al.*, 2002). Sacred groves within

the Tropical Dry Evergreen Forests (TDEF) of Tamil Nadu are primarily located along the Coromandel Coast, spanning districts such as Kanchipuram, Tiruvallur, Villupuram, Cuddalore, Nagapattinam, Pudukkottai, and Thoothukudi. These groves are ecologically significant as they preserve rare plant species and serve as vital biodiversity hotspots. Sacred groves were first described by Brandis (1897). Sacred groves protect several plant and animal species valuable for food, medicine, and other uses (Ramakrishnan, 1998). This study employs a multi-faceted methodology to assess the ecological status of sacred groves, focusing on their size, canopy cover, species diversity, and overall biodiversity health by integrating field surveys, GIS mapping, and historical satellite imagery analysis. This study was conducted from 2021 to 2022 to evaluate the impact of environmental changes and human interventions on the sacred groves. The findings aim to highlight the vulnerability of these ecosystems, their role in biodiversity conservation, and the urgent need for protection and restoration efforts.

MATERIALS AND METHODS

A multi-pronged methodology was designed to gain the required insight into groves and to allow this assessment to be carried out. This approach included i) comprehensive field visits to all sites, ii) geo-referencing present sacred groves, including boundaries, temple infrastructure and water bodies, iii) analysis of canopy cover using historical and present Google Earth images, iv) quantitative and qualitative data analysis and v) biodiversity distribution analysis.

Study area

The study area was defined as 58 sacred groves within the Chengalpet, Cuddalore, and Villupuram districts, and corresponded to the study carried out by the Auroville Botanical team two decades prior. The map of the grove locations studied is given in Figure 1.

Study protocol

For each of the chosen locations, the following protocol for the rapid assessment was followed:

1. During field visits, ecological notes were recorded, including canopy and understory conditions, noteworthy species, regeneration, large specimens, temple development, and temple visit frequency by people.

2. A GPS technician used an "under-canopy" handheld GPS unit to map and geo-reference the grove's boundaries and key elements, such as temple infrastructure, water bodies, and notable species.
3. Botanists, using previous species lists, scanned the groves for key species and recorded their presence. Any newly observed plant species were added. These rapid assessments did not include formal vegetation surveys.

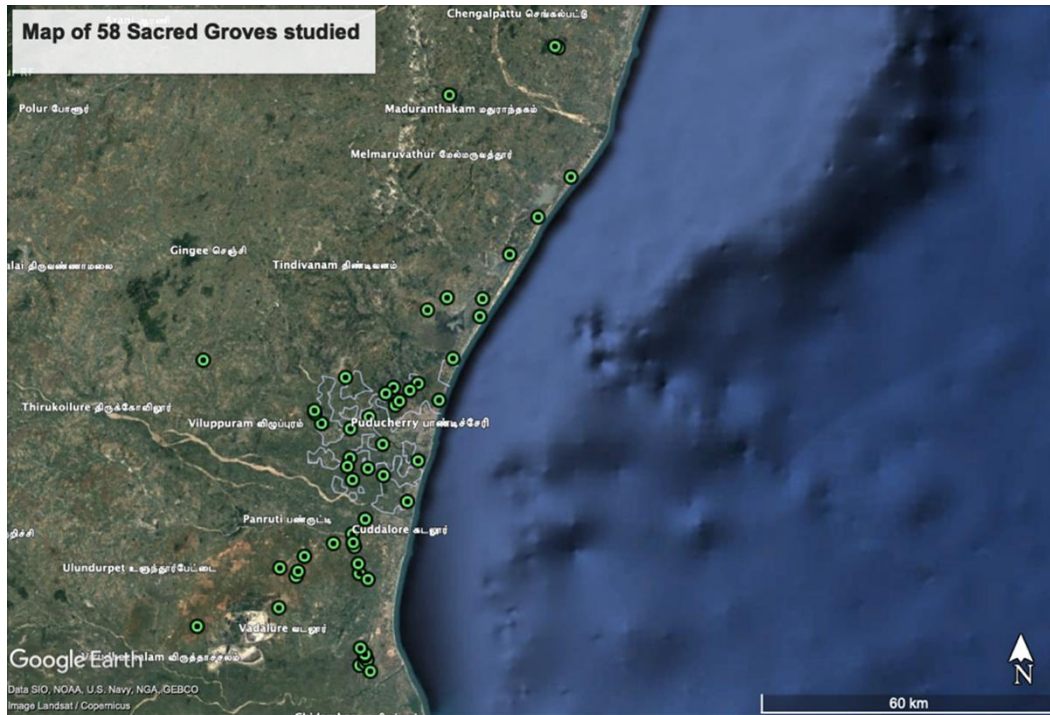


Figure 1. Map showing the locations where the field survey was conducted

4. GPS data was used to calculate and tabulate the total surface area of each grove.
5. Present canopy cover was determined from GPS data, excluding open spaces, temple infrastructure, and water bodies.
6. Historical Google Earth images were analysed, selecting two images per grove based on visual quality. Canopy polygons were created and quantified for both images, and the evolving canopy was saved as photographs for reference.
7. Present and past canopy cover was calculated as a percentage of the total grove area, allowing for an assessment of canopy loss or gain.

8. Field notes were used to categorize and tabulate canopy and understory conditions, providing comparable qualitative data. This was essential for ecological assessment, as canopy and understory quality needed to be understood.

As these assessments did not include full botanical surveys, it was decided that a list of the main 40 evergreen/ brevi-evergreen trees and woody shrubs would be used as a sample set to understand their presence, spatial distribution and the biodiversity of each grove. The list was determined and during the site visits the presence of these species was checked.

RESULTS

Sacred grove size analysis

The first step was to determine the current area of sacred groves in the zone. Using GIS data, maps were created for each grove (Fig. 2). Once grove sizes were determined, a table listing each name and size was compiled (Table 1). The total area of the 58 groves was calculated as 120 hectares.



Figure 2. Created map for a grove using GIS data

To clarify the analysis, groves were grouped by size, and their distribution was assessed (Table 2). Analysis revealed that 33 groves (58%) were under 1 hectare but

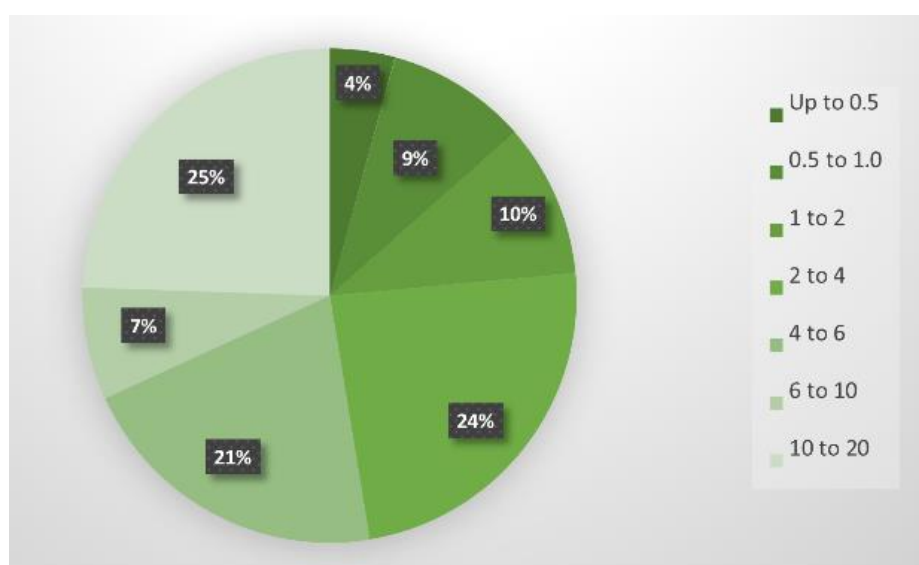
had the cover only 13% of the total area, whereas three groves (5%) ranged between 6 and 20 hectares, but accounted for 32% of the total area (Fig. 3). This indicates most groves are small, making them more vulnerable to disturbance. For instance, a temple expansion could significantly impact a small grove, whereas the effect on a larger grove would be relatively lower. Among the 58 groves, 41 (71%) were under 2 hectares (ha), covering only 23% (28 ha) of the total area, while 17 groves (29%) were between 2 and 20 ha accounted for 77% (92 ha).

Table 1. List of sacred groves studied and their areas in hectares (ha).

Sacred Grove name	Area (ha)	Sacred Grove name	Area (ha)
Athiyanallur 1	0.048	Puranakuppam	0.780
Nathamedu	0.110	Pannakuppam	0.790
Manapattu	0.180	Kasipalayam	0.810
Sedarapattu	0.190	Silukaripalayam	0.860
Puthupallayam	0.200	Mugaiyur	1.260
Gannachavadi	0.210	Periyamudaliyarchavadi	1.260
Irumbai	0.220	Tiruchitrampalam	1.260
Karasur	0.280	Periyakumatti	1.320
Athiyanallur 2	0.290	Thondamanatham	1.600
Nagari	0.320	Thirumannikuzhi	1.660
Kadagampet	0.360	Pudur	1.710
Ramanathapuram	0.380	Melvadakuthu	1.990
Vandikuppam	0.400	Cinnakumatti 2	2.140
Vennangupattu	0.460	Kulanthaikuppam	2.700
Thalaikanikuppam	0.490	Alamarathukuppam	2.750
Kumalam	0.500	Kodivinayagar	3.120
Vellazhakuppam	0.500	Velleripattu	3.120
Arasadikuppam	0.530	Suriyanpet	3.360
Kottakarai	0.530	Sendirakillai	3.500
Mangalam	0.570	Ramapuram	3.790
T. Murthikuppam	0.630	Konjikuppam	3.990
T. Puthupallayam	0.630	Muthanai	4.500
Cinnakumatti 1	0.650	Krishnavaram	4.560
Kunnathamankovil	0.650	Paalvathunnam	4.930
Kizhpettai	0.670	Urani	5.130
Odiyampet	0.670	Ommiper	5.600
Varakkalpattu	0.700	S Pudur	8.810
Akasampet	0.720	Puthupet	10.200
Kumaramangalam	0.770	Kothattai	19.000

Table 2. Sacred grove sizes in groups

Sacred Grove Size	Number
Up to 0.5 hectare	17
Between 0.5 to 1.0 hectare	16
Between 1 to 2 hectares	8
Between 2 to 4 hectares	9
Between 4 to 6 hectares	5
Between 6 to 10 hectares	1
Between 10 to 20 hectares	2

**Figure 3.** Sacred grove size group as a percentage of total grove area of 120 ha

This size distribution has a dual ecological impact. Small, dispersed groves, though more vulnerable, can serve as biodiversity banks and aid species regeneration if properly protected. However, the eight largest groves cover 64 ha (53% of the total), meaning significant degradation in these groves would drastically reduce overall coverage. This is evident in the Puthupet sacred grove, which lost 9% of its canopy (0.79 ha) over 20 years - a loss exceeding the size of more than half the groves studied.

Sacred grove canopy analysis

The next step was to determine the actual canopy cover of each sacred grove by subtracting open spaces, temple infrastructure, water bodies, and other non-vegetated areas from the total grove area. This analysis combined GIS data from site visits with historical and current Google Earth imagery.

For each grove, the oldest high-quality image was selected, and a polygon outlining the vegetation canopy was superimposed to calculate its size in hectares. The process was repeated for a recent high-quality image. Once all images were analyzed, canopy data was compiled into a table (Table 3), detailing grove size, historical and current canopy cover, and percentage change, while figure 4 illustrates the percentage of groves with canopy loss, no change, or gain.

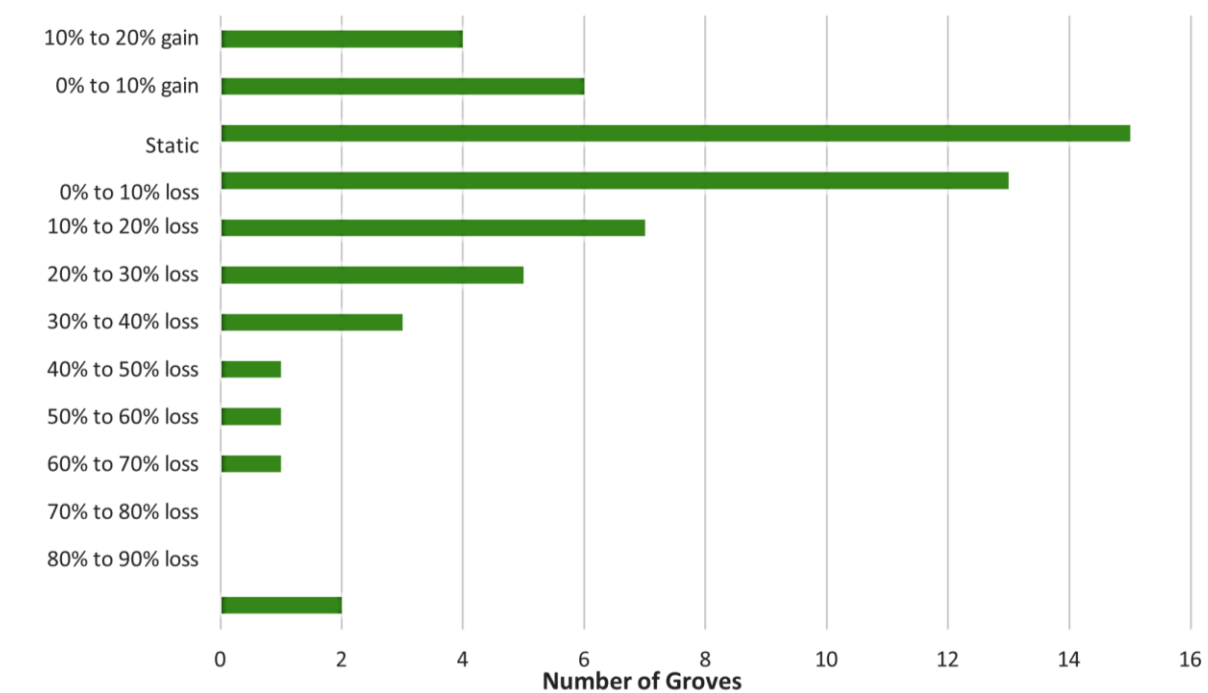


Figure 4. Sacred Groves canopy status

To quantify these changes in hectares, a summary table (Table 4) was created. The analysis showed that although the 58 groves cover 120 hectares, only 78 ha (65%) currently have vegetative cover. Historical data from 2002–2012 recorded 82 hectares (68%), indicating a 4 ha, or 5%, canopy loss.

Further analysis revealed that 58% of groves lost canopy, 24% remained unchanged, and 17% saw an increase. No correlation was found between grove size and canopy change, suggesting a random pattern of loss and gain.

Table 3. Grove sizes compared to canopy cover

Name of Grove	Total area of grove (ha)	Historical canopy area (ha)	Month and year of Historical data	Present canopy area (ha)	Month and year of present data	Loss or gain of canopy (%)
Athiyanallur 1	0.048	0.046	Oct. 2010	0.029	Apr. 2021	-37
Nathamedu	0.110	0.050	Oct. 2006	0.040	Feb. 2022	-20
Manapattu	0.180	0.170	Oct. 2006	0.170	Feb. 2022	0
Sedarapattu	0.190	0.190	Mar. 2010	0.190	Sep. 2021	0
Puthupallayam	0.200	0.190	Jun. 2006	0.190	Sep. 2021	0
Gannachavadi	0.210	0.190	Mar. 2011	0.100	Sep. 2021	-47
Irumbai	0.220	0	Jan. 2001	0	Feb. 2022	-100
Karasur	0.280	0.280	Mar. 2010	0.260	Sep. 2021	-7
Athiyanallur 2	0.290	0.270	Mar. 2011	0.270	Apr. 2021	0
Nagari	0.320	0.310	Mar. 2010	0.280	Sep. 2021	-10
Kadagampet	0.360	0.360	Jun. 2011	0.360	Sep. 2021	0
Ramanathapuram	0.380	0.310	Feb. 2010	0.360	Feb. 2022	16
Vandikuppam	0.400	0.360	Aug. 2006	0.360	Sep. 2021	0
Vennangupattu	0.460	0.310	Oct. 2010	0.340	Sep. 2021	10
Thalaikanikuppam	0.490	0.320	May 2012	0.300	Sep. 2021	-6
Kumalam	0.500	0.490	Mar. 2010	0.420	Sep. 2021	-14
Vellazhakuppam	0.500	0.270	May 2011	0.200	Feb. 2022	-26
Arasadikuppam	0.530	0.470	Mar. 2010	0.370	Sep. 2021	-21
Kottakarai	0.530	0.380	Jan. 2011	0.410	Sep. 2021	8
Mangalam	0.570	0.550	Sep. 2005	0.210	Sep. 2021	-62
T Murthikuppam	0.630	0.560	Jun. 2010	0.540	Sep. 2021	-4
T Puthupallayam	0.630	0.560	Jul. 2010	0.540	Sep. 2021	-4
Cinnakumatti 1	0.650	0.380	Oct. 2010	0.380	Apr. 2021	0
Kunnathamankovil	0.650	0.460	Sep. 2012	0.450	Feb. 2022	-2
Kizhpettai	0.670	0.510	Jan. 2005	0.410	Jan. 2022	-20
Odiyampet	0.670	0.560	Jul. 2011	0.560	Feb. 2022	0
Varakkalpattu	0.700	0.570	May 2011	0.490	Sep. 2021	14
Akasampet	0.720	0.390	Mar. 2010	0.460	Feb. 2022	18

Kumaramangalam	0.770	0.770	Jun. 2010	0.770	Feb. 2022	0
Puranakuppam	0.780	0.780	Mar. 2010	0.780	Sep. 2021	0
Pannakuppam	0.790	0.600	Jan. 2005	0.570	Feb. 2022	-5
Kasipalayam	0.810	0.350	Mar. 2012	0.290	Feb. 2022	-17
Silukaripalayam	0.860	0		0		-100
Mugaiyur	1.260	0.740	Mar. 2009	0.490	Feb. 2022	-34
Periyamudaliyarchavadi	1.260	0.920	Jan. 2005	0.420	Sep. 2021	-54
Tiruchitrampalam	1.260	0.680	Nov. 2012	0.420	Feb. 2022	-38
Periyakumatti	1.320	1.120	Mar. 2011	0.980	Feb. 2022	-13
Thondamanatham	1.600	1.100	Mar. 2011	1.180	Mar. 022	7
Thirumannikuzhi	1.660	1.620	Jun. 2010	1.630	Sep. 2021	1
Pudur	1.710	1.670	Mar. 2011	1.630	Sep. 2021	-2
Melvadakuthu	1.990	1.570	Mar. 2011	1.590	Feb. 2022	1
Cinnakumatti 2	2.140	2.000	Oct. 2010	2.000	May. 2021	0
Kulanthaikuppam	2.700	2.600	Jul. 2010	2.500	Apr. 2021	-4
Alamarathukuppam	2.750	1.820	Mar. 2010	1.720	Feb. 2022	-5
Kodivinayagar	3.120	2.610	Apr. 2002	2.510	Mar. 2021	-4
Velleripattu	3.120	1.850	Sep. 2012	1.880	Sep. 2021	2
Suriyanpet	3.360	3.330	Mar-11	3.310	Sep. 2021	-1
Sendirakillai	3.500	3.470	Oct. 2010	3.470	Jul. 2020	0
Ramapuram	3.790	2.230	Mar. 2011	2.580	Feb. 2022	16
Konjikuppam	3.990	2.620	Mar. 2011	2.260	Mar. 2011	-14
Muthanai	4.500	3.830	Mar. 2011	3.840	Apr. 2021	0
Krishnavaram	4.560	2.930	Jun. 2010	2.290	Feb. 2022	-22
Paalvathunnam	4.930	2.370	Oct. 2010	2.100	Apr. 2021	-11
Urani	5.130	4.160	Oct. 2010	3.980	Jan. 2022	-4
Ommiper	5.600	2.530	Mar. 2005	2.910	Sep. 2021	15
S Pudur	8.810	5.800	Mar. 2011	5.780	Mar. 2022	0
Puthupet	10.200	8.980	Jan. 2002	8.190	Jan. 2022	-9
Kothattai	19.000	6.900	Mar. 2011	6.900	Apr. 2022	0

Table 4. Quantification of changes in the canopy status

Canopy status	Number of groves	Area (ha)	Percentage of full canopy
Loss	33	5.92	7.60%
Static	15	0	0%
Gain	10	1.05	1.40%

Sacred grove ecological qualitative data analysis

With an understanding of each grove's size, canopy cover, and changes over time, the next step was to assess qualitative ecological factors, including canopy area and understory conditions across the 58 groves.

None of the groves qualify as forests due to their religious and cultural functions. However, some contain patches of remnant vegetation from the original Tropical Dry Evergreen Forest (TDEF). Site visits revealed that while certain groves retain remnant forest patches, much of their vegetation has been disturbed. During site visits, the canopy structure and understory quality were examined as indicators of ecological status. Key questions included: Does the grove contain remnant TDEF forest? A stand of TDEF trees? Or is it degraded?

To analyze this qualitative data, standardized categories were established. While categorization has limitations in defining abstract ecological elements, input from multiple team members improved accuracy.

The following categories were decided upon, and were applied to all of the groves:

- A. TDEF canopy with understory – Mainly TDEF evergreen canopy trees with lianas and an intact understory.
- B. TDEF canopy with partial understory – Mainly TDEF evergreen canopy trees with some lianas and a partially disturbed or cleared understory.
- C. TDEF canopy with no understory – Mainly TDEF evergreen canopy trees with a highly disturbed or cleared understory.
- D. Mixed canopy with understory – TDEF trees mixed with common/opportunistic species (e.g., Neem, Banyan, Country Mango, Tamarind) with an understory.
- E. Mixed canopy with partial understory – TDEF trees mixed with common/opportunistic species with a disturbed or partially cleared understory.

- F. Mixed canopy with no understory – TDEF trees mixed with common/opportunistic species with a highly disturbed or cleared understory.
- G. Low disturbed canopy with understory – Low vegetation, sometimes with Palmyra clumps and thorny/non-thorny climbers, with an undisturbed understory.
- H. Low disturbed canopy with partial understory – Low vegetation, sometimes with Palmyra clumps and thorny/non-thorny climbers, with a partially disturbed or cleared understory.
- I. Low disturbed canopy with no understory – Low vegetation, sometimes with Palmyra clumps and thorny/non-thorny climbers, with a heavily disturbed or cleared understory.
- J. No canopy/Fruit tree canopy – Canopy removed or grove developed as a fruit tree orchard, making it irrelevant for this study.
- K. Info unavailable – Newly found grove where border and canopy analysis are complete, but a detailed vegetation study is pending.

The next step, based on field visit notes, was to classify the 58 groves into the above predefined categories for analysis. This process was challenging, for instance, the Banyan tree was present in nearly all groves. If it grew undisturbed within the evergreen TDEF and emergent species, it was classified under the TDEF canopy category. If managed as a stand-alone sacred tree, it fell under the mixed canopy category. While this approach may raise concerns about accuracy, its primary goal was to indicate ecological status, making it a valid method for this study.

Another challenge was that some groves exhibited multiple ecological states, fitting into several categories. In such cases, the most dominant category was chosen, with mixed characteristics considered in the final analysis. To summarize the qualitative data, Table 5 presents the number of groves, their total area, and their percentage of the total.

Table 5. Number of groves, area and percentage of total area for each category.

Ecological category	No. of Groves	Area (ha)	% of Total Grove area
TDEF canopy with understory	8	20.1	17.0
TDEF canopy with partial understory	8	31.7	27.0
TDEF canopy with no understory	4	4.5	4.0
Mixed canopy with understory	1	0.6	0.5
Mixed canopy with partial understory	15	37.2	31.0
Mixed canopy with no understory	7	3.6	3.0
Low disturbed canopy with understory	2	0.9	0.8
Low disturbed canopy with partial understory	6	14.0	12.0
Low disturbed canopy with no understory	1	2.8	2.3
No canopy/Fruit tree canopy	4	1.8	1.5
No Information presently available	2	2.2	1.8

As these 58 groves potentially hold the last remnants of TDEF within this sector of the projected TDEF zone and house various species in a natural environment, it was necessary to assess how well they represented TDEF ecology. Although categorization is subject to some human error in assessment, the observations were based on extensive field visits conducted by the team. The analysis revealed the following key findings:

Only eight groves had vegetation resembling a TDEF canopy with an understory, suggesting a remnant forest. These groves covered 20 ha, or 17% of the total 120ha. An example being the Pudur sacred grove, with its intact TDEF canopy, undisturbed understory, and interconnecting lianas, and had present rare large specimens of *Diospyros ebenum* (Indian ebony).

A TDEF canopy with a partial understory covers 32ha. Some groves in this category showed signs of remnant TDEF forest but also exhibit understory disturbance. For example, the 10.2 ha Puthupet sacred grove, one of the largest and best-known remnants, faces issues like understory lopping for firewood, clearing for ceremonies, and plastic and glass waste hindering regeneration. Despite these disturbances, it retains significant areas indicative of remnant TDEF, justifying its classification under TDEF canopy with a partial understory.

At the other size extreme, Manapattu, one of the smallest groves at just 0.18 ha, remains undisturbed. Though species diversity is limited due to its size, its intact state

led to its classification as TDEF canopy with an understory. Some groves classified as mixed canopy with an understory or partial understory also contain areas suggestive of remnant TDEF, depending on their size and condition.

Given these complexities, applying this qualitative data with absolute precision is challenging, making the assessment an indicative rather than a definitive classification.

- Within the last 20 years, four scared groves, representing 1.76 ha no longer have any TDEF vegetation.
- In 16 groves there could be found areas with a TDEF canopy along with an understory, indicating a remnant, of varying degrees of coverage of the grove.
- In another 16 groves, though having the presence of non-TDEF species within the grove, also contained areas with a TDEF canopy along with an understory, indicating a remnant, of varying degrees of coverage of the grove.
- A further 11 groves contained a canopy or partial canopy of TDEF species but with no understory, and hence not the natural regeneration of species required needed for it to be representative of a remnant forest.
- A further nine groves could be categorised as highly disturbed.

Sacred grove species diversity and spatial distribution

Based on site visit data and biodiversity surveys by the AV botanical team in the early 2000s - where all woody, perennial species, and annual climbers were recorded - the 58 groves studied had an average of 69 species per grove, ranging from 28 to 114.

From a sample of 40 key evergreen/brevi-evergreen trees and woody shrubs, 25 were trees and 15 were shrubs. Their presence was recorded across groves.

Among the tree species, 22 of the 25 (88%) appeared in fewer than 20 groves, while only three were found in over 50%. *Lepisanthes tetraphylla* was present in nearly all groves, with mature specimens, canopy cover, and good regeneration. Of the 22 species, nine were recorded in 10–20 groves and considered vulnerable. For example, *Diospyros ebenum*, a dioecious species requiring both male and female trees for reproduction, showed limited regeneration. Some of these nine species were found in groves without an understory, further restricting regeneration. The remaining 13 species appeared in fewer than 10 groves, making them highly vulnerable. *Walsura*

trifoliata, for instance, was found in only five groves, two of which showed no regeneration.

Among the shrub species, 11 species out of the 15 species (73%) were in fewer than 20 groves. Only *Glycosmis mauritiana* was widespread, found in 49 of 58 groves. Six species, present in 13–24 groves, were less vulnerable due to short reproductive cycles aiding regeneration. However, eight species were found in fewer than five groves, indicating extreme vulnerability and biodiversity loss risk.

The dynamics of 40 main evergreen/brevi-evergreen species within each grove were calculated and tabulated. Figure 5 illustrates this for each grove. The chart showed that no grove contained more than 20 of these species. To understand the ecological dynamics of groves with the highest species count, the top seven groves (containing 16–20 species) are shown in figure 6. Canopy size did not influence species concentration, as grove sizes ranged from 0.45 to 8.19 ha.

Of the seven groves, three were categorized as A- areas with mainly TDEF evergreen canopy trees, lianas, and an understory. One was categorized as B-areas with mainly TDEF evergreen canopy trees, some lianas, and a partially disturbed or cleared understory. One was categorized as D-areas with TDEF trees mixed with common/opportune species (e.g., Neem, Banyan, country mango, tamarind) and an understory.

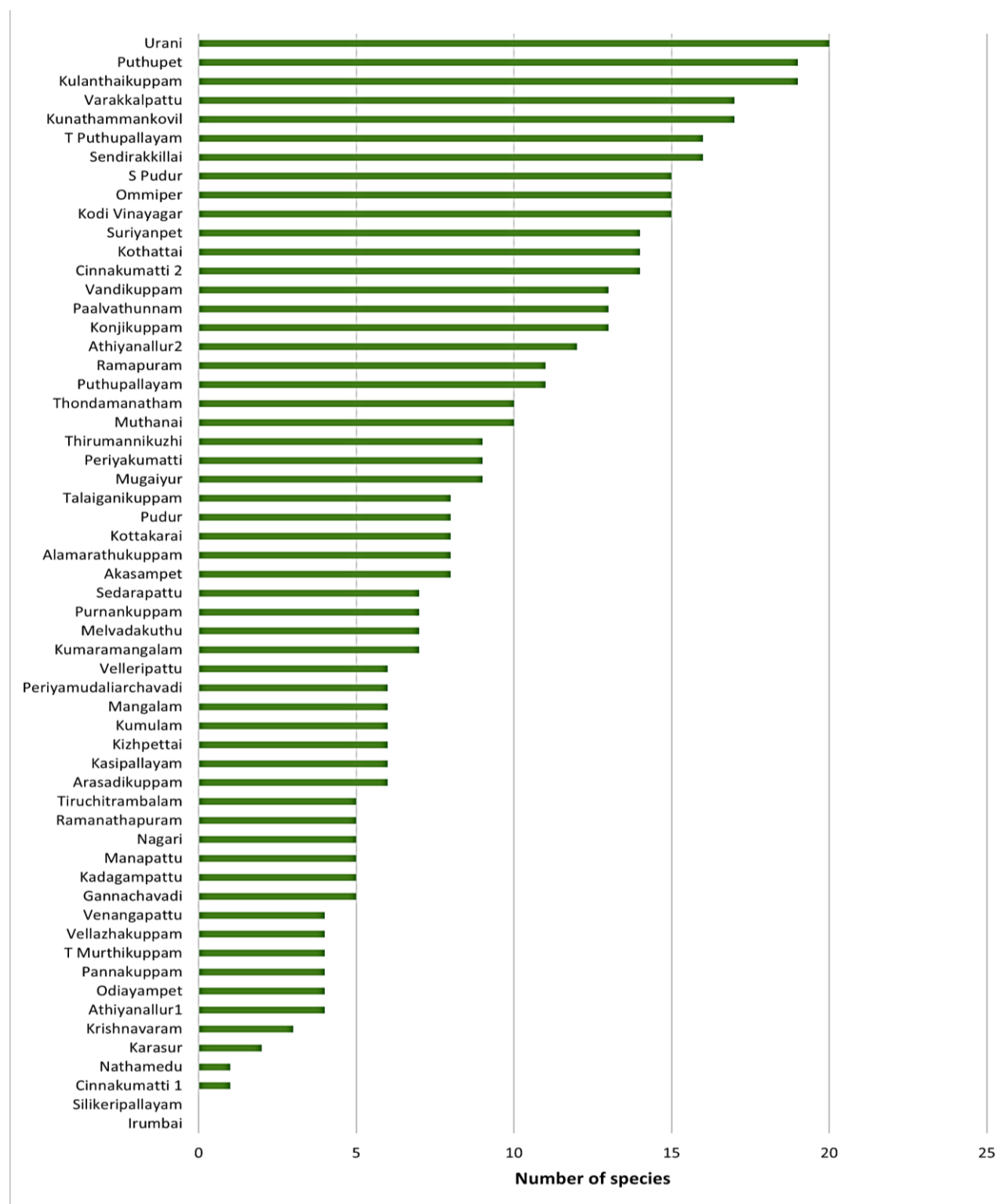


Figure 5. Number of the 40 species present per sacred grove

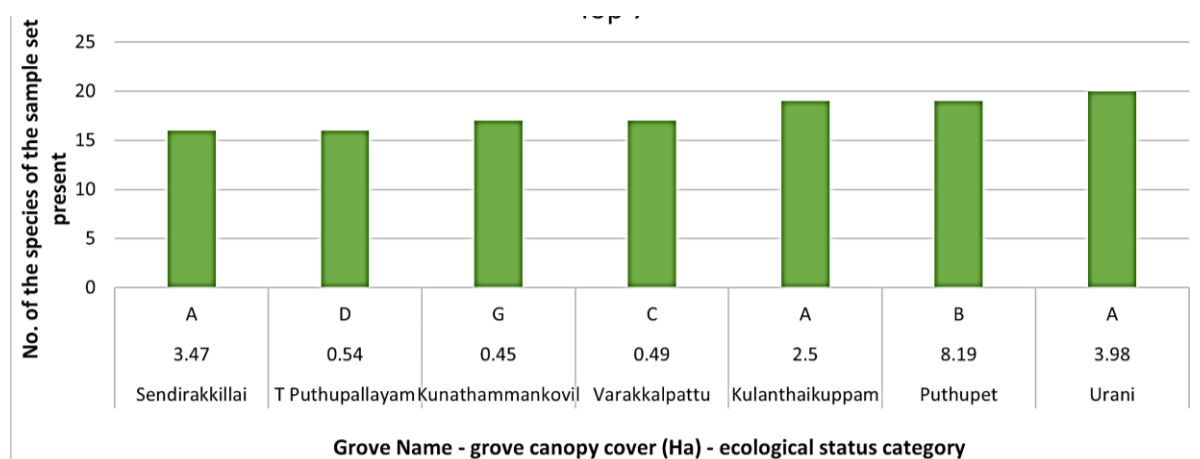


Figure 6. Details of the groves containing the most evergreen trees and shrubs - Top 7

Two anomalies were found among the top seven groves: Kunathamankovil (Category G) and Varakkalpattu (Category C). Kunathamankovil, now graded G - Low disturbed canopy with understory, was once nearly cleared in the early 2000s except for a few large *Madhuca longifolia*. Now the grove is regenerating from the remaining understory. The diversity of regrowth suggests it was once a healthy grove, making it valuable for monitoring how long re-establishment takes after significant disturbance. Varakkalpattu, now graded C - TDEF canopy with no understory, has been impacted by road development and temple expansion, now consists of diverse large specimen trees with no understory. However, some evergreen woody shrubs persist on the periphery, indicating biodiversity is not entirely lost. These cases highlight the importance of site visits for a deeper understanding of the analysed data.

DISCUSSION

The study highlighted the ecological and cultural significance of sacred groves while revealing a concerning decline in their vegetative cover. Canopy loss, recorded in 58% of groves, threatens biodiversity and disrupts ecosystem functions. The presence of rare and vulnerable species in only a few groves underscores the urgent need for conservation. Key drivers of degradation include temple expansion, understory clearing, and waste accumulation. The weakening of traditional conservation values has exacerbated these threats. Despite this, sacred groves still serve as biodiversity reservoirs, offering a chance for ecological restoration.

Effective conservation strategies should include community involvement, stronger legal protections, reforestation efforts, awareness campaigns, and sustainable waste management practices. Future research should focus on long-term ecological monitoring and integrating traditional knowledge into conservation plans. Protecting sacred groves is crucial for preserving both biodiversity and cultural heritage, requiring immediate and collaborative action.

CONCLUSION

The sacred groves of this TDEF forest zone still harbour valuable plant biodiversity and remnant forest patches. However, the study clearly indicates that their ecology is under pressure and degrading. Canopy loss, understory clearing, and tree cutting reduce biodiversity, lower canopy height, and enable invasive species to spread, further threatening TDEF plants. Continuous lopping and removal of regenerating species disrupt the ecosystem's natural cycle, while many species now survive in only a few groves. Additionally, the increasing presence of plastic and glass waste exacerbates the ecological decline, putting the last remnants of the TDEF forest at risk.

The primary reason for this degradation appears to be the weakening of the traditional belief that the surrounding forest is sacred. While most groves remain religiously active, extensive temple infrastructure development and waste accumulation indicate a shift in priorities. Population growth has also led to increased pilgrim visits, further straining these ecosystems. Other contributing factors include temple expansion, land encroachment, and infrastructure projects like road and water body development.

Despite this decline, the groves still contain significant biodiversity and function as crucial gene banks. If conservation efforts are prioritized, there is still time to reverse this downward trend. Awareness campaigns and education can help restore appreciation for these groves, not only for their sacred value but also for their ecological uniqueness and fragility, emphasizing the urgent need to protect this rare ecosystem.

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3 COMPREHENSIVE ANALYSIS OF ROAD KILLS IN TAMIL NADU HIGHWAY NETWORK: IDENTIFYING HOTSPOTS AND SUGGESTING MITIGATION MEASURES

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ABSTRACT

The expansion of road networks profoundly influences the environment and biodiversity. Roads often led to animal-vehicle collisions and act as a barrier to animal movement, thus increasing animal mortality. This study analysed roadkill hotspots within Tamil Nadu's extensive road network, spanning 1,99,040 km. The research aimed to identify spatial and temporal trends, compile species-specific roadkill data, identify vulnerable areas, and suggest appropriate mitigation strategies.

Tamil Nadu is a biodiversity hotspot with 26,451 sq. km of forest cover. Roadkill data were collected between 2018 and 2023 from 45 forest divisions through questionnaire surveys, online sources (e.g., iNaturalist, Indian Biodiversity Portal, etc.) and incidental sampling was used during road surveys. Hotspots were identified using QGIS, and road characteristics were evaluated at each hotspot. The collected data were evaluated using spatial, temporal and division-wise hotspots.

The study documented 1,552 roadkill incidents involving 68 species across mammals (69%), birds (27%) and reptiles (4%). Spotted deer (47%) and Peafowl (27%) were the most frequently encountered species, followed by Bonnet macaque (5%) and Wild pig (5%). Spatially, the Tiruchirappalli Forest Division had the highest incidents, with agricultural land being the primary hotspot. Temporal analysis revealed that the roadkill incident increased annually, peaking in 2022. Dry seasons witnessed higher mammal roadkill, while avian and reptile collisions peaked in wet season. In hotspot analysis, National and State highways were the most involved in animal road accidents. Tiruchirappalli, Perambalur, Villupuram, Tirunelveli and Dindugal forest divisions are the most roadkill hotspots.

Notable observations included the prevalence of collision hotspots in protected areas, blind curves along roads, the presence of roads between crop fields and reserved forests, poor visibility, and the absence of signage and caution boards, which emerged as significant issues contributing to these collisions. Given each region's unique characteristics, a multifaceted approach to mitigating wildlife-vehicle collisions is imperative. Continuous monitoring and adaptive strategies are vital for the long-term effectiveness of conservation efforts and for reducing wildlife mortality on roads.

Keywords: Animal-vehicle collision, conservation strategies, wildlife mortality, protected areas, road network.

INTRODUCTION

Roadkill occurrences often exceed natural mortality rates and possess the capacity to impact all members of a population uniformly, in contrast to predation dynamics (Periquet *et al.*, 2018; Prakash & Karthik, 2021). Roads are widely recognized as significant sources of disturbance to wildlife (Plante *et al.*, 2019), extending into remote wildlife habitats where they can create enduring obstacles to animal movements (Dean *et al.*, 2019). However, roads undeniably play a crucial role in commuting and transportation (Aquino & Nkomo, 2021). Generally, the impacts encompass habitat fragmentation, animal distribution patterns, movement disruptions, population aberrations, biological modifications, and direct mortalities (Row *et al.*, 2007; Shepard *et al.*, 2008; Prakash & Karthik, 2021). Extensive research has been conducted globally (Forman *et al.*, 2003) regarding the influence of vehicular traffic on biodiversity and its correlation with road infrastructure. However, within India, minimal focus has been directed towards ecological studies about roads (Sunder, 2004).

India boasts the second-largest road system globally, covering an extensive 62.16 lakh km, with projections indicating substantial expansion in the years ahead (Annual Report-2020-21, Ministry of Road Transport & Highways) Tamil Nadu, one of India's states, maintains a significant road network spanning 1,99,040 km. While roads are unquestionably essential for commuting and transportation, their proliferation has posed challenges to natural landscapes, resulting in alterations and degradation (Aquino & Nkomo, 2021). The presence of highways intersecting Reserved Forests and Protected areas in India has been a notable concern (Baskaran & Boominathan, 2010).

Extensive literature suggests that road infrastructure growth adversely affects flora and fauna, disrupting ecological processes such as habitat fragmentation (Trombulak & Frissell, 2000), increasing the risk of wildlife-vehicle collisions in Protected areas (Rytwinski & Fahrig, 2012), and acting as barriers to animal movements due to the substantial width of four-lane national highways in India (Behera *et al.*, 2021). These impacts, including reduced genetic diversity, elevated risks of local extinctions, altered animal behaviour, population isolation, and modified species interactions, highlight the complex challenges posed by road development (Benítez-López *et al.*, 2010). It also creates a barrier to wildlife movement (Selvan, 2011), and wildlife is affected directly by mortality through collisions with vehicles (Oldham & Swan, 1991) and indirectly with the ecosystem (Seiler, 2001), which effects in habitat loss and fragmentation. The animals affected are mammals (Richardson *et al.*, 1997), birds (Drews, 1995), reptiles (Das *et al.*, 2007) and amphibians (Selvan, 2011; Baskaran & Boominathan, 2010).

This current research provides a thorough and detailed examination of roadkill patterns and wildlife mortality among mammals in Tamil Nadu's diverse wildlife terrain over five years, spanning from 2018 to 2023. This study seeks to elucidate the frequency, distribution, and trends of roadkill incidents, offering valuable insights into the repercussions of road infrastructure on wildlife populations in the region. The present study was undertaken with the aim to (i) Prepare a database of species often involved in road kills, (ii) Delve into identifying the spatio-temporal trends of roadkill and (iii) Map the hotspots of roadkill across the Tamil Nadu highway network and suggest mitigation measures to reduce the issue.

MATERIALS AND METHODS

Study area

The study focuses on examining the extensive and varied highway network situated within the state of Tamil Nadu (08.000° N, 76.000° E and 13.500° N, 80.500° E) (Fig. 1). Tamil Nadu stands out as a biodiversity hotspot, boasting a wide variety of flora and fauna. This lush biodiversity is encompassed within the state's expansive 26,451 square km of forest cover, which accounts for approximately 17.41% of its total area (Shameer *et al.*, 2023). The state has biosphere reserves, National Parks, Tiger Reserves, Wildlife Sanctuaries, and Ramsar sites. The Western Ghats region within Tamil Nadu is

recognized as a biodiversity hotspot, underscoring the ecological significance and worldwide importance of the state's diverse ecosystems (Mittermeier *et al.*, 2004). Furthermore, Tamil Nadu's geographical expanse comprises an intricate mosaic of urban, suburban, and rural landscapes. Its critical highway network plays a pivotal role in connecting these various regions, facilitating the movement of goods and people, and significantly contributing to the state's socioeconomic development. Over the years, there has been a consistent increase in the vehicular population (Rawal & Devadas, 2015), concurrent with the expansion of road length.

Extraction of road network

The process of extracting Tamil Nadu's road network data from OpenStreetMap (<https://www.openstreetmap.org>), categorising and extracting into distinct categories such as State Highways (SH), National Highways (NH), and Major District Roads (MDR) was done using QGIS, a software for geographic information systems. The total length of roads in Tamil Nadu amounts to 2,39,557 km, comprising 530 highways with a combined length of 21,119 km. Within this total, are 49 National highways covering 7,208 km, 481 State highways totaling 13,911 km, and 935 Major district roads spanning 11,942 km (Tamil Nadu Highways Department, 2023).

Data Collection

The roadkill data were collected across 45 forest divisions in Tamil Nadu from 2018 to 2023 through the questionnaire survey and from online portals such as iNaturalist (<https://www.inaturalist.org/>), Indian Biodiversity Portal (<https://indiabiodiversity.org/>) and Global Biodiversity Information Facility (<https://www.gbif.org/>). The collected dataset underwent meticulous spatial analysis using Quantum Geographic Information System (QGIS ver. 3.24.2), affording insights into the geographical distribution and intensity of roadkill incidents. A road survey was conducted to understand the factors contributing to roadkill, noting specific details at each hotspot. During the hotspot survey, primary data was collected using the incidental sampling method (direct survey) (Baskaran & Boominathan, 2010).

Data analysis

The collected data were entered into Microsoft Excel spreadsheets (Version 2019). The dataset encompassed 1,552 roadkill incidents documented from 2018 to 2023. The

spatio-temporal variations in roadkill incidents were analyzed using non-parametric statistical tests, such as the Mann-Whitney U test (Mann & Whitney, 1947) (MWU) (For pairwise comparisons between two variables) and the Kruskal-Wallis H test (KWH) (Kruskal & Wallis, 1952) (For comparisons involving three or more variables) were employed.

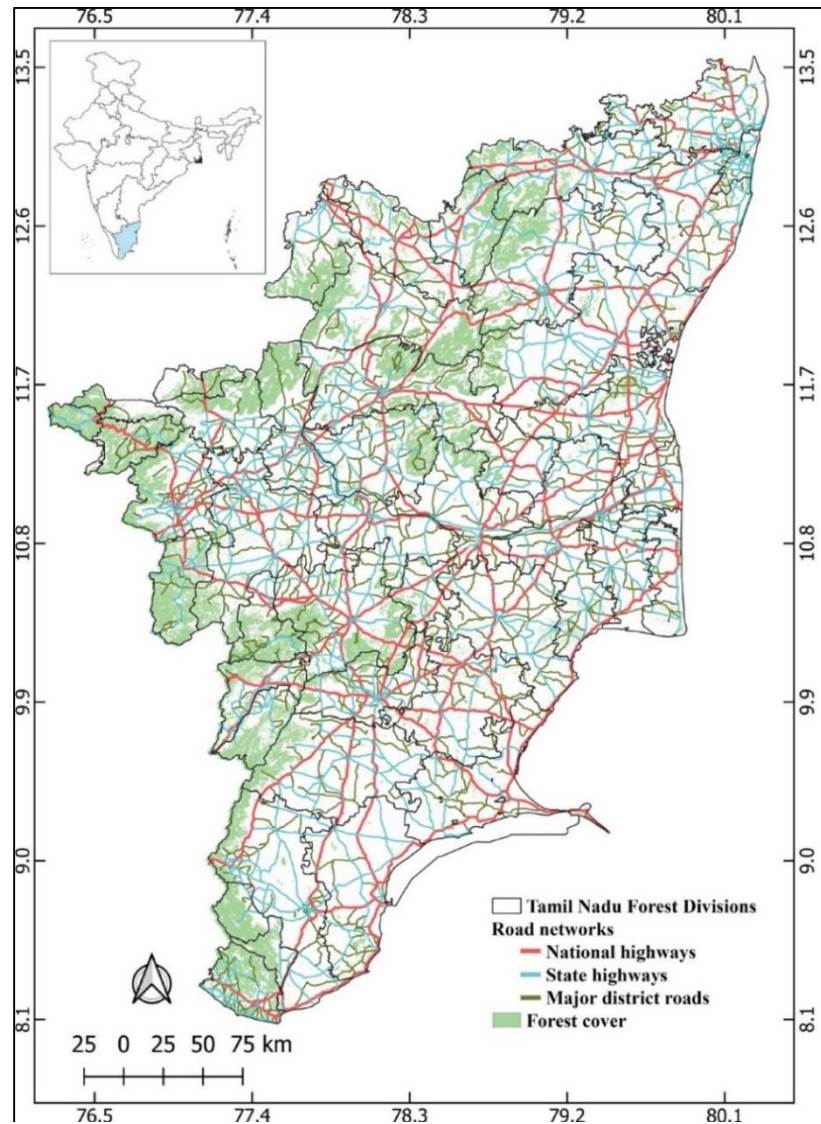


Figure 1. Map shows the primary categories of road networks and forest cover in Tamil Nadu

Spatial variation

In spatial analysis, we investigated the variation among the 45 forest divisions of roadkill incidents. KWH test was used to explore the variation in roadkill incidents across forest divisions. Additionally, roadkill geo-coordinates were processed in QGIS using the 'Join attributes by location' tool to associate each roadkill incident with the

corresponding land cover or land type. It allowed for the classification of roadkill occurrences based on the adjacent environment.

Temporal variation

To comprehensively understand temporal variation in roadkill incidents, we examined variation across multiple years and identified patterns of change over time, thereby providing insights into long-term trends in wildlife mortality along the road network. The Mann-Kendall (M-K) Trend Test (Jin *et al.*, 2021; Yue *et al.*, 2002) was employed to quantitatively assess temporal trends in wildlife mortalities along the highways of Tamil Nadu spanning the years 2018 to 2023. The partitioning of the roadkill dataset in Tamil Nadu into two distinct seasons, the dry season (from February to July) and the wet season (from August to January), is supported by various ecological and climatic factors specific to the region. The MWU test was employed to analyze the variation in roadkill incidents between the dry and the wet seasons.

Hotspot analysis of the roadkill

Furthermore, to identify roadkill hotspots within the study area, Kernel Density Estimation (KDE) was used. KDE is a widely used technique for hotspot analysis of roadkill incidents (Karanasios *et al.*, 2021; Bíl *et al.*, 2016; Grilo *et al.*, 2021; Trombulak & Frissell, 2000). The utilization of KDE in hotspot analysis enhances our understanding of the spatial dynamics of roadkill incidents, facilitating proactive measures to mitigate the impacts of roads on wildlife populations (Malo *et al.*, 2004; Dickson *et al.*, 2005).

RESULTS

Overall roadkill

Table 1 shows the database of roadkill for various species. A total of 1,552 roadkill incidents have been documented, involving 68 species categorised into three taxonomic groups: mammal (69%), avian (27%), and reptile (04%) (Fig. 2). Notably, the spotted deer and peafowl stand out as the most encountered roadkill, accounting for 731 kills (47%) and 420 kills (27%), respectively. Subsequently the Bonnet macaque and Wild pig each contributed 80 and 76 kills, respectively, representing 5% of the total incidents. Similarly, the Sambar deer and Indian bison or gaur accounted for 43 kills, comprising 2% of the total roadkill incidents. The remaining 63 species collectively represented less than one percentage of the incidents.

Table 1. Overall roadkill recorded in Tamil Nadu Highway Network from 2018 to 2023.

Sl. No	Common name	Scientific name	No. of roadkill	% of roadkill
1	Spotted deer	<i>Axis axis</i>	731	47.10
2	Peafowl	<i>Pavo cristatus</i>	420	27.06
3	Bonnet macaque	<i>Macaca radiata</i>	80	5.15
4	Wild pig	<i>Sus scrofa</i>	76	4.9
5	Sambar deer	<i>Rusa unicolor</i>	43	2.77
6	Indian bison or gaur	<i>Bos gaurus</i>	32	2.06
7	Leopard	<i>Panthera pardus</i>	15	0.97
8	Indian rock python	<i>Python molurus</i>	13	0.84
9	Asian palm civet	<i>Paradoxurus hermaphroditus</i>	11	0.71
10	Leopard cat	<i>Prionailurus bengalensis</i>	10	0.64
11	Grey slender loris	<i>Loris lydekkerianus</i>	9	0.58
12	Porcupine	<i>Hystrix indica</i>	8	0.52
13	Jungle cat	<i>Felis chaus</i>	7	0.45
14	Monitor lizard	<i>Varanus bengalensis</i>	6	0.38
15	Small Indian civet	<i>Viverricula indica</i>	5	0.32
16	Barking deer	<i>Muntiacus muntjak</i>	4	0.26
17	Common barn owl	<i>Tyto alba</i>	3	0.19
18	Common langur	<i>Semnopithecus entellus</i>	3	0.19
19	Indian gerbil	<i>Tatera indica</i>	3	0.19
20	Jungle palm squirrel	<i>Funambulus tristriatus</i>	3	0.19
21	Lion-tailed macaque	<i>Macaca silenus</i>	3	0.19
22	Nigiri keelback	<i>Sahyadriophis beddomei</i>	3	0.19
23	Olive keelback	<i>Atretium schistosum</i>	3	0.19
24	Sloth bear	<i>Melursus ursinus</i>	3	0.19
25	Southern earth snake	<i>Uropeltis nitida</i>	3	0.19
26	Streaked kukri snake	<i>Oligodon taeniolatus</i>	3	0.19
27	Travancore hills thorn-tail snake	<i>Platyplectrurus madurensis</i>	3	0.19
28	Blackbuck	<i>Antelope cervicapra</i>	2	0.13
29	Chequered keelback	<i>Fowlea piscator</i>	2	0.13
30	Golden jackal	<i>Canis aureus</i>	2	0.13
31	Green keelback	<i>Rhabdophis plumbicolor</i>	2	0.13
32	Malabar giant squirrel	<i>Ratufa indica</i>	2	0.13
33	Rusty spotted cat	<i>Prionailurus rubiginosus</i>	2	0.13
34	Striped coral snake	<i>Calliophis nigrescens</i>	2	0.13
35	Three-striped palm squirrel	<i>Funambulus palmarum</i>	2	0.13
36	Argus shield tail	<i>Uropeltis ocellata</i>	1	0.06
37	Oriental garden lizard	<i>Calotes versicolor</i>	1	0.06
38	Asian elephant	<i>Elephas maximus</i>	1	0.06
39	Black-naped hare	<i>Lepus nigricollis nigricollis</i>	1	0.06
40	Common bamboo viper	<i>Craspedocephalus gramineus</i>	1	0.06
41	Common cat snake	<i>Boiga trigonata</i>	1	0.06

42	Common Indian trinket snake	<i>Coelognathus helena</i>	1	0.06
43	Common kestrel	<i>Falco tinnunculus</i>	1	0.06
44	Common krait	<i>Bungarus caeruleus</i>	1	0.06
45	Common wolf snake	<i>Lycodon aulicus</i>	1	0.06
46	Dhole	<i>Cuon alpinus</i>	1	0.06
47	Golden tree snake	<i>Chrysopelea ornata</i>	1	0.06
48	Greater coucal	<i>Centropus sinensis</i>	1	0.06
49	Horsfield spiny lizard	<i>Salea horsfieldii</i> Gray	1	0.06
50	Indian cobra	<i>Naja naja</i>	1	0.06
51	Indian grey mongoose	<i>Herpestes edwardsii</i>	1	0.06
52	Indian orange-headed Thrush	<i>Geokichla citrina</i>	1	0.06
53	Indian pangolin	<i>Manis crassicaudata</i>	1	0.06
54	Indian saw-scaled viper	<i>Echis carinatus carinatus</i>	1	0.06
55	Indian wolf snake	<i>Lycodon aulicus</i>	1	0.06
56	Malabar pit viper	<i>Trimeresurus malabaricus</i>	1	0.06
57	Montane trinket snake	<i>Coelognathus helena</i>	1	0.06
58	Mouse deer	<i>Tragulus meminna</i>	1	0.06
59	Nigiri burrowing snake	<i>Plectrurus perroteti</i>	1	0.06
60	Nigiri langur	<i>Semnopithecus johnii</i>	1	0.06
61	Sand boa	<i>Eryx johnii</i>	1	0.06
62	Shortt's shield tail Snake	<i>Uropeltis shorttii</i>	1	0.06
63	Snake - Unidentified	Nil	1	0.06
64	Striped hyaena	<i>Hyaena hyaena</i>	1	0.06
65	Striped narrow-headed snake	<i>Xylophis perroteti</i>	1	0.06
66	Travancore cat snake	<i>Boiga dightoni</i>	1	0.06
67	Travancore wolf snake	<i>Lycodon travancoricus</i>	1	0.06
68	Vellore bridal snake	<i>Lycodon nympha</i>	1	0.06
Total			1552	100

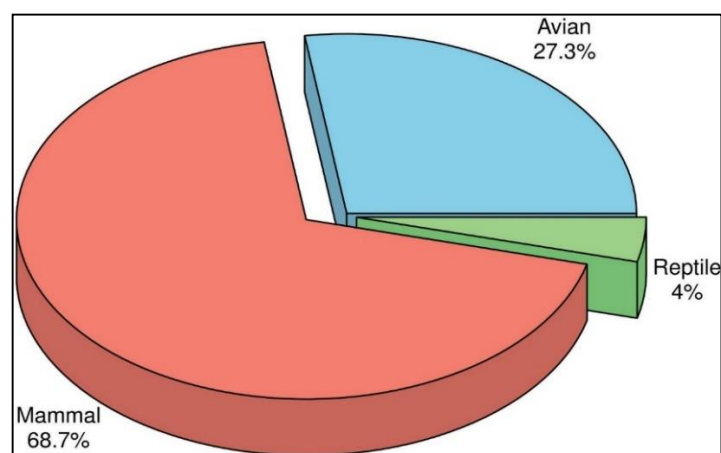


Figure 2. Percentage of roadkill in different taxonomic classes during 2018 – 2023

Number of species and roadkill across IUCN categories

Figure 3 illustrates the number of species and the percentage of roadkill recorded in each IUCN category in the Tamil Nadu Highway Network from 2018 to 2023. Around 68 species belonging to six IUCN red list categories were documented. Notably, the 'Critically Endangered' category includes only one species (Shortt's shield tail snake) with 0.1% in total kills. Similarly concerning is the "Endangered" category, comprising four species (Asian elephant, Dhole, Lion-tailed macaque, and Travancore hills thorn tail snake) collectively representing 0.5% of the total kills. The "Vulnerable" and "Near Threatened" categories included six species, respectively, making up 11% and 2% of the total species documented. On the other hand, the "Least Concern" classification encompasses the most significant number of species (n=49) with 85.7% of kills (Fig. 3).

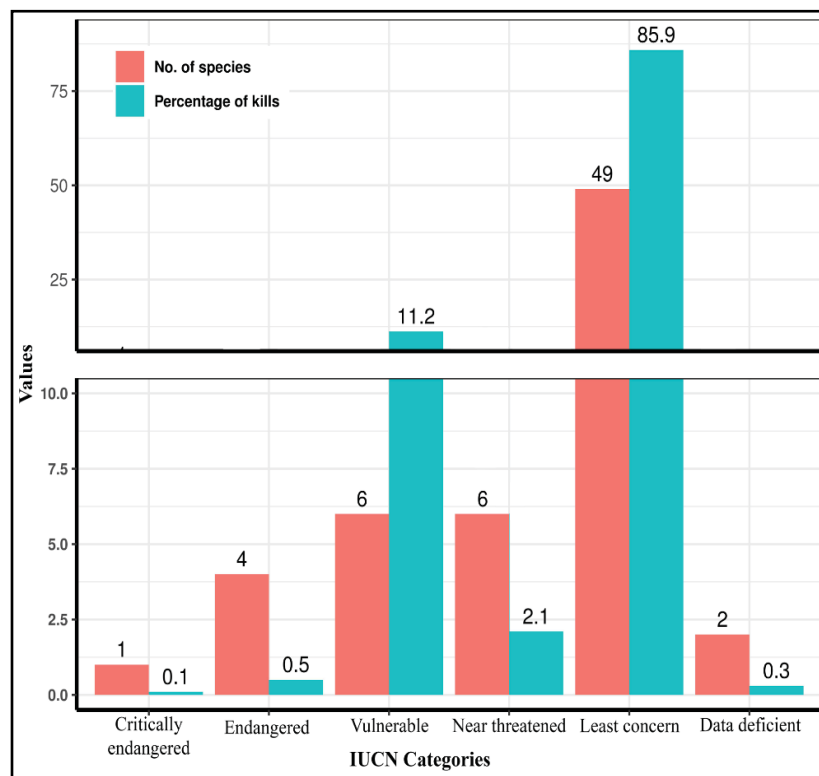


Figure 3. Number of species and percentage of roadkill recorded in each IUCN red list category in Tamil Nadu highway network from 2018 to 2023.

Spatial variation

Forest division-wise: Roadkill data has been recorded for 41 out of the total 45 forest divisions. Among these, Tiruchirappalli recorded the highest number of roadkill incidents, with 215 kills, accounting for 14% of the total kills. Following closely behind

were Perambalur with 138 kills (9%) and Villupuram with 99 kills (6%). The remaining forest divisions each had roadkill incidents of less than 5% (Fig. 4).

Roadkill across the adjoining land covers: The distribution of roadkill across different land types reflects a significant level of mortality associated with this land use. Agricultural land emerges as the primary contributor to kills with 48%. The uncultivated land (18%) follows closely behind, indicating that even areas not actively utilized for agriculture can still pose risks to wildlife. In contrast, water bodies exhibited the lowest percentage of kills (1%), suggesting a comparatively lesser impact on species kill (Fig. 5).

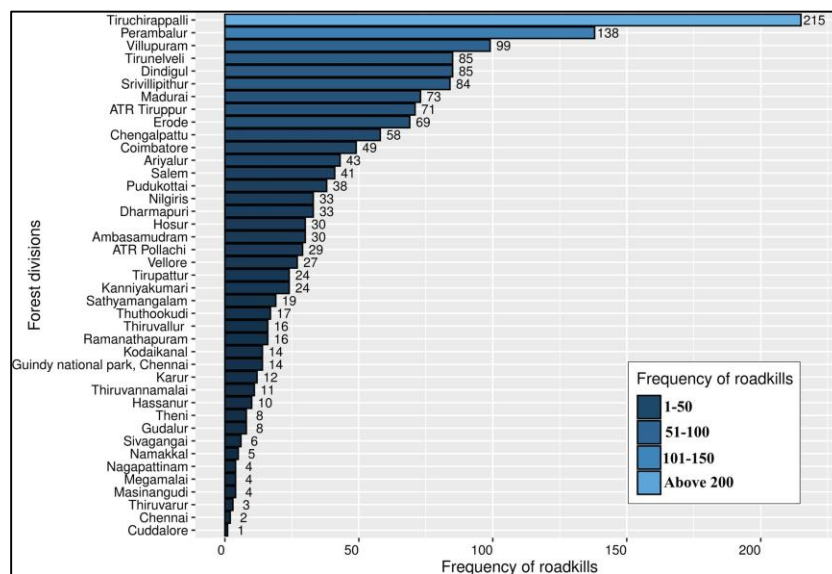


Figure 4. The distribution of roadkill occurrences categorized by forest divisions.

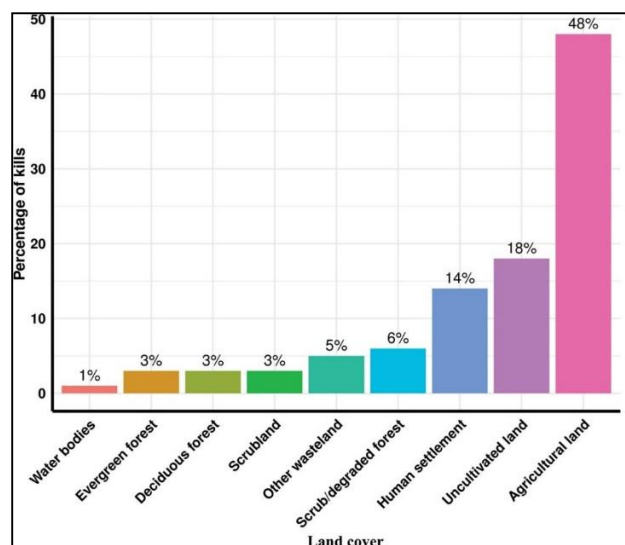


Figure 5. Illustration of the percentage of roadkill categorized by adjoining habitats

Temporal variation

Annual roadkill trend of all the species: Annual roadkill trends have increased from 2018 to 2022. The highest percentage of road kill was in 2022 (25%). In 2018, 7%, the percentage steadily climbed, reaching 17% by 2019. Despite a slight dip to 15% in 2020, the trend persisted upwards, reaching 20% in 2021 and a peak of 25% in 2022. The overall trend indicates a notable increase in roadkill incidents over the observed period (Fig. 6).

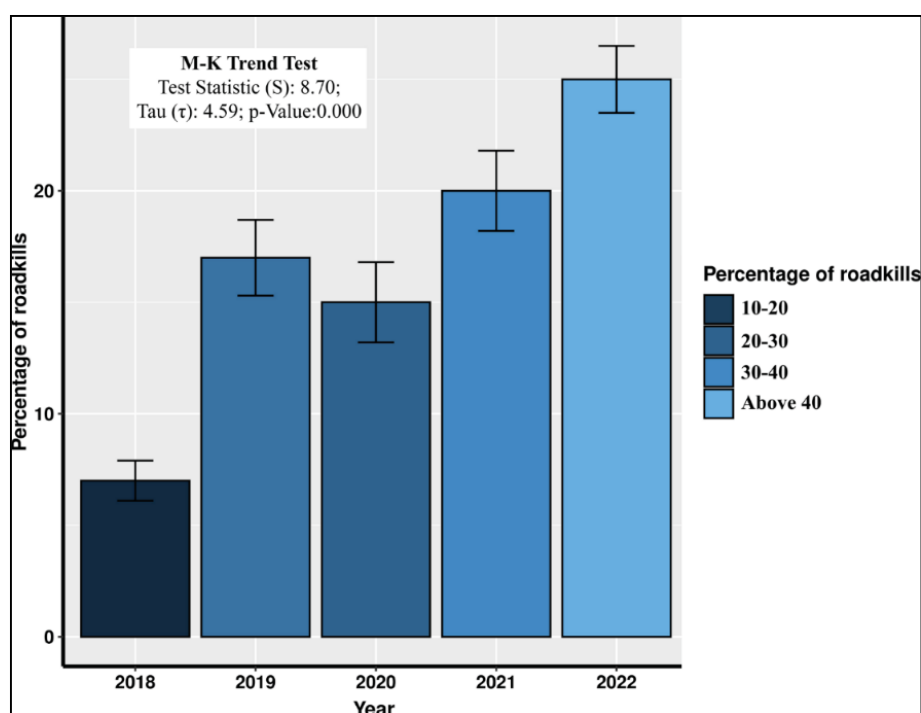


Figure 6. Roadkill percentage increase over the year (2018-2022).

Monthly variation of roadkill across the year: The heatmap visualizes the percentage of roadkill incidents recorded monthly on the Tamil Nadu highway network from 2018 to 2023. There are noticeable peaks in road-kill frequency from February to July 2021. Conversely, there are months and years with lower frequencies of roadkill incidents, represented by lighter shades on the heatmap (Fig. 7). These periods may correspond to seasons or conditions where wildlife movement is less pronounced.

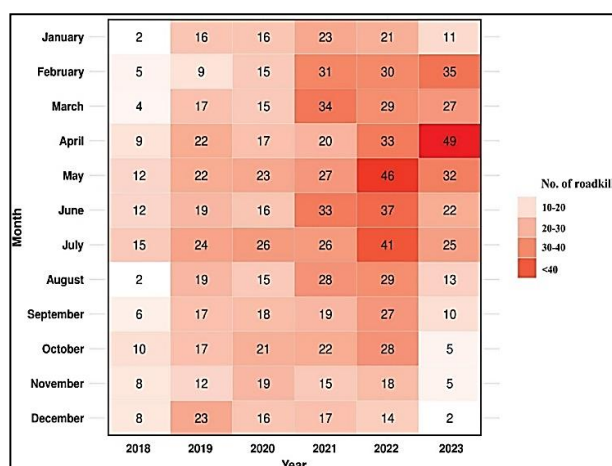


Figure 7. Number of roadkill throughout the month from 2018 to 2023.

Seasonal variation of roadkill: The seasonal fluctuations in the percentage of roadkill incidents were analyzed between the dry and wet seasons. Notably, the dry season exhibited a higher percentage of roadkill incidents (n=54) compared to the wet season (n=38), indicating a significant difference between the two seasons (Mann-Whitney U: 399.00, P value: 0.044) (Fig. 8A).

Additionally, among the three taxa studied, mammals showed significantly higher occurrences in both the dry and wet seasons, followed by avian and reptile species (KWH: 23.73; P value: 0.000). Conversely, avian and reptile roadkill incidents were more prevalent during the wet season compared to the dry season. In contrast, mammal roadkill incidents were notably higher during the dry season compared to the wet season (Fig. 8B).

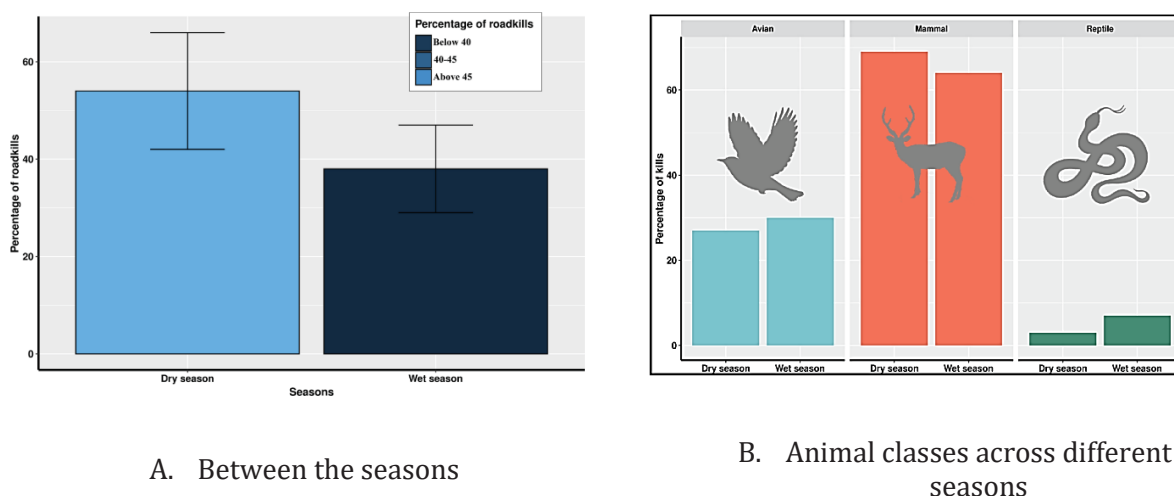


Figure 8. Percentage of roadkill (error bars are SE) in between the seasons and various animal classes across different seasons across the Tamil Nadu road highway network during 2018 – 2023.

Variations in roadkill incidents in different day sessions

Among the four-day sessions, the morning session contributes to half the total roadkill percentage, accounting for 50%. Following this, the night session constituted 21% of the roadkill incidents, while the evening and afternoon sessions exhibited more comparable percentages at 15% and 21%, respectively (Fig. 9).

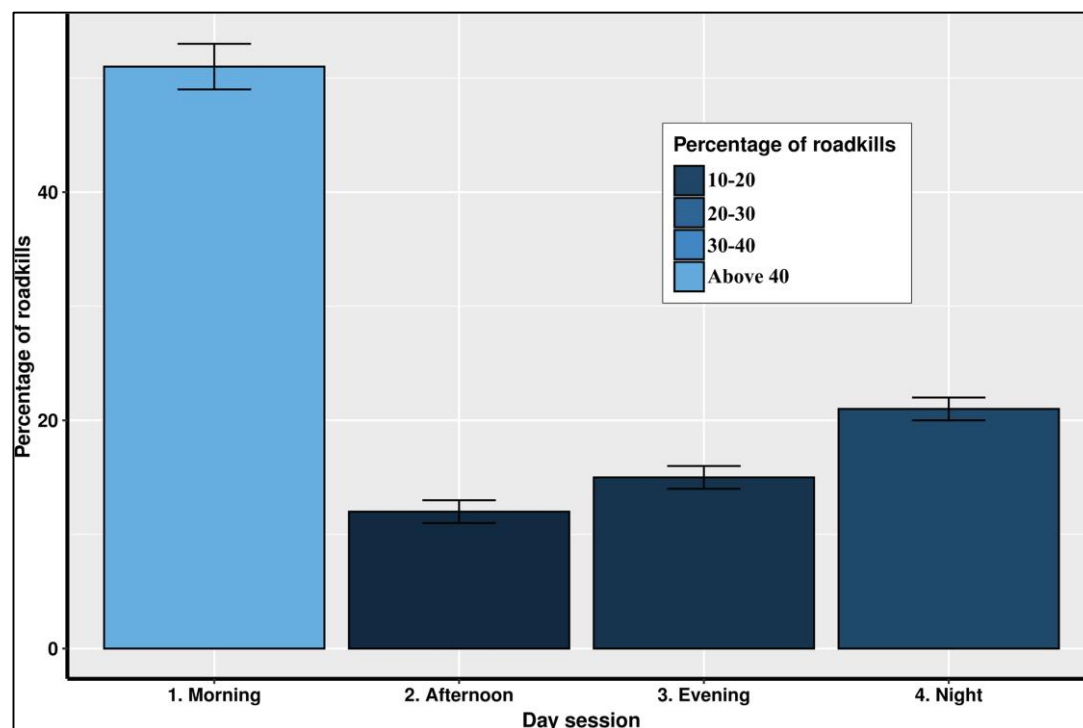


Figure 9. Percentage of roadkill of various day sessions in Tamil Nadu road highway network.

Hotspot Analysis

Overall Roadkill distribution and roadkill hotspot: The overall roadkill distribution map (Fig. 10) and roadkill hotspot analysis in Tamil Nadu forest divisions (Fig. 11) revealed spatial patterns, indicating areas with high concentrations of wildlife fatalities on roads. These hotspots often coincide with regions intersecting critical wildlife habitats and extensive road networks. This analysis informs targeted interventions like wildlife crossings or speed reduction zones to mitigate roadkill and enhance biodiversity conservation efforts.

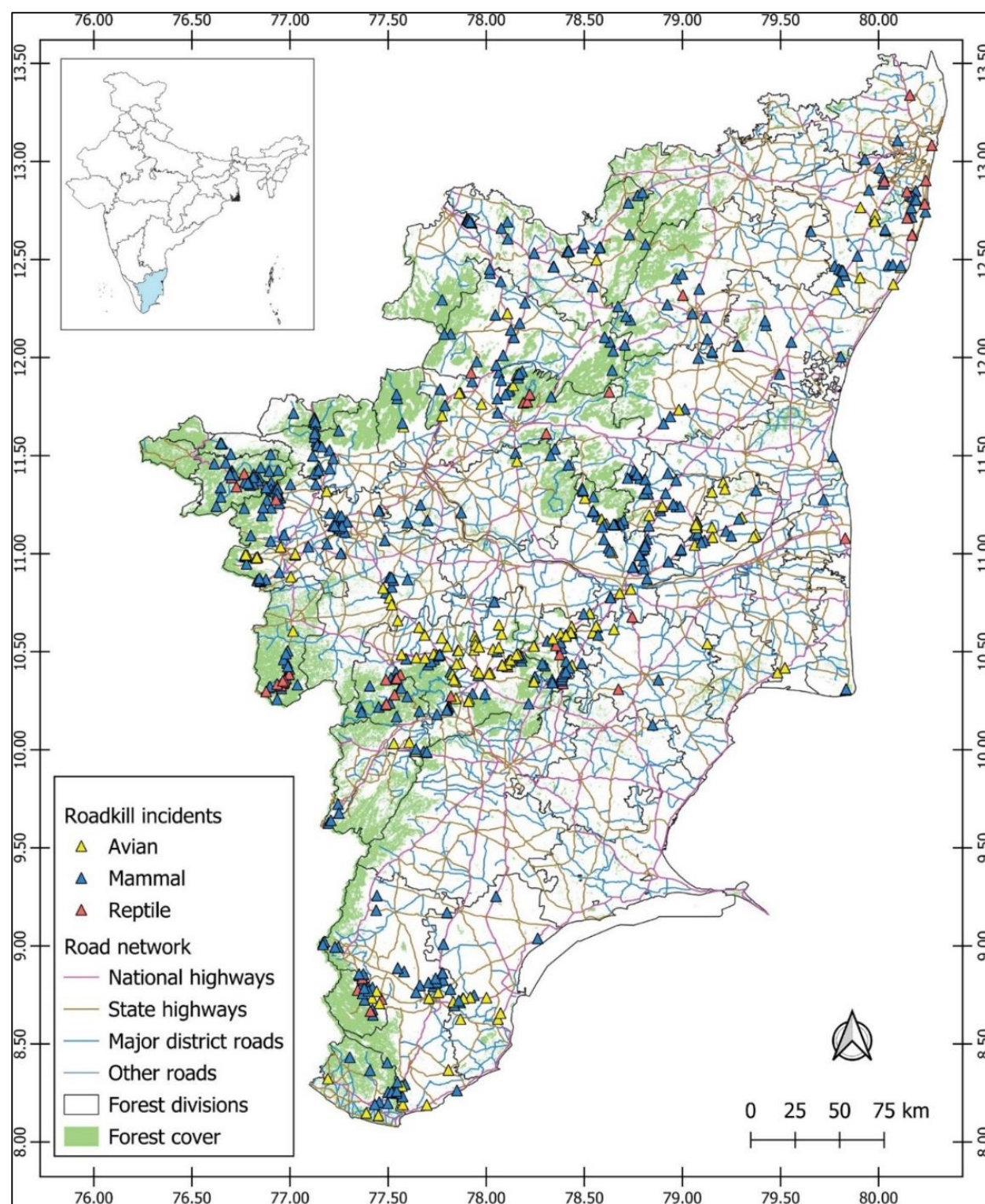
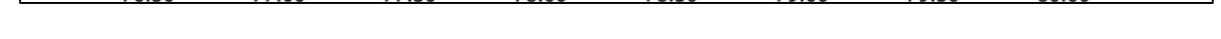


Figure 10. Map illustrating the distribution of roadkill in the Tamil Nadu road highway network.



DISCUSSION

In prior investigations into roadkill phenomena, methodologies often entailed examining singular road stretches over substantial distances, scrutinizing kills with a focus on specific taxonomic categories, such as mammals or reptiles. In contrast, our present study adopts a comprehensive approach by gathering secondary data from the forest department via structured questionnaires spanning the temporal scope of 2018 to 2023, supplemented by data aggregation from diverse online platforms such as iNaturalist and biodiversity portals. Within this timeframe, we meticulously documented a total of 1,552 roadkill incidents, encompassing 68 distinct species and 03 taxonomic classifications. Our analysis revealed a pronounced impact on taxa mammals, constituting 68.7% of the documented roadkill instances, with subsequent prominence observed in taxa avian 27.3% and reptiles 4%, respectively.

Spatial variation

The roadkill dataset covers 41 forest divisions out of 45, revealing Tiruchirappalli had the highest with 215 kills (14% of the total), followed by Perambalur at 138 (9%) and Villupuram at 99 (6%). The prevalence of roadkill was the highest in agricultural land, accounting for 48% of incidents, followed by uncultivated land at 18% and water bodies at 1%. Mammals exhibited the highest mortality rate, particularly in scrub forests, while avian species faced elevated risks near human settlements and agricultural areas. This pattern suggested a potential correlation with adjacent land use practices, where agricultural areas may offer abundant food resources without the need for extensive foraging efforts, thus increasing the likelihood of wildlife encountering roads. Reptiles were predominantly affected at road-water body intersections or in evergreen forests. It can be due to earlier studies where thermoregulation is a unique characteristic for reptiles (Das *et al.*, 2007), which leads them to come out of their habitat to roads. It underscores the diverse impacts of roads on wildlife across different ecological settings and taxa.

Temporal variation

The annual trend analysis of roadkill incidents from 2018 to 2023 revealed a consistent increase, with the highest percentage recorded in 2022. The trend exhibited a steady rise from 2018 to 2019, peaking at 25% in 2022. The analysis also identified prominent peaks in roadkill frequency observed between February and July of 2021. Furthermore, seasonal variations were examined, highlighting a significantly higher percentage of roadkill incidents during the dry season compared to the wet season. In contrast, earlier studies performed by (Prakash & Karthik, 2021) have shown high mortality in the wet season as compared with dry season and Bhupathy *et al.* (2011) have shown high mortality in the monsoon (reptiles & amphibians). Mammals consistently showed the highest occurrences in both seasons. The fluctuations in collision patterns exhibited temporal variations unique to each vertebrate class, with peak incidents aligning with optimal environmental conditions conducive to heightened activity, as documented by (Arca-Rubio *et al.*, 2023). Captivatingly, avian and reptile roadkill incidents were more prevalent during the wet season in the case of birds, the greater proximity of accidents to water masses was expected since most species depend on water points, so they should preferably be located close to them (Arca-Rubio *et al.*, 2023). While mammal roadkill incidents were notably higher during the dry season, observing the movement in search of resources, majorly for water sources during the dry season. Analysis of roadkill incidents by session revealed that the morning session contributed to more percentage (Lyamuya *et al.*, 2021), followed by the night, evening and afternoon sessions.

CONCLUSION

The analysis of roadkill data has provided valuable insights into the prevalence distribution and impact of roadkill on wildlife populations in study area. Through the same analysis of roadkill data, we have identified hotspots of wildlife mortality and gained a deeper understanding of the species most affected. This information helped develop conservation efforts and mitigate the negative effects of roads on wildlife. Over five years (2018-2023), the present study showed an annual upward trend in roadkill incidents. Primary and secondary data revealed in total 1,552 recorded kills, with the highest occurrences documented in the Tiruchirapalli forest division,

followed by Perambalur, Villupuram, Tirunelveli, and Dindigul forest divisions. Comprehensive monitoring and recording of all taxa are imperative to quantify roadkill accurately. Based on field surveys and road characteristics assessment, the present study suggests that implementing safe speed limits through speed breakers or barricades is essential in areas prone to animal crossings. Fluorescent signboards indicating animal corridors should be strategically placed for visibility and effectiveness. Planting specific plant species with less density cover on roadsides, usage of advanced techniques, limiting vehicle passage and resource management and coordination may be followed. By incorporating these findings into future planning and development processes, we can strive towards achieving a more harmonious coexistence between human activities and the natural world.

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4 SPATIAL PATTERNS OF SEA URCHIN DIVERSITY AND THEIR RELATIONSHIP TO ECOSYSTEM HEALTH IN THE GULF OF MANNAR

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ABSTRACT

The Gulf of Mannar, a marine biodiversity hotspot, is home to diverse ecosystems, including significant sea urchin populations. A survey conducted from July 2023 to October 2024 across 13 islands in the Gulf of Mannar, a marine biodiversity hotspot, identified six sea urchin species. Hare Island exhibited the highest species richness, hosting five species (*Salmacis virgulata*, *Temnopleurus toreumaticus*, *Gymnechinus* sp., *Brissopsis alta* and *Lovenia elongata*) with a total of 110 individuals, alongside diverse macroalgae and coral. This island displayed high biodiversity (Simpson's $D' = 0.6774$, Shannon-Wiener $H' = 1.2340$) and even species distribution (Evenness Index $E = 0.7667$). Notably, *Gymnechinus* sp. was recorded for the first time in the Hare Island region. The Vhaan Island showed moderate diversity with three species (*S. virgulata*, *S. bicolor*, and *T. toreumaticus*) and 36 individuals. The Kasuwari Island had the lowest diversity, with only two species (*S. virgulata* and *S. bicolor*) and nine individuals, resulting in lower diversity indices ($D' = 0.3457$, $H' = 0.5297$) and uneven distribution ($E = 0.7642$) due to the dominance of *S. virgulata*. The Sea urchin distribution correlated with specific macroalgae and coral species, emphasizing the importance of healthy benthic habitats. This study highlights the need for conservation measures, including bycatch reduction, predator monitoring, and long-term population tracking, to protect sea urchin populations and overall ecosystem health in the Gulf of Mannar.

Keywords: Sea urchin diversity, Gulf of Mannar, species richness, benthic habitat, conservation.

INTRODUCTION

Echinoids, with approximately 800 global species, play a pivotal role in marine ecosystems. India's coastline hosts 130 species, with 105 found along the east coast, including 30 in Tamil Nadu. Notably, the Gulf of Mannar, a biodiversity-rich region on India's southeast coast, harbours 24 echinoid species among its 112 recorded echinoderms (Raghunandan *et al.*, 2016; Saravanan *et al.*, 2017). The Sea urchin spatial distribution is a critical determinant of marine ecosystem health, particularly in coral reefs. Balanced populations regulate macroalgae, fostering coral growth and overall biodiversity (Ditzel *et al.*, 2022). Disruptions, such as the mass mortality of *Diadema antillarum* in the Caribbean, leading to algal dominance and coral decline (Edmunds & Carpenter, 2001), or the formation of 'urchin barrens' due to overgrazing (Davidson & Grupe, 2015), underscore the sensitivity of these systems.

Beyond their grazing role, sea urchins are vital bioindicators. Their populations reflect environmental changes, including habitat destruction, pollution, and predator depletion (Okamoto *et al.*, 2020; Mishra *et al.*, 2015). The shifts in species composition and density also reveal broader impacts from ocean warming, acidification, and nutrient alterations (Suryanti *et al.*, 2024), influencing larval recruitment and reproductive success.

Understanding sea urchin diversity's spatial patterns is crucial for marine conservation. Climate change, habitat loss, and overfishing have significantly impacted global populations, necessitating targeted conservation strategies (Ditzel *et al.*, 2022). The marine protected areas, sustainable fisheries management, and predator restoration are key tools for maintaining ecological balance. This study investigated the drivers of sea urchin distribution in the Gulf of Mannar, their role as ecosystem indicators, and their implications for conservation. By analysing spatial diversity patterns, we aimed to inform sustainable management strategies for coral reefs and other marine habitats. As anthropogenic pressures intensify, this research is essential for preserving biodiversity and ensuring the resilience of marine environments.

MATERIALS AND METHODS

This study investigated the diversity and distribution of sea urchin species through surveys conducted across 13 islands within the Gulf of Mannar (Fig. 1) between July

2023 and October 2024. For analytical purposes, the study area was divided into two distinct island groups: the Mandapam group, comprising Hare, Pullivasal, Poomarichan, Shingle, Kurusadai, and Manoli islands (6 islands); and the Tuticorin group, consisting of Vhaan, Kasuwari, Velangu Challi, and Kariya Challi islands (4 islands).

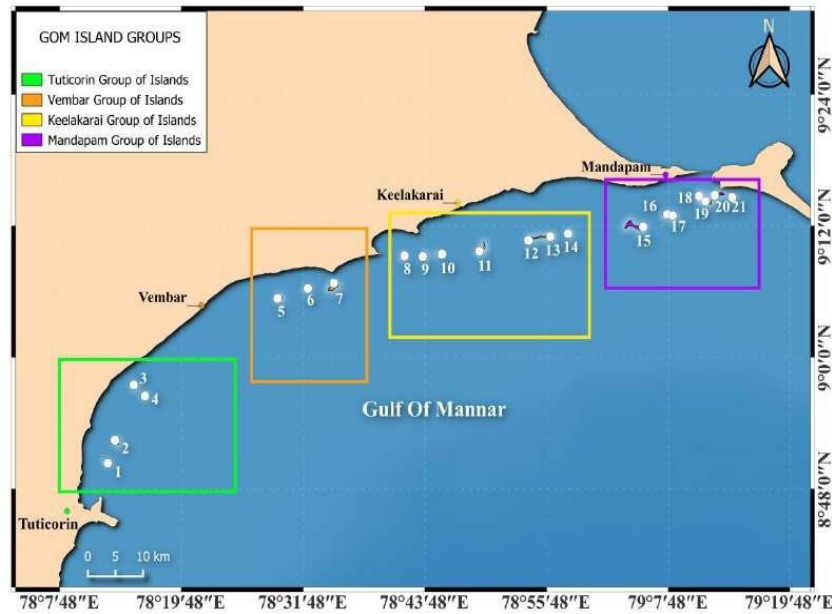


Figure 1. Gulf of Mannar island groups

Major substrate types and substrate cover

Seagrass, coral, and macroalgal cover were quantified using the Point Intercept Transect (PIT) method (Hill & Wilkinson, 2004). Along a 20-meter transect line, initiated at 0.5 meters and extending to 20 meters, benthic cover was recorded at regular intervals. Data were subsequently processed in MS Excel to determine the percentage cover of each habitat type.

$$L = Li / N \times 100\%$$

Where, L = Percentage of coverage; Li = sum of each component; N = Total components (20 m). Substrate assessment criteria was based on substrate percentage (Table 1). Data were analysed to determine the dispersion of sea urchins through Morisita Index (Id) (Morisita, 1962)

$$Id = n \sum x^2 - \sum x / (\sum x)^2 - \sum x$$

Where, Id = Morisita Index; n = number of sampling quadrats; $\sum x$ = sum of individuals in each transect ($x_1 + x_2 + \dots$)

Table 1. Substrate assessment criteria

Substrate coverage	Category
0-24	Poor
25-49	Moderate
50-74	Good
75-100	Excellent

Belt transect surveys

Belt transect surveys were conducted along the islands up to a depth of 2 m and general biodiversity was measured using skip-count method (Hill & Wilkinson, 2004). The diversity indices were also worked out in PAST software version 4.03 (Hammer *et al.*, 2001)

Catch per Unit effort

To assess sea urchin abundance, landings data from the Vedalai Landing Centre (Ramanathapuram) and the Inigo Nagar Landing Centre (Tuticorin) were analysed to calculate Catch Per Unit Effort (CPUE). The sea urchins were identified as a significant by catch in crab nets deployed near the Mandapam Islands in the Gulf of Mannar (Fig. 2a, 2b). The CPUE trends were interpreted to reflect potential environmental changes impacting sea urchin populations, serving as a tool for long-term monitoring. A declining CPUE was considered indicative of potential overexploitation, while a stable or increasing CPUE suggested sustainable harvesting practices.

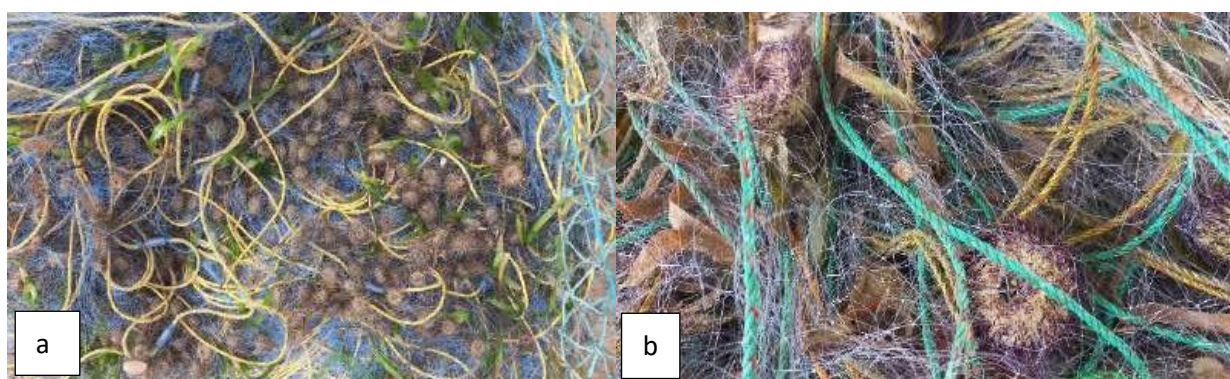


Figure 2. Seaurchin as by catch in crab nets (a) *Temnopleurus toreumaticus* (b) *Salmacis virgulata*

Gonadosomatic Index and Gastrosomatic Index

To gain a comprehensive understanding of the reproductive and feeding dynamics of sea urchins, Gonadosomatic Index (GSI) and Gastrosomatic Index (GaSI) were examined.

$$\text{GSI} = \text{Gonad weight (g)} / \text{Total body weight (g)} \times 100$$

$$\text{GaSI} = \text{Intestine weight (g)} / \text{Total body weight (g)} \times 100$$

Physico-chemical parameters

Water physico-chemical parameters, including temperature, salinity, dissolved oxygen (DO), and pH, were monitored using an El Water quality meter (Model 7200 - Waterproof IP 57) to assess environmental conditions.

RESULTS

A survey of 13 islands in the Gulf of Mannar (July 2023 - October 2024) revealed six sea urchin species, with Hare Island (Mandapam group) exhibiting the highest species richness (five species: *Salmacis virgulata*, *Temnopleurus toreumaticus*, *Gymnechinus* sp., *Brissopsis alta*, *Lovenia elongata*; 110 individuals). Hare Island demonstrated high biodiversity (Simpson's $D' = 0.6774$, Shannon-Wiener's $H' = 1.2340$) and even species distribution (Evenness $E = 0.7667$), supported by diverse macroalgae (e.g., *Caulerpa racemosa*, *Padina boergesenii*). Notably, *Gymnechinus* sp. was recorded for the first time in this region.

The Vhaan Island (Tuticorin group) showed moderate diversity (three species: *S. virgulata*, *S. bicolor*, *T. toreumaticus*; 36 individuals), while Kasuwari Island had the lowest diversity (two species: *S. virgulata*, *S. bicolor*; nine individuals). The dominance of *S. virgulata* on Kasuwari Island (77.78%) resulted in low diversity ($D' = 0.3457$, $H' = 0.5297$) and uneven distribution ($E = 0.7642$). Sea urchin distribution correlated with specific macroalgae (*Padina boergesenii*, *Halimeda* spp.) and coral species, emphasizing the importance of healthy benthic habitats. Absence of sea urchins led to barren landscapes and algal overgrowth.

Mandapam group exhibited greater species richness, higher diversity, and more balanced species distribution compared to the Tuticorin group (Morisita Index = 0.708). Mandapam showed higher seagrass and crustose coralline algae cover, and more sessile invertebrates, indicating a more structured and diverse habitat. Tuticorin showed barer substrate, indicating potential stressors.

Catch Per Unit Effort (CPUE) analysis of *T. toreumaticus* revealed peaks coinciding with Gonadosomatic Index (GSI) and Gastro-somatic Index (GaSI) peaks (May), indicating strong activity during feeding and reproduction. A CPUE decline in August aligned with GSI and GaSI decreases, suggesting post-spawning depletion. *S.*

virgulata CPUE was high when GaSI was low (March, August) and low when GaSI was high (April-May), suggesting reduced mobility during feeding and reproduction. A CPUE increase in August coincided with GaSI decline, possibly indicating post-spawning recovery.

The Mandapam group, with slightly higher temperature and lower salinity, supported higher species diversity, suggesting these parameters are key drivers. Dissolved oxygen levels did not appear to impact biodiversity.

DISCUSSION

The observed ecological shifts in the Gulf of Mannar, where the absence of sufficient sea urchin populations led to macro algal dominance and reduced reef complexity, align with findings from Edmunds and Carpenter (2001). This highlights the critical role of sea urchins in maintaining coral reef health. Salinity emerged as a key environmental factor influencing sea urchin distribution. Sea urchins, being stenohaline organisms, are intolerant to low salinities, impacting larval and juvenile survival (Drouin *et al.*, 1985). As observed by Hayati *et al.* (2019), low salinity can induce pigment changes and spine loss. The salinity range of 34-35 ppm recorded in this study, consistent with Azwir *et al.* (2019), likely supported the observed sea urchin populations.

Substrate composition also played a vital role in sea urchin distribution. The varied substrates, including sandy, rocky, and rocky-sand, provided suitable habitats. This observation corroborates studies by Maharani and Nugraha (2022), which noted sea urchins' preference for flat coral reef, rocky-sand, sandy-rock, and seagrass areas. Furthermore, the mutualistic relationship between sea urchin abundance and coral, seagrass, and algal cover, as emphasized by Nadiarti *et al.* (2021), underscores the interconnectedness of these ecosystem components. Any instability in one component can cascade through the system, affecting overall biodiversity.

CONCLUSION

In conclusion, this study demonstrated the significant influence of both biotic and abiotic factors, specifically salinity and substrate composition, on the diversity and distribution of sea urchin populations within the Gulf of Mannar. The observed ecological dynamics, including the impact of sea urchin abundance on macro algal

growth and reef health, emphasized the need for integrated conservation strategies. These strategies should focus on maintaining optimal environmental conditions and preserving habitat integrity to ensure the long-term stability and biodiversity of this vital marine ecosystem. Monitoring and management efforts should prioritize maintaining optimal salinity levels, protecting diverse substrate types, and safeguarding the intricate relationships between sea urchins and other benthic organisms.

ACKNOWLEDGEMENTS

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5 DISTRIBUTION AND HABITAT USE BY SHOLA BIRDS OF THE NILGIRIS

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ABSTRACT

Economic development and food security have led to significant land-use changes worldwide, posing challenges for conserving biodiversity and natural systems. Protected Areas offer a safe refuge for wildlife, but their coverage is often inadequate. In the Western Ghats biodiversity hotspot, habitat loss and fragmentation threaten endemic and endangered bird species. The most at risk are restricted-range species such as shola specialists of the high elevations. This study assessed bird diversity and abundance in the montane Nilgiris landscape by conducting point counts across a complex habitat matrix, emphasising the shola bird community. Fieldwork was carried out from March 2023 to June 2023.

Natural forests and urban parks showed high species richness. But when obligate commensals like crows and pigeons were excluded, bird abundance decreased significantly in settlements and parks. Urban parks appeared to play a role in providing refuge and improving connectivity for birds in the landscape. Shola birds were mostly seen in natural forests and timber plantations, with the Nilgiri laughingthrush being partial to natural forests. Our mapping exercise also showed that the potential habitat available to high-altitude shola birds beyond Mukurthi National Park in the montane Nilgiris is around 500 sq. km.

The role of different land cover types and landscape contexts in shaping avian communities in human-dominated landscapes is emphasized. Protecting natural habitats and restoring other potential habitats can benefit endangered species like the Nilgiri laughingthrush and Nilgiri sholakili. The need for sustainable land-use practices in conservation efforts to secure the future of montane shola birds in the Nilgiris is highlighted.

Keywords: Endemic birds, forest specialists, habitat use, land-use, land cover, shola

INTRODUCTION

The drive for economic development and food security has driven major changes in land-use in the world over the past few decades. Multiple studies have identified land-use and land cover change as a major challenge for preserving natural systems and ecological processes (Ojima *et al.*, 1994; Lambin & Meyfroidt, 2010). While Protected Areas (PAs) exist as safe sanctuaries for wildlife, the coverage provided by them may not be sufficient for long term survival of populations (Brooks *et al.*, 2004). Further, intensive land-use changes surrounding a sanctuary can have effects trickling into their bounds (Hansen & Rotella, 2001). The result is a persistent conflict between the strive for higher quality of human life and preservation of biodiversity (Mora & Sale, 2011). In landscapes of high conservation value, it is imperative that we identify crucial wildlife habitats within and beyond protected areas, and recognize what features make them hospitable for the organisms concerned (McPeck, 1996).

Organisms with specific habitat requirements can thus provide powerful insights into the consequences of land-use change on ecosystems. For the purpose of such understanding, birds are often the vessels through which we explore the associations of species and habitats (O'Connell *et al.*, 2000). They are better equipped to navigate complex landscapes compared to non-volant animals of similar sizes. Across the diversity of species, we also have assemblages that are specialists for a certain habitat, or are generalists. As habitat specialists tend to be particularly reliant on specific environmental conditions, they are disproportionately affected by habitat loss and land-use change. Mapping out the responses of assemblages and of species in a landscape, in the context of their functional traits, allows us to unravel the complex relationships between human activities, changed habitats, and biodiversity conservation. For endemic species confined to a small geographic area, this translates into an understanding of the entire habitat available to them, indicating their current conservation status.

The Western Ghats in India is a hotspot of endemism. A fraction of the endemic birds is also globally threatened. Species like the Nilgiri laughingthrush (*Montecincla cachinnans*) and Nilgiri sholakili (*Sholicola major*) are categorized as Endangered on the IUCN Red List (IUCN, 2024) , and studies suggest that the current estimates of population and range sizes may be an overestimate (Ramesh *et al.*, 2017). The region is

riddled with a history of colonial expansion of human habitation and plantations. The high reaches of the Nilgiri Hills were particularly targeted for the conducive weather conditions to grow tea and pine (Joshi *et al.*, 2018). As a consequence, the evergreen forests and montane grasslands of this region were converted, degraded, and fragmented. This poses a significant threat to the endemic species that have nowhere else to occupy save this human dominated sky island.

Our understanding of avifauna response to habitat change in the Nilgiris is still in its formative stages. One possible reason, is that our knowledge of the species' evolutionary history is fairly recent (Robin *et al.*, 2017). This new understanding of the evolutionarily distinct species meant that the ranges of each are even more restricted than previously thought

It becomes pertinent to ask how the distribution and habitat use of shola birds are impacted by the different land cover types and their landscape context. Further, we focus at the species level for four birds for which the Nilgiri Hills represents a significant portion of their global home ranges: Nilgirilughingthrush, Nilgiri sholakili, Nilgiri flycatcher and black and orange flycatcher.

MATERIALS AND METHODS

Study area

The study was carried out across the montane Nilgiris landscape in the state of Tamil Nadu, India (Fig. 1). The study area is a part of the Nilgiri Biosphere Reserve that covers 5520 sq.km within the Western Ghats Biodiversity Hotspot (Daniels, 1993). We worked in the upper reaches of the hills from 1600 m all the way to the highest part, Doddabetta Peak. At 2634 m, Doddabetta is the second tallest peak in all of Western Ghats.

The study area includes Mukurthi National Park and several Reserved Forests (RF) including Avalanche RF, Cairn Hill RF, Pykara RF, etc. Although there is fair variation in rainfall levels received, the area overall is wet with some parts getting over 5000 mm of annual rainfall (Singh, 2008).

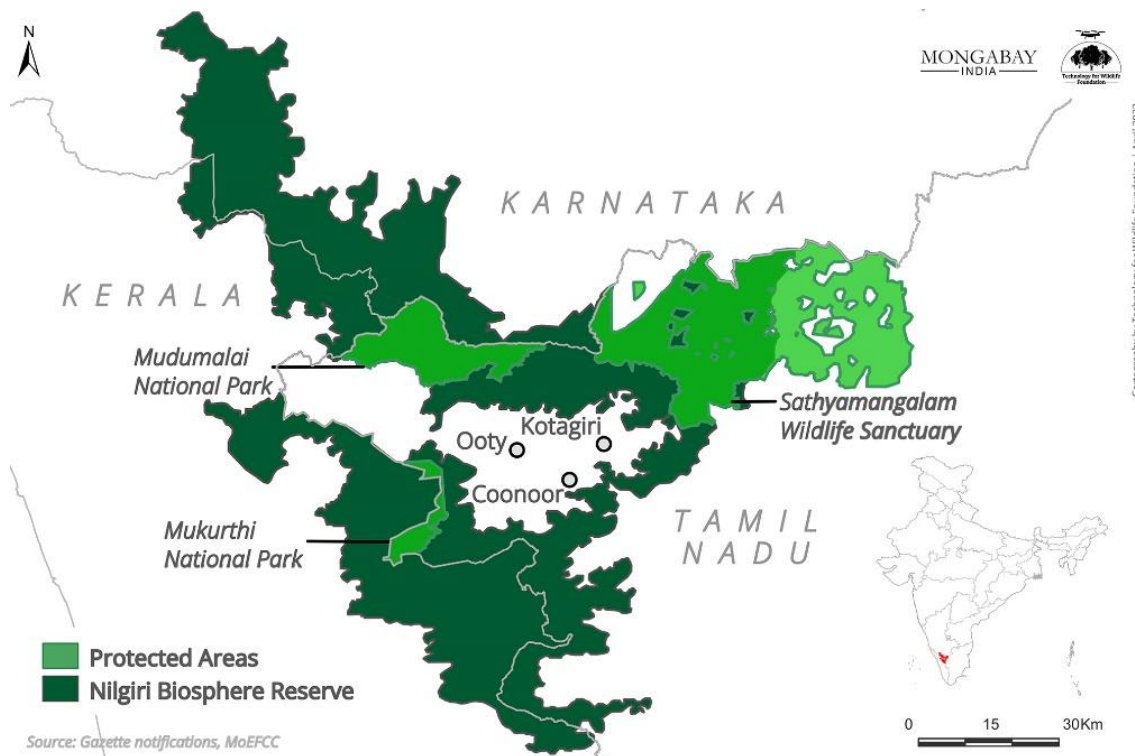


Figure 1. Map of Nilgiri Biosphere Reserve (Source: Mongabay India)

Consequently, the native vegetation is primarily montane wet evergreen forests (*sholas*) and high elevation grasslands. The Nilgiris have seen the spread of plantations since the late 1800s (Joshi *et al.*, 2018). Tea estates are a characteristic feature of the region (Fig. 2), as are *Acacia*, *Eucalyptus* and Pine plantations. Today, the natural forests are retained in only a small fraction of the landscape. The once common grasslands are now confined mostly to protected parts of the Nilgiris. The hills also have some major towns, out of which Ooty (Udhagamandalam), Kotagiri and Coonoor have the highest population and tourism. Around these towns and the many villages, vegetable cultivation remains an important source of income. For the purpose of this study, we identified seven distinct land cover types. These are: Agriculture (A), Natural Forests (NF), Plantations without Understorey (P), Plantations with Understorey (PU), Settlements (S), Tea (T), and Urban Parks (U) (Fig. 3).

However, this human-dominated landscape houses rich biodiversity including endemic and threatened species. Indian Bison or Gaur (*Bos gaurus*) are a common sight as are the Nilgiri langur (*Trachypithecus johnii*), a Western Ghats endemic. Leopard

(*Panthera pardus*) and Sloth Bear (*Melursus ursinus*) are not rare, and the occasional Tiger (*Panthera tigris*) is sighted too.

Several range-restricted species like Nilgiri wood pigeon (*Columba elphinstonii*), Nilgiri thrush (*Zoothera neilgherriensis*), Nilgiri sholakili (*Sholicola major*), Nilgiri flycatcher (*Eumyias albicaudatus*), Black and orange flycatcher (*Ficedula nigrorufa*) and, the Nilgiri laughingthrush (*Monetcincla cachinnans*) are found in this region. While all these species are restricted to the Western Ghats, Nilgiri laughingthrush is found only in the upper reaches of the Nilgiri hills above 1500m between the Chaliyar Valley in the North and the Palakkad Gap in the South (Robin *et al.*, 2017).

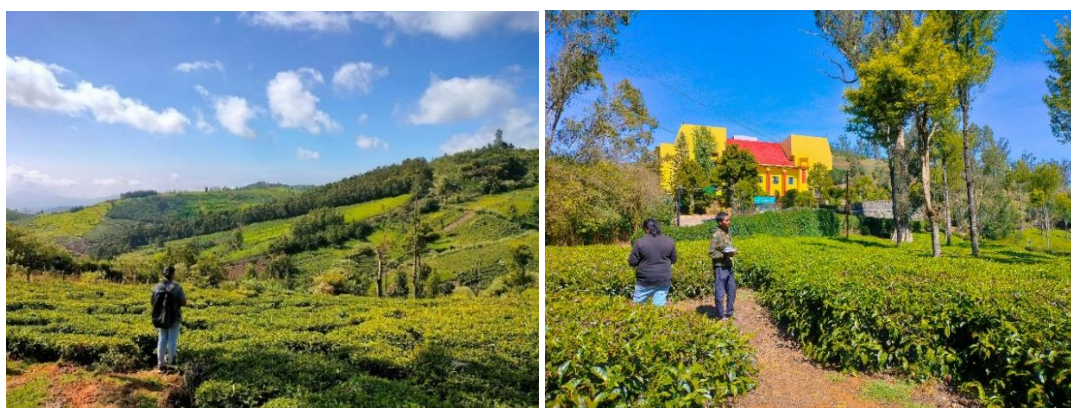


Figure 2. Tea estates in the study area

In each of the seven land cover types, 30 m fixed-radius point counts were carried out for birds (Ralph *et al.*, 1995; Shankar Raman, 2003). Owing to the complex nature of the mosaic, we made sure that the land cover assigned to a point is true for a 50 m radius around said point. Each count was ten minutes long, and any two points were at least 150 m apart to reduce spatial dependence. Counts were carried out between 0630 h and 1030 h. We aimed at 50 points per land cover, but we were limited to 29 points in urban parks owing to a small area of coverage. For every other land cover we reached 50 points, and for agriculture we reached 70. For this exercise and the pilot survey, we covered a cumulative distance of approximately 2950 km.

We noted every species seen or heard in the 30m radius, the flock size for every detection, and the mode of detection (visual or aural). For each point, we also recorded some additional information, such as the altitude, and mean sound levels in decibels during the first five minutes of the point count. The latter was achieved using the Sound

Meter App v2.17 on Android phone. While the accuracy absolute numbers from such apps is debated, especially at values higher than 90dB, mean values are lower and can be used for comparative evaluation of environmental noise (Murphy & King, 2016; McLennon *et al.*, 2019). Sampling was done between March and June of 2023.

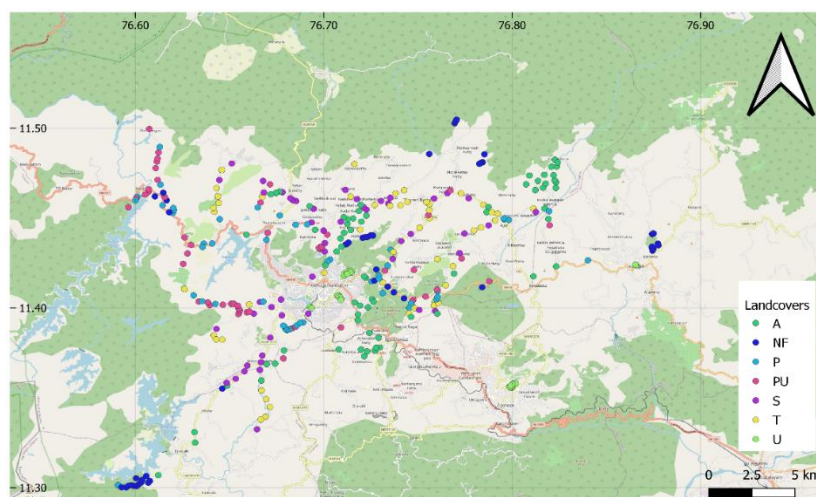


Figure 3. Map depicting the location of sampled points in the study area

RESULTS

Distribution of Shola species across land cover types

Our four focal species are understood to be partial to natural Shola forests. We examined the richness and abundances of these four across the Nilgiri landscape.

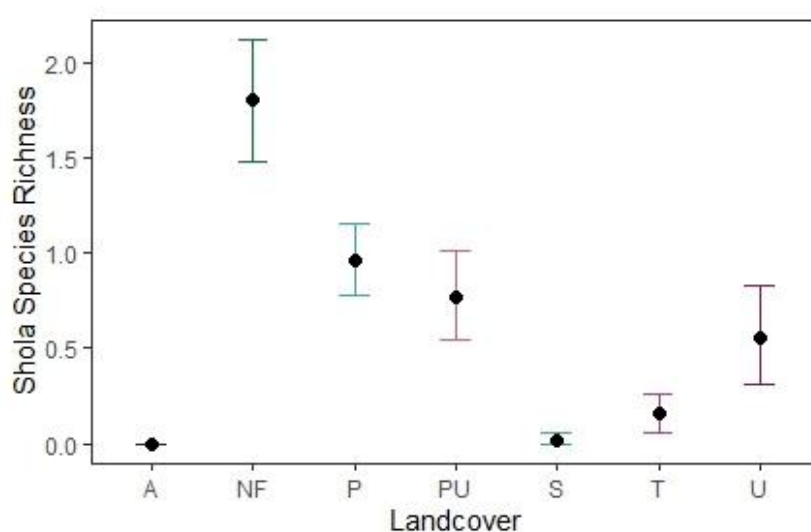


Figure 4. Shola species richness per point across all land cover types. Graph represents bootstrapped means and 95% Confidence Interval.

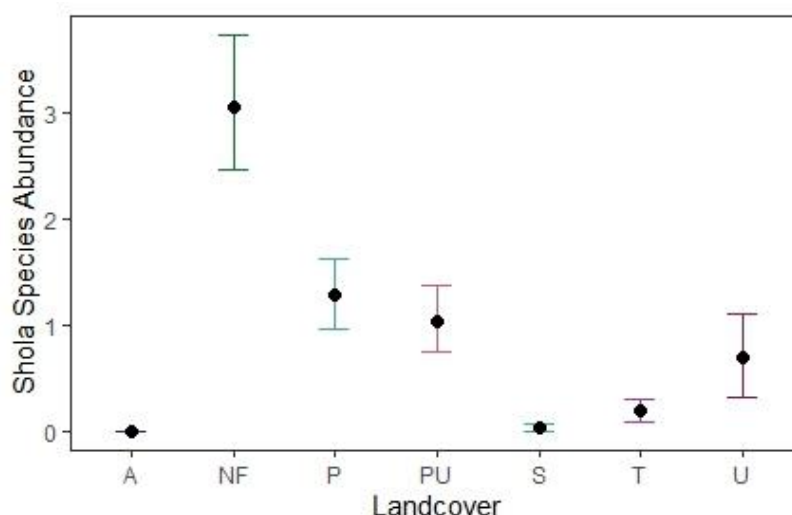


Figure 5. Shola species abundance per point across all land cover types. Graph represents bootstrapped means and 95% Confidence Interval.

The patterns of richness and abundance are similar (Fig. 4 & 5). Mean values are much higher in Natural Forests than in any other habitat. Plantations with or without understoreys also have around one individual of shola species at each point. Notably, plantations devoid of understorey layer have higher mean values, and a positive lower confidence limit. This may be driven by individual species preferences, as will be examined further. We see here that shola species as a group barely use agriculture, settlements, or tea plantations.

4. Species-level distribution across land cover types

a. Nilgiri sholakili

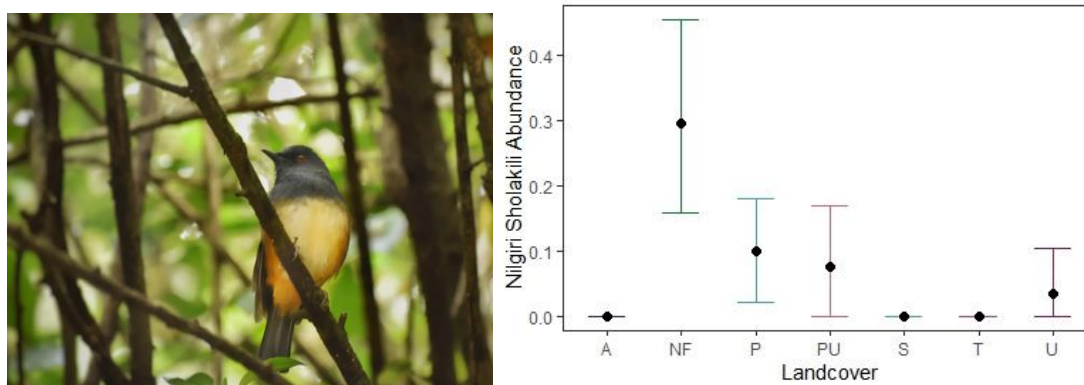


Figure 6. Nilgiri sholakili abundance per point across all land cover types. Graph represents bootstrapped means and 95% C.I.

b. Black and orange flycatcher

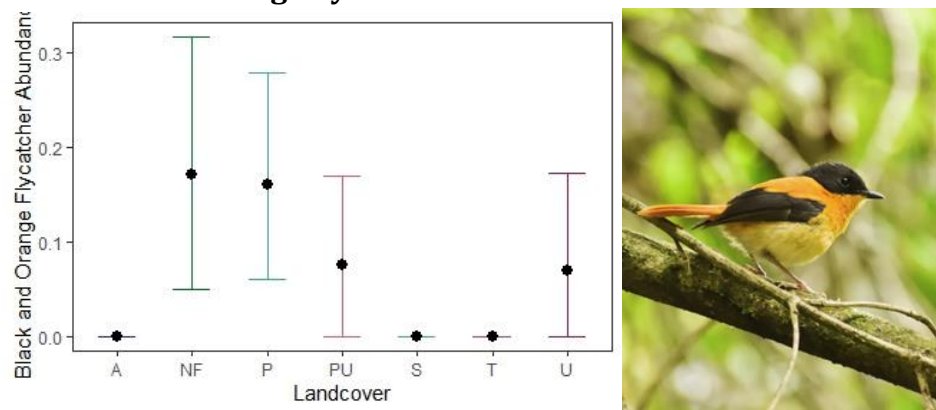


Figure 7. Black and orange flycatcher abundance per point across all land cover types. Graph represents bootstrapped means and 95% C.I.

c. Nilgiri flycatcher

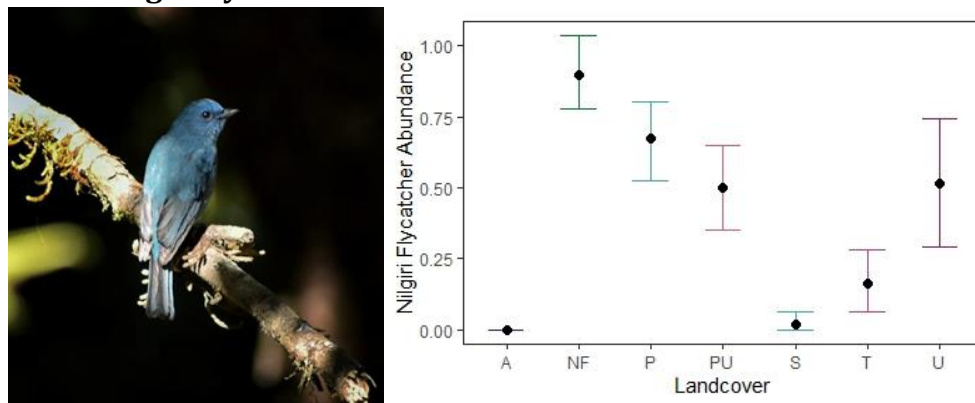


Figure 8. Nilgiri flycatcher abundance per point across all land cover types. Graph represents bootstrapped means and 95% C.I.

d. Nilgiri laughingthrush

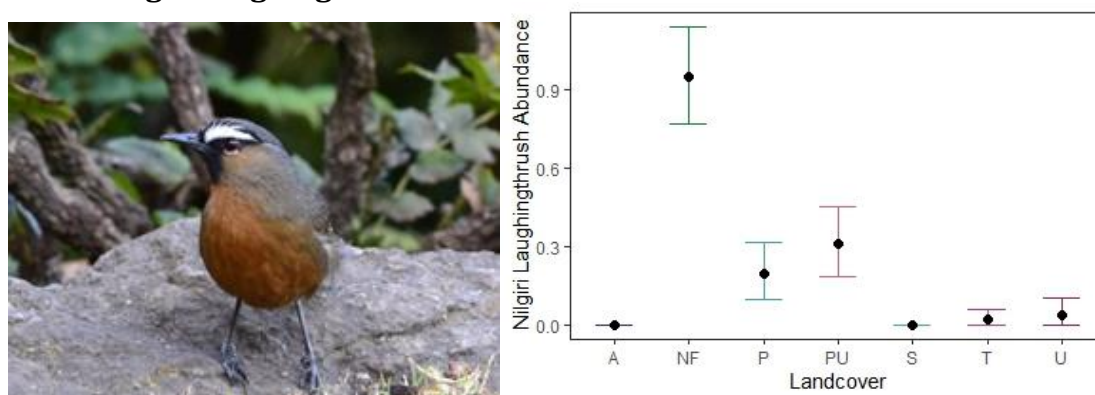


Figure 9. Nilgiri laughingthrush abundance per point across all land cover types. Graph represents bootstrapped means and 95% Confidence Interval.

Both Sholakili and Black and orange flycatchers were detected fewer times than the other two, resulting in larger confidence intervals (Fig. 6 & 7). Nevertheless, these two species were never detected in agriculture, settlements, or tea plantation. Nilgiri sholakili also showed a markedly higher abundance in NF compared to timber plantations or parks.

Nilgiri flycatcher also showed a preference for wooded habitats like timber plantations and of course forests, although it is present in parks and tea plantation in fair numbers (Fig. 8). The preference for habitats is perhaps most stark in the Nilgiri laughingthrush, with a point level abundance close to 1 in NF (Fig. 9). Second in line are the two timber plantation categories, but the drop is distinct. Mean values are close to 0 in all other land covers. It was never detected in Agriculture or Settlements, and observed only once in Tea plantation. For a species as restricted as the Nilgiri laughingthrush, for which the montane parts of Nilgiri plateau represent most of its global distribution, such a pattern further restricts the actual area it might be distributed across.

Indicator species analysis

We carried out indicator species analysis to understand significant species habitat associations for these shola birds (De Cáceres *et al.* 2012) and the results of which are depicted below (Table 1). The highlighted cells indicate the land cover types with which a species showed significant habitat associations.

Table 1. Significant shola bird species associated with different habitat types

Species	A	NF	P	PU	S	T	U
Nilgiri laughingthrush							
Nilgiri sholakili							
Nilgiri flycatcher							
Black and orange flycatcher							

A-Agriculture; NF-Natural Forests; P-Plantations without Understorey; PU-Plantations with Understorey; S-Settlements; T-Tea; U-Urban parks

We also took into account the land use-land cover map of the Nilgiri plateau above 1600 m outside PA network. This region has only one Protected Area: Mukurthi National Park. Beyond this, the area is a tapestry of all the land covers we sampled in, as

is represented by this open-access map created by the scientists of the Sky Island working group (Fig. 10).

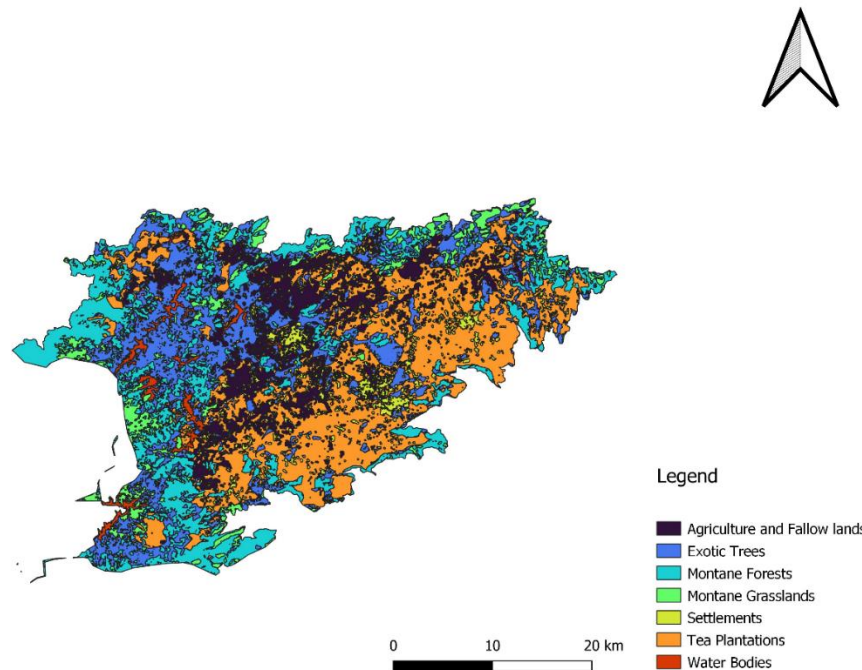


Figure 10. Land cover map of the Nilgiri plateau above 1600 m altitude

Here, ‘Exotic Trees’ represent the two plantation types put together. Putting this in the context of our shola species distribution, it appears that these birds have a potential habitat of around 500 sq. km outside protected areas. For the Nilgiri laughingthrush, with its preference for natural forests, it may be even further restricted.

DISCUSSION

These results should be examined in the context of past and present trends of land-use change in the Nilgiris. While the rate of forest conversion to plantations has slowed down, tourism has been driving infrastructure development in the region (Nunna & Banerjee 2022). With increasing demands for food, the area and intensity of agriculture is likely to increase as well (Tscharntke *et al.* 2012; Kuyper & Struik 2014). All this will put additional pressure on a bird community that is already grappling with navigating this complex web of habitats. And the first to bear the brunt of it could be the endemic habitat specialists.

The four shola species are almost restricted to three habitats: NF, PU, and P. This takeaway makes a strong case to further research the role of landscape context on distribution of the shola birds within these three land cover types.

For individual species, the presence of understorey in plantations does not seem to play a huge role in determining bird numbers. The average values of P and PU remain quite close across four species, with some showing slight preference for either. Of the four species, Nilgiri laughingthrush showed the clearest preference for NF compared to any other habitat.

However, the area that appears to be the potential habitat currently, is rather small. The results highlight the need of ecosystem preservation in the region's forests. Much of the region's forests are small and surrounded by human habitation. The people are directly or indirectly dependent on the forests much like these shola birds. And their dwindling numbers and distribution should be a call to action for landscape scale conservation action in the sky islands of the Nilgiris.

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6 SEASONAL DIVERSITY OF THE FINFISH COMMUNITY IN A TROPICAL ESTUARY, SOUTH-EAST COAST OF INDIA, TAMIL NADU

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ABSTRACT

Efficacious management and health assessment of estuarine ecosystems is augmented when comprehensive data on biodiversity is accessible. Correlations between species diversity and physicochemical factors are core information for directing management tactics and conservation planning. Present study was conducted from January to December 2023 to evaluate the measures of finfish diversity in the Muthupet estuary as a component of the Ramsar site, Point Calimere wetland complex. The diversity indices were unraveled monthly and seasonally (post-monsoon, summer, pre-monsoon, and monsoon). The ranges of Shannon-Wiener diversity (H'), Margalef's richness (d), Pielou's evenness (J'), Simpson diversity ($1-\lambda$), Taxonomic diversity (Δ), Taxonomic distinctness (Δ^*), Average taxonomic distinctness (Δ^+) and Total phylogenetic diversity ($s\Phi_i^+$) were 2.467 to 3.858, 3.945 to 10.935, 0.935 to 0.977, 0.934 to 0.984, 69.290 to 76.551, 74.158 to 77.787, 74.066 to 78.519 and 800 to 3060 respectively for monthly gillnet finfish samples and 3.34 to 4.26, 6.82 to 15.43, 0.956 to 0.963, 0.970 to 0.987, 73.798 to 76.114, 76.045 to 77.092, 76.129 to 78.014, and 1800 to 4420 respectively for seasonal data.

The Bray-Curtis similarity was zenithal between the pre-monsoon and summer, at 64.93%. The monthly and seasonal fluctuations in diversity were analysed using non-metric multidimensional scaling (NMDS), which showed 40% resemblance across the monthly samples and indicating that the monsoon unveiled the highest species richness. The temporal oscillations in diversity were influenced by various environmental drivers, such as rainfall, tidal fluctuations, freshwater influx and seasons. Effective

management inputs, such as ecological monitoring and assessment, community participation and governance, policy and regulatory frameworks, capacity building and education, economic incentives, and infrastructure and technology, are essential for sustaining resources that enhance the livelihoods of local people in this estuary.

Keywords: Estuarine ecosystem, diversity indices, physicochemical parameters, management.

INTRODUCTION

An estuary is a moderately encased coastal body of brackish water with one or more rivers or streams flowing into it and a free connection to the open sea (Pritchard *et al.*, 1967). They are widely recognized as among the most prolific aquatic systems in the world (Selleslagh & Amara, 2008) and play a vital role in the population dynamics of numerous fish and invertebrate species. They offer migratory paths for both catadromous and anadromous fish species, and nidification grounds for several marine organisms (McLusky & Elliott, 2004; El-Amier *et al.*, 2024).

India's wetlands cover an area of 15.98 million hectares, playing a vital role in the country's ecosystem. Among these 113 wetlands are internationally significant, with 85 officially designated as RAMSAR sites around 1.35 Mha. The Muthupet estuary is one of the coastal wetlands of India and provides various habitats and ecosystem functions, such as brackish to saline lagoons, mangrove forests, forested wetlands and intertidal salt marshes (Suganthi *et al.*, 2018). The key functions of estuarine systems include the purveying of food (mostly fish and shellfish), freshwater storage, maintaining hydrological balance, climate regulation, flood protection, water purification, oxygen production, fertility, recreation, and ecotourism (Barbier, 2019). This estuary is disturbed by tourism, over fishing and pollution from the saltpans, numerous aquaculture farms and agricultural land on both the east and west sides of the mangrove forest (Rajaram *et al.*, 2017). The effluent emitted by shrimp farms during their post-harvest cleaning procedures might significantly affect the estuary's ecosystem, even if for a shorter duration. Anthropogenic activities have resulted in the unwanted addition of heavy metals and nutrients to the Muthupet estuary (Balakrishnan *et al.*, 2015).

Recent studies on biodiversity have concentrated on tackling the decline of wildlife and associated ecological issues (Thiel *et al.*, 1995). Fish diversity is essential to

maintaining the health and functioning of estuarine ecosystems (Pasquaud *et al.*, 2015). Comprehensive biodiversity data provides information regarding species distributions, notably those of rare, threatened and endangered species. This enables efficient oversight of marine ecosystems (Margules & Pressey, 2000; Jefferson *et al.*, 2021) and enhances comprehension of the interactions between species assemblies and their environments (Whittaker, 1960). Diversity indicators are a primary means of illustrating the composition of fish populations within estuaries (Harrison & Whitfield, 2006; Kindong *et al.*, 2020). The preservation of overall environmental quality, the stabilization of ecosystems, and our understanding of the inherent value of all species depend on biodiversity (Machado *et al.*, 2020). Studying fish diversity in the estuary is vital for creating conservation and management strategies to safeguard these species from overexploitation and extinction (Cowley *et al.*, 2022). There are limited studies on the finfish diversity from this estuary. Hence, the present research studied the diversity of finfish in the Muthupet estuary, situated in the Thiruvarur district of Tamil Nadu, India.

MATERIALS AND METHODS

The Muthupet Estuary is a part of the Point Calimere wetland complex and is located in Thiruvarur district, at the southernmost tip of the Cauvery Delta, Tamil Nadu (Lat. 10° 20'N and Long. 79° 35'E) (Fig. 1). Vennar, one of the subdivisions of Cauvery River, divides into five channels: Paminiyar, Koraiyar, Kilaithangiyar, Marakakoriyar, and Valavanar, which ultimately flow into the estuary. The Paminiyar and Koraiyar are combined and travel approximately 7 km before mixing at the Muthupet estuary and finally opening into the Palk Strait (Gupta *et al.*, 2006). Throughout the Northeast monsoon (October to January), the estuary receives an enormous amount of freshwater with excess nutrients (Santhanam *et al.*, 2019).

Sampling design

Fish samples were collected monthly from January 2023 to December 2023, representing the four seasons such as post-monsoon (January–March), summer (April–June), pre-monsoon (July–September) and monsoon (October–December) (Santhanam *et al.*, 2019).

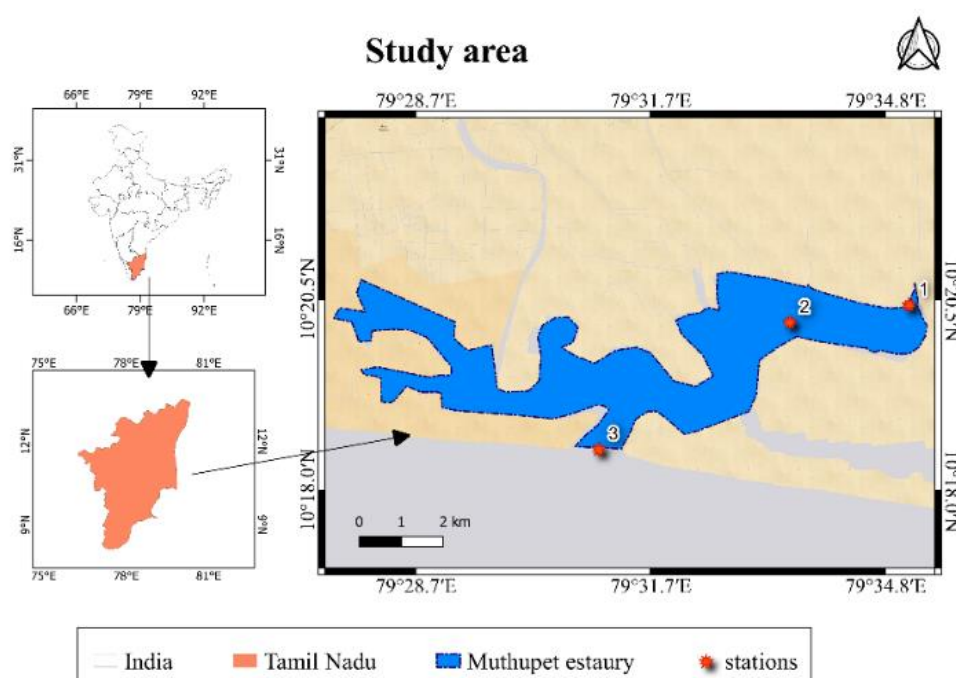


Figure 1. Map of study area showing sampling stations

Fish samples were collected once a month using two types of gill nets with a small-meshed gillnet (23 to 36 mm) for smaller fishes like anchovies, and a larger-meshed gillnet (55 to 70 mm) targeted at bigger fishes such as mullets and milkfishes. The gill nets ranging from 75 to 200 meters in length, were deployed for 1 h of soaking at each sampling station from a plank-built boat. The fish samples were collected during the low tide periods, due to the abundance of species richness and high catch rate (Vendel *et al.*, 2003). Fish samples were counted and identified using standard guides (Talwar & Jhingran, 1991; Jayaram, 1999; Day, 1876; Munro, 2000).

Data analysis

Plymouth Routines in Multivariate Ecological Research (PRIMER v6) software was used for the biodiversity assessment with species abundance as input data (Clarke & Warwick, 2001a). Univariate diversity indices like Shannon-Wiener diversity index (H'), Margalef's richness index (d), Pielou's evenness index (J'), Simpson diversity index ($1 - \lambda'$), Taxonomic diversity (Delta), Taxonomic distinctness index (Delta*), Average taxonomic distinctness index (Delta+) and Total phylogenetic diversity (sPhi+) were calculated (Prakash *et al.*, 2015). The multivariate biodiversity analysis incorporates multi dimensional scaling (MDS) (Kruskal & Wish, 1978), the K-

dominance curve was used to show how individual species confer on entire abundance and community data (Warwick *et al.*, 2008) and Bray-Curtis coefficient was used to afford the plots in cluster analysis to determine the similarity and disparity between samples or groups (Bray & Curtis, 1957), average taxonomic distinctness and variation in taxonomic distinctness.

RESULTS

Univariate biodiversity analysis

Biodiversity indices: The month-wise calculated finfish diversity indices from the Muthupet estuary are presented in Table 1. The Shannon Wiener diversity were found to be ranged from 2.467 (April 2023) to 3.858 (December 2023), Margalef's richness 3.945 (April 2023) to 10.935 (December 2023), Pielou's 0.935 (April 2023) to 0.977 (June 2023), Simpson diversity 0.934 (April 2023) to 0.984 (December 2023), Taxonomic diversity 69.290 (April 2023) to 76.551 (December 2023), Taxonomic distinctness 74.158 (April 2023) to 77.787 (December 2023), Average taxonomic distinctness 74.066 (April 2023) to 78.519 (December 2023) and Total phylogenetic diversity 800 (April 2023) to 3060 (December 2023).

The season-wise diversity indices of finfish species in the Muthupet estuary is given in Table 2. The seasonal values of Shannon-Wiener diversity were found to be in the orbit of 3.34 (summer) to 4.26 (monsoon). Margalef's species richness attained their zenith in the monsoon (15.43) and nadir in the summer (6.82). Pielou's evenness index values fall between 0.956 and 0.963 (monsoon and summer). Simpson diversity index disparates from 0.970 (summer) to 0.987 (monsoon). The monsoon had the utmost calculated values of taxonomic diversity (76.114) while the summer had the smallest values (73.798). The taxonomic distinctness was found to be superlative during the monsoon (77.092) and minimum during the summer (76.045). The average taxonomic distinctness was classified between 76.129 (summer) and 78.014 (monsoon). The total phylogenetic diversity was shown to be apex in the monsoon (4420) and marginal in the summer (1800).

Table 1. Month-wise univariate finfish diversity indices of in the Muthupet estuary during January to December 2023

Months	d	J'	H' (loge)	1-Lambda '	Delta	Delta*	Delta+	sPhi+
January	8.481	0.969	3.524	0.980	75.693	77.249	78.037	2340
February	7.703	0.966	3.379	0.977	75.215	76.993	77.197	2000
March	5.101	0.956	2.911	0.959	71.174	74.227	76.190	1280
April	3.945	0.935	2.467	0.934	69.290	74.158	74.066	800
May	4.552	0.962	2.668	0.957	72.667	75.915	76.167	1000
June	5.230	0.977	3.063	0.965	74.347	77.036	77.391	1480
July	7.042	0.966	3.319	0.974	74.854	76.862	76.989	1820
August	5.227	0.973	2.963	0.965	73.632	76.304	76.571	1340
September	7.184	0.969	3.328	0.976	74.280	76.119	76.473	1760
October	8.433	0.971	3.606	0.979	74.477	76.056	76.902	2380
November	6.920	0.956	3.283	0.970	75.175	77.513	77.763	1980
December	10.935	0.967	3.858	0.984	76.551	77.787	78.519	3060

S – Total number of species; d – Margalef's species richness; J' - Pielou's species evenness; H'(loge) – Shannon-Wiener diversity index; 1-Lambda' - Simpson diversity index; Delta - Taxonomic diversity; Delta* - Taxonomic distinctness index; Delta+ - Average taxonomic distinctness; sPhi+ - Total phylogenetic diversity.

Table 2. Season-wise univariate diversity indices of finfish collected in the Muthupet estuary during January to December 2023

Seasons	d	J'	H' (loge)	1-Lambda '	Delta	Delta*	Delta+	sPhi+
Post-monsoon	10.503	0.961	3.814	0.981	75.075	76.497	77.039	2940
Summer	6.824	0.963	3.338	0.970	73.798	76.045	76.129	1800
Pre-monsoon	10.389	0.957	3.783	0.981	75.107	76.571	77.044	2760
Monsoon	15.426	0.956	4.259	0.987	76.114	77.092	78.041	4420

S – Total number of species; d – Margalef's species richness; J' - Pielou's species evenness; H'(loge) – Shannon-Wiener diversity index; 1-Lambda' - Simpson diversity index; Delta - Taxonomic diversity; Delta* - Taxonomic distinctness index; Delta+ - Average taxonomic distinctness; sPhi+ - Total phylogenetic diversity.

Multivariate biodiversity analysis

Dominance plot: The K-dominance curve is used to compare the dominance of individual species over time and space. Dominance plots were created by ranking the species in decreasing order of abundance using the x-axis (logarithmic scale) for their contribution to living coverage and the y-axis (cumulative scale) for their percentage

dominance (Lambshead *et al.*, 1983; Clarke & Warwick, 2001a). In the K-dominance curve, the steepest curve denotes poor diversity of species and a disturbed system state; the quiet pitch with a medium starting point curve indicates moderate diversity with minimal disturbance and the S- shaped curve displays sterling species diversity and a typically unruffled ecosystem (Whittaker, 1965; Rice, 2000). The curves of April and May depict a slightly perturbed system state driven by environmental stress and January, October and December curves indicate healthy species diversity. The summer curve, which was found to be at the upper level of the plot, shows the lesser richness components of the diversity, while the monsoon curve, which was found to be at the lower level and achieves the cumulative 100%, is clearly visible in the K-dominance plot, indicating increasing dominance and diversity. In the K-dominance curve, the most predominant 15 species accounted to 50-60% of the finfish diversity of the Muthupet estuarine system (Fig. 2). An elevated curve can be observed in the K dominance plotted for the seasonal abundance data (Fig. 3), which also indicates a stronger seasonal influence on the species composition in the seasonal abundance of finfish in the Muthupet estuary.

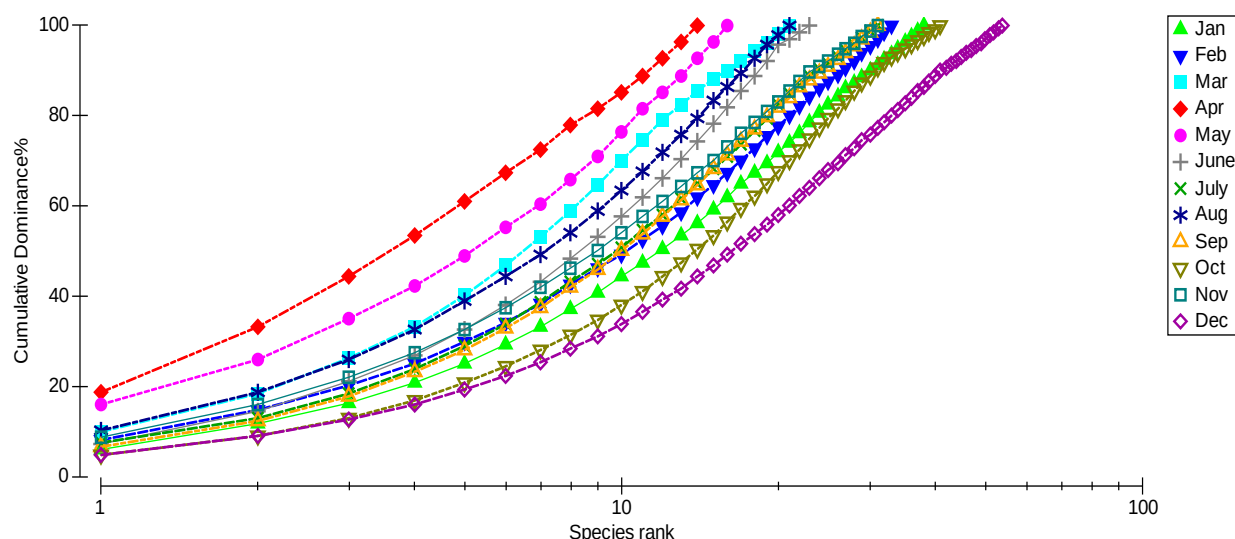


Figure 2. Dominance and diversity curve for the month-wise abundance of finfish assemblages at Muthupet estuary

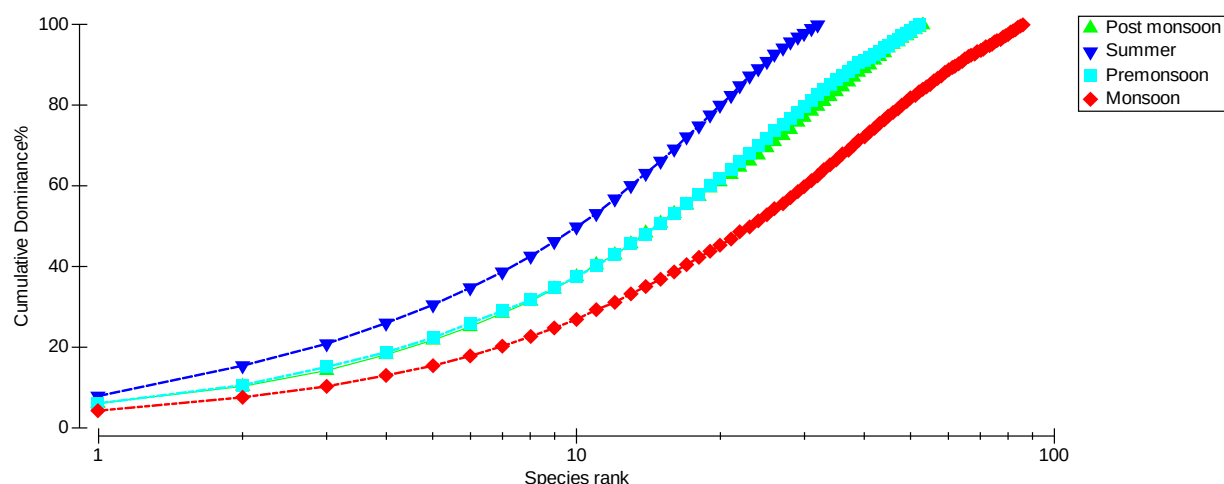


Figure 3. Dominance and diversity curve for the season-wise abundance of finfish assemblages at Muthupet estuary

Bray-Curtis similarity index

Bray- Curtis similarity is useful in quantifying the compositional similarity between groups, months and seasons (Bray & Curtis, 1957). The month-wise highest similarity was observe between June and August (72.35%), and highest heterogeneity noticed between January and November (20.26%) (Fig.4). The B-C analysis revealed that the similarity was maximum between the pre-monsoon and summer (64.93%). The maximum variability was between monsoon and summer (43.04%) (Fig. 5).

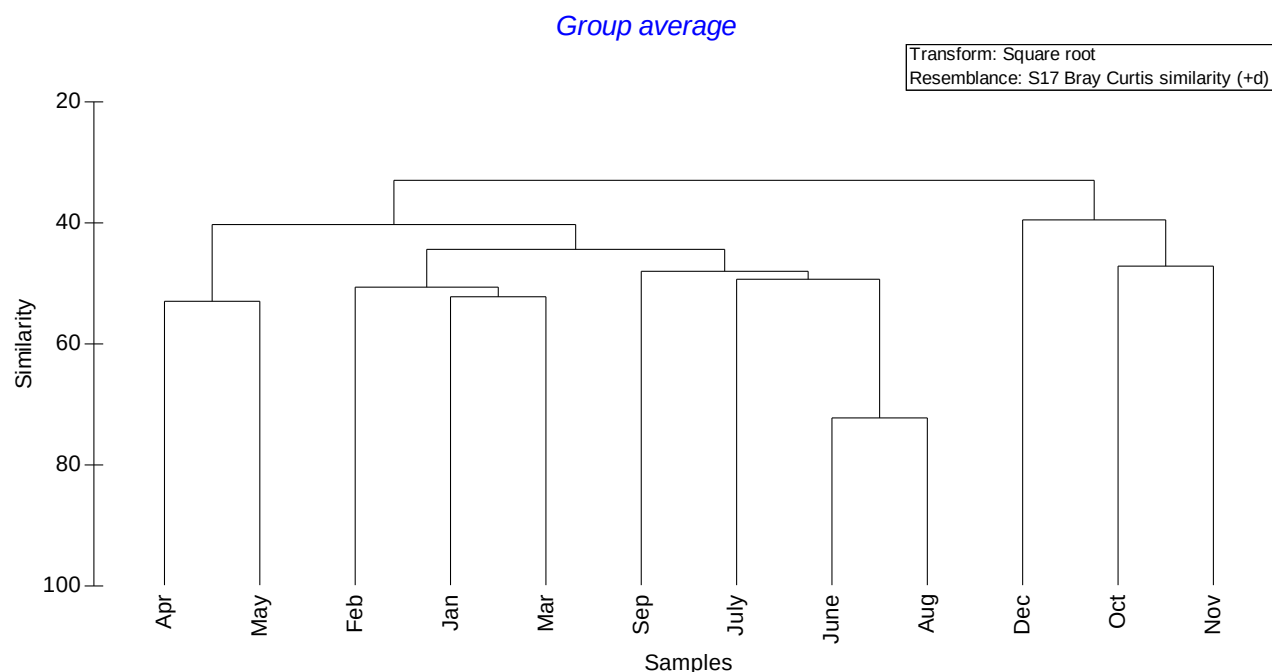


Figure 4. Dendrogram illustrating the similarities between months based on the composition of finfish collected at Muthupet estuary from January to December 2023

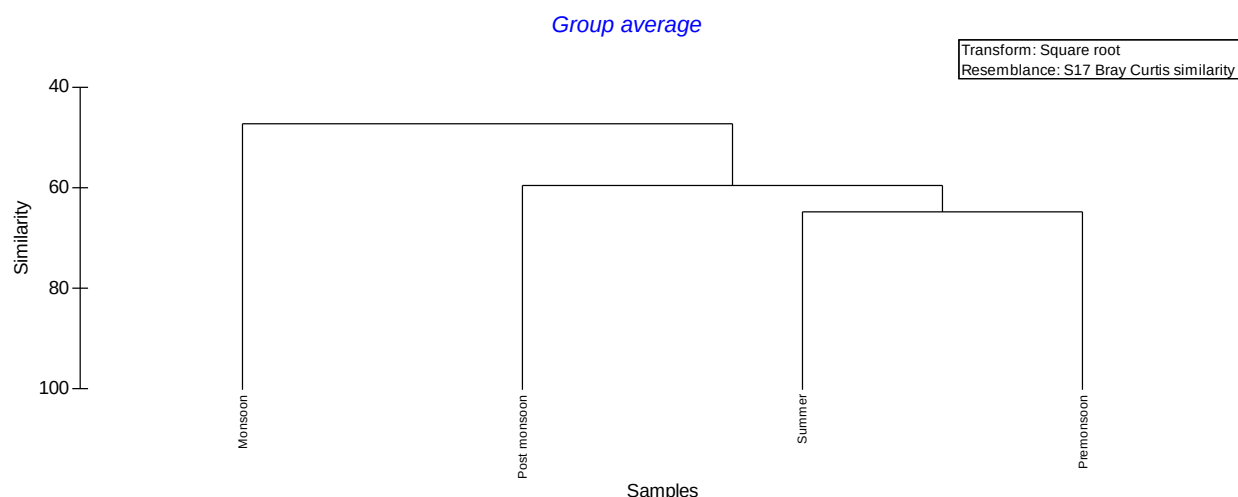


Figure 5. Dendrogram illustrating the similarities between seasons based on the composition of finfish collected at Muthupet estuary from January to December 2023

Non-metric multidimensional scaling (NMDS)

In the non-metric multidimensional scaling plot, a stress value of 0.13 (13%) denotes a strong portrayal of lower parameters, whereas a stress value of 0.3 denotes weak representation. The estuarine finfish had a more or less similar finfish species composition throughout the study period, except in October, November and December during the study period and provided a 2D stress value of 0.13 and a 3D stress value of 0.08. The 2D-MDS plot of estuary is given in Figure 6.

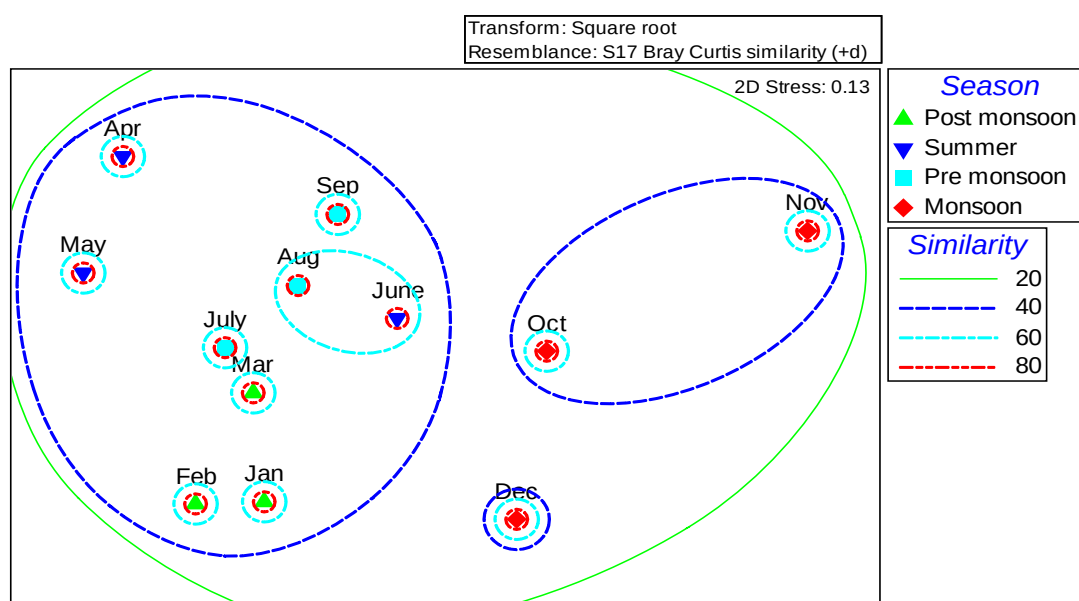


Figure 6. MDS ordination for the finfish community during seasons and monthly abundance

Average taxonomic distinctness

The Funnel plot was drawn by simulation for various months with average taxonomic distinctness ($\Delta+$) values (Fig. 7). The findings showed that, with the exception of April, which dipped below the funnel, every month fell inside the 95% confidence threshold. Values for the January and November months fell exactly on the mean, while those for the other months varied slightly from the mean.

A simulation test performed on average taxonomic distinctness using a funnel for finfish samples corresponding to the four seasons (Fig. 8) showed that all the seasons fell within the 95% confidence limit except for summer, which fell below the funnel. Values for the monsoon fell exactly on the mean.

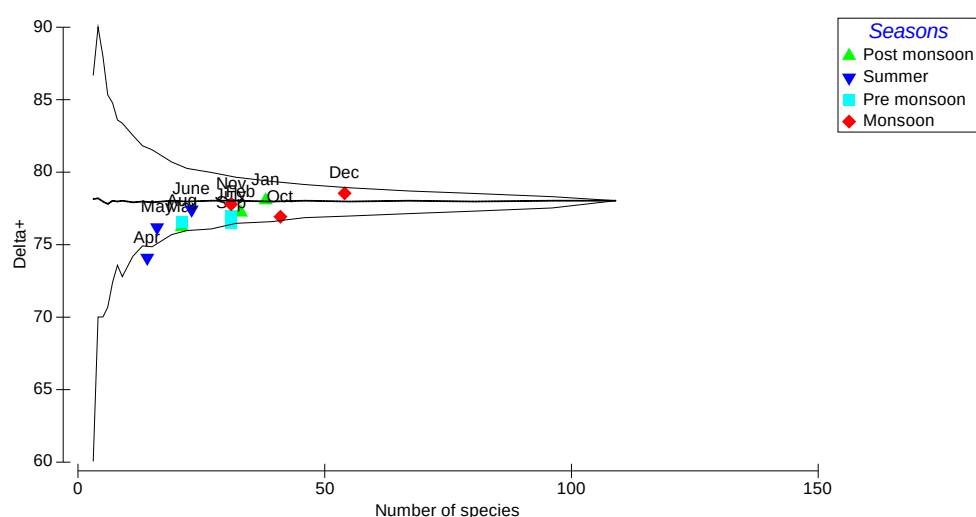


Figure 7. Funnel plot simulated for various months with average taxonomic distinctness ($\Delta+$)

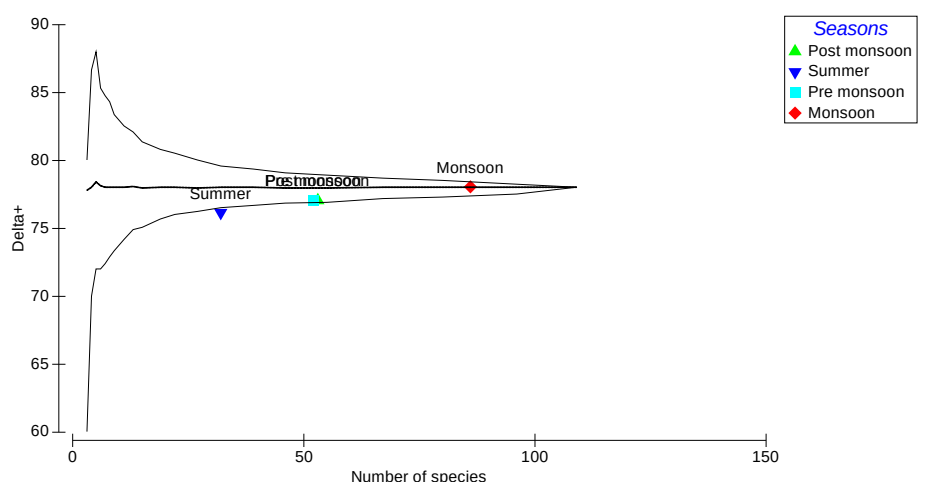


Figure 8. Funnel plot simulated for various seasons with average taxonomic distinctness ($\Delta+$)

Variation in taxonomic distinctness

A simulation test performed on variation in taxonomic distinctness ($\lambda+$) using the funnel (Fig.9) with respect to samples collected on months indicated 11 months to keel over the 95% confidence limit and April month only fell above the funnel. The June and December months raze on the mean.

The $\lambda+$ values of the samples collected based on the seasons shown in Figure 10. All the seasons fall inside the 95% probability contours. While $\lambda+$ values of monsoon tumble exactly on the mean, the post monsoon and pre monsoon marginally diverged from the mean and fell above the mean respectively.

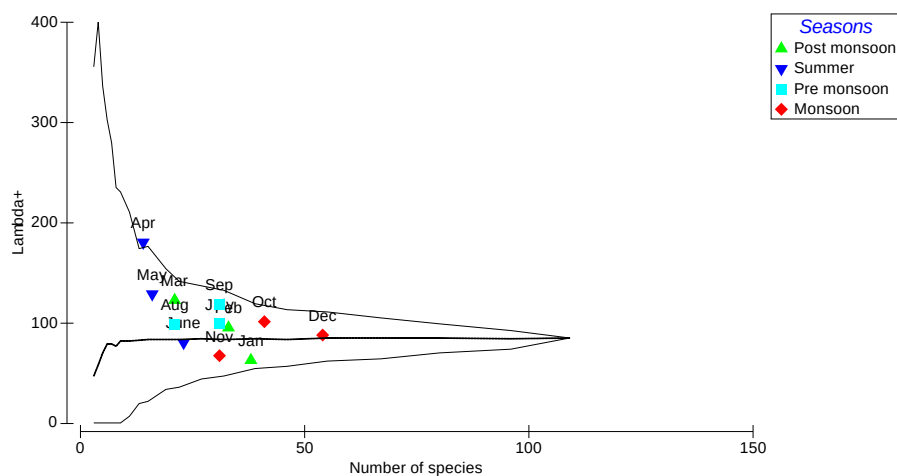


Figure 9. Funnel plot simulated for various months with variation in taxonomic distinctness ($\lambda+$)

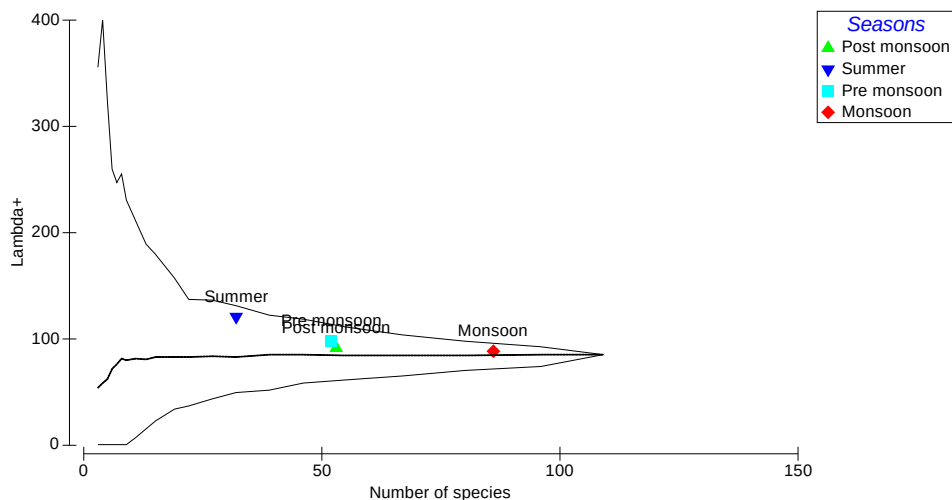


Figure 10. Funnel plot simulated for various seasons with variation in taxonomic distinctness ($\lambda+$)

Ellipse plot

A simulation test executed with ellipses (Fig. 11) on Δ^+ and λ^+ unanimously displayed all the months to drop inside the 95% confidence interval. The ellipse plot of simulated Δ^+ and λ^+ braces revealed that all the seasons were found to fall within the 95% probability curves (Fig. 12).

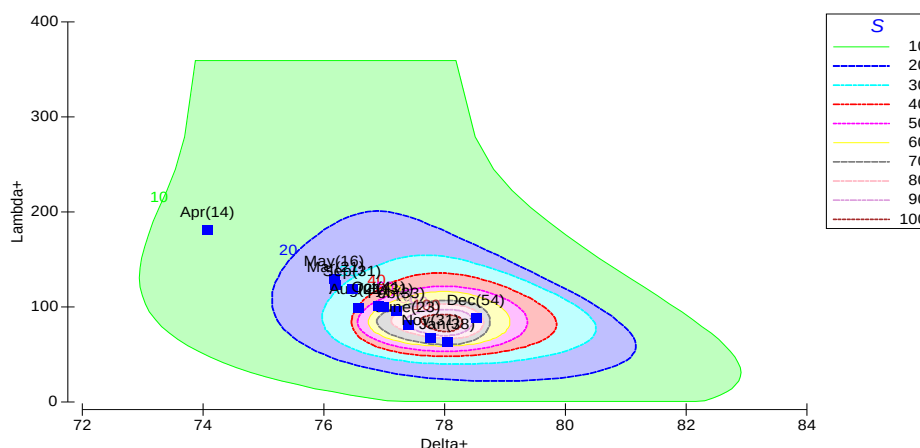


Figure 11. Simulation test performed using ellipses for different months with average in taxonomic distinctness (Δ^+) and variation in taxonomic distinctness (λ^+)

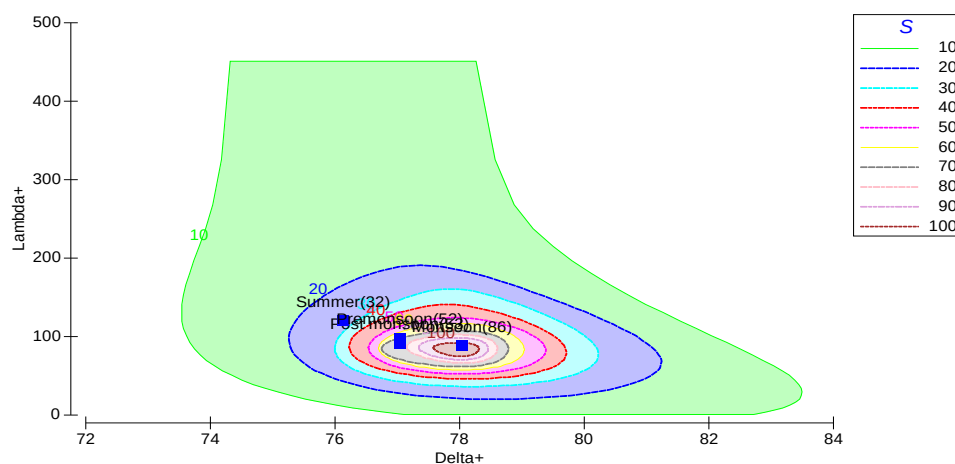


Figure 12. Simulation test performed using ellipses for different seasons with average in taxonomic distinctness (Δ^+) and variation in taxonomic distinctness (λ^+)

DISCUSSION

In ecological study, the Shannon-Weiner index is a commonly used statistic to quantify biodiversity. The advantage of this index is that it takes into consideration both species abundance and diversity. Increased evenness or the possession of more rare species can boost the index (Magurran, 2003). If the Shannon value is less than 2, the

ecosystem is less diverse, 2.5 to 3 indicates moderately diverse, and 3.5 to 4 means profoundly diverse (Ajmal Khan, 2008). Clarke & Warwick (2001b) noted that Shannon merits of 3 and above are found only in healthy and biodiversity rich areas. In the present study, the Shannon Wiener diversity index (H') value lies between 2.467 (April 2023) and 3.858 (December 2023). Seasonal variations were observed in the gillnet finfish collections' Shannon Weiner diversity (H') value, which ranged from 3.338 to 4.259. The monsoon displayed the highest value, while the summer displayed the lowest. Prior research carried out by Suganthi *et al.* (2018) indicated that the Shannon diversity index (H') ranged from 2.521 (April 2014) to 2.762 (November 2014) and 2.603 (March 2015) to 2.82 (October 2015) and Rajakumar (2016) reported that the H' value ranged from 1.36 (December 2014) to 3.01 (February 2015) both values were slightly lower than the present study.

In the Coleroon estuary, the finfish's Shannon index value ranged from 1.5 in November to 3.2 in June (Bharadhirajan *et al.*, 2015). It was reported that the Muthukuda mangroves' maximal Shannon diversity index (H') was recorded in July (2.811), while it remained flat in October (2.025) (Vasanthi and Muthukumaravel, 2024). Muthukumaravel *et al.* (2021) reported that the H' value ranged from 2.025 (October) to 2.811 (July) in the Karankadu estuary. The Kumarakom region of the Vembanad lake had the Shannon index (H') of 3.72 (July) to 3.86 (August) (Ansar *et al.*, 2017). Kiranya *et al.* (2018) found that the Poonthura estuary recorded a month-wise Shannon diversity index (H') value ranging from 2.526 (June) to 3.66 (September) and season-wise H' index value ranging from 4.03 to 4.29, which was equally consistent with the findings of the present study.

The results of this study were in line with the season-wise H' values reported by Roshini *et al.* (2021) from the Vembanad Lake, which was 3.5 to 4.0, Murugan *et al.* (2014) from the Vellar estuary, which was 4.52 to 5.81 and Pavinkumar *et al.* (2015) from the Manakudy estuary, which was 3.3 to 4.1. The higher H' values of the estuary imply the presence of varied fauna with general wellness and diversification. The values are consistent with the predicted range seen in other tropical estuaries, according to a comparison with the findings of other investigators. In the present study, the species diversity value was recorded as maximum during the monsoon and minimum during the summer. The maximum species diversity during the monsoon was already reported

by Brinda *et al.* (2010) from the Vellar estuary and Suganthi *et al.* (2018) from the Muthupet estuary and they concluded that the good species diversity during the monsoon which may prefer low salinity and low temperature and the current findings are align with their conclusions. The finfish collected from the present study's month-wise Margalef richness ranged from 3.945 (April 2023) to 10.935 (December 2023) and season-wise Margalef richness varied from 6.82 (summer) to 15.43 (monsoon).

In a preceding study, Margalef richness index recorded from 1.01 (October) to 3.01 (March) by Rajakumar (2016) in the Muthupet estuary, which was lower than the present study. As per the report by Muthukumaravel *et al.* (2021), the Karankadu estuary's d' value fluctuated between 3.04 in October and 5.218 in July. According to Benjamin *et al.* (2023), the Margalef richness of the Chettuva estuary ranged from 2.9 to 8.16 and Poonthura estuary, the value varied from 2.30 (March) to 4.51 (November) (Kiranya *et al.*, 2018). The erstwhile research in the Vellar estuary (Murugan *et al.*, 2014) estimated the maximum species richness index (d) as 10.13 during post monsoon and the minimum value as 4.83 during the monsoon. The previous study from the Manakudy estuary documented the apex value of species richness index (d) as 13.45 in summer and the minimum value as 7.07 in monsoon (Pavinkumar *et al.*, 2015). Present calculated Margalef richness index was superior than the above earlier reports indicated that the Muthupet estuary had a rich diverse of finfish fauna. In the present study, the species richness value was reported as maximum during the monsoon and minimum during the summer. Low salinity, cold temperatures, and nutrient-rich surface water influenced the estuarine ecosystem's primary productivity, supporting the juvenile pelagic fishes (Sreekanth *et al.*, 2016). This was the reason for the maximum species richness during the monsoon, which was previously reported by Mogalekar *et al.* (2015) from the Vembanad Lake. This indicates that the present study observed a significant concentration of pelagic species during the monsoon.

In the present study, Pielou's evenness index (J') values ranged from 0.935 to 0.977 for month-wise gill net samples and 0.956 to 0.963 for season-wise gill net samples. The minimum and maximum values noted during April and June in the present study. This could be influenced by the result of elevated individual dominance and extensive species richness. Suganthi *et al.* (2018) reported monthly evenness values ranging from 0.76 (November and January) to 0.82 (April) and Rajakumar (2016) found

that the J' value ranged from 0.71 (December) to 0.97 (May) for gill net finfish samples in the Muthupet estuary. Muthukumaravel *et al.* (2021) recorded the zenith J' value of 0.9837 in September and the minimal value of 0.9525 in March. In the study from the Vembanad lake, the calculated Pielou's evenness index (J') value was found to be maximum during the month of October as 0.9671 and minimum during the month of April as 0.9739 (Ansar *et al.*, 2017). In the other study from the Vembanad lake, the maximal species evenness index (J') noted during the pre-monsoon season (0.97) and minimal value was recorded during the southwest and post-monsoon (0.95) (Mogalekar *et al.*, 2015). Pielou's evenness index (J') values ranged from 0.79 to 0.92 for month-wise gill net samples and 0.81 to 0.82 for season-wise gill net samples from the Poonthura estuary (Kiranya *et al.*, 2018). Akin to the current study, the lowest levels were seen in the two previous studies during the monsoon season.

The probability evenness was assessed using the Simpson diversity index ($1-\lambda$), and the Shannon and Simpson diversity indices can be scattered around the abundance-weighted diversity family (Guariento *et al.*, 2020). In the present study, Simpson diversity index ($1-\lambda$) lays between 0.934 and 0.984 for month-wise gill net samples, 0.970 and 0.987 for season-wise gillnet sample. The least evenness index reported during April and summer and the uppermost evenness ensued during December and monsoon month-wise and season-wise, respectively. Kiranya *et al.* (2018) taped that the month-wise and season-wise Simpson diversity index ($1-\lambda$) ranged from 0.766 to 0.908 and 0.88 to 0.91 in the Poonthura estuary, which was lower than the present study. They also reported that the monsoon had the highest Simpson diversity index as in the present study.

The taxonomic diversity (Δ) values vacillated between 69.290 (April) and 76.551 (December) for monthly gill net collections and 73.798 (summer) to 76.114 (Monsoon) for seasonal gill net finfish collections. As stated by Pavinkumar *et al.* (2014) the taxonomic diversity values of from the Korampallam-Thermal estuary ranged from 78.06 to 82.12, from the Manakudy estuary 80.22 to 84.83 and from the Punnakayal estuary they ranged from 81.35 to 85.04. In the Vembanad Lake, the lowest was recorded during south west monsoon (86.87) and the highest during pre-monsoon (91.42) (Mogalekar *et al.*, 2015). Higher taxonomic diversity index values suggest that the species in the assemblage are generally not closely linked, indicating rich

biodiversity (Patricio *et al.*, 2009). Ansar *et al.* (2017) reported that the taxonomic diversity value ranged from 65.42 (June) to 70.6 (November) in the Vembanad Lake at Kumarakom region on the lower side.

The primary purpose of the taxonomic distinctness measure (Δ^*) is to assess the degree of taxonomic divergence or uniqueness among species within a given ecological community (Gaston & Spicer, 2013). In the present study, the taxonomic distinctness (Δ^*) values varied from 74.158 (April) to 77.787 (December) and 76.045 (summer) to 77.092 (Monsoon). These values in line with previous studies by Pavinkumar *et al.* (2014), who recorded the taxonomic distinctness (Δ^*) ranged from 80.51 to 83.81 in the Korampallam-Thermal estuary, 83.30 to 86.22 in the Punnakayal estuary and 82.62 to 85.89 in the Manakudy estuary.

The total phylogenetic diversity index (sPhi+) estimated for different months ranged from 800 (April) to 3060 (December) and for various seasons ranges from 1800 (summer) to 4420 (Monsoon). The average and overall phylogenetic diversity are higher in a healthy ecosystem because of the taxonomic breadth or abundant fish assemblages (Khan *et al.*, 2005), as reflected in the total phylogenetic diversity index (sPhi+), which unequivocally highlights the taxonomic range of the biota (Clarke & Warwick, 1999). Pavinkumar (2014) provided the seasonal values of sPhi+ for the Korampallam-Thermal estuary ranged from 1633 to 2300 and Manakudy estuary varied from 1966 to 3966. Mogalekar *et al.* (2015) proclaimed that the total phylogenetic diversity index (sPhi+) values wavered between 1633 and 2333 in the Vembanad Lake. Comparison with the results of these authors showed that the Muthupet estuary had a rich fish assemblage structure.

The K- dominance curve revealed that the weighty 15 species contributed to 50-60% of the finfish diversity in the Muthupet estuarine system. Monthly and seasonal surveys of gill net finfish specimen assemblages indicated that the pinnacle count of species reported during December and Monsoon, respectively. Akin to the present study Kiranya *et al.* (2018) noted that the maximal diversity occurred during the monsoon for cast net samples in the Poonthura estuary.

Temporal Bray-Curtis similarity was highest between pre-monsoon and summer (64.93%) and between June and August (72.35%). The dendrogram showed that December, October and November months formed one cluster and all other months

formed another cluster. A similarity score of 47.41% was found between monsoon and the cluster formed by post-monsoon, summer and pre-monsoon. The cluster analysis revealed that the seasons were similar, with the monsoon being the most distinct. The second phase was characterized by the post-monsoon, with the cluster (summer and pre-monsoon) having a similarity level of 59.71%. This supports the assumption that post-monsoon is less likely to be combined with a cluster of summer and pre-monsoon. The final step was combining summer with pre-monsoon, yielding a similarity level of 64.93%. The non-metric multidimensional scaling showed a 40% parallelism between the samples. Similar MDS results were obtained in the Poonthura estuary by Kiranya *et al.* (2018).

Simulation test performed on average taxonomic distinctness ($\Delta+$) using a funnel plot for gill net samples, all the seasons except summer and all the months except April fell inside the 95% confidence contour. The January and November months and monsoon fell exactly on the mean, others slightly deviated from the mean. In the present study, the average taxonomic distinctness ($\Delta+$) values ranged from 74.158 (April) to 77.787 (December) and 76.129 (summer) and 78.014 (monsoon) for month-wise and season-wise, respectively. Mogalekar *et al.* (2015) noted that the $\Delta+$ values varied between 91.80 and 93.28 in the Vembanad Lake for fish, and a Simulation test executed on cast net samples of the Poonthura estuary revealed all the seasons fell within the 95% confidence level (Kiranya *et al.*, 2018). According to their results, the average taxonomic index was maximum in the warm season but in the, present study the $\Delta+$ index was higher in the monsoon season. Simulation test for variation in taxonomic distinctness ($\lambda+$) for gill net samples showed all the months except April and the entire season keel over the 95% confidence funnel, notably June and December months and monsoon season raze on the mean.

The study is an innovative effort that thoroughly examines the finfish variety in the Muthupet Estuary.

CONCLUSION

Muthupet estuary is an important ecosystem with rich diversity of fishes. The higher diversity index values recorded in the study distinctly revealed the healthy nature of the estuary. The K- dominance curve offered a graphical analogy of diversity among samples, highlighting the 15 most dominant species that together contribute to

50-60% of the estuarine system's total finfish diversity. A 40% commonality across all samples was also shown by non-metric multidimensional scaling, which cited the estuary's varied community structures. The diversity indices that have been recorded will serve as important benchmarks for future research in order to evaluate the estuary's health, compare its diversity with that of other estuarine ecosystems, and determine any changes that occur in this productive estuarine habitat. The Muthupet estuaries have been heavily impacted by discharges of agricultural runoff and shrimp pond water outflows, but fish diversity has remained stable so far. This circumstance requires close monitoring and concern. The long-term effects of these environmental pressures could catastrophe the ecosystem's balance. It is essential to adopt appropriate conservation and sustainable management practices, like habitat restoration, sustainable fishing practices, pollution control measures, integrated coastal zone management, community-based resource management, establishment of marine protected areas, and environmental monitoring, to protect the health of the estuary.

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7 CHECKLIST OF ICHTHYOFAUNAL DIVERSITY IN THE MUTHUPET COASTAL ECOSYSTEM: BIODIVERSITY INSIGHTS AND CONSERVATION IMPLICATIONS

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ABSTRACT

Documenting ichthyofaunal diversity is essential for understanding biodiversity patterns and informing conservation efforts. This study presents a comprehensive checklist of fish species from the Muthupet region from January 2023 to December 2023. The checklist encompasses 105 species, two classes, 23 orders, 48 families, and 88 genera. Notably, 60 species were exclusive to the lagoon. Teleostei was the most diverse class (100 species, 83 genera, 44 families, and 20 orders), while Elasmobranchii was the least diverse (5 species, 5 genera, 4 families, and 3 orders). The order Eupercaria/misc (19%) was the richest, followed by Clupeiformes (16%), Carangiformes (10.5%), and Acanthuriformes (8%). Carangidae was the most species-rich family (10 species), followed by Engraulidae and Sciaenidae (8 species each). According to the IUCN Red List, 86 recorded fish species were categorized as "Least Concern," 8 as "Not Evaluated," 4 as "Vulnerable," 3 as "Data Deficient," and 1 each as "Critically Endangered" and "Near Threatened." More than 95% of the recorded species have commercial significance, contributing to subsistence fisheries year-round. The findings of this study provide baseline data for conservation planning and sustainable fisheries management in the Muthupet coastal ecosystem.

Keywords: Ichthyofaunal diversity, wetland, red list, checklist, Muthupet lagoon, conservation

INTRODUCTION

Wetlands are transitional ecosystems between terrestrial and aquatic environments, where the water table is typically at or near the surface, or the land is covered by shallow water (Prasad *et al.*, 2002). Coastal wetlands, found across all latitudes from the Polar Regions to the tropics, function as complex socio-ecological systems (Newton *et al.*, 2020). These ecosystems provide invaluable services, including climate regulation, water purification, and biodiversity conservation (Costanza *et al.*,

1997). They support diverse habitats, sustaining a wide range of species, including fish, invertebrates, amphibians, and birds (Ghermandi *et al.*, 2007). Among the most direct benefits of wetlands to humans is their role in food production, particularly rice, fish, and crustaceans, which serve as staple foods for more than half of the world's population (Gopal, 2015).

India hosts a diverse array of wetlands, spanning from the Himalayan region to the Deccan Plateau (Prasad *et al.*, 2002). The country is home to 3,497 coastal wetlands, covering an area of 3,880,569 hectares, which accounts for 24.27% of India's total wetland area (Garg & Patel, 2007; Bassi *et al.*, 2014). These coastal wetlands serve as critical habitats for endemic, charismatic, and flagship species, enriching the biodiversity of the ecosystem. Additionally, they play a vital role in supporting the blue economy, contributing significantly to India's GDP and providing livelihoods for millions of people.

Palk Bay, a semi-enclosed shallow water body situated between the southeast coast of India and Sri Lanka, harbors a diverse range of fragile ecosystems, including mudflats, sea grass meadows, coral reefs, seaweed beds, estuaries, and mangrove forests (Salagrama, 2014). This ecologically rich region supports an extraordinary diversity of marine life, comprising 128 coral species, 651 crustacean species, 733 molluscan species, 273 echinoderms, and 580 species of fish (kumaraguru *et al.*, 2008). At the northern end of Palk Bay, the Cauvery River and its tributaries form a network of rivulets that drain into the sea, giving rise to Muthupet Lagoon, the largest brackish water lagoon in the region.

The Muthupet coastal ecosystem, located at the southernmost part of the Cauvery Delta in Tamil Nadu, is an ecologically dynamic wetland system. It forms a part of the Point Calimere Wetland Complex, which was designated as Tamil Nadu's first Ramsar site and is now recognized as one of the world's most significant wetlands (Arasumani *et al.*, 2024). This lagoon comprises a unique mosaic of mangrove forests, mudflats, estuarine waters, and tidal creeks, creating a highly productive environment that fosters ichthyofaunal diversity. The hydrodynamics of this ecosystem, shaped by freshwater inflows, tidal interactions, and monsoonal variations, make it an essential breeding, nursery, and feeding ground for numerous fish species (Abinaya *et al.*, 2025). The ichthyofaunal community plays a crucial role in nutrient cycling, ecological balance,

and sustaining both artisanal and commercial fisheries of the wetland ecosystem (Brraich & Saini, 2019). Despite its ecological and economic importance, detailed assessments of fish diversity in the Muthupet coastal ecosystem remain limited. Habitat degradation, overfishing, pollution, and climate change threaten the sustainability of fish populations in this region. Therefore, documenting species composition and distribution patterns is crucial for conservation planning, fisheries management, and ensuring the long-term sustainability of aquatic resources (Gebremedhin *et al.*, 2021).

This study aims to provide a comprehensive checklist of the ichthyo faunal diversity in the Muthupet coastal ecosystem. By offering baseline data on species richness and habitat associations, the findings of this research will contribute to the formulation of effective conservation strategies. Additionally, this study highlights the importance of protecting mangroves and estuarine ecosystems, which serve as critical habitats for commercially and ecologically significant fish species. Through biodiversity insights and conservation implications, this research supports broader efforts toward sustainable coastal resource management in India.

MATERIALS AND METHODS

Study Area

The Muthupet coastal ecosystem (latitudes 10°32' N and longitudes 79°30'–79°54'E) is situated at the southernmost part of the Cauvery River Delta, along the southeast coast of Tamil Nadu, India (Fig.1). It encompasses a vast expanse of estuarine waters, mangrove forests, mudflats, and interconnected creeks. It forms an integral part of the Point Calimere Wildlife and Bird Sanctuary, a Ramsar-designated wetland recognized for its rich biodiversity and ecological significance.

This coastal ecosystem is shaped by both freshwater and marine influences, receiving fluvial inputs from the Cauvery, Paminiyar, and Koraiyar Rivers, while also being subjected to tidal exchanges with the Bay of Bengal (Abinaya *et al.*, 2025). The region experiences a tropical monsoon climate, with peak rainfall occurring between October and December, primarily due to the northeast monsoon. The hydrology of the Muthupet Lagoon plays a critical role in maintaining suitable habitats for various aquatic organisms, including commercially and ecologically important fish species.

The mangrove vegetation, predominantly composed of *Avicennia marina*, serves as a crucial nursery ground for ichthyofauna, supporting a wide diversity of fish populations (Sarkar, 2022). The lagoon and its estuarine system sustain artisanal fisheries, with local communities heavily dependent on fish and crustacean resources for their livelihoods. However, the expansion of aquaculture, overfishing, pollution, and habitat degradation pose serious threats to the sustainability of this ecosystem.

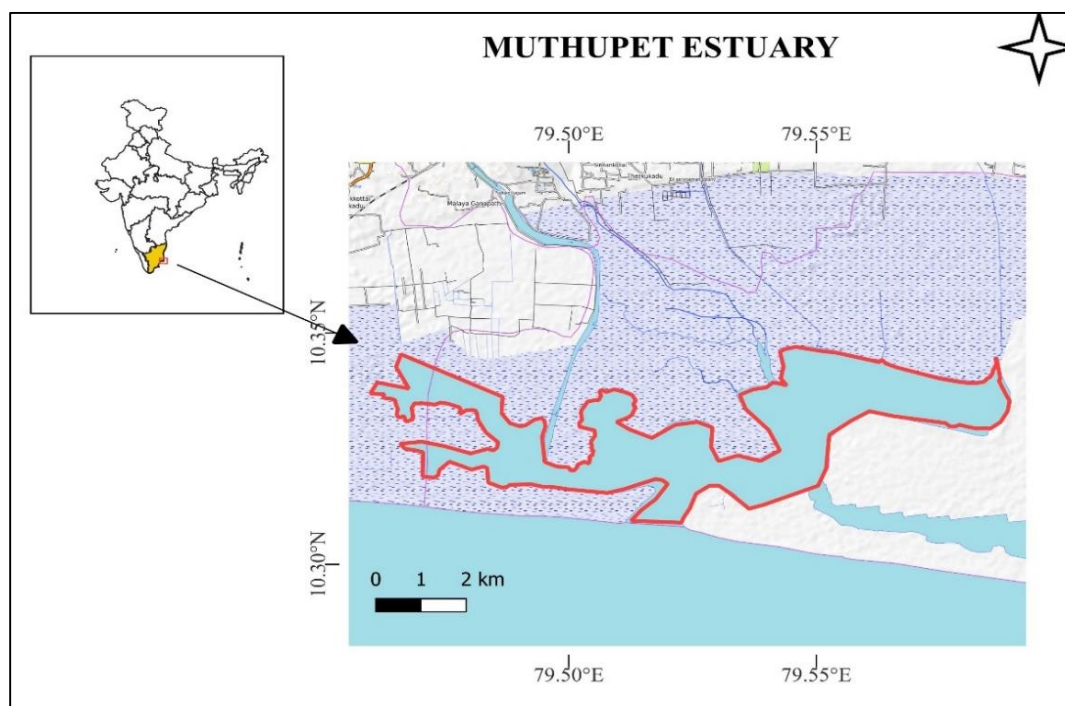


Figure 1. Study area map

Data Collection

Field surveys were conducted from January 2023 to December 2023, covering different seasons of the Muthupet Lagoon. Fish samples were obtained from local landing centers and an experimental fishing, to ensure a comprehensive representation of species across varying environmental gradients. Experimental sampling was primarily carried out within the lagoon, using surface gillnets (mesh size: 40 mm), operated by a Tamil Nadu Forest Department fibre reinforced plastic (FRP) boat during early morning hours. Fish specimens were identified on board based on morphological characteristics, using standard taxonomic keys (Fischer & Bianchi, 1984; Talwar & Jhingran, 1991). Photographs of the specimens were taken before releasing them back into the water to minimize disturbance. Species identification was further validated

using Fish Base (Froese & Pauly, 2023) and by consulting local fisheries experts and taxonomists. The conservation status of each identified fish species was determined based on the IUCN Red List of Threatened Species (IUCN, 2024) to assess their vulnerability and conservation needs.

RESULTS

This study provides a comprehensive checklist of fish species recorded in the Muthupet coastal ecosystem during 2023 (Table 1).

A total of 105 species were documented, representing two classes, 23 orders, 48 families, and 88 genera. Among them, 60 species were exclusively found within the lagoon. The class Teleostei exhibited the highest diversity, comprising 100 species, 83 genera, 44 families, and 20 orders, whereas the class Elasmobranchii was the least diverse, with only 5 species, 5 genera, 4 families, and 3 orders. Order-wise species richness is presented in Figure 2. As shown, the most species-rich order was Eupercaria/misc (20 species), followed by Clupeiformes (17 species), Carangiformes (11 species), and Acanthuriformes (8 species).

Family-wise species richness is depicted in Figure 3. Among the families, *Carangidae* was the most diverse, with 10 recorded species, followed by *Engraulidae* and *Sciaenidae*, each represented by 8 species. Genus-wise species richness is shown in Figure 4. As illustrated in Fig. 4, the genera *Nemipterus* and *Stolephorus* had the highest species count, with three species each, followed by *Chirocentrus*, *Cynoglossus*, *Johnius*, *Leiognathus*, *Lutjanus*, *Oreochromis*, *Otolithes*, *Planiliza*, *Sardinella*, *Saurida*, *Sphyræna*, *Coilia*, and *Strongylura*, each represented by two species. The remaining genera were represented by only one species.

According to the IUCN Red List (2021), 86 species were classified as Least Concern (LC), while 8 species were Not Evaluated (NE) (Fig. 5). Four species such as *Chiloscyllium griseum*, *Hyporhamphus xanthopterus*, *Oreochromis mossambicus*, and *Maculabatis gerrardi* were categorized as Vulnerable (VU). Three species, *Stolephorus indicus*, *Stolephorus insularis* and *Cynoglossus arel*, were listed as Data Deficient (DD). One species, *Rhynchobatus laevis*, was identified as Critically Endangered (CR), while *Gymnura poecilura* was classified as Near Threatened (NT).

Table 1. Checklist of finfishes from Muthupet coastal ecosystem, Palk Bay, Tamil Nadu during the study period

Species	Genus	Family	Order	Class	IUCN status (2024)
* <i>Acanthopagrus berda</i> (Fabricius, 1775)	Acanthopagrus	Sparidae	Eupercaria/misc	Teleostei	LC
* <i>Acanthurus mata</i> (Cuvier, 1829)	Acanthurus	Acanthuridae	Acanthuriformes	Teleostei	LC
* <i>Alepes djedaba</i> (Fabricius, 1775)	Alepes	Carangidae	Carangiformes	Teleostei	LC
<i>Anabas testudineus</i> (Bloch, 1792)	Anabas	Anabantidae	Anabantiformes	Teleostei	LC
* <i>Arius maculatus</i> (Thunberg, 1792)	Arius	Ariidae	Siluriformes	Teleostei	LC
<i>Atropus hedlandensis</i> (Whitley, 1934)	Atropus	Carangidae	Carangiformes	Teleostei	LC
* <i>Caranx ignobilis</i> (Forsskal, 1775)	Caranx	Carangidae	Carangiformes	Teleostei	LC
<i>Cephalopholis sonnerati</i> (Valenciennes, 1828)	Cephalopholis	Epinephelidae	Perciformes	Teleostei	LC
* <i>Chiloscyllium griseum</i> Müller & Henle, 1838	Chiloscyllium	Hemiscylliidae	Orectolobiformes	Elasmobranchii	VU
<i>Chirocentrus dorab</i> (Fabricius, 1775)	Chirocentrus	Chirocentridae	Clupeiformes	Teleostei	LC
<i>Chirocentrus nudus</i> Swainson, 1839	Chirocentrus	Chirocentridae	Clupeiformes	Teleostei	LC
* <i>Coilia neglecta</i> Whitehead, 1968	Coilia	Engraulidae	Clupeiformes	Teleostei	LC
* <i>Coilia dussumieri</i> Valenciennes, 1848	Coilia	Engraulidae	Clupeiformes	Teleostei	LC
<i>Crenimugil seheli</i> (Fabricius, 1775)	Crenimugil	Mugilidae	Mugiliformes	Teleostei	LC
<i>Cynoglossus arel</i> (Bloch & Schneider, 1801)	Cynoglossus	Cynoglossidae	Pleuronectiformes	Teleostei	DD
<i>Cynoglossus puncticeps</i> (Richardson, 1846)	Cynoglossus	Cynoglossidae	Pleuronectiformes	Teleostei	LC
* <i>Daysciaena albida</i>	Daysciaena	Sciaenidae	Eupercaria/misc	Teleostei	LC

(Cuvier, 1830)					
<i>*Dendrophysa russelii</i> (Cuvier, 1829)	Decapterus	Carangidae	Carangiformes	Teleostei	LC
<i>*Decapterus russelli</i> (Rüppell, 1830)	Dendrophysa	Sciaenidae	Eupercaria/misc	Teleostei	LC
<i>*Elagatis bipinnulata</i> (Quoy & Gaimard, 1825)	Elagatis	Carangidae	Carangiformes	Teleostei	LC
<i>*Eleutheronema tetradactylum</i> (Shaw, 1804)	Eleutheronema	Polynemidae	Carangiformes	Teleostei	EN
<i>*Ellochelon vaigiensis</i> (Quoy & Gaimard, 1825)	Ellochelon	Mugilidae	Mugiliformes	Teleostei	LC
<i>*Elops machnata</i> (Forsskal, 1775)	Elops	Elopidae	Elopiformes	Teleostei	LC
<i>Ephippus orbis</i> (Bloch, 1787)	Ephippus	Ephippidae	Acanthuriformes	Teleostei	LC
<i>*Epinephelus undulosus</i> (Quoy & Gaimard, 1824)	Epinephelus	Ephinephelidae	Perciformes	Teleostei	LC
<i>*Escualosa thoracata</i> (Valenciennes, 1847)	Escualosa	Dorosomatidae	Clupeiformes	Teleostei	LC
<i>*Etroplus suratensis</i> (Bloch, 1790)	Etroplus	Cichlidae	Cichliformes	Teleostei	LC
<i>*Eubleekeria splendens</i> (Cuvier, 1829)	Eubleekeria	Leiognathidae	Acanthuriformes	Teleostei	LC
<i>Flavocaranx bajad</i> (Fabricius, 1775)	Flavocaranx	Carangidae	Carangiformes	Teleostei	LC
<i>*Gerres erythrouros</i> (Bloch, 1791)	Gerres	Gerridae	Eupercaria/misc	Teleostei	LC
<i>Gymnura poecilura</i> (Shaw, 1804)	Gymnura	Gymnuridae	Mylobatiformes	Elasmobranchii	NT
<i>*Hyporhamphus xanthopterus</i> (Valenciennes, 1847)	Hyporhamphus	Hemiramphidae	Beloniformes	Teleostei	VU
<i>*Johnius belangerii</i> (Cuvier, 1830)	Johnius	Sciaenidae	Eupercaria/misc	Teleostei	LC
<i>Johnius amblycephalus</i> (Bleeker, 1855)	Johnius	Sciaenidae	Eupercaria/misc	Teleostei	LC
<i>*Lates calcarifer</i> (Bloch, 1790)	Lates	Latidae	Carangaria	Teleostei	LC

<i>*Leiognathus brevirostris</i> (Valenciennes, 1835)	Leiognathus	Leiognathidae	Acanthuriformes	Teleostei	LC
<i>*Leiognathus equula</i> (Forsskal, 1775)	Leiognathus	Leiognathidae	Acanthuriformes	Teleostei	LC
<i>Lobotes surinamensis</i> (Bloch, 1790)	Lobotes	Lobotidae	Acanthuriformes	Teleostei	NE
<i>Lutjanus lutjanus</i> Bloch, 1790	Lutjanus	Lutjanidae	Eupercaria/misc	Teleostei	LC
<i>*Lutjanus rivulatus</i> (Cuvier, 1828)	Lutjanus	Lutjanidae	Eupercaria/misc	Teleostei	LC
<i>*Maculabatis gerrardi</i> (Gray, 1851)	Maculabatis	Dasyatidae	Mylobatiformes	Elasmobranchii	VU
<i>Megalaspis cordyla</i> (Linnaeus, 1758)	Megalaspis	Carangidae	Carangiformes	Teleostei	EN
<i>Mene maculata</i> (Bloch & Schneider, 1801)	Mene	Menidae	Carangaria/misc	Teleostei	LC
<i>*Mugil cephalus</i> Linnaeus, 1758	Mugil	Mugilidae	Mugiliformes	Teleostei	LC
<i>Muraenesox bagio</i> (Hamilton, 1822)	Muraenesox	Muraenesocidae	Anguilliformes	Teleostei	LC
<i>*Mystus gulio</i> (Hamilton, 1822)	Mystus	Bagridae	Siluriformes	Teleostei	LC
<i>*Nematalosa nasus</i> (Bloch, 1795)	Nematalosa	Dorosomatidae	Clupeiformes	Teleostei	LC
<i>Nemipterus bipunctatus</i> (Valenciennes, 1830)	Nemipterus	Nemipteridae	Eupercaria/misc	Teleostei	LC
<i>Nemipterus japonicus</i> (Bloch, 1791)	Nemipterus	Nemipteridae	Eupercaria/misc	Teleostei	LC
<i>Nemipterus nematophorus</i> (Bleeker, 1854)	Nemipterus	Nemipteridae	Eupercaria/misc	Teleostei	LC
<i>Nibea maculata</i> (Bloch & Schneider, 1801)	Nibea	Sciaenidae	Eupercaria/misc	Teleostei	LC
<i>Nuchequula gerreoides</i> (Bleeker, 1851)	Nuchequula	Leiognathidae	Acanthuriformes	Teleostei	LC
<i>Ophichthus naevius</i> Kodeeswaran, Kathirvelpandian, Mohapatra, Kumar & Sarkar, 2023	Ophichthus	Ophichthidae	Anguilliformes	Teleostei	NE

<i>*Opisthopterus tardoore</i> (Cuvier, 1829)	Opisthopterus	Pristigasteridae	Clupeiformes	Teleostei	LC
<i>*Oreochromis mossambicus</i> (Peters, 1852)	Oreochromis	Cichlidae	Cichliiformes	Teleostei	VU
<i>*Oreochromis niloticus</i> (Linnaeus, 1758)	Oreochromis	Cichlidae	Cichliiformes	Teleostei	LC
<i>*Osteogeneiosus militaris</i> (Linnaeus, 1758)	Osteogeneiosus	Ariidae	Siluriformes	Teleostei	LC
<i>Ostorhinchus fasciatus</i> (White, 1790)	Ostorhinchus	Apogonidae	Kurtiformes	Teleostei	LC
<i>*Otolithes cuvieri</i> (Trewavas, 1974)	Otolithes	Sciaenidae	Eupercaria/misc	Teleostei	LC
<i>Otolithes ruber</i> (Bloch & Schneider, 1801)	Otolithes	Sciaenidae	Eupercaria/misc	Teleostei	LC
<i>*Pampus chinensis</i> (Euphrasen, 1788)	Pampus	Stromateidae	Scombriformes	Teleostei	NE
<i>*Panna microdon</i> (Bleeker, 1849)	Panna	Sciaenidae	Eupercaria/misc	Teleostei	LC
<i>Parapercis alboguttata</i> (Günther, 1872)	Parapercis	Pinguipedidae	Perciformes/ Uranoscopoidei	Teleostei	LC
<i>Parascolopsis aspinosa</i> (Rao & Rao, 1981)	Parascolopsis	Nemipteridae	Eupercaria/misc	Teleostei	LC
<i>Parupeneus indicus</i> (Shaw, 1803)	Parupeneus	Mullidae	Mulliformes	Teleostei	LC
<i>Pastinachus sephen</i> (Fabricius, 1775)	Pastinachus	Dasyatidae	Mylobatiformes	Elasmobranchii	LC
<i>*Pelates quadrilineatus</i> (Bloch, 1790)	Pelates	Terapontidae	Centrarchiformes	Teleostei	LC
<i>*Pellona ditchela</i> Valenciennes, 1847	Pellona	Pristigasteridae	Clupeiformes	Teleostei	LC
<i>*Planiliza parsia</i> (Hamilton, 1822)	Planiliza	Mullidae	Mulliformes	Teleostei	LC
<i>*Planiliza macrolepis</i> (Smith, 1846)	Planiliza	Mullidae	Mulliformes	Teleostei	NE
<i>Plicofollis dussumieri</i>	Plicofollis	Ariidae	Siluriformes	Teleostei	LC

(Valenciennes, 1840)					
<i>*Plotosus canius</i> Hamilton, 1822	Plotosus	Plotosidae	Siluriformes	Teleostei	LC
<i>*Pomadasys kaakan</i> (Cuvier, 1830)	Pomadasys	Haemulidae	Eupercaria/misc	Teleostei	LC
<i>*Psammoperca waigiensis</i> (Cuvier, 1828)	Psammoperca	Latidae	Carangaria/misc	Teleostei	NE
<i>Pseudotriacanthus strigilifer</i> (Cantor, 1849)	Pseudotriacanthus	Triacanthidae	Tetraodontiformes	Teleostei	LC
<i>Rachycentron canadum</i> (Linnaeus, 1766)	Rachycentron	Rachycentridae	Carangiformes	Teleostei	LC
<i>Rhynchobatus laevis</i> (Bloch & Schneider, 1801)	Rhynchobatus	Rhinidae	Rhinopristiformes	Elasmobranchii	CR
<i>Sardinella albella</i> (Valenciennes, 1847)	Sardinella	Dorosomatidae	Clupeiformes	Teleostei	LC
<i>*Sardinella gibbosa</i> (Bleeker, 1849)	Sardinella	Dorosomatidae	Clupeiformes	Teleostei	LC
<i>Saurida tumbil</i> (Bloch, 1795)	Saurida	Synodontidae	Aulopiformes	Teleostei	LC
<i>*Saurida undosquamis</i> (Richardson, 1848)	Saurida	Synodontidae	Aulopiformes	Teleostei	LC
<i>Scarus ghobban</i> Fabricius, 1775	Scarus	Scaridae	Eupercaria/misc	Teleostei	LC
<i>Scolopsis aurata</i> (Park, 1797)	Scolopsis	Nemipteridae	Eupercaria/misc	Teleostei	LC
<i>Scomberoides lysan</i> (Fabricius, 1775)	Scomberoides	Carangidae	Carangiformes	Teleostei	LC
<i>Selaroides leptolepis</i> (Cuvier, 1833)	Selaroides	Carangidae	Carangiformes	Teleostei	LC
<i>Seriola quinqueradiata</i> Temminck & Schlegel, 1845	Seriola	Carangidae	Carangiformes	Teleostei	LC
<i>*Setipinna taty</i> (Valenciennes, 1848)	Setipinna	Engraulidae	Clupeiformes	Teleostei	LC
<i>*Siganus canaliculatus</i> (Park, 1797)	Siganus	Siganidae	Acanthuriformes	Teleostei	LC
<i>*Sillago sihama</i> (Fabricius, 1775)	Sillago	Sillaginidae	Eupercaria/misc	Teleostei	LC

<i>*Sphyraena acutipinnis</i> Day, 1876	Sphyraena	Sphyraenidae	Carangaria/misc	Teleostei	LC
<i>Sphyraena obtusata</i> Cuvier, 1829	Sphyraena	Sphyraenidae	Carangaria/misc	Teleostei	LC
<i>*Stolephorus commersonnii</i> Lacepède, 1803	Stolephorus	Engraulidae	Clupeiformes	Teleostei	LC
<i>*Stolephorus indicus</i> (van Hasselt, 1823)	Stolephorus	Engraulidae	Clupeiformes	Teleostei	DD
<i>Stolephorus insularis</i> Hardenberg, 1933	Stolephorus	Engraulidae	Clupeiformes	Teleostei	DD
<i>*Strongylura leiura</i> (Bleeker, 1850)	Strongylura	Belonidae	Beloniformes	Teleostei	NE
<i>*Strongylura strongylura</i> (van Hasselt, 1823)	Strongylura	Belonidae	Beloniformes	Teleostei	NE
<i>Synaptura albomaculata</i> Kaup, 1858	Synaptura	Soleidae	Pleuronectiformes	Teleostei	LC
<i>*Terapon puta</i> Cuvier, 1829	Terapon	Terapontidae	Centrarchiformes	Teleostei	NE
<i>*Thrissina vitrirostris</i> (Gilchrist & Thompson, 1908)	Thrissina	Engraulidae	Clupeiformes	Teleostei	LC
<i>*Thryssa mystax</i> (Bloch & Schneider, 1801)	Thryssa	Engraulidae	Clupeiformes	Teleostei	LC
<i>Trachinocephalus myops</i> (Forster, 1801)	Trachinocephalus	Synodontidae	Aulopiformes	Teleostei	LC
<i>*Triacanthus biaculeatus</i> (Bloch, 1786)	Triacanthus	Triacanthidae	Tetraodontiformes	Teleostei	LC
<i>*Tylosurus crocodilus</i> (Péron & Lesueur, 1821)	Tylosurus	Belonidae	Beloniformes	Teleostei	LC
<i>Upeneus tragula</i> Richardson, 1846	Upeneus	Mullidae	Mulliformes	Teleostei	LC
<i>Zebrias quagga</i> (Kaup, 1858)	Zebrias	Soleidae	Pleuronectiformes	Teleostei	LC

*Recorded finfishes of Muthupet lagoon

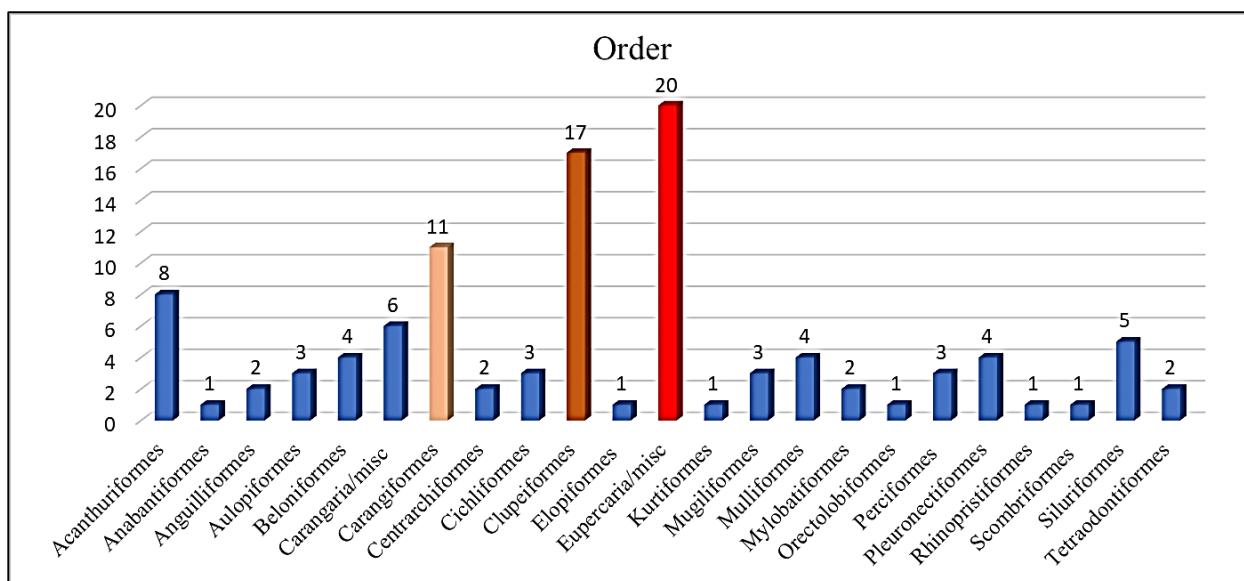


Figure 2. The distribution of fish species richness across Orders from Muthupet coastal ecosystem, Palk Bay, Tamil Nadu during the study period

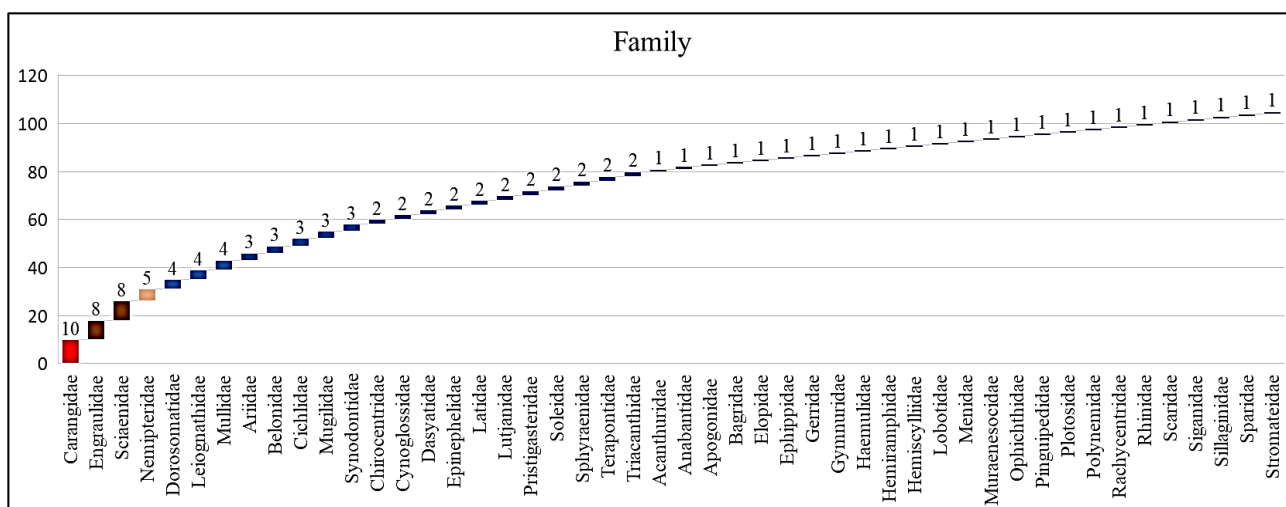


Figure 3. The distribution of fish species richness across Families from Muthupet coastal ecosystem, Palk Bay, Tamil Nadu during the study period

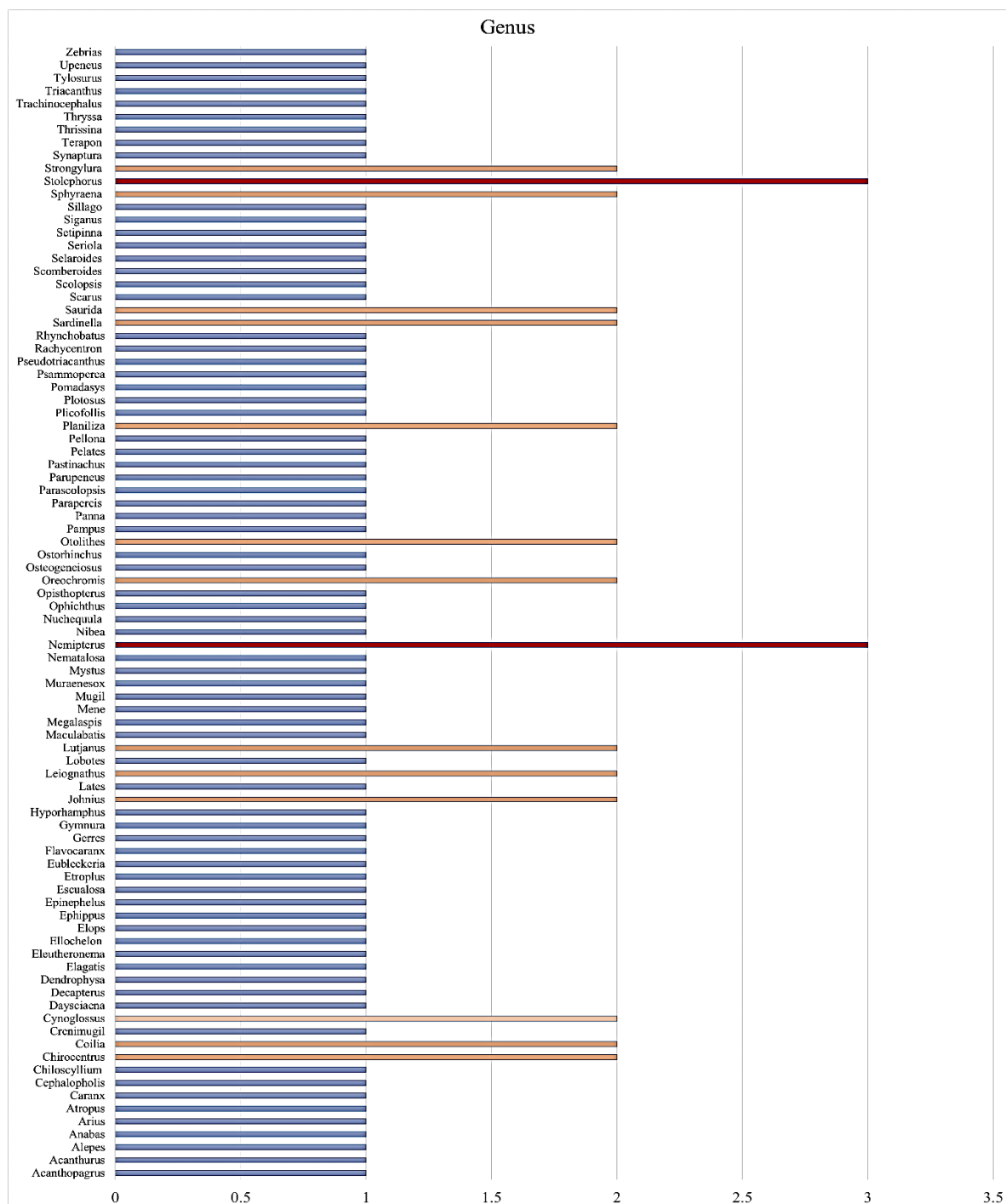


Figure 4. The distribution of fish species richness across Genus from Muthupet coastal ecosystem, Palk Bay, Tamil Nadu during the study period

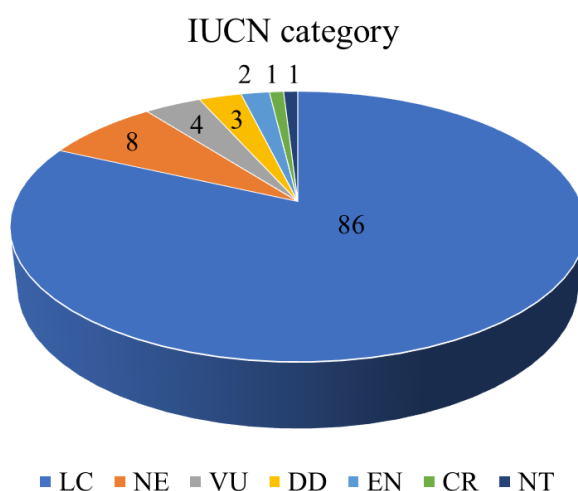


Figure 5. The distribution of fish species across IUCN category from Muthupet coastal ecosystem, Palk Bay, Tamil Nadu during the study period

The most common species in the estuarine system included *Etroplus suratensis*, *Oreochromis mossambicus*, *Gerres erythrouros*, *Ellochelon vaigiensis*, *Mugil cephalus*, and *Arius maculatus*. Among them, *Mugil cephalus* and *Oreochromis mossambicus* were recorded consistently throughout the year during the study period.

More than 95% of the recorded species have economic importance, playing a crucial role in subsistence and artisanal fisheries throughout the year. The high diversity of fish species within the Muthupet Lagoon showed its importance as a nursery ground and feeding habitat, sustaining local fisheries and contributing to the livelihoods of coastal communities.

DISCUSSION

The ichthyofaunal diversity recorded in the Muthupet coastal ecosystem showed the ecological significance of this dynamic wetland system. The documentation of 105 species across 23 orders and 48 families reflected the rich biodiversity of the lagoon and its associated estuarine waters. This record was more than Rajakumar (2016) study who found out that 53 finfish species with 18 shellfish species and Pandian (1985) who recorded 73 finfish species from Muthupet estuary. The recorded species richness of the Agniyar nearby estuary (76 species) is also indicative of high fish diversity. Ramanujam and Anbarasan (2009) and Mogalekar *et al.* (2017) recorded more than 70 species of fishes from Punnakayal and Yedayanthittu estuaries of Tamil Nadu. Similarly, the Adyar estuary complex in Chennai Corporation documented 98 species (Ramanujam *et al.* 2014), whereas the Kaliveli floodplain and Uppukalli creek in Pondicherry exhibited 40

species (Ramanujam, 2005). These comparisons suggest that Muthupet estuary is the most species-rich estuarine system in Tamil Nadu, reinforcing its importance as biodiversity hotspots.

The dominance of Teleostei aligns with global trends in fish diversity, as teleosts exhibit high adaptability to varying environmental conditions (Nelson *et al.*, 2006). In contrast, the lower diversity of Elasmobranchii due to their physiological limitations in dealing with fluctuating salinity levels in brackish water (Wosnick & Freire, 2013). The high species richness within Clupeiformes and Carangiformes reflects the presence of diverse feeding guilds and trophic interactions in the ecosystem (Olher & Gasalla, 2023). The dominance of Carangidae, Engraulidae, and Sciaenidae suggests that small pelagic and demersal fish play a key role in local fisheries and food webs (Willems *et al.*, 2015). The abundance of filter-feeding species such as *Mugil cephalus* and *Ellochelon vaigiensis* indicated the high primary productivity of the lagoon which supporting nutrient cycling and energy transfer within the ecosystem (Cardona, 2016).

The presence of 60 species exclusive to the lagoon reinforces its function as a critical nursery and breeding ground. The lagoon provides a sheltered environment with nutrient-rich waters, supporting the growth and recruitment of juvenile fish before they migrate to deeper estuarine or marine areas (Brehmer *et al.*, 2013). Species such as *Etroplus suratensis* recorded throughout the year, demonstrate the resilience of euryhaline species to fluctuating salinity levels, a characteristic feature of estuarine environments. Marbade *et al.* (2023) also stated that *E. suratensis* is naturally found in estuarine environments and has been noted to have a high salinity tolerance.

The high frequency of *Arius maculatus* and *Gerres erythrouros* in the study suggests that estuarine specialists thrive in Muthupet, utilizing its mangrove and mudflat habitats for foraging and reproduction. Mangrove-associated fish species benefit from the structural complexity of mangrove roots, which provide shelter from predators and strong currents, enhancing juvenile survival rates (Nanjo *et al.*, 2014). The IUCN Red List assessment indicates that 87 species are categorized as LC, suggesting that the majority of the recorded species are relatively stable. However, the presence of four VU species, one CR species, and two Data Deficient DD species highlights the conservation challenges facing the ecosystem. The CR species recorded in the study requires urgent conservation attention, as its population is likely threatened by overfishing, habitat degradation, and climate change.

The expansion of aquaculture, overfishing, and habitat modification in the Muthupet region are significant threats to fish diversity. Unregulated fishing practices, including the use of small-mesh nets, could lead to the depletion of juvenile fish populations, impacting the recruitment potential of commercially important species. Mangrove deforestation and increased pollution from coastal settlements may further degrade the habitat, reducing its ability to support fish populations. With over 95% of the recorded species having economic value, the socio-economic dependence on fisheries in the Muthupet Lagoon is evident. Subsistence and artisanal fisheries form the backbone of local livelihoods, relying heavily on species such as *Mugil cephalus*, *Ellochelon vaigiensis*, and *Arius maculatus* for daily sustenance and trade. The year-round occurrence of economically valuable species suggests that Muthupet supports a stable fishery, but sustainable management strategies must be implemented to prevent overexploitation. Encouraging community-based conservation programs, promoting seasonal fishing bans, and adopting gear regulations could help maintain fish stocks at sustainable levels while preserving biodiversity.

CONCLUSION

The findings of this study provide baseline data for conservation planning and sustainable fisheries management in the Muthupet coastal ecosystem. The high species diversity and the presence of vulnerable and endangered species showed the need for conservation interventions, including mangrove restoration initiatives to enhance habitat quality, sustainable fisheries policies to regulate fishing pressure on vulnerable species, long-term biodiversity monitoring to track changes in species composition over time. Future research should focus on understanding population trends, genetic diversity, and the impacts of climate change on ichthyofaunal communities to ensure the long-term ecological and economic sustainability of this critical coastal habitat.

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8 FIRST SYNCHRONIZED POPULATION ESTIMATION AND SOCIAL ORGANIZATION OF NILGIRI TAHR *NILGIRITRAGUS HYLOCRIUS* IN TAMIL NADU, SOUTH INDIA

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ABSTRACT

The Nilgiri tahr (*Nilgiritragus hylocrius*) is an endangered and endemic mountain ungulate of the Southern Western Ghats of India. The tahr population is threatened by habitat loss, fragmentation, and population isolation in its distributional ranges. Though the population estimates from certain protected areas were available for the study species, it was not comprehensive. The first synchronized survey on Nilgiri tahr in its distributional range was surveyed in 140 survey blocks, in 36 forest ranges using bounded count method in fragmented forests and double observer method in contiguous forests during April 29, 30 and May 1, 2024. The estimated population of Nilgiri tahr was 1,031 with an average detection probability of 0.5. The Anamalai hills, Srivilliputhur, Megamalai, and Nilgiri Hills hold 90% of the population. The Anamalai and Nilgiri hills hold 41% and 24% respectively, of the metapopulation that serves as the source population for the long-term conservation of the species in the fragmented landscape. The male-female sex ratio was 1:2 and the female-calf ratio was 2:1. The age composition revealed that adult female constituted 42.2%, followed by adult male (25.1%), young (19.1%) and yearling (13.6%). Further, the study has identified newly colonized habitats of Nilgiri tahr in the Pasumalai habitat in the Chinnamanur range of the Megamalai division. This is the first synchronized survey of the tahr population as part of Project Nilgiri tahr's initiative to conserve Nilgiri tahr in Tamil Nadu.

Keywords: Nilgiri tahr, population estimation, Anamalai hills, Nilgiris, age composition, newly colonized habitats of tahr

INTRODUCTION

Estimation of wildlife population with precision and accuracy is essential in wildlife management (Williams, 2002). Population density and age structure are essential to understand the population biology of species. Estimating proper density and age composition is essential for assessing the impact of poaching, habitat management, and population management of endangered species. Wild ungulates help to maintain stable ecosystem by altering vegetation structure, plant species composition and nutrient recycling through foraging (Bagchi & Ritchie, 2010). They also influence predator abundance being prey species for the carnivores. Thus, estimation of population of essential with a robust method is essential to understand the implication of a management action, prey-predator interaction and population trend for planning conservation action of an endangered species.

Nilgiri tahr (*Nilgiritragus hylocruis*) is a mountain ungulate belongs to the tribe Caprini, which is endemic to Southern Western Ghats, India (Davidar, 1978; Ropiquet & Hassanin, 2005). It is categorized as an endangered species in the red list of IUCN and also listed in the Schedule I of the Indian Wildlife (Protection) Act, 1972. The estimated population to be 2000-3000 individuals based on literature survey and existing data (Daniel *et al.*, 2008; Predit *et al.*, 2015). The population of Nilgiri tahr have been monitored for several years for the specific protected areas such as Anamalai Tiger Reserve (Kumar *et al.*, 2002; Suryawanshi *et al.*, 2020) and the Nilgiris (Schaller, 1970; Davidar, 1963; Sumithran, 1997). The most recent estimate for the Anamalai Tiger Reserve and Nilgiris was 510 and 246 respectively in the year 2018 (Suryawanshi *et al.*, 2021; Murugan, 1997). Though the population estimation was available for certain protected areas, the estimate could not be directly compared due to differences in the methods adapted and sample area. In the current study, we sampled almost entire distributional ranges of the Nilgiri tahr habitat. Hence, it is comprehensive estimation of population and can be used as baseline data for further monitoring.

The Nilgiri tahr is a social animal found in mixed herds composed of adult females and their young. Adult males associate with mixed herds during the breeding season, but are often solitary or found in smaller male groups during the non-breeding season (Davidar, 1978; Rice, 1984). Female herds inhabit particular home ranges while adult males move freely among mixed herds. Males are larger than females, and rut is

during the monsoon season though breeding may occur throughout the year. The gestation period is about six months (Prater, 1971; Davidar, 1978). We report changes in the group size, composition, sex ratio and female-kid ratio in the fragmented and intact habitats.

MATERIALS AND METHODS

Study area

To identify all potential tahr habitat across the distributional range, we collected exiting data on the historical distribution of tahr by extensive examination and reference of available literature. The potential distribution area of Nilgiri tahr is 5713.8 sq.km of that 58.3% area is in the Tamil Nadu and 41.6% in Kerala (Predit *et al.*, 2015). We also used habitat requirement of Nilgiri tahr such as grassland, sholas and cliff to identify potential distributional area (Fig.1). The landscape is classified into four major areas, *i.e.* Nilgiris, Anamalai Tiger Reserve (ATR), Srivilliputhur-Megamalai Tiger Reserve (SMTR), and Kalakkad-Mundanthurai Tiger Reserve (KMTR).

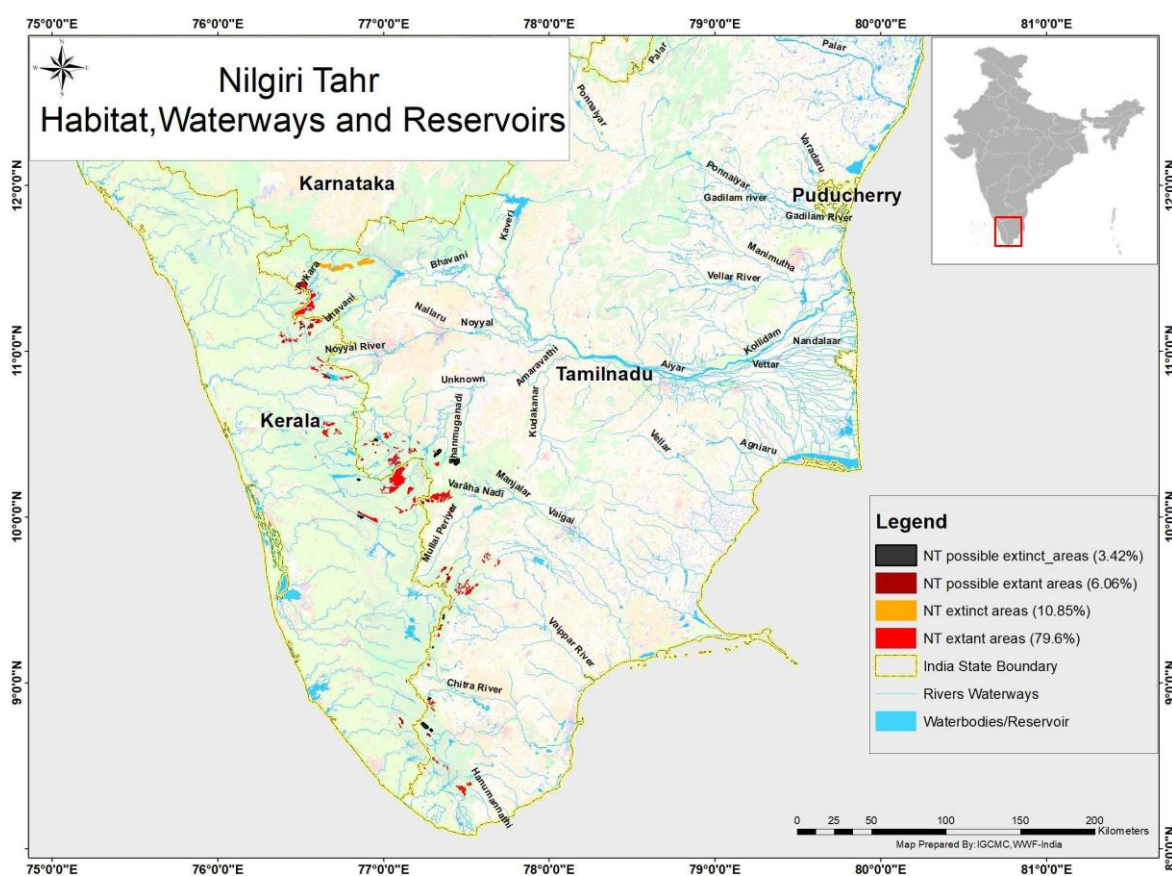


Figure 1. Map showing the distributional area of Nilgiri tahr in the different landscapes

Pilot survey

We conducted a preliminary study of the habitats to determine survey blocks for the synchronized population estimation. A pilot survey was carried out by using four methods viz., total count (Overton *et al.*, 1969), bounded count, double observer method, and drone count in Grass Hill National Park (GHNP). In the total count method, we recorded the total number of Nilgiri tahr observed within the sample area. The Nilgiri tahr population was surveyed using DJI MAVIC 3 drones equipped with high-definition 20-megapixel cameras, 7x focal length Hasselblad telescopic lenses, and high-precision global navigation systems, including Galileo and BeiDou. The total sample area for the pilot survey was 31.23 sq.km within GHNP, with an elevation over 2000 meters above mean sea level (MSL) in the Anamalai Tiger Reserve.

The Nilgiri tahr distribution range is divided into 13 divisions, Gudalur, Nilgiris, Coimbatore, Pollachi, Tiruppur, Theni, Srivilliputhur, Megamalai, Tirunelveli, Kalakad, Ambasamudram and Kanyakumari. The sampling was done in the 36 forest ranges, 101 forest beats and 140 survey blocks. In total 708 field staffs covered foot survey of 1862 km in various landscapes.

Training and capacity building

Organized training program for frontline field staff on using equipment and methods to be followed in the survey. The experts from the International Union for Conservation of Nature (IUCN), Wildlife Institute of India (WII), Advanced Institute for Wildlife Conservation (AIWC), Vandalur and WWF-India participated in the planning and execution of the survey. A total of 336 field staff were trained on the use of field equipment such as binoculars (Olympus 10x50), spotting scope (25-75, x100mm), GPS (Garmin e-trex 22x), field compass, Range finder, and wireless communication devices. Frontline staff were trained on the methods used for the survey, such as bounded count, double-observer method and age-sex classification of Nilgiri tahr.

Survey methods

The synchronized survey was conducted for three days using bounded count and double observer methods (Nichols *et al.*, 2000) from April 29, 30 and May 1, 2024. Among 140 blocks, bounded count was carried out in the 128 blocks and double observer method was followed in 12 blocks of contiguous habitats and three blocks in

the adjacent Kerala, namely Sispara, Vembanthanni and Poovar. The survey route within the block was recorded using mobile application GPS logger or GPS device. On sighting of the Nilgiri tahr, the team observer has recorded the number of individuals, GPS location, and classified the individuals into different age-sex classes using binoculars and photographs.

Nilgiri thar were classified into different age-sex class based on Schaller (1970) and Davidar (1978), and provided in the table 1.

Table 1. Classification of Nilgiri tahr based on age-sex class

Sl. No.	Age-sex class	Description
1	0-6 months New-born	Fawn-coloured; sprouting horns; primarily associated with adult females, and the presence of a white patch on the dorsal nostril.
2	0-1 year Young	Grey-brown or light brown coat; horns are straight, growing up to 7cm; height 45 cm at the shoulder.
3	1-2 years Yearling	Grey-brown coat; horn size is 12 cm, tends to curve backwards; carpal patch on front legs; height 60 cm at shoulder.
4	2+ years Adult Female	Grey-brown coat with paler under parts; shoulder height 70-80 cm, backwards curved horns with more inter-horn space and slightly diverged, with a length of 80 cm; presence of a distinct carpal patch.
5	2-4 years Light-brown Male	Similar in body size and pelage to adult females; horns are thicker with less inner horn space, and distinct facial markings; distinguished based on genitals.
6	4-6 years Dark-brown male	Grey-brown coat; larger horns and more distinct facial strip running towards muzzle; white carpal patches, paler underparts and well-developed scrotal sac.
7	6+ years Saddle-back male	Alpha male; Dark brown coat with an area of light brown/white/silvery hair covering lower back; prominent facial markings and carpal patches

Double observer method

Estimating the abundance of mountain ungulates is challenging due to rugged terrain and associated logistics problems (Singh & Milner-Gulland, 2011). The double observer survey method (DO) allows for estimation of detection probability with a cost-effective survey design (Caughley, 1974; Magnusson *et al.*, 1978). The method is based on two observers independently counting animals at the sample time, and the count data are subsequently compared with a mark-recapture procedure, a Lincoln-Peterson-like approach (Forsyth & Hickling, 1997; Sutherland, 2006). This method allows a

mark-resight analysis without the need to mark individuals, with only a single visit to each location, and is relatively easy to perform in the field. This method has been successfully used to monitor mountain ungulates (Ghoddousi *et al.*, 2019; Suryawanshi *et al.*, 2020). The DO method is generally performed only in relatively large areas; we applied this method to estimate the population of tahr in the intact forest areas of Anamalai and Nilgiris.

We ensured the assumptions of this method are met, such as 1. Closure of population during the survey: The survey duration was short, and three days ensured population closure. 2. Detected groups should be individually identifiable by the observers. We identified groups based on location, group size, composition, distinct trait and movement direction (Otis *et al.*, 1978). 3. To ensure the independence of the two counts (Magnusson *et al.*, 1978), in this method, two observers survey a trail simultaneously with an interval of 30 minutes, and they do not cue each other about the presence of the animal. The data was compiled based on both observers' findings, and the group size was validated. The detection was coded as 1-1 (detected by both observers) and as 1-0/0-1 (detected by either of the observers). The actual number of groups present in the area is estimated with equation (1) by Forsyth and Hickling (1997), derived from the Lincoln-Petersen approach in the capture-mark-recapture framework, but conducted on groups rather than on individuals.

$$G_{est} = \frac{(B+S_1+1)(B+S_2+1)}{B+1} - 1$$

Where G_{est} = estimated number of groups; B = group seen by both observers, S_1 = groups detected only by observer 1, S_2 = groups detected only by observer 2.

Group detectability (p) is estimated for each observer as the number of groups detected (G_{det}) divided by the number of groups estimated (G_{est})

$$p = G_{det}/G_{est}$$

Estimated population (N_{est}) is given by the estimated number of groups (G_{est}) multiplied by the estimated mean group size (S_{est}) calculated as the average size of all groups observed (Forsyth & Hickling, 1977; Suryawanshi *et al.*, 2020).

$$N_{est} = G_{est} \times S_{est}$$

We estimated the total number of Nilgiri tahr groups using the two-survey mark-recapture in the multmark R package which uses the Bayesian analysis of conventional capture-recapture in R. 4.4.1 (McClintock, 2015; R Core Team, 2018).

Bounded count method

The population of mountain ungulate is generally estimated using outer bound/bounded count method, due to inaccessible terrain, changes in detection probability across sample area (Regier & Robson, 1966). Survey was carried for three consecutive days, counting all the Nilgiri tahr encountered during the survey from morning to evening in the specified sample area. Sample blocks were surveyed from a vantage point for greater visibility and sampled for three days.

The population of Nilgiri tahr (N) is estimated as follows

$$N = X_m + [X_m - X_{m-1}]$$

Where $X_{(1)} \leq X_{(2)} \dots X_{(m)} X_{(m-1)}$ denotes the number of Nilgiri tahr observed in consecutive days, arranged in the increasing order.

The lower confidential limit (N_L) is the largest count observed in the block (*i.e*) $N_L = X_m$

$$N_U = X_m + [X_m - X_{m-1}][1 - \alpha/\alpha]$$

Where X_m is the largest count and X_{m-1} is the second largest count of Nilgiri tahr pertaining to each block. Similarly, α is the standard type-I error. In this study α is fixed as 20% as per the protocols adopted by Seber (1973) and Routledge (1982). Data from 128 fragmented habitats was analysed using bounded count method.

RESULTS

The pilot survey results provide insight on different methods of population estimation of Nilgiri tahr. Among the four methods evaluated, bounded count and DO method estimates with 95% CI of mean were similar with 350 (220-350) and 323 (113-652). The estimates from the other methods were relatively less 220 and 187 in the total and drone survey methods respectively. The DO method and bounded count method were adopted for the synchronised survey.

Estimated population at Nilgiris

The estimated population of Nilgiri tahr in the Mukuruthi National Park and adjacent Kerala using DO method is 203 (76-514). The estimated number of groups being 24 with mean group size of nine. The probability of detection of the first and second observers were 0.67 and 0.37. The estimated Nilgiri tahr in the fragmented areas of Nilgiris (Nilgiris South and North Forest division and Gudalur) was 53 individuals based on bounded count method. Thus, total estimated population of tahr was 256.

Estimated population at Grass hills National Park

The estimated population of Nilgiri tahr in the Grass hills National Park is 276 (51-976). The mean group size was 14. The probability of detection of first and second observer was same (0.5). The Nilgiri tahr population in the fragmented habitats of ATR (Tiruppur and Pollachi) is 148 individuals. Thus, the total population for the Anamalai hills was 424.

Estimated population in the fragmented habitats

The estimated total population of Nilgiri tahr in the fragmented habitat is 552 (363-1119). The estimated Nilgiri tahr population in different landscapes, Nilgiris, ATR (Tiruppur and Pollachi), SMTR (Theni, Megamalai, and Srivilliputhur) and KMTR zones (Tirunelveli, Ambasamudram and Kalakkad) are 53, 148, 250 and 101 respectively (Fig.2).

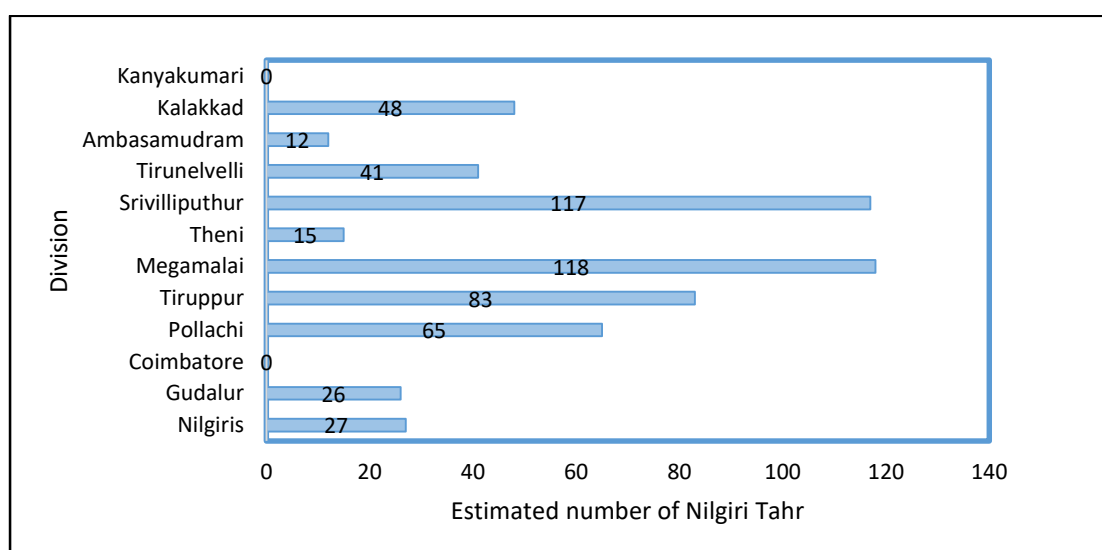


Figure 2. Estimated Nilgiri tahr population in the fragmented habitats of Tamil Nadu

Based on the synchronized survey, the estimated population of Nilgiri tahr in Tamil Nadu is 1031. The estimated population in the adjacent Eravikulam National Park in Kerala is 827. Thus, total population of Nilgiri tar in their distributional range is 1858. The population of tahr in the contiguous and fragmented landscape of Nilgiris and ATR constitute 65% (680) of the population. The habitats in the southern region SMTR and KMTR zones holds 25% (250) and 10% (101) of the population respectively

Social organization

The mean herd size of the Nilgiri tahr was higher in the Grass hills followed by Mukuruthi with 15.2 and 8.3, respectively. The herd size was larger in the intact habitats than the fragmented area (Fig 3).

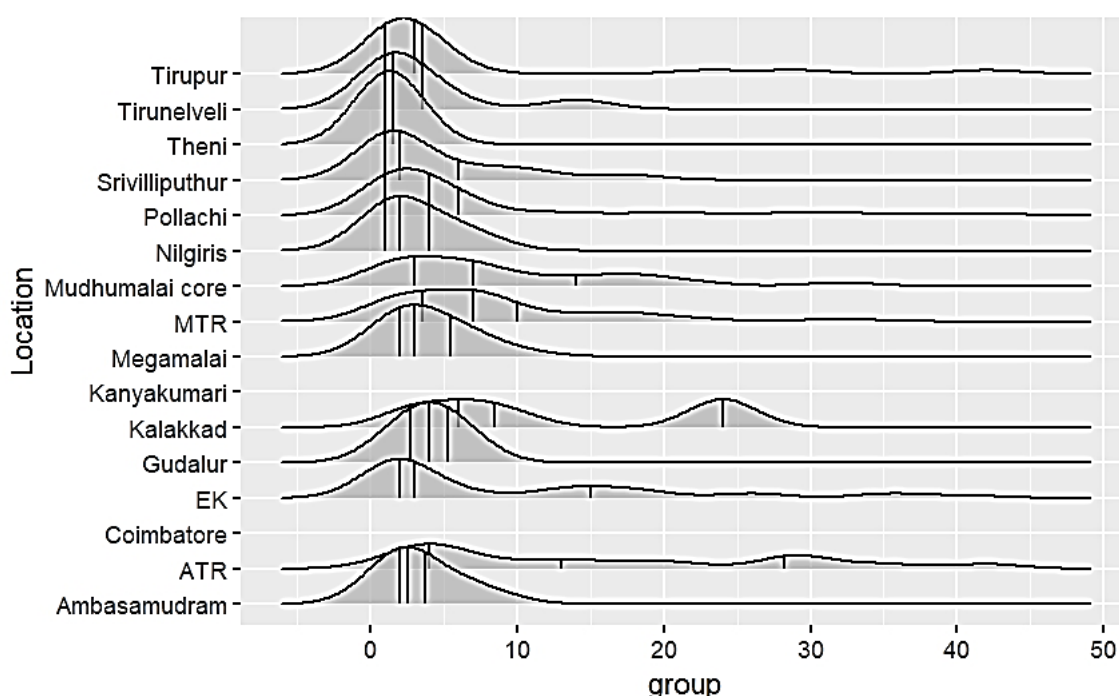


Figure 3. Group size distribution of Nilgiri tahr across the habitats in Tamil Nadu and Kerala with mean group size and (95% CI of mean)

Age-sex composition

The age composition revealed that adult females constituted 42.2%, followed by adult males (25.1%), young ones (19.1%) and yearlings (13.6%). The male-female sex ratio was 1:2 and the female-calf ratio was 2:1.

DISCUSSION

An assessment of the population using reliable methods is crucial for evaluating population trends and the effects of management interventions. Among the four methods studied, the double observer method and the bounded count method yielded similar results and provided statistically robust estimates. Therefore, in the current survey, the bounded count method was applied to fragmented landscapes. In contrast, the double observer method was utilized in intact areas to estimate the Nilgiri tahr population in Tamil Nadu.

Nilgiri tahr population in the intact habitats

Despite the Nilgiri tahr's endangered status and high endemism, few studies have been conducted to assess the extent of its population within its distribution range. This report presents the first population estimate for the entire distribution area. Among the 13 forest divisions surveyed, the majority of the Nilgiri tahr population is concentrated in two protected areas of Tamil Nadu: Mukurthi National Park and Grass Hill National Park. The estimated population in Mukurthi National Park, including the adjacent Silent Valley National Park area, is 203, which is consistent with the earlier estimate from 1997 (Murugan, 1997) but lower than the more recent estimate of 463 from 2015 (Predit *et al.*, 2015). Previous population estimates from earlier studies were 176, 450, and 152, based on the research of Schaller (1970), Davidar (1978), and Smithran (1997), respectively. The population estimates may not be directly comparable due to differences in methods and survey efforts. However, the overall Nilgiri tahr population has fluctuated between 176 and 400 individuals in Mukuruthi National Park.

In the fragmented habitats of the Nilgiris, there were no direct sightings of tahr in the Terrace estate/Gundukal parai, Pandiyar top, and Kinnakorai. However, anthropogenic pressures, including plantation activities, the spread of invasive species (*Acacia mearnsii*), and cattle grazing, were recorded in these areas.

The estimated population of Nilgiri tahr in the Grass Hill National Park was 276, which aligns with earlier estimates for the area (Rice, 1984; Mishra & Johnsingh, 1998). However, this figure is lower than a more recent estimate of 510 (Suryawanshi *et al.*, 2020). In the earlier study the duration of survey span was about a month, which could

potentially influence herd movement among survey patches and validity of population closure assumption and thus overall estimate. Grass Hill National Park is connected landscape along with Eravikulam NP in Kerala, thus movement of herds between the landscapes is possible. Specific sites such as Navamalai and Thadaganachi Malai have apparently experienced a significant decline in their tahr populations, which numbered approximately 50 in the late 1970s (Davidar, 1978). Currently, only 15 tahrs have been recorded in this area. Cattle grazing and human disturbances have been observed in these regions.

In the adjacent Eravikulam National Park, Kerala, the estimated tahr population is 827. Similarly, the estimated tahr populations in the adjoining Parambikulam Tiger Reserve, Chinnar Wildlife Sanctuary, and Munnar are approximately 19, 33, and 135 individuals, respectively (Predit *et al.*, 2015).

Invasion threatens the Niligiri tahr habitat

Further invasion of pine, eucalyptus and wattle plantations into the grasslands of the montane habitats of the Anamalai and Palani Hills poses a significant threat to native grasslands (Arasumani *et al.*, 2018). Many of these planted trees have escaped from managed plantations and invaded the adjacent shola grasslands. One of the objectives of Project Nilgiri Tahr is to restore grassland habitats.

Srivilliputhur-Megamalai Tiger Reserve (SMTR)

In the Theni territorial division, Nilgiri tahr was observed at Meesapulimalai in the Kurangani south beat of the Bodi range. There are 28 fragmented Nilgiri tahr habitats within the Srivilliputhur division, covering 863.85 sq.km in the SMTR. Nilgiri tahr was also sighted in the Thanakkadi Mottai of the Watrap range in Srivilliputhur division and the Bommarajapuram Varaiyattumottai area in Megamalai division. The declaration of the tiger reserve, restrictions on tourism, and the eviction of illegal encroachments are progressive measures aimed at securing the existing habitats of the Nilgiri tahr. Furthermore, the study has identified newly colonized habitats of Nilgiri tahr in the Pasumalai area of the Chinnamanur range within the Megamalai division.

In the Kalakkad division, Nilgiri tahr was observed in Winch Varaiyattu Mottai, Muthukuzhi Vayal, and Varaiyattu Mudi within the Upper Kodayar range. Similarly, in the Ambasamudram division, tahr was sighted at Thevar Pudavu and Varaiyattu Mottai.

Unfortunately, we were unable to record any sightings of tahr in the Kanyakumari Wildlife Sanctuary during the survey.

The mean herd size of the Nilgiri tahr was higher in the Grass hills followed by Eravikulam National Park and Mukurthi. The herd size was larger in the intact forests than the fragmented area. The variation in the herd size may be attributed to the forage patch size, abundance of tahr, and social organization. The herd size of tahr was low in the fragmented landscapes.

CONCLUSION

This is the first comprehensive survey that covers the entire Nilgiri tahr habitat in Tamil Nadu. This survey provides baseline data on the population of Nilgiri tahr for future monitoring. Applying the double observer method and using drones should be evaluated to obtain a more accurate estimate of the Nilgiri tahr population. Further implementation of drone-based survey with better sampling protocol, adaptive double observer survey method (Panaccio *et al.*, 2024) and rigorous sampling (Brack *et al.*, 2023) with drone would help to estimate Nilgiri tahr population with higher precision. The major threats to the Nilgiri tahr population include population isolation, the vulnerability of small habitat patches to human disturbance, diseases, poaching, habitat loss and fragmentation, and invasion and degradation.

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9 UNDERSTANDING THE ECOLOGY OF LESSER-KNOWN MAMMALS IN SATHYAMANGALAM TIGER RESERVE, TAMIL NADU

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ABSTRACT

Regional scientific research is critical for conserving threatened mammals, many of which are understudied. This study focused on two nocturnal, lesser-known, cryptic mammals under the IUCN Red List, the Indian pangolin (*Manis crassicaudata*) and the Grey slender loris (*Loris lydekkerianus*) in Sathyamangalam Tiger Reserve (STR), where there is no prior research available on both species. We studied the distribution of both mammals in STR, estimating the population density and habitat use of the Indian pangolin using burrow count surveys and a borescope, and determined the presence/absence of the Grey slender loris (GSL) in 21 study sites using passive acoustic monitoring (PAM) and BirdNET, a deep learning model. We encountered 62 pangolin burrows, out of which 19 were active. The population density was estimated to be 0.32 ± 0.24 (mean $\pm$ SD) individuals/km². For the GSL, we deployed AudioMoth audio recorders in two seasons: March-April 2024 and September-October 2024 and recorded between 1800 and 0500 hours for 17 days, and developed a BirdNET model for automatic prediction of GSL whistle calls. GSL presence was confirmed in 13 out of 21 sites in STR. The BirdNET model produced 625 true positive predictions with a precision rate of 76%. We did not observe any patterns in the vocalizing time of GSL across our study period. PAM and BirdNET were highly effective monitoring tools for cryptic vocalizing species, being non-invasive, cost-effective, and user-friendly. Our recommendations for management include a) create awareness and prepare a conservation for declaring STR as a good habitat for the pangolin and GSL, b) promote long-term population monitoring studies for the pangolin and GSL c) conduct the use of PAM in wildlife monitoring, and d) facilitate more research studies on lesser-known taxa.

Keywords: Indian pangolin, grey slender loris, burrow, PAM, BirdNET, STR

INTRODUCTION

Of 455 mammalian species distributed in India, 27.7% are threatened under the IUCN Red List (Sharma *et al.*, 2024). Although the diversity of research and conservation efforts in the country has been extending beyond conventionally popular and charismatic species, we still lack the ecological documentation and population monitoring for several taxa, especially cryptic animals. Regional scientific research is especially important to conserving threatened species (Hu *et al.*, 2019), as it can form the basis for context-specific management plans. For this study, we have chosen to study two threatened mammals in a protected area landscape -the Indian pangolin and the Grey slender loris—that are lesser known in conservation and challenging to study as they are nocturnal and hard to find.

Indian Pangolin

The Indian pangolin (*Manis crassicaudata*) is distributed in India, south of the Himalayas, excluding far north-eastern parts of the country, and also found in Pakistan, Nepal, Sri Lanka, and Bangladesh and is listed as an Endangered species that is largely threatened by illegal wildlife trade for its scales, making it the most trafficked mammal on Earth (Mahmood *et al.*, 2019; TRAFFIC & WWF India, 2023). Several researchers have studied the population and habitat preference of the species in Pakistan, Sri Lanka, Nepal, and Bangladesh (Akrim *et al.*, 2017; Irshad *et al.*, 2015; Karawita *et al.*, 2018; Mahmood *et al.*, 2014, 2015; Perera & Karawita, 2020; Trageser *et al.*, 2017). However, population estimates and habitat studies on these species from India are lacking, perhaps due to the need for a robust methodology. Aditya *et al.* (2021) conducted a camera trap study in the northern Eastern Ghats of India, but no pangolins were detected in the area. Although the most used population estimation method for ground-dwelling pangolins is the burrow count, solely counting burrows has been proven to have several limitations, and Willcox *et al.* (2019) suggest combining burrow counts with camera traps, borescope, and local community knowledge. For our study, we combined burrow counts, borescope, and community knowledge to study pangolins.

Grey slender loris

Two subspecies of the Grey slender loris (*Loris lydekkerianus*) have been recognized in South India—the Mysore slender loris in drier regions, and the Malabar slender loris in wet regions of the Western Ghats (Singh *et al.*, 2021). The species is Near

Threatened and has experienced a population decline, possibly due to habitat loss, road kills, superstitious beliefs, including use in traditional medicine (Nekaris *et al.*, 2020). Unlike the pangolin, this species' distribution, calculated using encounter rates and relative abundance behaviour, and reproduction has been well studied in India (Singh *et al.*, 2021). However, these studies were conducted using night transects, and many areas in the species' range remain unexplored. Since protected areas are usually inaccessible for conducting night surveys, we used a non-invasive alternative method for the loris, *i.e.*, passive acoustic monitoring (PAM).

Passive Acoustic Monitoring

PAM is an efficient method to study species that are hard to see but easy to hear (Kidney *et al.*, 2016). It has been used by researchers to study primates (Markolf *et al.*, 2022; Pérez-Granados & Schuchmann, 2021), and was found to be especially useful for cryptic mammals (Heinicke *et al.*, 2015; Kalan *et al.*, 2015; Whisson *et al.*, 2021; Zambolli *et al.*, 2023). Kalan *et al.* (2015) found that occupancy estimates for primates using PAM were as robust as conducting human transect surveys, sometimes even better. For large audio datasets, combining PAM with automated machine learning models, such as BirdNET has been found to be very effective (Clink *et al.*, 2024; Sossover *et al.*, 2024; Wood *et al.*, 2023). We thus chose to use PAM and BirdNET to study the Grey slender loris (GSL) focusing on detecting only the whistle call, which was the most common vocalization by the species (Radhakrishna & Singh, 2002).

Our study focused on the two nocturnal, lesser-known, cryptic mammals under the IUCN Red List: the Indian pangolin (*Manis crassicaudata*) and the Grey slender loris (*Loris lydekkerianus*) in Sathyamangalam Tiger Reserve (STR). No prior research is available on both species. We studied the distribution of both mammals in STR, further estimating the population density and habitat preference of the Indian Pangolin.

MATERIALS AND METHODS

Study area

This study was carried out in Sathyamangalam Tiger Reserve (11°38'24"N 77°13'34"E), which forms a meeting link between the Eastern and Western Ghats. Covering an area of 1408 sq.km, it is the largest tiger reserve in Tamil Nadu and a part of the Nilgiri Biosphere Reserve. The elevation in STR ranges from 300 m to 1600 m,

spanning various habitat types such as semi-evergreen, evergreen, mixed deciduous, dry deciduous, thorn scrub, riparian forests, and grasslands.

Indian pangolin surveys (data collection and analysis)

Areas with potential pangolin presence in our study sites were first identified by conducting interviews with local people of the Urali and Sholiga communities and consulting local forest department staff. Burrow count surveys were then conducted on random trails in these identified areas. With the help of anti-poaching watchers and barefoot ecologists in our team who are local guides trained in field ecology, pangolin burrows were distinguished from other burrows based on size and presence of indirect signs. The burrows were categorized as active or inactive based on whether signs such as fresh soil digging, claw marks, footprints, and scat were present. Inactive burrows were closed with dry leaves or cobwebs. Data collected included coordinates, elevation, dimensions (burrow opening height, width, depth), presence of rocks and slope, and surrounding vegetation. We also used a borescope (10 m long) inside active burrows to check for pangolin presence. Distance to the nearest human settlement was later obtained using QGIS software. Population density was estimated following Begon (1979) as $D=n/A$, where n equals the total number of active pangolin burrows observed, and A equals the total area sampled, assuming that one pangolin stays in each active burrow. We calculated the area (A) by counting the number of $1 \times 1 \text{ km}^2$ grids that were covered during our trail surveys.

Grey slender loris (data collection and analysis)

We used PAM to determine the presence of GSL. AudioMoth audio recorders (Hill *et al.*, 2019) were deployed across two seasons: March-April 2024 and September-October 2024. Audio recorders were programmed to continuously record data for 17 days from 1800 to 0500 hours, recording for four minutes every five minutes at a sampling frequency of 32 kHz. In the first season, the AudioMoth recorders were deployed in 22 sites, out of which 13 sites were repeated in the second season, removing locations that were less than 1 km apart and those that were inaccessible during the second season. The devices were placed on tree trunks in waterproof cases. The minimum distance between each recorder was 500 m, to ensure the independence of recordings. The recorders were deployed in dry deciduous, semi-evergreen, and riparian forests, at a minimum elevation of 350 m and a maximum of 1350 m.

Acoustic data analysis was done to obtain loris presence/absence by manually annotating sound clips using Raven Pro, and by using a deep learning model called BirdNET GUI. We annotated GSL calls for around 10% of the season 1 acoustic data by referring to a few sources: calls obtained from deploying AudioMoth recorders near Kadavur Slender loris Wildlife Sanctuary, Tamil Nadu, for one night, and two YouTube videos. 100+GSL calls were obtained by the annotation process and maximum number of calls were obtained from one of the sites (Athi mara naali). Only the whistle call was used for analysis, since other vocalizations of the species are not as well-known.

We used BirdNET to train models for the automatic prediction of GSL calls from large datasets. BirdNET requires a training dataset that includes 3-second sound clips or templates of the target call and 3-second audios of 'noise' which is any sound clip without the species' call (Kahl *et al.*, 2021). BirdNET also provides a confidence score for each prediction and allows the user to set a threshold, such as only collecting predictions above a 0.5 confidence score (Wood & Kahl, 2024). The calls obtained from the annotation process were used to build the training dataset. We checked the performance of the trained model by testing it on a sample dataset from the Athi mara naali site, which was completely analysed manually, and noting the number of true positives and false positive predictions. We improved our models by adding new templates to the training dataset and removing templates with loud background noise. The final model, named LORISLYD, had the highest number of true positives and was used to analyze the entire dataset from both seasons to obtain presence/absence. All predictions by BirdNET were viewed on Raven Pro and validated as true or false. Statistical analysis was done using R (R Core Team, 2022) to plot the logistic regression curve of BirdNET confidence scores, the GSL detection histories for both seasons, and the vocalizing time for both seasons.

RESULTS

Indian pangolin

We conducted 44 burrow count surveys and encountered 62 burrows, including those found in groups. Nineteen of these burrows were classified as active and the total area sampled was 68 km². Active and inactive burrows are shown in figures 1 (a) and (b), respectively. Pangolin dropping was recorded once (Fig. 1 (c)), outside an active burrow, and footprints (Fig. 1 (d)) were recorded eleven times.



Figure 1. Indirect signs of Indian pangolin; a) an active burrow, b) an inactive burrow, c) dropping outside an active burrow, d) footprints

Table 1 shows pangolin burrows' frequency of occurrence (Po) associated with some environmental variables. Burrows were recorded at all elevations sampled (550 m-1500 m), and most burrows were associated with the presence of rocks (n=43) and slopes (n=49). Most of the burrows we encountered were 1-2 km from a human settlement. We did not get any visuals of pangolins while using the borescope inside active burrows. We also revisited four locations of active burrows after 3-4 months and found that three of those burrows were now inactive.

Table 1. Po (frequency of occurrence) of pangolin burrows with different environmental features

Environmental feature	Description	Subcategory	Number of burrows	Po
Elevation	Metres	550-850	4	6.5%
		851-1150	26	41.9%
		1151-1500	32	51.6%
Rock	Yes	--	43	69.4%
	No	--	20	32.3%
Slope	Yes	--	49	79.0%
	No	--	14	22.6%
Distance to nearest human settlement	Metres	<500	1	1.6%
		501-1000	1	1.6%
		1001-2000	37	59.7%
		2001-3000	14	22.6%
		>3000	9	14.5%

Figure 2 shows a boxplot of burrow dimensions. Burrow opening height and width were similar, thus, most burrows were almost circular. The average dimensions of burrows were as follows: opening height 0.35 ± 0.26 m (mean $\pm$ SD), width 0.48 ± 0.25 m (mean $\pm$ SD) and depth 1.58 ± 1.08 m (mean $\pm$ SD).

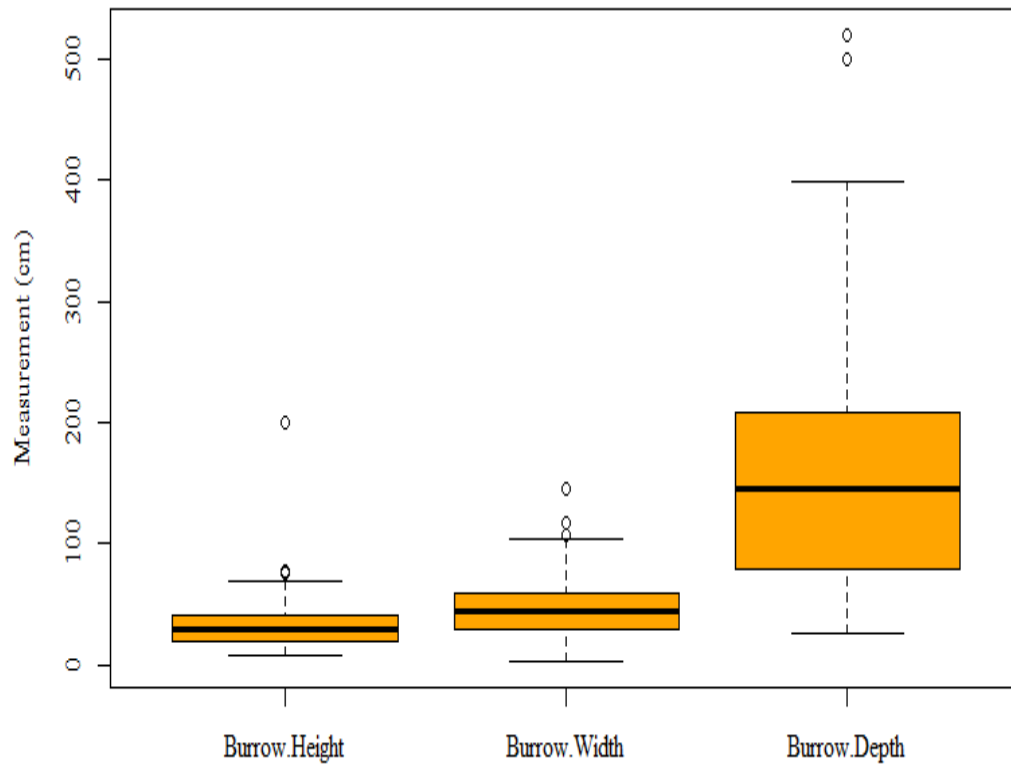


Figure 2. Boxplot of pangolin burrow dimensions

The average population density for the Indian pangolin in eight selected study sites was 0.32 ± 0.24 (Mean $\pm$ SD) individuals/km². Interestingly, two types of pangolins were identified by the local communities: the larger one called yaanai alungu and the smaller one called poonai alungu.

Grey Slender Loris

The AudioMoth devices (Fig. 3) collected 2984 hours of data from March-April 2024 in 20 sites (the remaining two devices had technical errors) and 1928 hours of data from September to October 2024 in 13 sites. Manual annotations were done for 10% of season one data to build the training dataset for BirdNET, which was used for acoustic data analysis. The GSL call (Fig. 4) was a shrill whistle and lasted around two seconds.



Figure 3. AudioMoth audio recorder labelled and deployed

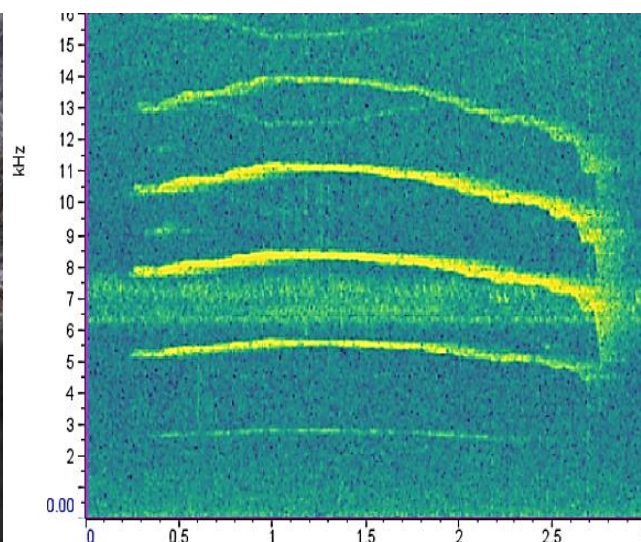


Figure 4. Spectrogram of Grey slender loris whistle call

BirdNET made a total of 817 predictions of GSL calls across all sites and both seasons, out of which 625 were true positives and 192 were false positives. The precision rate of the BirdNET model was 76%. GSL was detected in 11 sites in season 1 and eight sites in season 2, at a minimum elevation of 939 m and maximum elevation of 1211 m (Fig. 5).



Figure 5. Map of Grey slender loris distribution in Sathyamangalam Tiger Reserve

Based on logistic regression analysis (Fig. 6), we found that a threshold setting of 0.97 on BirdNET would give predictions that have a 95% probability of being a true positive. However, low confidence scores of 0.6 also had true positives. Thus, setting a high threshold would mean missing some calls.

Figure 7 (a & b) was plotted to determine if there is a peak calling time between 1800 and 500 hours. Although we did not observe a common peak calling time across all sites, the highest number of calls were made between 7:00 and 9:00 P.M. and 3:00 and 5:00 A.M. Figure 8 (a & b) shows the detection history across our study period in the first and second seasons. While most sites with deployment in two seasons had detections in both seasons, two sites (Soppalakarai and Mathingudi kere) showed GSL presence only in one of the seasons.

A lot of variation was observed in the frequency of calling. Some sites had calls almost every day, others had calls only on some of the 17 days, and a couple of sites only had a single call throughout the study period. The frequency of calling and the number of calls detected also differed across the two seasons within the same sites, for instance, Kaatrayan Kovil and Idi Odagu sites had more calling activity in September compared to March. However, Athi mara naali had more calling activity in March.

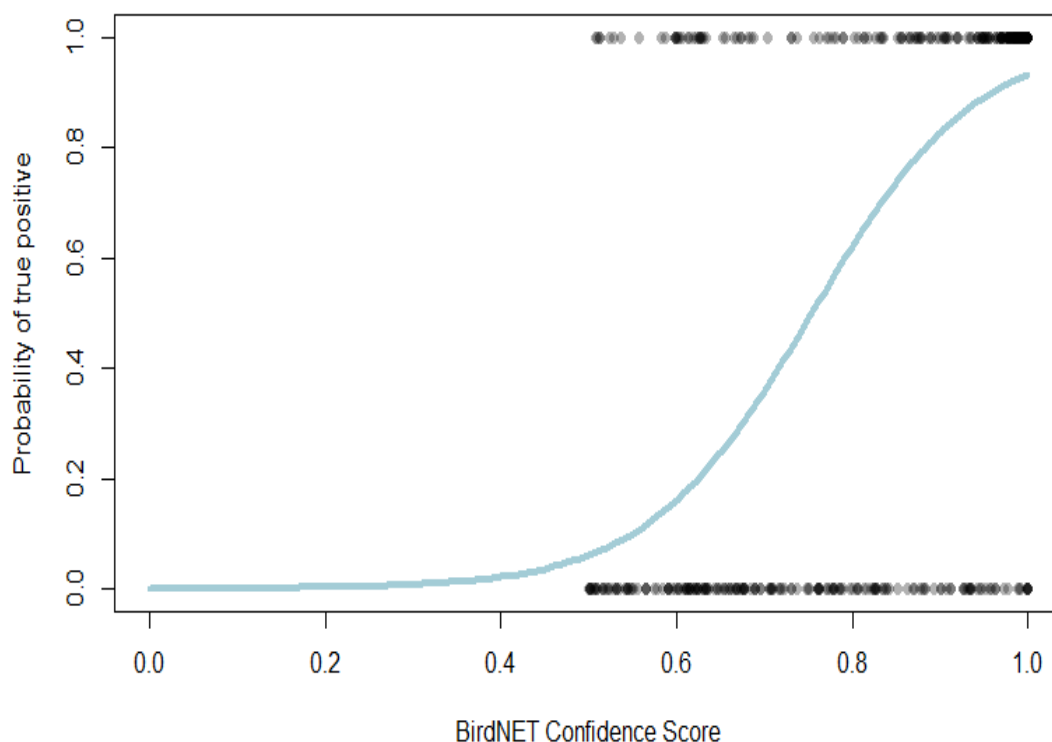


Figure 6. Logistic regression curve of BirdNET confidence scores

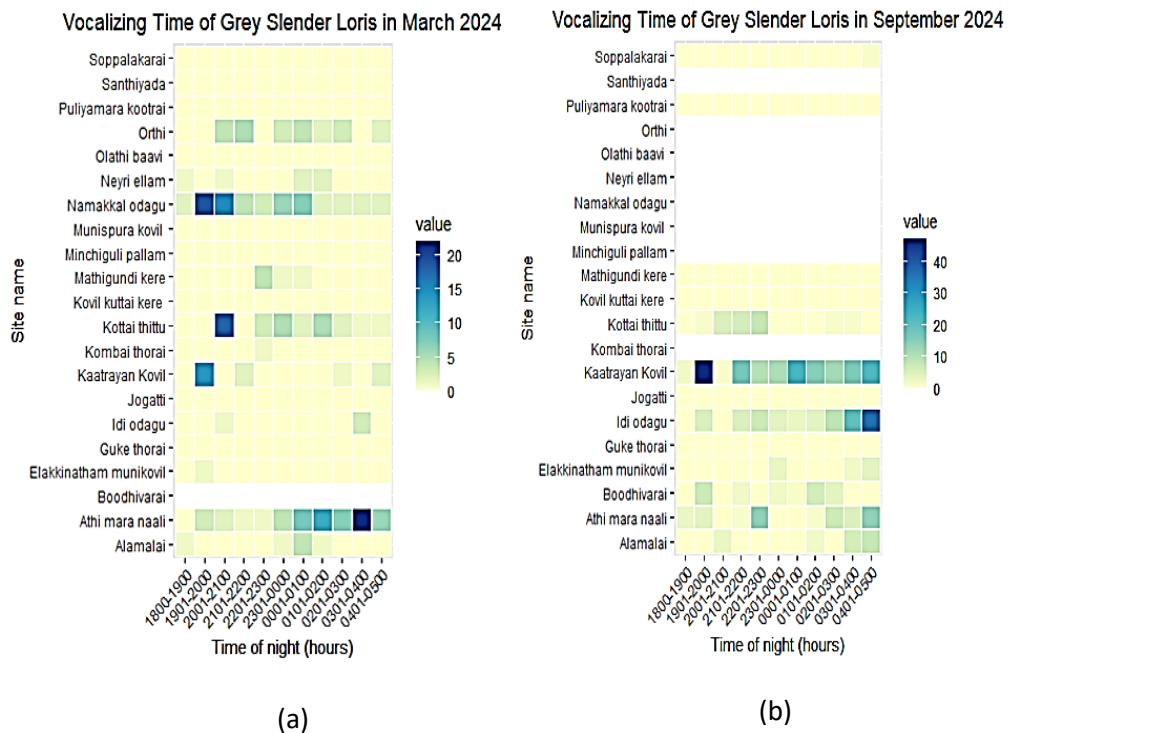


Figure 7. Vocalizing time of Grey slender loris plotted against all study sites in season-1 (a) & season-2 (b)

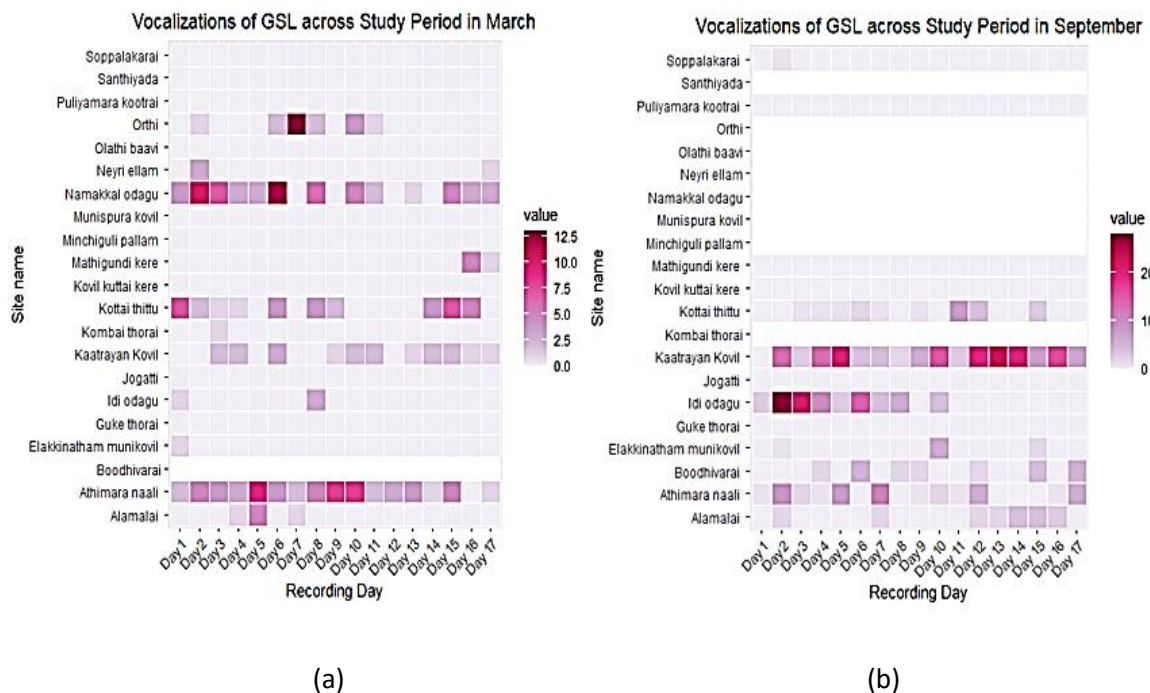


Figure 8. Detection history of Grey slender loris vocalizations across the study period in season-1 (a) & season-2 (b)

DISCUSSION

Our research found that the average pangolin population density in STR was 0.32 ± 0.24 (Mean $\pm$ SD) individuals/km². Comparing the density to estimates made by researchers in other areas of the species' range, the average population density from multiple study sites was estimated to be 0.36/km² in Margalla Hills National Park, Pakistan (Mahmood *et al.*, 2015) and 0.77 ± 0.34 (Mean $\pm$ SD) individuals/km² in Pir Lasura National Park, Pakistan (Akrim *et al.*, 2017). Irshad *et al.* (2015) found that the average population density decreased from 1.15 ± 0.18 (Mean $\pm$ SD) in 2010 to 0.37 ± 0.12 (Mean $\pm$ SD) individuals/km² in 2012 in Potohar Plateau, Pakistan. Our findings also showed that pangolin burrows were present between 550 and 1500 m asl. Similarly, Mahmood *et al.* (2015) found pangolin presence from 462 m to 1046 m and Akrim *et al.* (2017) found presence up to 1540 m.

Although the Indian Pangolin was assessed as Endangered under the IUCN, the assessment was only based on levels of exploitation as data on wild population decline is still lacking in most of its distribution range (Mahmood *et al.*, 2019). Considering the magnitude of poaching that the species still faces (TRAFFIC & WWF India, 2023), we must conduct long-term population monitoring to ascertain the rate of decline. Understanding pangolin population dynamics will inform conservation management plans in STR, which has suitable habitats for the pangolin.

While burrow count is the most common method used to study ground-dwelling pangolins, it has several limitations because pangolins can dig multiple burrows in a short period (Willcox *et al.*, 2019). We thus combined burrow counts with a borescope examination (Trageser *et al.*, 2017). However, we found that borescopes are hard to manually maneuver in the deep burrows and could be highly invasive for the pangolin. Further research on burrow usage and the home range of pangolins could help inform population density estimates to make the burrow count method more accurate.

We used bioacoustics to study slender lorises for the first time in India and detected GSL presence in 13 out of 21 sites in STR, indicating that the protected area has suitable habitats for the loris as well. We also developed a model on BirdNET for the automatic detection of GSL whistle calls with a precision rate of 76%. BirdNET is freely available and user-friendly, and this model could be used by researchers to study GSL occupancy and monitor its populations in other areas.

Using PAM to study GSL over the traditional methods of night transects had several advantages: a) eliminating risk of adverse effects to lorises caused by exposure to flashlights at night (Singh *et al.*, 2021), b) better detections of species that are visually hard to detect (Kalan *et al.*, 2015), c) capacity to sample areas that are inaccessible for conducting night surveys, d) cost-effective for long-term monitoring of populations (Heinicke *et al.*, 2015; Markolf *et al.*, 2022), and e) less labor-intensive (Whisson *et al.*, 2021; Zambolli *et al.*, 2023). Although the population density of GSL cannot be estimated from PAM alone, it can be estimated if combined with distance sampling (Markolf *et al.*, 2022), or it can be inferred from large temporal and spatial scale data. Considering the continuing decline of mature individuals of the species (Nekaris *et al.*, 2020), it is important to conduct long-term monitoring of populations and habitats in different areas of the species' distribution range.

CONCLUSION

Sathyamangalam Tiger Reserve has a good distribution of the Indian Pangolin and Grey Slender Loris, and it is imperative to continuously monitor the populations of both species to determine if there are any local threats to the species. We recommend further research and conservation efforts on lesser-known taxa in the landscape, and the use of passive acoustic monitoring as a tool for wildlife monitoring.

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10 ASSESSING THE WILDLIFE-DOMESTIC DOG INTERFACE IN MUDUMALAI TIGER RESERVE, TAMIL NADU

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ABSTRACT

Dogs are considered to be a destructive invasive species, harming wildlife by preying on native herbivores, competing with native carnivores, mating with wild canids and transmitting disease to wild populations. This issue is particularly pressing in India, where large dog populations are closely connected with fragmented natural ecosystems harbouring diverse wildlife. This study was conducted from February to March 2025 to understand the spatial and temporal overlap between dogs and mammalian wildlife in the Masinagudi and Singara ranges of Mudumalai Tiger Reserve, focusing on the interface with the dog populations in five villages. Camera trapping was carried out for two weeks each within the boundaries of each village, and this data was compared with forest camera trapping data from 2021 to understand how dogs' use of space and time overlap with different wild species in the village versus the forest. We found that wildlife adjust their activity patterns to be more active at night and less active during the day close to villages, compared to the forest. Dogs, being diurnal, were therefore less likely to encounter wildlife near villages compared to the forest. A similar pattern was found with respect to space – certain wildlife species were present at fewer sites closer to villages compared to forest sites, reducing the risk of encountering dogs or other sources of disturbance. Overall, despite the high dog population in the region (n=1200), they may be less likely to encounter wildlife than expected, as the wildlife species adjust their use of space and time to avoid them. This indicates that the dog population that resides in villages may not be of significant concern. Rather, the minority of the dog population that regularly enters the forest needs to be monitored and controlled where necessary.

Keywords: *Canis familiaris*, mammals, camera trapping, spatio-temporal overlap

INTRODUCTION

Dogs were the first animal to be domesticated by humans, with a long history of close association with human settlements and livelihoods (Miller *et al.*, 2014). They are the most common member of the order Carnivora on the planet, with an estimated population of approximately 1 billion worldwide as of 2014 (Gompper, 2014). A separate population of up to 100 million is estimated to be free-ranging (Gompper, 2014), free to roam without constraint, whether entirely feral, community-owned, or partially owned by individuals. The threat posed to wildlife by free-ranging dogs is therefore one that has attracted increasing attention in recent years (Bryce *et al.*, 2021; Gompper, 2021).

Studies from across the world have validated different dimensions of this threat. Dogs have been implicated in the extinction of eleven species and threaten nearly 200 species worldwide as an invasive threat to native wildlife (Doherty *et al.*, 2017). They are known vectors of multiple diseases and there is documented evidence of dogs exposing co-occurring wildlife to pathogens. Dogs also impact prey species through direct predation, sometimes far above their energetic requirements, and may also induce fear through chasing and harassment (Ritchie *et al.*, 2014; Young *et al.*, 2011). Overall, they have been shown to pose a threat as hyper predators or competitors with native predators, as carriers of disease, as prey that may subsidize predators and bring them into conflict with humans, and as sources of interbreeding with wild *Canis* species (Bryce *et al.*, 2021).

However, this may not always be the case. For example, though dogs were found to be a significant threat to vulnerable pudu in Chile (Silva-Rodríguez & Sieving, 2012), they were only a minor management problem for widespread white-tailed deer in the USA, though they preyed on both deer species (Gompper, 2021; Parsons *et al.*, 2016). Additionally, it is reasonable to suppose that in areas where dogs have been long established, native wildlife is likely to have adapted to coexist with them and sustain the effects of the dog population (Gompper, 2021). Hybridisation may also be specific to populations where wild canids have restricted mating opportunities and need not have large-scale, drastic impacts on their populations (Bryce *et al.*, 2021). As such, dog-wildlife dynamics are not invariably generalizable as severely harmful to wildlife (Bryce *et al.*, 2021). In this context, critical assessment of the various aspects of possible dog

impact on wildlife is necessary to substantiate the need for dog management in a given area and design effective, scientific management strategies where required.

The need for such studies is most pressing in India, which has one of the highest populations of dogs in the world, estimated at 58.5 million in 2014 (Gompper, 2014), supported by the high human population, poor pet ownership laws, and lack of waste management (Home *et al.*, 2018). A large free-ranging dog population with limited avenues for management results in added pressure on India's natural ecosystems, which are already under threat across the country. Given the country's rich and varied wildlife, there is an abundance of situations where studies on dog-wildlife dynamics may not only be fruitful but urgently necessary.

Therefore, in this study, the objective was to investigate dog-wildlife spatio-temporal overlap at village boundaries in Mudumalai Tiger Reserve, Tamil Nadu using camera trap data to assess the scope for encounter between dogs and wild mammal species of interest. We hypothesized that potential for encounter would be higher at village boundaries and lower in the forest as distance from the village increased.

MATERIALS AND METHODS

Study area

Mudumalai Tiger Reserve (MTR) is a protected area covering 688.59 sq.km in the Nilgiri district of the state of Tamil Nadu, Southern India. It is part of the Nilgiri Biosphere Reserve, which provides Indian wildlife with critical refuge and facilitates connectivity for one of the largest tiger and elephant populations in the country (Puyravaud *et al.*, 2016). MTR experiences two distinct seasons: summer from March to mid-May and winter from November to February. As part of MTR lies east of the Western Ghats, in a rain shadow area, it experiences a decreasing rainfall gradient from the west and south to the east and north (ranging from 1800 mm to 600 mm). Consequently, there is a vegetation gradient from tropical moist deciduous forest and patches of semi-evergreen forest, to dry deciduous forest, to tropical dry thorn forest towards the east (Suresh *et al.*, 1996; Suresh *et al.*, 2010).

MTR is an ideal location for a dog-wildlife study as it contains several human settlements in scattered enclaves. This population includes several tribal communities, such as the Soligas, Irulas, and Betta Kurubas (Enters, 2000), and dog-keeping is a

common practice. The intensive study area includes five settlements in the centre of the Reserve. This area includes part of the core and a large part of the buffer, where dry deciduous and/or dry thorn forest is present. It is situated in a relatively narrow east-west corridor approximately 11 km in width, bordered by the Moyar River to the north and Nilgiri hills to the south (Silori and Mishra, 2001). The five villages included in the study area are Bokkapuram, Masinagudi, Mavanalla, Moyar, and Vazhaithottam, all of which have unique local contexts. The villages and their locations are shown in figure 1.

MTR already has active dog management undertaken by the Worldwide Veterinary Service, which supports vaccination and sterilization drives in Mudumalai carried out by India Project for Animals and Nature (Airikkala-Otter I, pers. comm.). As such, the dog-wildlife interface in MTR provides scope for a valuable, informative case study in a wildlife diverse region where dog management is already in practice.

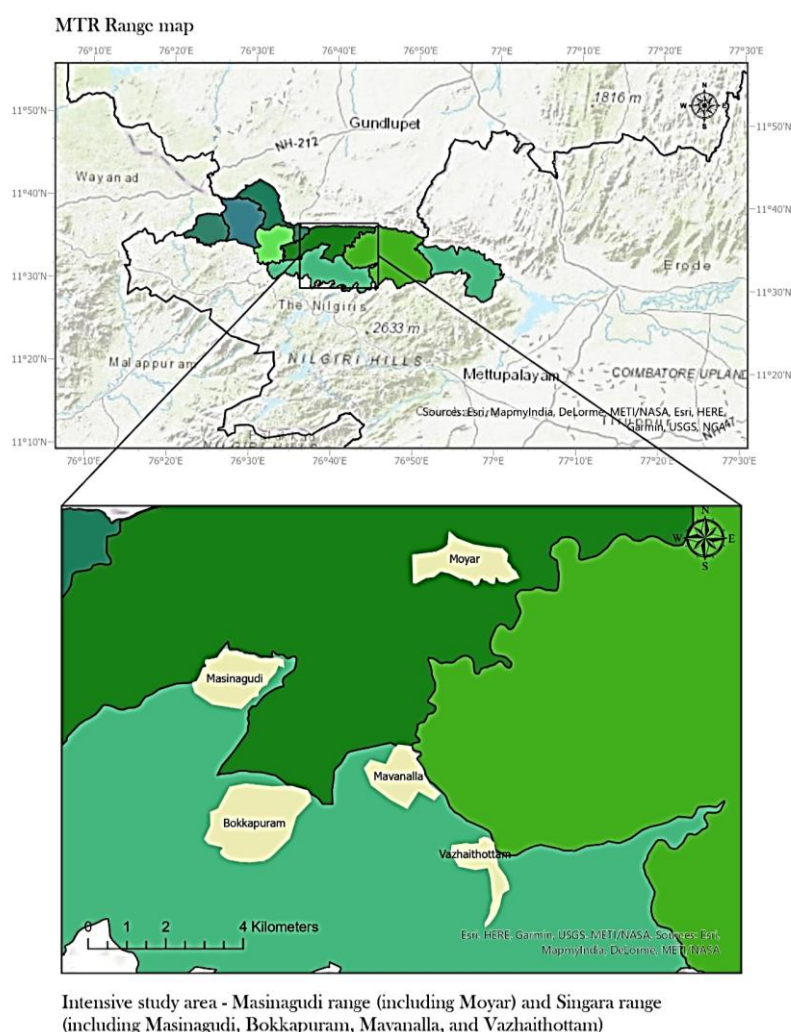


Figure 1. Study area: Mudumalai Tiger Reserve, including range map and village locations

Field methods

To quantify the dog-wildlife interface in terms of spatial overlap between dogs and wild mammal species, camera traps were placed along the periphery of each village between February to March of 2024. Each camera site was approximately 500 m apart, though this varied from 400 m up to 1000 m depending on land type. Where there was sufficient distance between the settled area and the village boundary to allow for multiple cameras, two cameras were stationed 50m-100m apart from each other in order to increase the sample size per site. All sites are shown in figure 2. The cameras were mostly placed on animal trails to maximize the likelihood of both dog and wild animal capture, and were placed for 15 days in each village. They were set to be triggered by motion and capture images without delay. Cameras were placed in two villages simultaneously for each 15-day phase; trapping began on the 26th of February 2024 and concluded on the 17th of March 2024. In each village, 6 to 9 sites were present, resulting in a total of 37 sites across all villages.

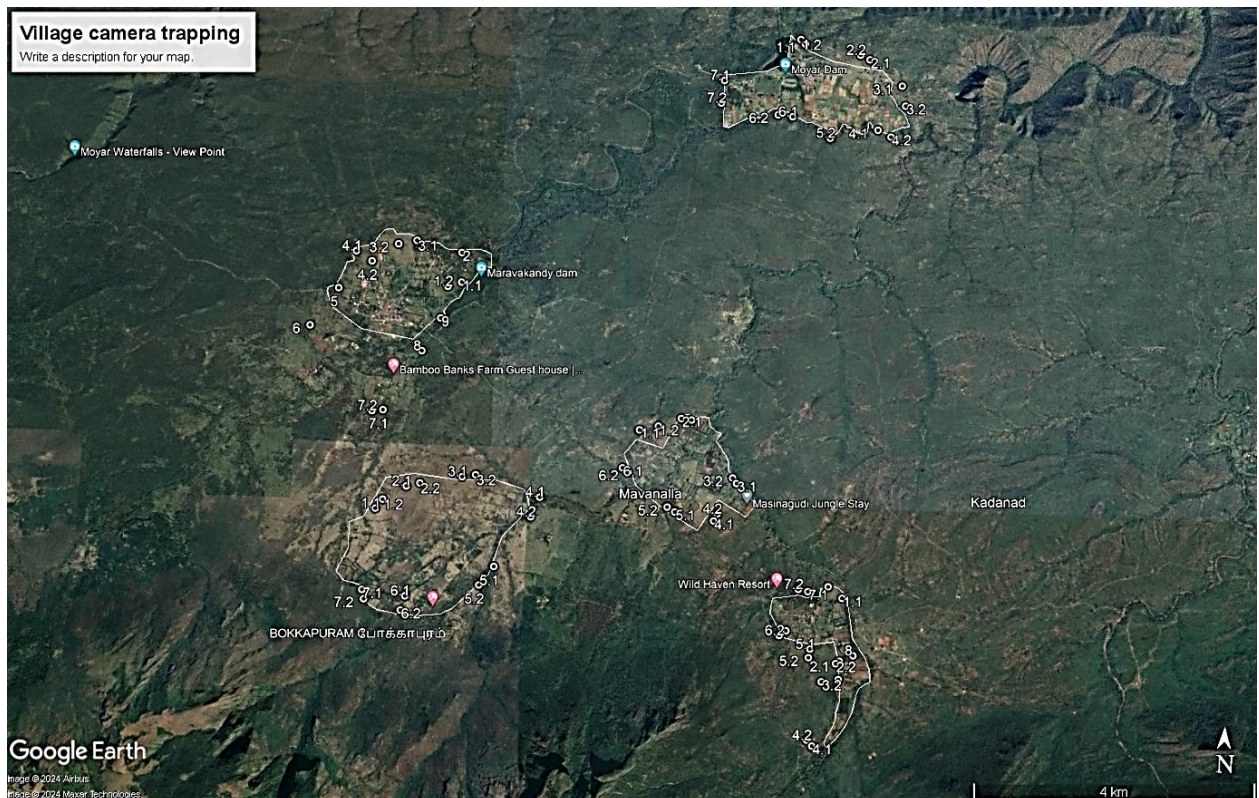


Figure 2. Mapped camera trap locations at the boundaries of all villages

Analysis

The total number of photographs obtained across all villages was 34,127, with a total of 21 wild species as well as cattle, goats, buffalo, humans and dogs. An interval of 30 min between consecutive photographs was used to ensure independence of captures. For temporal analysis, kernel density estimation was used to determine activity patterns and quantify overlap. All times were first converted into radians using the *gettime* function from the *activity* package (Rowcliffe, 2023) in R (R Core Team, 2021). The temporal overlap between dogs and wild species was calculated using the *overlapEst* function from the *overlap* package (Meredith *et al.*, 2024), using Dhat1 as the estimator of overlap value when captures were below 50 and Dhat4 when captures were above fifty, as recommended by the package documentation. Only the wild species with more than ten captures were included (11 out of 21 species). The confidence intervals were calculated by bootstrapping the Dhat1 or Dhat4 estimates for each species combination 500 times, then using the function *bootCI* to estimate the 95% confidence interval. Domestic animals and humans were also included in the analysis since dogs accompany humans and livestock into forest areas.

For spatial overlap, naive occupancy estimates were used to estimate overlap between different species and dogs (the number of sites where both dogs and the wild species were present, divided by the total number of sites where dogs were present). More robust models of occupancy were not appropriate to use with these data due to the relatively short distance between sites and the small sample size, which would have introduced bias (Mckann *et al.*, 2013). A simple composite spatio-temporal score was calculated by averaging the spatial and temporal scores for each species (i.e., (spatial overlap + temporal overlap)/2). While previous studies have used different composite scores, such as spatial adjusted or prey mass adjusted scores to look at prey selection (Allen *et al.*, 2021), these were not used here as dogs are subsidized, domestic predators and their movement and hunting behaviour is unlikely to conform to traditional models of niche overlap in the wild.

These procedures were also followed to estimate spatial and temporal overlap from 2021 camera trapping data from the relevant ranges (Masinagudi and Singara), which were obtained from a recent cycle of tiger estimation (Tiger Cell, WII). These

data, from 110 sites across the two ranges, were analysed to estimate spatio-temporal overlap in the forest to compare to village boundary areas.

RESULTS

The wild species with >10 captures included chital (*Axis axis*), sambar (*Rusa unicolor*), Indian hare (*Lepus nigricollis nigricollis*), jungle cat (*Felis chaus*), dhole (*Cuon alpinus*), Indian leopard (*Panthera pardus fusca*), elephant (*Elephas maximus*), peafowl (*Pavo cristatus*), Indian crested porcupine (*Hystrix indica*), and wild pig (*Sus scrofa*). The results for village camera trapping and forest camera trapping are presented below:

Village spatio-temporal overlap

When temporal overlap was quantified between dogs and the eleven wildlife species, the following results were obtained, arranged in descending order of Dhat values (Table 1). Similarly, the results for spatial overlap are presented in table 2 in descending order.

The spatial scores were plotted versus temporal scores for each species to determine which species have the highest probability of encounter with dogs (fig. 3). The overlap with humans has also been provided for reference. The upper right quadrant indicates species with both spatial and temporal overlap above 0.5, which are the most likely to encounter dogs. Species in the lower right quadrant have high spatial overlap but low temporal overlap, indicating that direct contact is unlikely but signs such as scat or marking by dogs may affect the distribution and/or movement of prey species. Species with low temporal and spatial overlap are present in the lower left quadrant, while species with high temporal overlap and low spatial overlap are in the upper left quadrant. This quadrant being empty, as well as most wildlife species having less than 0.5 temporal overlap, indicates that these species adopt a nocturnal or crepuscular activity pattern at village boundaries, as dogs are diurnal.

Table 1. Dog temporal overlap with wildlife and livestock at village boundaries
(Highlighted cells indicate occurrences under 50, due to which Dhat1 was calculated instead of Dhat4)

Species	Temporal overlap (Dhat value)	CI ₁	CI ₂	No. of occurrences
Cattle	0.75352	0.70803	0.79745	792
Goat	0.61391	0.56587	0.66352	378
Chital	0.59232	0.55573	0.62972	1355
Peafowl	0.55358	0.49682	0.61023	136
Dhole	0.51014	0.41486	0.60176	43
Wild pig	0.41751	0.34922	0.48489	137
Elephant	0.23404	0.15501	0.31764	77
Hare	0.23172	0.16247	0.30589	101
Sambar	0.2214	0.15664	0.28811	108
Leopard	0.1664	0.07159	0.2754	23
Sloth bear	0.15409	0.04873	0.29528	14
Jungle cat	0.12986	0.02884	0.25243	12
Porcupine	0.08192	0.03499	0.13331	75

The species with the maximum spatio-temporal overlap with dogs in village areas are goats and cattle, which is to be expected and given that dogs routinely accompany both (Table 2).

Table 2. Dog spatial overlap with wildlife and livestock at village boundaries, calculated by naïve occupancy with respect to dog-occupied sites.

Species	Naïve occupancy overlap	Species	Naïve occupancy overlap
Cattle	1.00	Peafowl	0.65
Chital	0.94	Porcupine	0.65
Goat	0.97	Hare	0.58
Sambar	0.74	Dhole	0.52
Wild pig	0.81	Leopard	0.35
Elephant, Hare	0.58	Sloth bear	0.23
		Jungle cat	0.23

Chital has the highest overlap of all wild species, which is also reasonable due to their high abundance, similar to peafowl. Dholes seem to have moderate overlap with dogs, using approximately half of the same camera trapped sites and being active for at least part of the day, generally the mornings and late afternoons. The other two predator species, leopards and jungle cats, have quite low composite overlap scores, as does sloth bear. Apart from chital, all other prey species (sambar, wild pig, and Indian hare) all have higher spatial overlap but low temporal overlap in the lower right quadrant of the graph. Porcupine has the lowest temporal overlap of all species

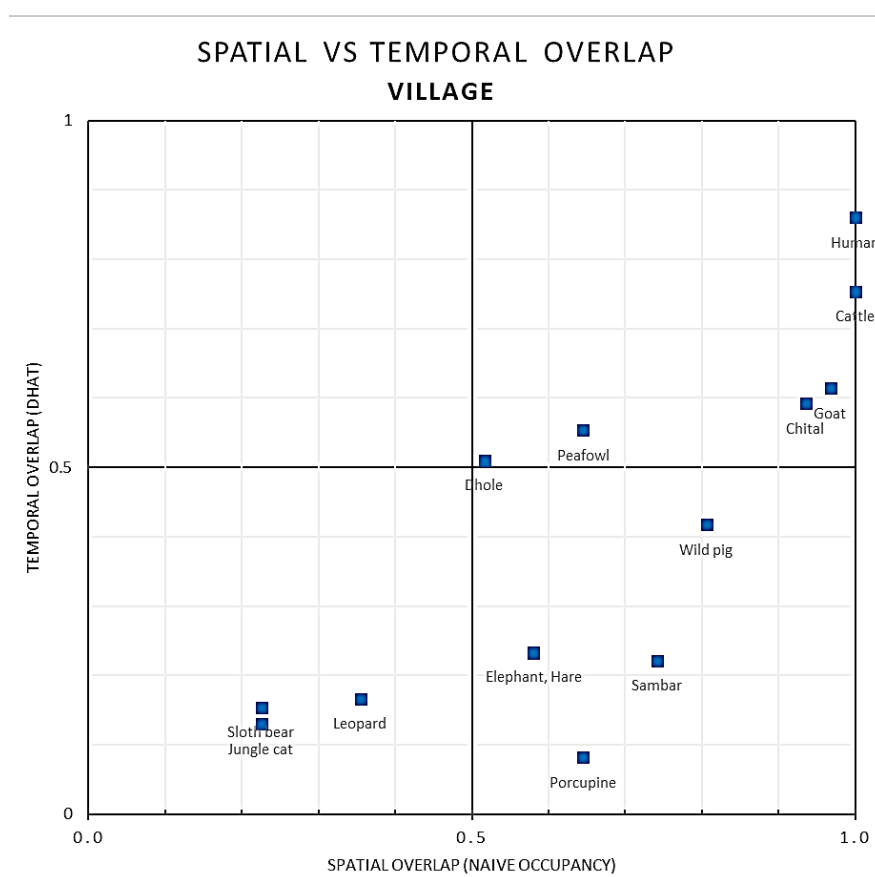


Figure 3. Dog-wildlife spatial overlap versus dog-wildlife temporal overlap, at village boundaries

Forest spatio-temporal overlap

Dogs were detected 120 times at 17 out of 109 forest sites during a three month sampling period (Dec 2020 - Feb 2021). Of these, 5 sites were <500 m from settlements; the average of the distance of the remaining 12 sites was 3040 m. These sites are mapped in figure 4. The data for temporal overlap and spatial overlap, arranged in descending order, are presented in tables 3 and 4.

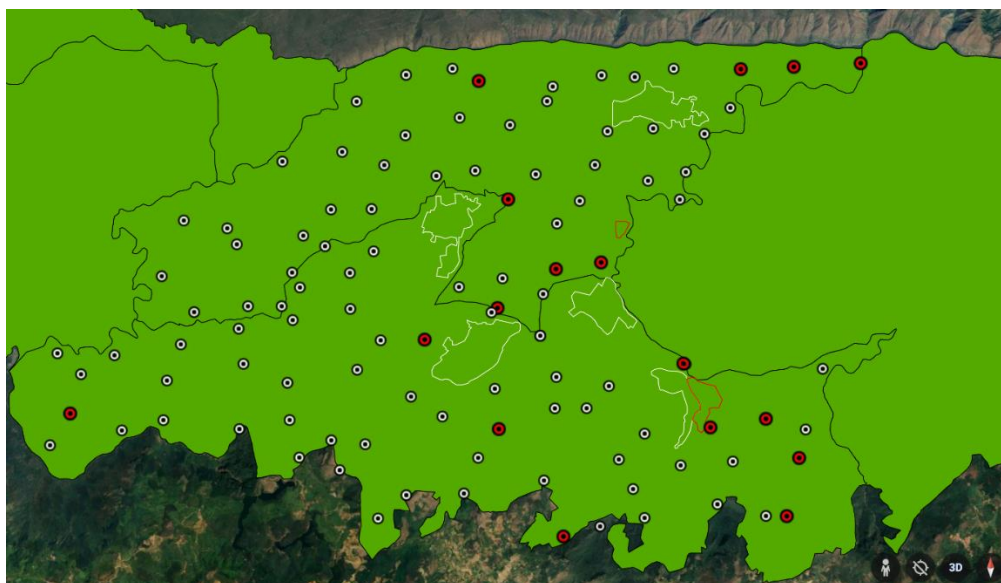


Figure 4. All forest camera trapping sites in Masinagudi and Singara ranges (2021 data). Villages are outlined in white (for villages included for sampling in this study) and red (village excluded from sampling). Sites with dog captures are shown in red.

Table 3. Dog temporal overlap with wildlife and livestock at forest sites. All species had >50 occurrences.

Species	Temporal overlap (Dhat value)	CI1	CI2	Number of occurrences
Cattle	0.85778	0.80091	0.90581	12566
Goat	0.65313	0.58135	0.72511	538
Chital	0.51503	0.4473	0.58057	50415
Peafowl	0.53012	0.45487	0.60178	513
Dhole	0.45474	0.38052	0.52784	371
Wild pig	0.5128	0.44338	0.57931	4456
Elephant	0.55209	0.4911	0.61009	4751
Hare	0.08217	0.04025	0.12609	1392
Sambar	0.51106	0.43606	0.58183	6798
Leopard	0.429	0.34574	0.51502	240
Sloth bear	0.57374	0.49329	0.65071	382
Jungle cat	0.11062	0.05878	0.16927	184
Porcupine	0.04771	0.01045	0.08977	1190

Table 4. Dog spatial overlap with wildlife and livestock at forest sites, calculated by naïve occupancy with respect to dog-occupied sites.

Species	Overlap occupancy		Species	Overlap occupancy
Cattle	0.94		Porcupine	0.94
Chital	0.88		Hare	0.82
Goat	0.35		Dhole	0.41
Sambar	1.00		Leopard	0.35
Wild pig	0.82		Sloth bear	0.59
Elephant	0.76		Jungle cat	0.47
Peafowl	0.65			

Spatial overlap and temporal overlap were also plotted for forest data (Fig. 5), showing a marked shift in the position of most species along the Y axis. Sloth bear, sambar, elephant and wild pig shifted to the upper right quadrant. Cattle remained in the same location, but goat shifted to the left upper quadrant, indicating much less spatial overlap. This is likely because people do not tend to take small-bodied livestock far into the forest due to predation risk. Porcupine and hare both showed increased spatial but decreased temporal overlap with dogs. Jungle cat also shifted towards higher spatial overlap, while leopard shifted towards a much higher temporal overlap. Dhole decreased slightly in both measures of overlap.

Composite spatio-temporal overlap scores are presented in Figure 6, for both village and forest data:

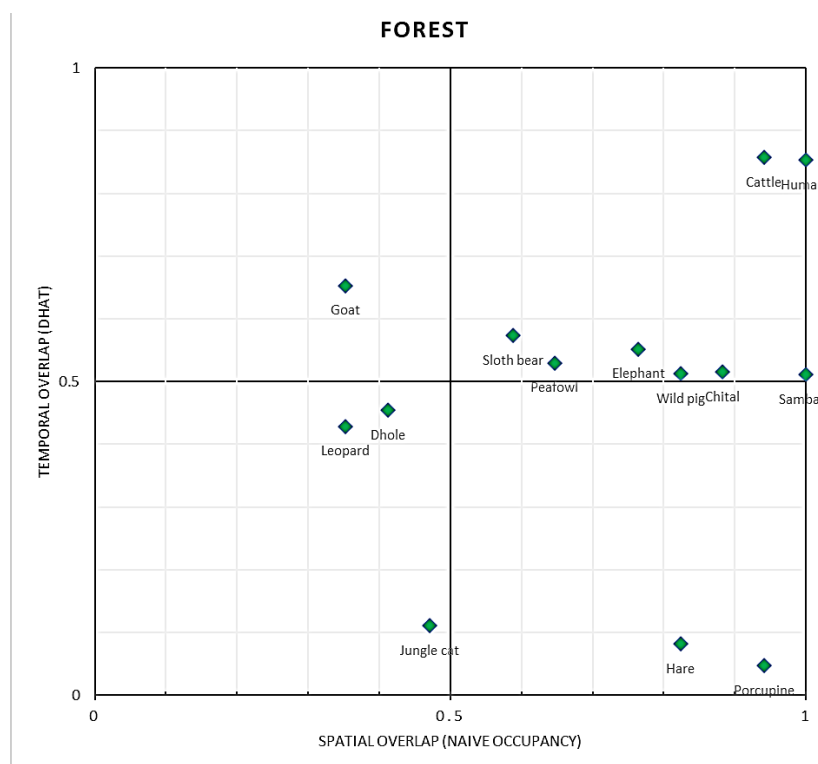


Figure 5. Dog-wildlife spatial overlap versus dog-wildlife temporal overlap at forest sites

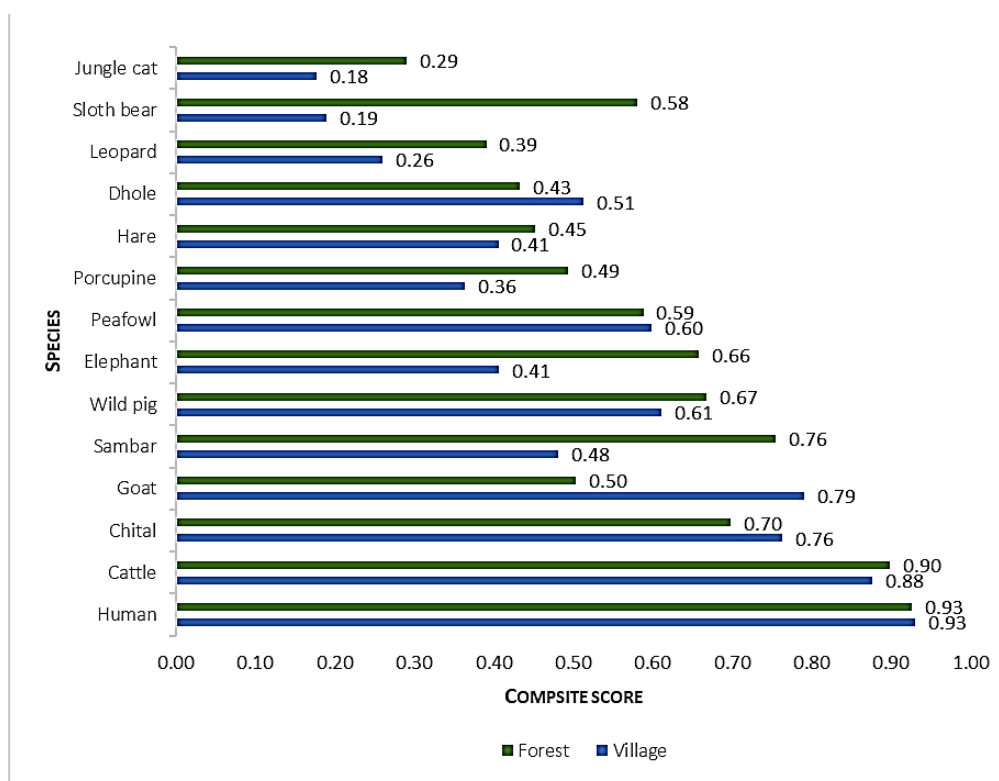


Figure 6. Composite spatio-temporal overlap scores, comparing village and forest overlap.

The composite scores allow a side-by-side comparison of overlap with dogs in village areas and forest, and quantify the shifts in position displayed in Figures 3 and 5. Sloth bear and sambar showed the most dramatic increases in overlap from village to forest, while porcupine, wild pig, jungle cat and leopard showed moderate increases. Goat, dhole and chital are the only species which showed an increase from forest to village, with the increase of dhole and chital being fairly small. Overall, spatial and temporal overlap between dogs and wildlife was higher in the forest than at the village boundaries.

DISCUSSION

Since no general assessment of the spatio-temporal overlap of dogs with wildlife has been done in India, it is uncertain whether the estimates obtained from this study support immediate management intervention in Mudumalai. Previous studies in other parts of the world primarily use occupancy modelling and temporal overlap as two distinct components, and include studies in Taiwan (Yen *et al.*, 2019), Thailand (Marshall *et al.*, 2023), China (Weng *et al.*, 2022), and Brazil (Carvalho *et al.*, 2019). Three of these studies found spatial and temporal segregation between dogs and wildlife, arguing that avoidance of dogs by wildlife indicated that dogs have a negative impact on wildlife, while Carvalho *et al.* (2019) report that dogs themselves may be altering their activity patterns to better overlap with wild prey and avoid ocelots. In this context, the shift in temporal activity patterns of wildlife from day to night between forest and village areas indicates that such segregation occurs only at the village interface, not in the forest. The higher forest composite overlap scores compared to village overlap composite overlap scores are due to the lack of this temporal overlap, as well as the low number of sites with dog occupancy (17 out of 109), which ensures that reasonably widely distributed species, such as sambar (present at 102 sites) or porcupine (present at 90 sites), will inevitably overlap with dogs at most if not all locations.

Similarly, wildlife richness and abundance may not allow for significant spatial segregation at village perimeters. Wildlife may choose to remain in proximity to villages for several reasons, including food and shelter. Therefore, wildlife seems to be mainly adopting temporal segregation at village boundaries in order to minimize interaction

with dogs (as well as humans and other disturbances, such as vehicles), while they do not do so in the forest, where they utilize space and time freely. While this segregation may be interpreted as a negative impact in itself, it can also be considered as an indication of wildlife adjusting to dog-related disturbance in order to successfully utilize boundary areas. Dogs that routinely venture into the forest past boundary areas, rather than those normally residing in villages, therefore pose the highest risk to wildlife.

It should be noted that patterns of avoidance are also likely to be village specific, depending on the local context. Masinagudi, a built-up village with little open space and high open food availability for dogs within the settlement, had fewer captures of both dogs and wildlife at the boundary than Vazhaithottam, a village with a longer perimeter with the forest and much higher occurrences of wildlife, as well as several dogs that displayed cathemeral activity patterns. The wildlife in such villages is at higher risk of dog-wildlife interaction; while temporal segregation may take place, the abundance of so many species so close to settlements ensures that encounters will inevitably occur eventually.

CONCLUSION

Camera trap data from Mudumalai Tiger Reserve showed that wildlife prey species change their usage of time and space to avoid disturbance near villages, actively avoiding disturbances like dogs. Therefore, any negative impacts of the dog population on wildlife are likely to be relatively low. Ongoing dog management programmes should continue, particularly in boundary areas, to minimize dogs foraging into the forest where wild species are unconstrained in their use of space and time. This study is a preliminary report, since the data used are from different years with different study durations, providing only indicative estimates. Further analysis with more robust data is required for conclusive results.

ACKNOWLEDGEMENTS

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11 EFFECT OF LAND-USE CHANGE ON THE ABUNDANCE OF GRIZZLED GIANT SQUIRREL (*RATUFA MACROURA*), AROUND THE PROTECTED AREA OF SRIVILLIPUTHUR-MEGHAMALAI TIGER RESERVE, SRIVILLIPUTHUR DIVISION, TAMIL NADU

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ABSTRACT

Human-induced land-use changes have significantly altered wildlife habitats, affecting biodiversity worldwide. In the Western Ghats of India, extensive conversion of forests into agricultural land and plantations has reshaped ecosystems, influencing species distribution and behavior. The Grizzled giant squirrel (*GGs- Ratufa macroura*), an endemic and Near Threatened species, faces increasing habitat fragmentation due to such land-use changes. This study examines the impact of land-use transitions on GGS abundance in the Srivilliputhur-Meghamalai Tiger Reserve (SMTR) and its surrounding eco-sensitive zone (ESZ). A decadal land-use land-cover (LULC) analysis for the ESZ from 1993 to 2023 revealed a 152.76% increase in plantation area, while fallow land declined by 42.97%. Squirrel and drey densities were estimated in protected areas and in ESZ using distance sampling techniques, with sightings recorded along transects.

The results indicate that GGS density varied significantly across habitats, with the highest densities observed in plantations with both coconut and mango in the ESZ. However, the lowest density was found in riparian forests within the protected area. The species is increasingly utilizing plantations, likely due to food availability and canopy connectivity. The expansion of plantations has facilitated greater movement of squirrels into farmlands, intensifying human-wildlife conflicts. This study highlights the importance of understanding habitat preferences and land-use dynamics to develop conservation strategies for the GGS. The findings underscore the need for sustainable plantation management, habitat restoration, and conflict mitigation measures to ensure the long-term survival of this species. Future conservation efforts should focus on maintaining tree canopy connectivity.

Key words- Land-use and land cover, protected area, eco-sensitive zone, Grizzled giant squirrel, density estimation, distance sampling

INTRODUCTION

In recent years, humans have drastically modified the global environment to meet their requirements and have consequently altered the ecology of many wild animals (Ojima *et al.*, 1994; Mannion, 2014). The major cause of such changes has been the increasing need for energy extraction and food production (Turner and Meyer, 1994). The most prevalent method of agricultural expansion involves converting forests into agricultural land, which is regarded as the primary driver of global forest loss and degradation (Kissinger *et al.*, 2012). Such changes in land use can lead to significant environmental impacts, especially affecting biodiversity (Alroy, 2017).

The Western Ghats (WG) of India, one of the most significant biodiversity hotspots globally, has experienced substantial land-use and land-cover (LULC) changes in recent years (Kale *et al.*, 2016). Land-use changes driven by agricultural expansion, conversion to monoculture plantations, and non-timber forest product harvest have resulted in significant forest loss, posing a major threat to the biodiversity of the Western Ghats (Shahabuddin & Prasad, 2004). The Western Ghats have witnessed a significant increase in tea, coffee, cardamom, rubber, and teak plantations over the past few decades, leading to ecological disruption and biodiversity loss (Menon & Bawa, 1997). However, there is substantial evidence suggesting that plantations can still serve as important habitats, thus supporting certain threatened and endangered species (McKinney & Lockwood, 2001). Moreover, plantations might contribute to biodiversity conservation through various mechanisms by providing food resources, shelter, and refuge from predators (McKinney, 2006). For instance, several species, including Nilgai (*Boselaphus tragocamelus*), Blackbuck (*Antelope cervicapra*), Elephants (*Elephas maximus*), Chital (*Axis axis*), Primates, and wild pigs (*Sus scrofa*), utilize agricultural lands for food, water, and shelter. This results in significant damage to farms and exacerbates human-wildlife conflict (Karanth *et al.*, 2012). In recent years, even giant squirrels such as the Malabar giant squirrel (*Ratufa indica*) and Grizzled giant squirrels (*Ratufa macroura*) are utilizing agricultural lands for food resources (Govind & Jayson, 2018).

In recent years, a similar trend has been observed with the grizzled giant squirrel (GGS) in southern India. The GGS is endemic to southern India and Sri Lanka.

Distribution of GGS is mostly restricted to patchy riverine habitats in the rain shadow region of southern India. It is found as an isolated population in the Western and Eastern Ghats and is increasingly affected by land use changes and fragmentation (Joshua, 1992; Harlekar, 2010; Thomas & Nameer, 2018). In India it is known to occur in Srivilliputhur GGS Sanctuary, Tamil Nadu (Joshua, 1992), Chinnar Wildlife Sanctuary, Kerala (Ramachandran, 1993; Kumar *et al.*, 2007, Thomas & Nameer, 2018), Anamalai Tiger Reserve, Tamil Nadu (Kumar *et al.*, 2007), Theni forest Division (Babu *et al.* 2013), Sirumalia (Sathasivam *et al.*, 2008), Tiruvannamalai forest division (Babu & Kalaimani, 2014), Pakkamalai Reserved forest, (Vimalraj *et al.*, 2018) Palani Hills (Davidar, 1989). The Kanakapura Forest Division, in southern Karnataka (Kumara & Singh, 2006; Baskaran *et al.*, 2011), which is considered as the northern-most population (Kumara & Singh, 2006). Jatbana *et al.* (2008) recorded the presence of this species in Hosur forest division along the Cauvery riverine forest. Molur *et al.* (2005) reported that in the last 25 years the population size of the GGS has declined by about 30%.

The Srivilliputhur Grizzled squirrel sanctuary supports the largest population of Grizzled giant squirrel followed by Chinnar Wildlife Sanctuary. The GGS is listed as Near Threatened in the IUCN Red List (IUCN, 2018). This species is listed under the Schedule I (Part I) of the Indian Wildlife (Protection) Act (1972), and is listed on CITES Appendix II regulating international trade in this species. Arboreal dwellers, including the GGS, generally favor habitats with dense canopy cover and taller canopy heights (Baskaran *et al.*, 2011). GGSs build their nests, known as dreys, using twigs and leaves in the upper canopy, specifically at the forked branches where the crowns of adjacent trees meet (Vanitharani & Bharathi, 2011). These squirrels prefer areas with abundant food and well-connected canopies for their nests. They typically select significantly larger trees with greater girth at breast height (GBH), taller heights, and numerous branches for nest building. The composition of tree species and the structural attributes of forests play a crucial role in habitat utilization by the GGS (Ramachandran, 1993).

To date, all studies on the GGS have focused exclusively on its population, behavior and ecology within protected areas (Joshwa, 1992; Thomas, 2014). In contrast, the present study examines how land use changes around these protected areas impact GGS density and habitat. Notably, the land around the protected areas, especially around the Srivilliputhur region of Srivilliputhur-Megamalai Tiger Reserve (SMTR), has

significantly transformed into farmland. The increased connectivity provided by these plantations is leading squirrels to venture into farmlands (Rao *et al.*, 2015), causing substantial damage to crops and resulting in significant losses for farm owners. To understand these effects, we compared the density of squirrels across different habitats both inside and outside the protected areas. The findings offered valuable insights into the impact of land use changes on wildlife and inform strategies for mitigating human-wildlife conflicts.

MATERIALS AND METHODS

Study area

The study was carried out from December 2023 to July 2024 in Srivilliputhur-Meghamalia Tiger Reserve, Srivilliputhur Division and its Eco-Sensitive Zone situated in the Southern Western Ghats of Tamil Nadu (Fig. 1). The geographical coordinates range from 09° 23' 38" N to 09° 49' 51" N latitude and from 77° 21' 51" E to 77° 47' 20" E longitude. It predominantly lies within the Srivilliputtur and Rajapalayam taluks of Virudhunagar district and the Peraiyur taluk of Madurai district. The survey was conducted only in deciduous and riparian forests within the Protected Area.

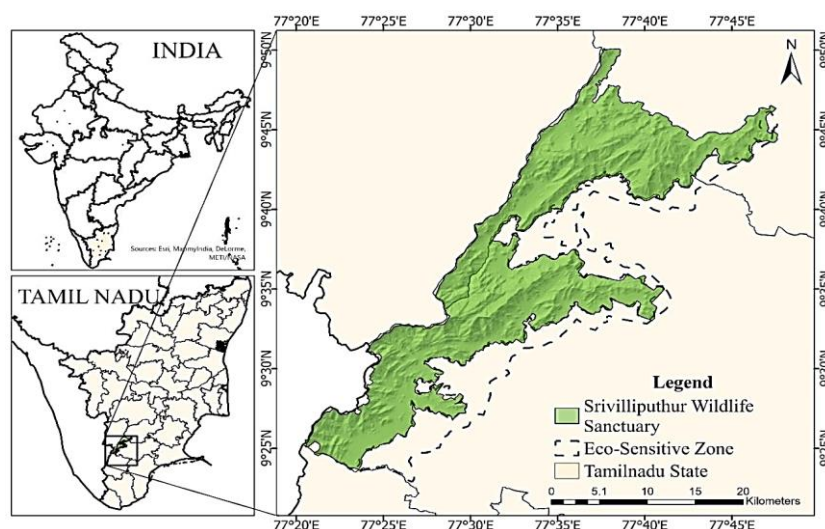


Figure 1. Map of the study area in Virudhunagar district of Tamil Nadu, India showing Srivilliputhur Grizzled squirrel Wildlife Sanctuary and Eco-Sensitive Zone

The eco-sensitive zone (ESZ) for this protected area was officially designated in 2020 (smtr.org.in). The extent of the ESZ ranges from zero kilometers, due to the inter-state boundary, to 6.2 km around the perimeter of the protected area. The total area of

the ESZ 208 sq km. The majority of the ESZ consists of private/patta lands that encompass mango and coconut plantations, teak plantations as well as agricultural land. Mainly three types of plantation are present, namely coconut plantation, mango plantation and coconut mix mango plantation. An Intensive Study Area (ISA) of 250 sq.km was selected based on the dense cultivation of plantations in the ESZ and adjacent Protected Area was chosen using Google Earth Pro.

Land-use Land-cover change

A decadal Land use Land cover (LULC) analysis was conducted for the years 1993 and 2023 within the ESZ to assess the expansion of plantation land using Arc GIS pro and Google Earth Engine (GEE). High-resolution satellite images from Landsat 5 TM (1993) and Landsat 8 OLI/TIRS (2023) were obtained from Google Earth Engine (GEE) dataset repository. Cloud-free images were filtered, a median composite was applied to reduce noise, and cloud masking functions removed clouds and shadows.

Polygons representing four land cover types (plantation, fallow land, water body and others) were created in GEE for training data. A Random Forest algorithm classified the images for both years. For accuracy assessment, 70% of the data was used for training and 30% for validation, with metrics such as overall accuracy and the Kappa coefficient calculated.

Classified Geo TIFF images from both years were imported into ArcGIS Pro, clipped to the study area, and standardized. The Change Detection Wizard highlighted land use transitions between 1993 and 2023. The area for each class was calculated, and percentage changes were derived.

Squirrel and drey survey

To conduct the survey in the protected area, existing beat transects, patrolling tracks, and fire lines were delineated as line transects to estimate the density of squirrels. A total of 17 line transects, varying in length from 450 meters to 2750 meters, were sampled, encompassing a total effort of 18 kilometers across Riparian Forest and deciduous forests within the protected area. Additionally, 67 transects, ranging from 100 to 500 meters in length, were established in the eco-sensitive zone across different plantation types (mango, coconut, and mixed). The length of each transect depended on the length of the plantation, fencing, and crop type. Distances of approximately 250

meters were maintained between each transects in the plantation to avoid the double counting of GGS. Twenty transects were sampled in mixed plantations with a total effort of 4.5 kilometers, 25 transects in coconut plantations with a total effort of 5.5 kilometers, and 20 transects in mango plantations with a total effort of 5.7 kilometers. The total survey effort in the plantations within the eco-sensitive zone amounted to 15.8 kilometers. All transects were replicated four times during the study duration, dreys were counted only once (in 1st replicate) during the entire study period.

All sightings of squirrels and dreys along transects were recorded, along with the following data: tree species, count of individuals, distance from the observer, and angle of sighting. The locations were determined using a handheld GPS device (Garmin eTrex 20X), while distances were measured using a laser rangefinder (Nikon Forestry Pro). Angles were recorded using a compass-enabled mobile handset. Surveys were conducted during the morning hours, between 0700 and 1200 hours, coinciding with peak squirrel activity (Joshua, 1992). Predefined line transects were walked at a uniform speed, and the identification of dreys inside the protected area was confirmed by consulting two individuals.

RESULTS

Land-use and land- cover change

The land-use and land-cover change data from 1993 to 2023 reveals significant transformations in the landscape (Table 1 & Fig. 2). Plantation areas showed substantial growth, increasing from 47.793 sq. km in 1993 to 120.805 sq. km in 2023, representing a 152.76% rise. In contrast, fallow land experienced a significant reduction, decreasing from 121.009 sq. km in 1993 to 68.284 sq. km in 2023, which is a 42.97% loss. Water bodies also increased dramatically, expanding from 2.63 sq. km in 1993 to 5.136 sq. km in 2023, marking a 95.28% rise. Meanwhile, the category classified as "Others," which includes barren and scrub land, declined by 22.319 sq. km, reflecting a 44.99% loss. The land-use and land-cover classification effectively differentiated between plantation and fallow land, with the majority of conversions occurring between these two categories. The overall accuracy of the classification was 86.9%, with a Kappa coefficient of 89.5%.

Table 1. Changes in the major land-use and land-cover classes within the eco-sensitive zone between 1993 and 2023 with absolute change and percentage

Sl. No	land-use land-cover type (class)	Area (sq. km)		Change	
		1993	2023	Absolute change (sq. km)	Percent
1	Plantation	47.793	120.805	73.012	152.76
2	Fallow Land	121.009	68.284	-52.725	42.97
3	Water Body	2.63	5.136	2.506	95.28
4	Others	30.447	8.128	-22.319	73.3

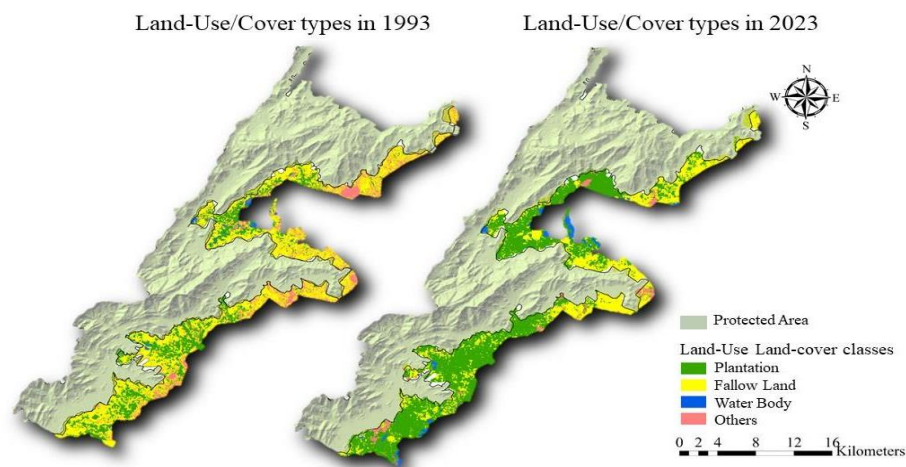


Figure 2. Extent of land-use and land-cover change in the eco-sensitive zone between 1993 and 2023 with major land-use classes as plantation, fallow land, water body and others.

Density of Squirrels and dreys

To run the detection function in the R program, only sightings within 35 m were considered to achieve a better fit of the model (Fig. 3). Separate model was run for the squirrels and dreys. The half normal model with null adjustment was deemed to be the best model for Squirrels. The hazard-rate model with null adjustment was deemed to be the best model for dreys. The density estimate varied considerably between the different habitat types. In general, densities were higher in the plantations when compared to the protected area. In the plantations, mix plantations had the highest density with 72.95 ± 22 (Mean $\pm$ SD) squirrels (Fig. 4a) per sq. km and 400.62 ± 93 (Mean $\pm$ SD) dreys per sq. kmm (Fig. 4b), followed by coconut plantations with 57.28 ± 19 (Mean $\pm$ SD) squirrels per sq. km and 68.92 ± 28 (Mean $\pm$ SD) dreys per sq. km. Mango

plantations had very less density with an estimated 5.21 ± 6 (Mean $\pm$ SD) squirrels per sq. km and 18.12 ± 23 (Mean $\pm$ SD) dreys per sq. km. In the case of the protected area, deciduous forests had an estimated density of 14.31 ± 9 (Mean $\pm$ SD) squirrels per sq. km and 289.70 ± 110 (Mean $\pm$ SD) dreys per sq. km, which slightly reduced to 10.59 ± 6 (Mean $\pm$ SD) squirrels per sq. km and 7.26 ± 6 (Mean $\pm$ SD) dreys per sq. km in the case of Riparian forests. Due to less sampling effort, the CV for the density estimates of the protected area was relatively higher. Thus, the estimate for the protected area should be considered as a conservative estimate.

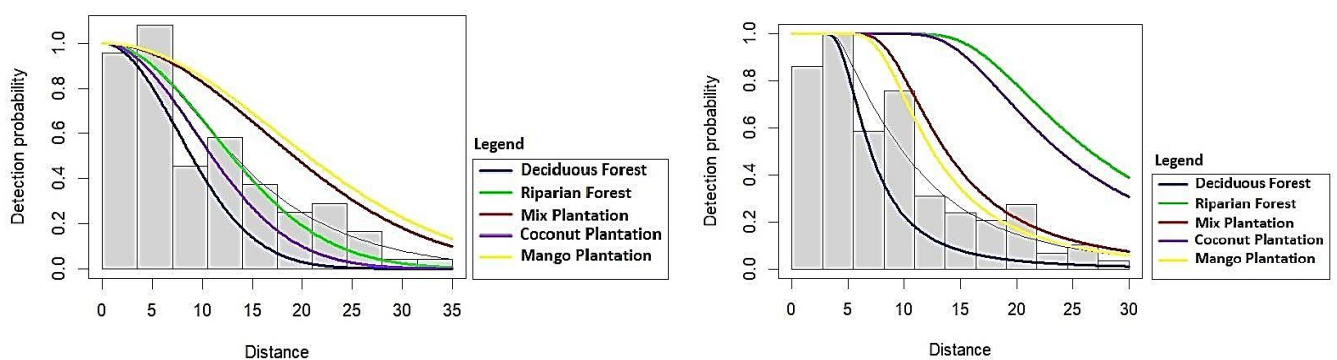


Figure 3. a) Detection probability of GGS in different habitat types; b) Detection probability of dreys in different habitat types

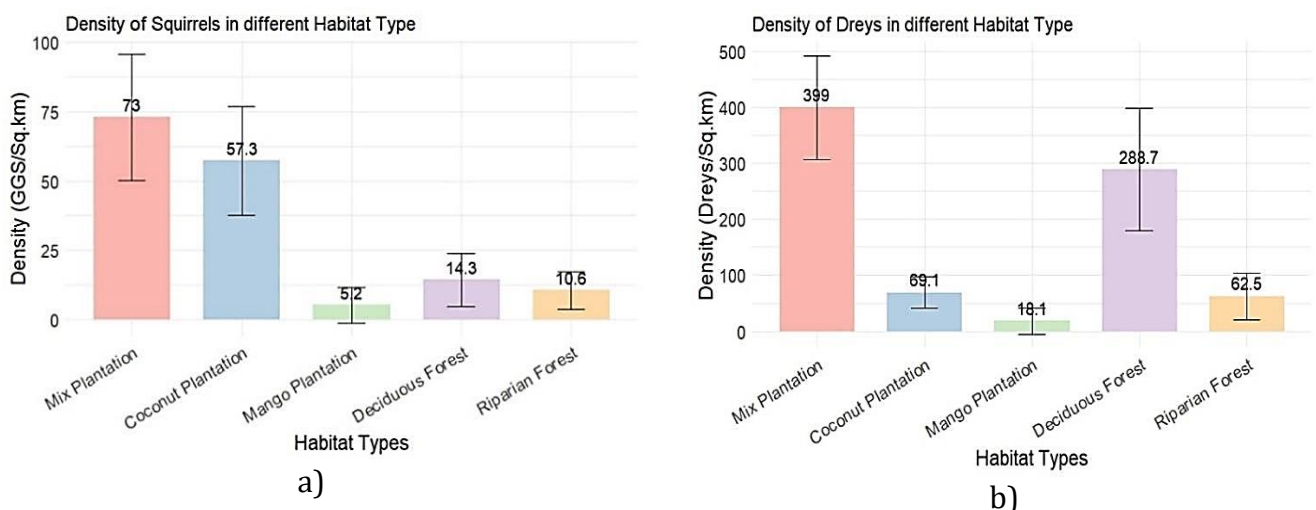


Figure 4. a) Density of GGS in different habitat types with standard error; b) density of dreys in different habitat types with standard error

DISCUSSION

Effect of land-use change around protected area

Over the past 30 years, the land around the Srivilliputhur region of Srivilliputhur-Megamalai Tiger Reserve (SMTR) has undergone significant conversion from barren land to mango and coconut plantations. This change has increased connectivity between natural and human-modified landscapes, encouraging wildlife species to venture into farms. The fruits from these farms are energy-rich, easily digestible, and often clumped in plantations, offering substantial energetic advantages over natural foods for wildlife in the agriculture-forest ecotones (Sukumar, 1990). Studies have shown that increasing conversion of natural habitats to alternative land uses, particularly around protected areas (PAs), causes wildlife residing within these PAs to become increasingly dependent on cultivated foods (Paterson & Wallis, 2005; Hockings & McLennan, 2012). The movement and ranging patterns of wildlife are primarily influenced by the availability of food, water, and mates. The same holds true for GGS, which have adapted their feeding ecology to exploit these plantations.

Density estimate of GGS and dreys in different habitat types

The density estimate obtained from this study should be considered a conservative estimate due to several factors such as variations in the detectability of GGS across different habitats, influenced by vertical stratification, canopy cover, and the squirrels' shyness within protected areas. Additionally, the difficulty in distinguishing active from abandoned dreys further impacts the accuracy of the density estimate.

The result of this study indicates that density of GGS and its dreys was higher in plantations compared to the protected area, which might be due to increased amount of food resources available throughout the year. Furthermore, the density of GGS and dreys was higher in mixed plantations, followed by coconut plantations and mango plantations. This could be attributed to the presence of both nesting and fruiting trees in mixed plantations, providing a more favorable habitat in terms of increased canopy connectivity, canopy cover, which helps GGS to move easily and escape from aerial predators (Joshua & Johnsingh, 1994).

CONCLUSION

This study highlights the significant impact of converting Fallow lands into mango and coconut plantations on the population and habitat of the grizzled giant squirrel (GGS) around the SMTR in southern India. Over the past three decades, these land-use changes have enhanced connectivity between natural forests and plantation areas, providing energy-rich fruits that attract wildlife, including GGS. However, this shift has also altered ecological dynamics, increasing wildlife reliance on cultivated foods and influencing their movement patterns. Density estimates indicate higher concentrations of GGS and nesting sites (dreys) in plantations compared to protected areas, with mixed plantations showing the highest densities due to abundant nesting sites and the availability of fruiting trees. Notably, GGS demonstrates a preference for mango trees over coconut trees in plantations for nesting, attributed to the structural support and protection mango trees offer.

From a conservation perspective, it is essential to maintain critical habitats within protected areas, establish buffer zones between plantations and natural forests, and encourage biodiversity-friendly practices in monoculture plantations. Community-based conservation efforts and adaptive management strategies are crucial for reducing human-wildlife conflicts.

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12 AGE AND SEX INFLUENCE SEED DISPERSAL OF NATIVE AND NON-NATIVE PLANTS BY LION-TAILED MACAQUES *MACACA SILENUS*

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ABSTRACT

Intraspecific variation in seed dispersal by vertebrates due to differences in body size, foraging behaviours, and ranging patterns within a species is relatively understudied. Among vertebrates, primates play a critical role in seed dispersal and exhibit behavioural differences between age and sex categories, making them a suitable study system for intraspecific variation in seed dispersal. Lion-tailed macaques, an endemic frugivorous primate species in the Western Ghats, provide an excellent model for such studies. We examined the influence of age and sex on 1) the diversity and 2) the quantity of native and non-native fruits consumed, 3) the number of seeds dispersed, 4) seed dispersal distance, and 5) seed deposition substrates in lion-tailed macaques. We conducted over 375 hours of focal animal watches, distributed evenly across adult males, females, and subadults. Our findings showed that subadults consumed a higher diversity of native and non-native fruits than females and males. They dispersed fewer *Ficus sp* seeds than females. We found differences in the proportions of non-native fruits in the diets of different age-sex categories. Adult males consumed more *Coffea liberica*, whereas adult females and subadults (both sexes) fed on *C. liberica* and *Lantana sp*. We found weak evidence suggesting that males were dispersing more *Ficus* seeds. Our study highlights that age and sex influenced seed dispersal patterns of native and non-native plant species by an endemic, frugivorous primate species with potential influence on plant recruitment.

Keywords: Alien invasive species; anthropogenic disturbance; primate seed dispersal; Western Ghats.

INTRODUCTION

Seed dispersal is a key ecological process influencing plant diversity at local, regional, and continental scales (Levine & Murrell, 2003; Plue & Cousins, 2018). In the tropics, animals play a critical role in seed dispersal, dispersing seeds of up to 90% of the plant species (Farwig & Berens, 2012; Howe & Smallwood, 1982). While the variation in seed dispersal outcomes due to differences in the morphology and ecology of different seed disperser species is well-documented, intraspecific variation caused by the influence of individual animals' personalities and behaviour on seed dispersal outcomes is less explored (Zwolak & Sih, 2020).

Variations in seed dispersal effectiveness within a species may be driven by size, age, sex classes, social status, or individual personalities (Zwolak & Sih, 2020). These variations can lead to differences in seed dispersal effectiveness, including the number of seeds dispersed, dispersal distance, and the quality of the seed deposition site (Snell *et al.*, 2019). For example, subordinate females in Japanese macaques *Macaca fuscata* may swallow fruits likely to avoid harassment by dominant individuals, thereby providing better seed dispersal services (Tsuji *et al.*, 2020; Tsuji & Takatsuki, 2012), highlighting the role of dominance in influencing seed dispersal. Additionally, recent review emphasises the importance of understanding the linkages between behavioural types and their impact on seed dispersal (Zwolak & Sih, 2020).

Seed dispersal effectiveness encompasses qualitative and quantitative components (Schupp, 1993; Schupp *et al.*, 2010). The qualitative components include seed handling behaviour, gut treatment of seeds, and the suitability of seed deposition sites, while the quantitative component refers to the number of seeds dispersed. In the context of intraspecific variation, the quantitative component of seed dispersal can be influenced by differences in relative abundance and body sizes, whereas the quality component can be impacted by variations in ranging patterns, physiology and fruit handling among individuals within a species. Age-sex categories within a species often exhibit differences in relative abundance, body sizes, dietary preferences, ranging patterns, and fruit handling (Benitez-Malvido *et al.*, 2016; Celebias *et al.*, 2024; Dhawale *et al.*, 2020). Most studies on intraspecific variation in seed dispersers tend to focus on particular stages of seed dispersal process, e.g., de Camargo *et al.* (2014) studied

variations in the quantity of seeds dispersed by male and female agile opossum *Gracilinanus agilis*. Studies that examine multiple quantitative and qualitative components of the seed dispersal process are relatively limited (Tsuji *et al.*, 2020).

Primates are one of the important seed dispersers in tropical forests (Chaves *et al.*, 2011; Sengupta *et al.*, 2020). In addition to age-related differences, primates often exhibit sexual dimorphism, with males typically larger than females (Plavcan, 2001). Most frugivorous primates are group-living and have a strong social organisation within their troops (Snaith & Chapman, 2007). The combination of dominance hierarchies and morphological differences among individuals in frugivorous primates makes them an ideal study system to examine the intraspecific variations in seed dispersal patterns.

The lion-tailed macaque *Macaca silenus* (LTM) is an endemic, habitat specialist, primarily arboreal, and frugivorous primate found in the central and southern portions of the Western Ghats, a Biodiversity Hotspot in India (Singh *et al.*, 2002; Umapathy & Kumar, 2000). Fruits are a significant component of LTM's diet, constituting up to 70% of consumed food items (Santhosh *et al.*, 2015; Singh, 2019). Their diet includes native fruit species such as *Artocarpus heterophyllus*, *Cullenia exarillata*, *Ficus* spp., *Litsea floribunda*, and *Syzygium cumini*, among others. In the severely fragmented rainforests of Anamalai hills, LTMs also consume exotic species, including *Persea americana*, *Maesopsis eminii*, *Coffea canephora*, *Coffea liberica*, *Lantana camara*, and *Psidium guajava* (Dhawale *et al.*, 2020; Menon & Poirier, 1996; Singh *et al.*, 2002). LTMs exhibit a social system characterised by despotism and a linear dominance hierarchy (Singh *et al.*, 2006, 2011). An aggressively structured dominance hierarchy exists among males, females, and among the sexes (Singh *et al.*, 2006, 2011). Furthermore, male and female LTMs have been reported to exhibit different levels and types of curiosity, with females demonstrating a greater propensity to locate food resources (Rouff *et al.*, 2005). Given the importance of fruits in their diets and their distinct social hierarchy, LTMs are a suitable species for studying intraspecific variation in seed dispersal.

Puduthottam is a private, degraded rainforest fragment that has the highest density (>100 individuals/km²) of LTMs among the 45 rainforest fragments in the Anamalai hills of Tamil Nadu (Dhawale & Sinha, 2023; Singh *et al.*, 2002). The LTM troops in this fragment have been extensively studied for several decades and are well-

habituated (Dhawale *et al.*, 2020; Singh *et al.*, 2002; Umapathy & Kumar, 2000). Additionally, this severely degraded rainforest fragment has a high density of invasive species, constituting a significant part of the LTM diet. This allows us to examine the influence of age and sex on the differential seed dispersal of alien, invasive plant species in a degraded landscape.

Given the intraspecific differences in LTM behaviour, we examined whether different seed dispersal parameters differed across age-sex categories. Specifically, we examined: 1) the diversity of native and non-native fruits foraged by different age-sex categories of LTMs, 2) the relative contributions of native and non-native fruits in the diets of different age-sex categories, 3) the daily distance travelled by individuals of different age-sex categories, 4) the number of *Ficus* seeds deposited by individuals belonging to different age-sex categories, and 5) the substrates where different age-sex categories deposit *Ficus* seeds. This study provides valuable insights into the role of the endemic, forest specialist LTM as a disperser of native and non-native plant species, an area that has been underexplored in the literature.

MATERIALS AND METHODS

Study area

The lion-tailed macaque is distributed across eight locations in India's Karnataka, Kerala and Tamil Nadu states (Kurup & Kumar, 1993; Singh, 2019; Singh *et al.*, 2002). The Anamalai Hills of Tamil Nadu harbours the largest metapopulation within the LTM's distributional range (Kumara *et al.*, 2014; Singh, 2019). Once a contiguous stretch of tropical rainforest, the area has experienced forest loss and severe degradation over the past two centuries due to land clearing for tea, coffee, and cardamom cultivation. At the centre of these hills lies the Valparai plateau, a 220 km² heterogeneous landscape dominated by tea and coffee plantations interspersed with several rainforest fragments ranging from <10 ha to >100 ha in size (Umapathy & Kumar, 2000).

We conducted the study in one of the larger fragments, Puduthottam, which spans 92 ha. The fragment is bordered by coffee and tea plantations and human settlements, including plantation labour lines and the nearby town of Valparai. Additionally, the Pollachi-Valparai National Highway cuts through the fragment. The

macaques use all available habitat types (Dhawale *et al.*, 2020). Puduthottam harbours five LTM troops with approximately 200 individuals (Dhawale & Sinha, 2023). Of these, BK observed individuals from four troops: BT, NTT, RT, and PAP, consisting of ca. 116, 39, 25 and 12 individuals, respectively (Dhawale & Sinha, 2023; Bindu, K., Pers. Obs.).

Field methods

The study involved non-invasive behavioural observations of LTMs. We selected the first troop encountered in the field for observation. We restricted observations to individuals from three age-sex categories: adult males, adult females, and subadult males (Table 1, adapted from Singh *et al.* (2002)). We used focal animal sampling methodology, observing a single individual for up to six hours daily. We started the observations from 0700 hr.

Table 1. Age-sex classification of lion-tailed macaques (adapted from Singh *et al.*, 2002)

Age-sex class	Age range
Adult male	> 8 years
Subadult male	4–8 years
Adult female	> 6 years
Subadult female	4–6 years
Juvenile	1–4 years
Infant	<1 year

We consecutively sampled adult males, females and subadults to ensure interspersed and minimise potential biases arising from temporal variation in foraging across age-sex categories. We sampled an average of 19.8 (SE±1.84) days per month for four months. The total sampling effort encompassed 375.9 hours of focal observations, distributed among the different age-sex categories: adult males, adult females, and subadult males (Table 2). We followed the troop in fragments, plantations, and plantation labour lines. However, we stopped observations when the troop moved into the adjacent town, as they rarely consumed fruits and primarily fed on human-origin food. While our sampling effort varied across troops, it was similar across age-sex categories (Table 2). We did not observe subadult females due to difficulty in distinguishing them from adult females and juvenile males.

Table 2. Sampling effort (hours) across four troops distributed across three age-sex categories. “NA” indicates no observations for the particular age-sex category within the respective troop.

Troop ID	Adult Female	Adult Male	Subadult	Total duration (hr)
BT	66.50	70.71	85.57	222.8
NTT	40.41	27.51	29.67	97.6
PAP	14.57	28.10	7.40	50.1
RT	NA	4.41	0.96	5.4
	121.48	130.72	123.6	375.9

We categorised the observed activities into moving, resting, grooming, vocalisation, foraging, and feeding (Tsuji *et al.*, 2020). When the focal individual engaged in feeding behaviour, we classified the food items into plant, invertebrate, human-origin food, or unidentified material. When feeding on fruits, we collected additional details like the fruit species identity, the number of fruits consumed, and the state of fruit ripeness (ripe/unripe). Ripeness was visually determined based on the fruit colour.

To determine the daily distance covered by focal individuals, we tracked their movements using a Garmin eTrex 20x GPS. To determine the number of seeds dispersed by LTMs of different plant species, we investigated faeces from individuals of known age-sex categories upon observing defecation events. We recorded the substrate of the deposition sites. We followed established methods and identified seeds to the species level, except for *Ficus* and *Coffea* seeds, which require molecular techniques for identification. We analysed only *Ficus* seeds since other seeds appeared infrequently in the faeces.

1.1. Analysis

All statistical analysis was performed in R (ver. 4.2.1) and visualised using ggplot2 (Wickham *et al.*, 2007; R Core Team, 2022).

We evaluated sampling completeness for each age-sex category using sample coverage, which estimates the proportion of the total community represented in the sample (Roswell *et al.*, 2021). The sample coverage for all three cohorts (adult male, adult female and subadults) was >99%, indicating sampling adequacy.

To compare the diversity of fruits consumed by the three age-sex categories, we computed Hill-Shannon diversity for native and non-native fruits consumed by each age-sex category using the R package 'iNEXT' (Hsieh *et al.*, 2016). We bootstrapped the data 50 times to obtain 95% confidence intervals. We compared the diversity metric across three age-sex categories and inferred statistically significant differences if the confidence intervals did not overlap (Cumming *et al.*, 2007). We chose Hill-Shannon ($q = 1$) over species richness ($q = 0$) as it incorporates abundance information, unlike species richness, which treats all species equally regardless of their representation in the diet. Since the study focuses on frugivory and seed dispersal, relative abundance information is crucial, as macaques are likely to contribute less to the dispersal of infrequently consumed species.

We performed the Chi-square test to examine: 1) differences in the proportions of ripe and unripe native and non-native fruits consumed across age-sex categories, and 2) differences in the proportions of different non-native species consumed across age-sex categories. We used general linear models to determine whether daily movement (per hour) differed across the age-sex categories. The data were log-transformed to approximate normality. We used generalised linear models to examine whether the number of *Ficus* seeds dispersed differed across age-sex categories. Since the data was over-dispersed, we fitted a negative binomial regression model. We performed a Chi-square test to examine the association between age-sex cohorts and the different kinds of substrates (forest floor and tree) where the faeces were found.

RESULTS

Fruit Diversity in Diet

We recorded 24 species of plants in the diet of LTM (Table 3). The species richness of fruits consumed by females, males, and subadults was 17, 17, and 19, respectively. The Hill-Shannon diversity of fruits in the diets of females, males, and subadults was 6.4, 3.9, and 8.2 species, respectively. Hill-Shannon Diversity differed significantly among the three age-sex categories as inferred from non-overlapping 95% confidence intervals (CI) (Fig. 1). A similar pattern was observed for native fruit diversity, with subadults feeding the most diverse array of fruits (6.3 species), followed by females (4.2 species) and males (2.8 species). The diversity of non-native fruits

consumed by males (3.1 species) was lower than that consumed by females (3.9 species) and subadults (3.7 species).

Table 3. Number of fruits of different plant species that we observed the different age-sex categories of Lion-tailed macaques feeding on during the study period.

Species	Family	Type	Female	Male	Subadult
<i>Artocarpus heterophyllus</i>	Moraceae	Native	13	28	37
<i>Coffea arabica</i>	Rubiaceae	Non-native	154	350	146
<i>Coffea robusta</i>	Rubiaceae	Non-native	261	47	110
<i>Cullenia exarillata</i>	Malvaceae	Native	0	0	1
<i>Eugenia uniflora</i>	Myrtaceae	Non-native	0	38	0
<i>Ficus amplissima</i>	Moraceae	Native	16	556	356
<i>Ficus exasperata</i>	Moraceae	Native	96	92	108
<i>Ficus microcarpa</i>	Moraceae	Native	1001	259	705
<i>Ficus nervosa</i>	Moraceae	Native	33	2	0
<i>Ficus racemosa</i>	Moraceae	Native	91	102	65
<i>Ficus religiosa</i>	Moraceae	Native	15	0	0
<i>Ficus superba</i>	Moraceae	Native	0	0	68
<i>Ficus tinctoria</i>	Moraceae	Native	1974	3647	1554
<i>Ficus tsihela</i>	Moraceae	Native	165	240	317
<i>Lantana camara</i>	Verbenaceae	Non-native	284	79	133
<i>Litsea nigrescens</i>	Lauraceae	Native	24	28	35
<i>Litsea floribunda</i>	Lauraceae	Native	0	0	57
<i>Maesa indica</i>	Primulaceae	Native	0	0	65
<i>Persea americana</i>	Lauraceae	Non-native	0	1	0
<i>Psidium guajava</i>	Myrtaceae	Non-native	13	13	7
<i>Scurrula parasitica</i>	Loranthaceae	Native	771	50	600
<i>Spathodea campanulata</i>	Bignoniaceae	Non-native	36	11	21
<i>Syzygium aqueum</i>	Myrtaceae	Non-native	16	0	0
<i>Syzygium rubicundum</i>	Myrtaceae	Native	0	0	3

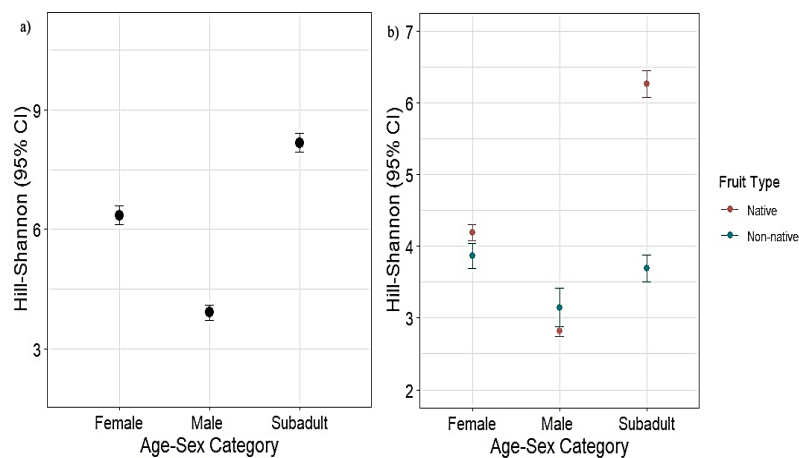


Figure 1. Taxonomic diversity (Hill-Shannon Diversity Measure) of a) all fruits (pooled native and non-native) and b) native and non-native fruits consumed across age-sex categories. Bars represent bootstrapped 95% confidence intervals.

Quantity of Fruits in Diet

We found that subadults consumed a higher proportion of native fruits, while females consumed a higher proportion of non-native fruits than the other age-sex categories ($\chi^2 = 306.31$, $df = 2$, $p < 0.001$; Fig. 2a). Up to 25% of the diet of the female and male LTMs consisted of non-native species. Males consumed a higher proportion of *Coffea liberica* and a lower proportion of *Lantana camara* than females and subadults ($\chi^2 = 425.11$, $df = 14$, $p < 0.001$; Fig. 2b). These two alien species collectively contributed to up to 90% of the invasive in the diet of LTMs.

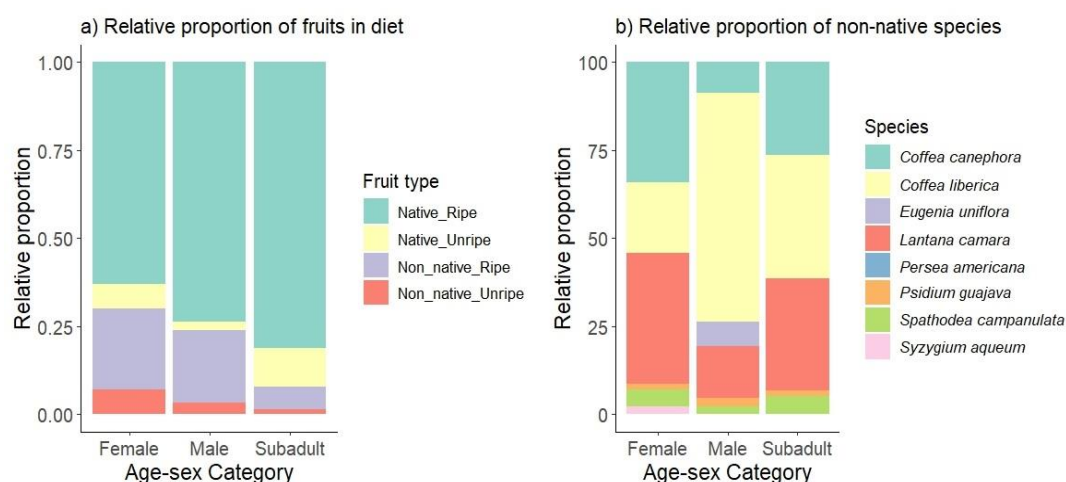


Figure 2. a) Relative proportions of fruits in the diet, showing a lower representation of unripe fruits and higher proportions of non-native and native fruits in the diets of females and subadults, respectively. b) Relative proportions of different non-native species in the diet. Adult males consumed more *Coffea liberica* compared to other alien fruit species, while *Lantana camara* formed a significant part of the diet of females and subadults.

Daily Movement

We recorded 107 tracks of varying lengths during the study. There was no significant effect of age-sex category on daily movement ($F_{2, 104} = 0.8787$, $p = 0.42$; Table 4; Fig. 3).

Table 4. Results of General Linear Model (Gaussian error structure) examining differences in the distance travelled across age-sex categories

Predictor	Estimate	SE	t	p
Intercept: Female	-0.2766	0.04223	-6.551	<0.001
Male	0.00764	0.05761	0.133	0.895
Subadult	0.06607	0.05626	1.174	0.243

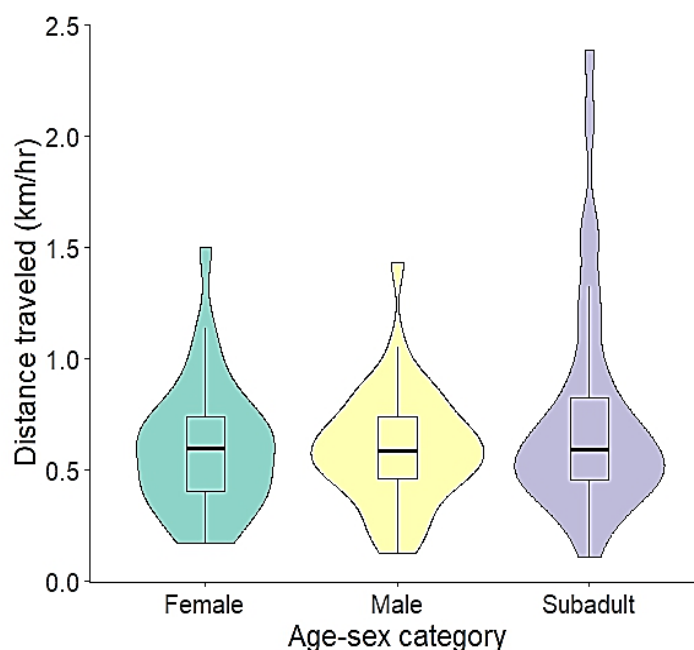


Figure 3. Daily distance travelled (km hr^{-1}) across age-sex categories.

Seed Dispersal Quantity

During the study, from 51 fresh faecal deposits investigated, 121,375 seeds belonging to six plant species were identified, including *Ficus* spp., *Coffea* spp., *Maesopsis eminii*, *Spathodea campanulata*, *Scurrula parasitica*, and *Lantana camara*. Since seeds from other plant species appeared infrequently in the faeces, only *Ficus* seeds were considered for further analysis. Subadults dispersed significantly fewer *Ficus* seeds than the other age-sex categories (Fig. 4a, Table 5).

Seed Deposition Site

We found 51 faecal deposits (females: 20, males: 18, subadults: 13). The relative proportions of faecal deposits across different substrates differed marginally among age-sex categories ($\chi^2 = 11.63$, $\text{df} = 6$, $p = 0.07$; Fig. 4b). There was weak evidence that male LTMs were more likely to disperse *Ficus* seeds on trees, which are more suitable habitats for the germination of *Ficus* seeds.

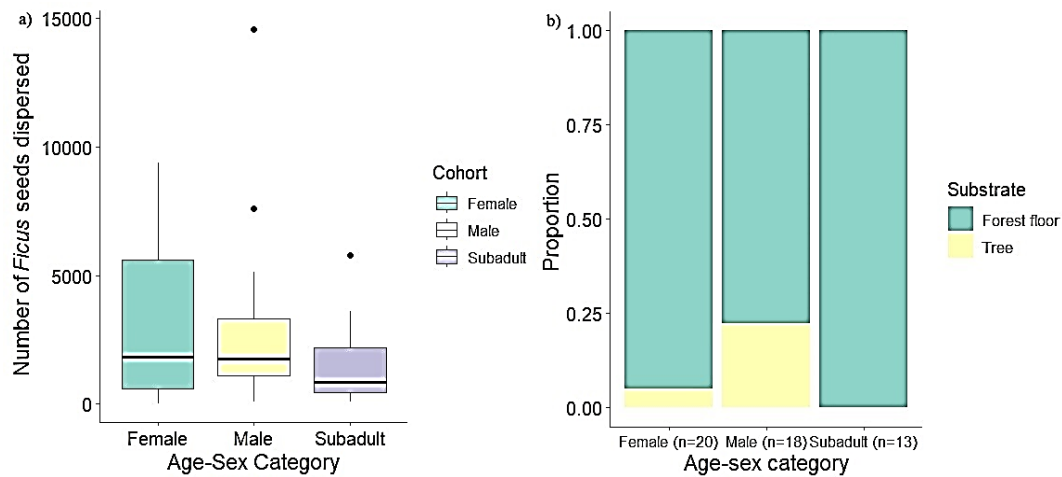


Figure 4. a) Number of *Ficus* seeds dispersed per scat by each age-sex category. b) Relative proportion of seed deposition substrates across age-sex categories.

Table 5. Results of the Generalised Linear Model (negative binomial error structure) examining differences in the number of *Ficus* seeds dispersed across age-sex categories.

Predictor	Estimate	SE	t	p
Intercept: Female	8.064	0.241	33.403	<0.001
Male	-0.074	0.346	-0.214	0.830
Subadult	-0.766	0.379	-2.021	0.043

DISCUSSION

This study is one of the few to examine intraspecific variation in frugivory and seed dispersal by an endemic frugivorous primate. Our results demonstrate that the age and sex of lion-tailed macaques influence their role in seed dispersal. We found that subadults had higher diversity and greater representation of native fruits in their diet than adult females and males, although they dispersed fewer *Ficus* seeds. In contrast, males tended to disperse *Ficus* seeds on trees, which are more suitable sites for seedling establishment (Laman, 1995; Shanahan, 2016). There were also differences in the consumption of non-native fruits, with a greater diversity in the diet of subadults. Males consumed more *Coffea liberica*, whereas females and subadults fed on both *C. liberica* and *Lantana camara*. The variation in the relative abundance of females, males, and subadults within a troop can significantly influence the dispersal patterns of native and non-native seeds across the landscape.

Factors influencing intraspecific variation

Limited evidence suggests that individual variations within populations, including social hierarchy and differences in morphology and behaviour, can influence seed dispersal patterns (Bartel & Orrock, 2021; Zwolak & Sih, 2020). The limited evidence on intraspecific variation in seed dispersal indicates contrasting results in the diversity of food items consumed by adults versus juveniles. The juvenile howler monkeys *Alouatta pigra* fed on a lower diversity of fruits than adults (Benítez-Malvido *et al.*, 2014). In contrast, we found that sub-adult LTMs consumed a greater diversity of fruits than adult male LTMs. While there was no difference in the richness of seeds dispersed by Japanese Macaques (Tsuji *et al.*, 2020), information on the diversity of fruits they consumed is absent.

Factors influencing intraspecific variation in fruit consumption have been attributed to greater experience in adult howler monkeys (Benitez-Malvido *et al.*, 2016). This variation could also be influenced by dominance hierarchies, as observed in Japanese macaques (Tsuji *et al.*, 2020; Campos-Arceiz *et al.*, 2020). Behavioural differences in social status and foraging patterns have been reported across different age-sex categories of LTMs (Dhawale *et al.*, 2020; Singh *et al.*, 2011). Adult male LTMs are dominant and display agonistic behaviour towards females and other males, indicating their dominance over females and subadults (Singh *et al.*, 2011). This could compel the subadults to forage on a greater diversity of resources. Apart from dominance, the differences in time spent on foraging might also influence the intraspecific differences in the diversity of fruit items in LTM diets. Unlike previous studies, we found that adult males spent less time foraging and more time resting than subadults and females (Fig. 5). Foraging behaviour includes searching for food items in litter, bark, leaves or other substrate. We ran beta regression models to examine if there was a significant difference in time spent on feeding, foraging and resting behaviours across the age-sex categories. An animal that spends more time foraging and less time resting is likely to encounter more resources, which can explain the greater diversity of resource items in diets of subadults and females, an aspect that needs further investigation.

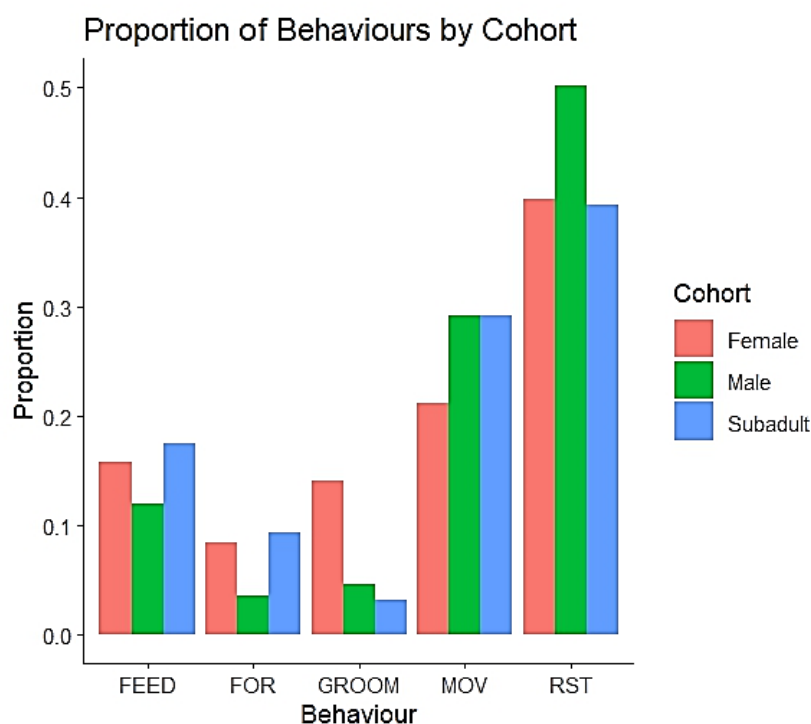


Figure 5. Bar plot showing the time spent on different behaviours by the three age-sex categories of lion-tailed macaques. Activities are abbreviated as FEED - Feeding, FOR - Foraging, GROOM - Grooming, MOV - Moving, RST - Resting.

Implications of intraspecific variations on frugivory and seed dispersal

To determine seed dispersal effectiveness, we evaluated both quantitative (number of seeds dispersed) and qualitative measures (fruit-handling behaviour, movement patterns of LTMs and seed deposition sites). We could determine the number of seeds dispersed only for *Ficus* spp. While the low representation of medium- and large-seeded species like *Artocarpus heterophyllus* is expected since LTMs mostly spit seeds of these species, the low representation of *Lantana camara* seeds was surprising, given their extensive consumption of *Lantana*. The sieve size used for determining the diversity and number of seeds in LTM faeces followed established methods (Tsuji *et al.*, 2020) and was smaller than *Lantana camara* seeds. Macaques are known to grind seeds more than swallowing and defecating them intact (David *et al.*, 2015; Stevenson, 2007). Therefore, it is likely that *Lantana* seeds are crushed, while the smaller *Ficus* seeds escape getting crushed.

Animals mainly disperse *Ficus* seeds in a clumped manner through their faeces (Zhou & Chen, 2010). There is no evidence indicating the negative impacts on germination or establishment due to the clumped dispersal of *Ficus* seeds. Males

showed a higher representation of *Ficus* in their diet than females and subadults (Fig. 6). Chi-square test was performed to examine the differences in the proportion of native species consumed across age-sex categories ($\chi^2 = 1156.2$, $df = 14$, $p < 0.001$). Although females and subadults consumed a similar proportion of *Ficus* fruits, the number of *Ficus* seeds dispersed in the scats was lower in subadults than in females. This is likely due to physiological differences in fruit processing among the age-sex categories, which need further investigation.

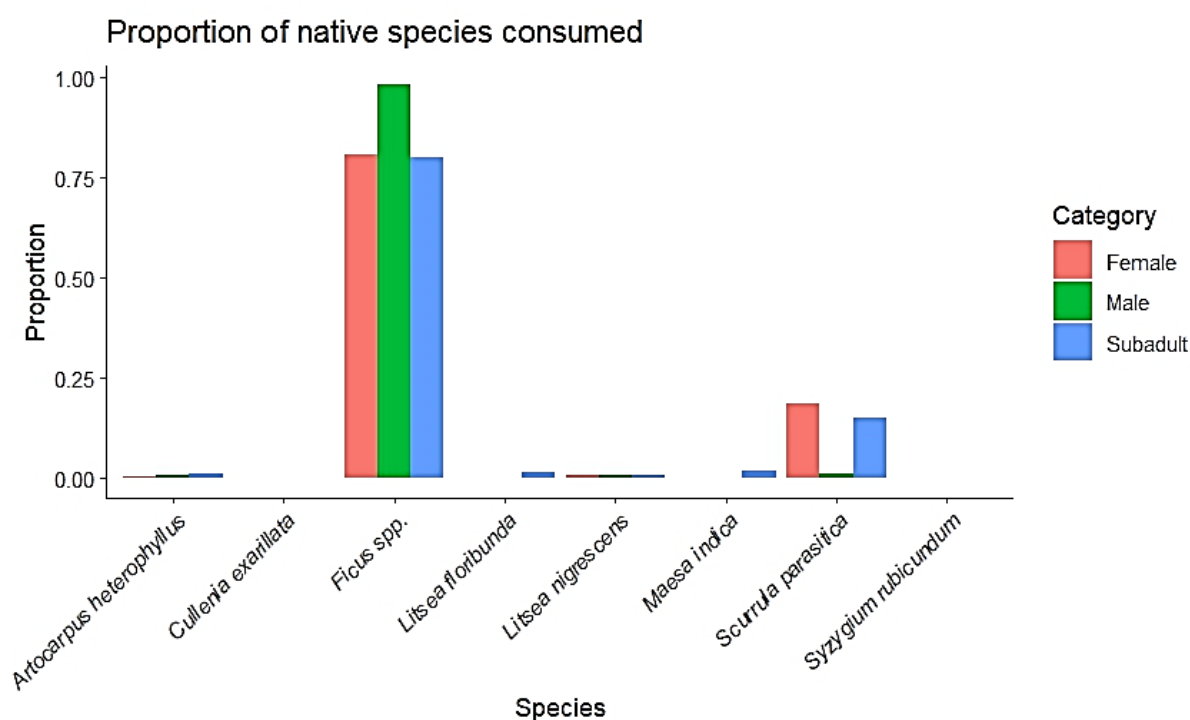


Figure 6. Bar plot showing the relative proportion of native fruit species consumed by different age-sex categories of lion-tailed macaques. The nine species of *Ficus* recorded in the diet were pooled as *Ficus* spp.

The quality of seed dispersal services is determined by fruit handling behaviour, dispersal distance and microhabitats where the seeds are dispersed (Schupp *et al.*, 2010). All three age-sex categories had a low representation of unripe fruits. Therefore, they mainly disperse mature seeds of species whose seeds are not destroyed by them (e.g., seeds of *Artocarpus* are also predated). When macaques spit seeds, the dispersal distances are generally short (~20 m), but defecated seeds may be dispersed up to 250 m from the parent tree (Tsuji & Su, 2018). Thus, macaques mainly disperse the seeds away from the parent tree, especially when they defecate and disperse. We did not find differences in movement patterns across the age-sex categories, suggesting that they

disperse seeds at similar distances unless there are systematic differences in seed retention times, which is currently unknown. The most suitable microsites for *Ficus* seed germination and seedling establishment are tree trunks and branches (Laman, 1995; Shanahan, 2016). We found weak evidence that male macaques tend to defecate on trees, making them more likely to disperse *Ficus* seeds in favourable microsites.

Implications on the dispersal of non-native species

In disturbed landscapes, primates feed on fruits of exotic invasive species, contributing more than 50% of their diet (Canale *et al.*, 2016; Wimberger *et al.*, 2017) and are major dispersers of these alien species (Cordeiro *et al.*, 2004; Dew & Wright, 1998; Silva *et al.*, 2018). While there is substantial evidence of frugivory and seed dispersal of alien invasive species by primates, there is limited literature on intraspecific variation. Given the long history of human use and associated forest degradation in our study area, there is a significant presence of non-native species, including alien invasives like *Coffea* sp and *Lantana* sp, which are among the most problematic invasives in the area (Joshi *et al.*, 2009, 2015). Interestingly, unlike females and subadults, males consumed a greater diversity of non-native fruits than native fruits, highlighting their role in dispersing invasive plants, especially coffee. The reason for intraspecific variation in consumption of *Lantana* sp, which was consumed more by females and subadults, is unclear. *Coffea* sp berries are more energy-rich, with higher lipid and protein content than *Lantana* sp berries (Embaby & Mokhtar, 2011; Osorio Pérez *et al.*, 2023). Like most primates which consumed the pulp of the exotics, dropping seeds under the mother tree (Canale *et al.*, 2016; Cordeiro *et al.*, 2004), LTMs spat *Coffea* sp seeds undamaged mainly under the mother plant (pers. obs.). However, the tiny *Lantana* sp seeds were probably destroyed by them. While there are reports of *Lantana* fruit consumption by LTMs (Singh *et al.*, 2002), no confirmed reports exist on the effective dispersal of *Lantana* seeds by LTMs. We found only one report of *Lantana* dispersal by *Papio anubis* (Simon *et al.*, 2016). Given the differences in relative abundances of males, females, and subadults in the troops, the overall number of seeds dispersed by these different age-sex categories is likely to differ.

The rainforest fragment where the study was conducted is highly degraded, yet supports among the highest recorded densities of LTMs. The densities of native

rainforest trees were significantly lower in the focal study area than in Protected Areas, but the density of non-native trees was substantially higher (Joshi *et al.*, 2009, 2015). Thus, given the low density of native trees in this fragment, alien species are an important food resource for the primates. While previous studies have suggested that provisioning may contribute to higher densities of LTMs in this fragment (Dhawale *et al.*, 2020), the hyperabundance of *Coffea* sp and *Lantana* sp fruits can also contribute to their relatively higher densities. This aspect must be investigated by comparing native and non-native fruit availability between rainforests and degraded fragments with alien species over space and time to assess their role in supporting primate populations.

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13 DEVELOPMENT OF NORMAL THERMOGRAPHY DATA FOR ASIAN ELEPHANTS AT ANAMALAI AND MUDUMALAI ELEPHANT CAMPS, TAMIL NADU

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ABSTRACT

The captive elephants at Anamalai and Mudumalai Elephant Camps, managed by the Tamil Nadu Forest Department for conservation and tourism, are integral to the cultural heritage of Tamil Nadu. However, these animals face a range of physiological, psychological, and pathological challenges. Infrared thermography has been proven in numerous studies to provide reliable, repeatable results in monitoring thermoregulation and surface temperature variations in animals, helping to identify potential health issues. This study applied infrared thermography as a diagnostic tool to assess the health of the captive Asian elephants at the Anamalai and Mudumalai elephant camps. The study was conducted over one year, with infrared thermal images captured periodically from October 2023 to May 2024. A total of 54 elephants were involved in this study, including 24 from the Anamalai camp, 19 from the Mudumalai camp, and 11 female elephants from the Elephant Rescue and Rehabilitation Centre, Tiruchirapalli. Baseline thermographic data for major body parts (head, ear, trunk, forelimbs, and hindlimbs) were recorded and established individually. The thermograph of the eye was also extensively recorded. Factors causing deviations from normal thermographic patterns were also observed and documented. The study explored the field applications of infrared thermography, while also highlighting its limitations. Additionally, the study successfully detected and monitored injuries and health conditions, such as inflammations, wounds, and abscesses, based on variations in surface temperature. In conclusion, the study underscores the significant potential of infrared thermography as an invaluable tool for enhancing the management and care of captive elephants.

Keywords: Infrared thermography; captive elephants; diagnostic tool; thermoregulation; surface temperature

INTRODUCTION

Elephants hold historical, cultural, social, and biological significance across the Indian subcontinent. As a keystone species, they are crucial for maintaining forest ecosystems, but their declining numbers threaten these environments (Poulsen *et al.*, 2018). Though initially used for logging activities, today, captive elephant camps are used in ecotourism to raise awareness of their ecological importance (Fowler & Mikota, 2008). Camp elephants face unique challenges due to restricted movement and grazing, leading to health issues like infections and foot problems (Ghimire *et al.*, 2022; Miller *et al.*, 2015). Regular health monitoring is essential, wherein infrared thermography can be viewed as an alternative non-contact diagnostic tool.

Infrared thermography (IRT), or thermal imaging, captures infrared radiation to visualise thermal energy (Meola & Carlomagno, 2004). In veterinary medicine, it has been used to detect inflammation and musculoskeletal issues in horses (Colahan *et al.*, 1991). It has also been applied to various wild animals, including apes, primates, canids and felids, to study thermoregulation, behaviour and disease diagnosis (Dezecache *et al.*, 2017; Nakayama *et al.*, 2005; Dunbar & MacCarthy, 2006; Mota-Rojas *et al.*, 2021; Stryker, 2016). IRT has also helped identify design flaws in zoo enclosures that cause dysfunction in animal thermoregulation (Hilsberg, 1998; Hilsberg-Merz, 2008). In elephants, thermographic studies have helped to explore the metabolic processes that help maintain homeostasis (Cena & Clark, 1973; Phillip & Heath, 1992).

IRT offers a non-invasive, contactless, and real-time method for assessing animals, unlike techniques such as ultrasonography, endoscopy, and radiography. This makes it highly suitable for evaluating elephants' primary health through surface temperature variations. The current study aims to explore the applications of IRT as a diagnostic tool for captive elephants and to establish baseline thermographic data.

MATERIALS AND METHODS

Places of Study

The study involved camp elephants from Anamalai Tiger Reserve (ATR) and Mudumalai Tiger Reserve (MTR). In ATR, elephants were housed at Kozhikamuthi (10° 44' 53.8" N; 76° 84' 88.5" E) and Varagaliyar (10° 41' 92.9" N; 76° 86' 66.1" E) camps. In MTR, the camps were Theppakadu (11° 57' 91.2" N; 76° 58' 40.3" E) and Abhyaranyam

(11° 55' 71.1" N; 76° 56' 19.5" E). The Elephant Rescue and Rehabilitation Centre (ERRC) in MR Palayam, Tiruchirapalli (11° 3' 10.872" N; 78° 48' 45.864" E), which primarily houses elephants under medical care, was also included in the study.

Data collection procedure

Infrared images (thermograms) of the elephants were captured using a FLIR E54 Advanced Thermal Imaging Camera (Teledyne FLIR, USA). The camera automatically calibrates parameters such as emissivity, reflected temperature, subject-camera distance, and air humidity based on the environmental conditions.

Infrared thermal images (thermograms) of camp elephants were captured periodically from October 2023 to May 2024, typically in the mornings (6 A.M. to 9 A.M.) and evenings (4 P.M. to 7 P.M.) to minimise solar heat effects. Elephants acclimated in the shade for 5 to 10 min before imaging. Thermograms were analysed with FLIR Thermal Studio (v4.0.30319), and statistical analyses were conducted using GraphPad Prism (version 8) and Microsoft Excel (version 2406).

RESULTS AND DISCUSSION

A total of 54 elephants were involved in this study. In ATR, 24 elephants (16 males and 8 females) were examined whereas in MTR, 19 elephants (14 males and 5 females) were involved. In addition, 11 female elephants from ERRC were also analysed in this study.

Developing Normal Thermography

For normal thermography analysis, healthy elephants from ATR and MTR camps were positioned 10 to 20 m from the thermal camera to capture thermograms in shaded conditions during early mornings or late evenings. The surface temperatures of the head, ear, torso, forelimb and hind limb were analysed, with the eye being analysed both alongside the head temperature calculations and separately. The compiled surface temperatures are listed in Table 1, with a graphical representation of the data pictured in Figure 1.

Table 1. Surface temperatures of elephants housed at ATR and MTR with mean and standard deviation (n=35)

Elephants		HST (°C)	EST (°C)	TST (°C)	FST (°C)	HLST (°C)
A1	Males	29.55	29.3	28.3	28.95	28.2
A2		27.95	25.45	27.0	26.2	25.9
A3		27.95	23.6	27.3	29.3	28.6
A4		33.1	31.9	33.06	31.1	31.3
A5		28.75	26.3	28.0	28.6	29.1
A6		25.3	22.4	24.7	24.7	24.85
A7		29.2	29.2	28.43	26.95	27.03
A8		25.6	23.4	24.8	25.4	24.9
A9		25.85	22.5	25.2	24.9	24.7
A10		29.25	28.4	28.65	27.8	27.4
A11		31.9	32.1	32.62	31.3	30.7
A12		25.95	22.8	25.23	25	24.4
A13		29.9	26.2	29.26	30.1	29.8
A14		27.05	26.3	27.15	28.5	27.5
A15		24.7	22.4	25.2	23.4	23.3
A16		31.5	28.7	32	31.4	31.2
A17		33.65	33.3	33.5	33	33.2
A18		27.1	23.5	25.8	26.5	26
A19		29.05	26.4	29.6	26.7	26.05
A20		25.65	22.1	25.65	26.5	25.92
A21		30.3	27.2	28.2	28.9	29.1
A22		26.2	22.6	25.84	26.4	25.7
A23		30.6	28.1	30.2	30.2	30.35
A24		28.95	27.1	27.87	26.9	25.5
A25		30.15	26	29.86	28.9	27.8
A26		25.15	22.05	24.53	24.8	24.4
A27	Females	30.7	26.9	29.33	30.1	29.75
A28		24.8	20.75	24.13	23.65	22.85
A29		29.25	26.65	28.65	29.7	30.05
A30		31.7	31.8	32.06	29.8	29.9
A31		33.2	32.2	33.7	33.3	33.3
A32		26.5	22.7	25.23	26.9	26.56
A33		26.85	23.9	28.1	25.5	25
A34		26.85	22.7	26.1	25.8	25
A35		28.8	25.6	28.4	28.75	28.8
Mean		28.54	26.07	28.1	27.88	27.54
Std. Deviation		2.54	3.44	2.75	2.56	2.73

HST-Head Surface Temperature; EST-Ear Surface Temperature; TST-Torso Surface Temperature; FST-Forelimb Surface Temperature; HLST-Hindlimb Surface Temperature

A1-Anna; A2-Ashok; A3-Barani; A4-Cherambadi Shankar; A5-Chinnathambi (A); A6-Chinnathambi (B); A7-Ganesh; A8-Kapildev; A9-Krishna; A10-Mariappan; A11-Muthu (A); A12-Muthu (B); A13-Narasimman; A14-Paari; A15-Raghu; A16-Ramu; A17-Sanjeev (A); A18-Sanjeev (B); A19-Saravanan; A20-Surya; A21-Suyambu (A); A22-Suyambu (B); A23-Tamizhan; A24-Udhayan; A25-Urigan (A); A26-Urigan (B); A27-Abinaya (A); A28-Abinaya (B); A29-Andal; A30-Bommi; A31-Deivanai (A); A32-Deivanai (B); A33-Durga (A); A34-Durga (B); A35-Selvi

A & B refer to thermograms recorded in the same elephant during different time periods

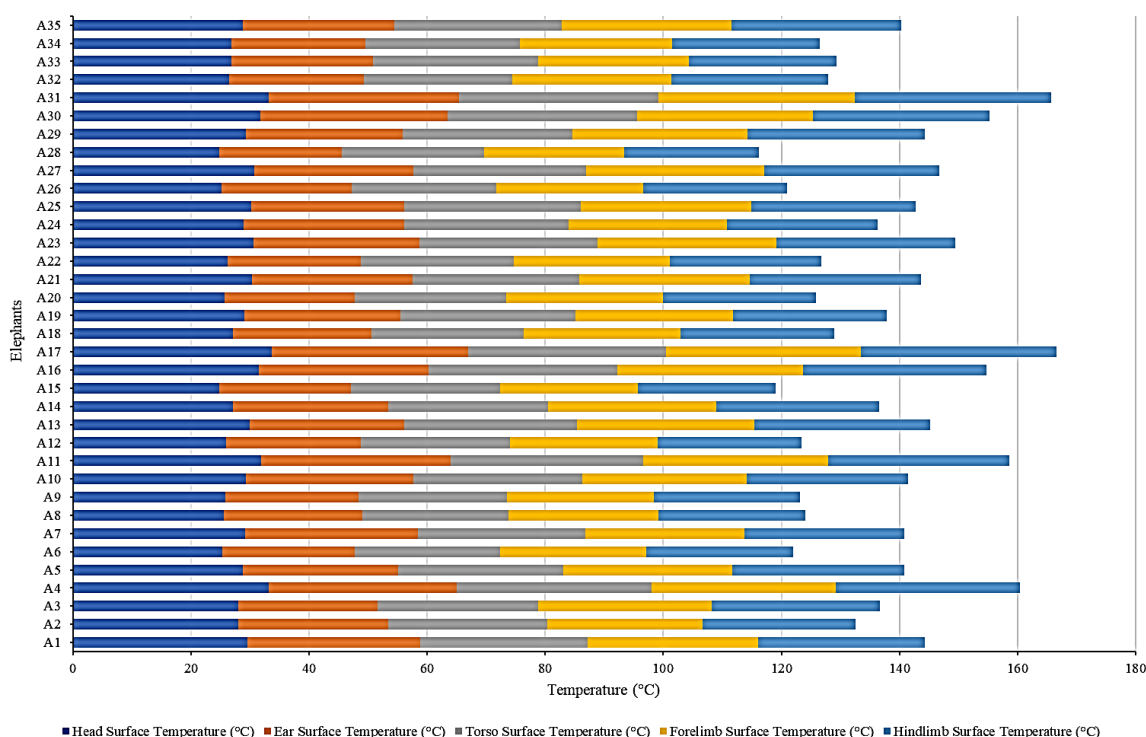


Figure 1. Surface temperatures of the head, ear, torso, forelimb, and hind limb of the elephants housed at ATR and MTR

i) Head

Male elephants had an average head surface temperature (Mean±Standard Deviation) of 28.47 ± 2.52 °C, while females averaged 28.73 ± 2.74 °C, with a coefficient of variation of 0.65%. The mean temperatures for males and females were similar. Welch's t-test showed no statistically significant difference between the sexes ($P = 0.8025$ at 95% CI). The combined average temperature for both sexes was 28.54 ± 2.54 °C.

ii) Ear

The term "ear" temperature refers to thermograms of the anterior ear pinna. The ears showed the most variance in overall surface temperature and was notably cooler than the rest of the body, indicating that the large ear pinnae are the primary site for thermoregulation. Males had an average ear surface temperature (Mean±Standard Deviation) of 26.12 ± 3.32 °C, while females had a slightly lower average of 25.91 ± 3.98 °C, with a coefficient of variation of 0.58%. Welch's t-test showed no statistically significant difference between the sexes ($P = 0.8865$ at 95% CI). The combined average temperature for both sexes was 26.07 ± 3.44 °C.

iii) Torso

Temperature measurements across the torso show variations within individuals due to issues such as localised inflammation, wounds, and uneven exposure to sunlight but care was taken to choose thermograms for analysis that exhibited uniform body temperatures. Male elephants had an average torso surface temperature (mean $\pm$ standard deviation) of 27.99 ± 2.68 °C, while females had a slightly higher average of 28.41 ± 3.08 °C, with a coefficient of variation of 1.03%. Welch's t-test showed no statistically significant difference between the sexes ($P = 0.7264$ at 95% CI). Research in both humans (Arciero *et al.*, 1993; Baker *et al.*, 2020) and laboratory rodents (Yang *et al.*, 2007) demonstrate that females maintain higher core body temperatures than males, despite males' higher resting metabolic rates, a phenomenon potentially attributed to hormonal differences. This could suggest that female elephants' slightly higher torso temperatures might be due to similar reasons, although no significant difference was found. The combined average temperature for both sexes was 28.1 ± 2.75 °C.

iv) Forelimbs and Hind limbs

On average, the surface temperatures (Mean $\pm$ Standard Deviation) of forelimbs (27.88 ± 2.56 °C) and hind limbs (27.54 ± 2.73 °C) showed little variation overall, though some sex-based differences existed. Females had slightly higher forelimb (28.16 ± 2.96 °C) and hind limb (27.91 ± 3.28 °C) temperatures compared to males (27.78 ± 2.46 °C for forelimbs and 27.41 ± 2.57 °C for hind limbs), continuing the temperature variation seen in the torso. The forelimb and hind limb coefficient of variation was 0.96% and 1.26%, respectively. However, Welch's t-test indicated no statistically significant sex differences in forelimb ($P = 0.7341$ at 95% CI) and hind limb ($P = 0.6896$ at 95% CI) temperatures.

v) Eye

In veterinary medicine, ocular temperature has been studied to assess stress in dogs (Budny-Walczak *et al.*, 2024), and horses (Aragona *et al.*, 2024). Based on this, thermograms of the eyes of healthy captive elephants at ATR were captured closely to analyse temperature variations. The maximum temperature (hotspot) was used to represent the right and left eye temperatures of individual male and female elephants.

The average temperature (Mean±Standard Deviation) of the right eye was 32.61 ± 0.39 °C, while the left eye averaged 32.53 ± 0.87 °C, with a coefficient of variation below 0.17%. A paired t-test showed no statistically significant difference between the temperatures of the left and right eyes ($P = 0.8035$ at 95% CI). Typically, the right eye temperature ranged from 32.22 to 33 °C, and the left eye from 31.66 to 33.41 °C. The compiled eye surface temperatures are listed in Table 2, with a graphical representation of the data pictured in Figure 2.

Table 2. Right and left eye temperatures of elephants with mean and standard deviation (n = 8)

Elephants	Right Eye Temperature (°C)	Left Eye Temperature (°C)
B1	32.0	31.3
B2	33.0	31.9
B3	32.8	31.6
B4	32.5	32.8
B5	32.4	32.5
B6	32.3	33.3
B7	32.7	33.1
B8	33.2	33.8
Mean	32.6	32.5
Standard Deviation	0.39	0.87

B1 – Kapildev; B2 – Muthu; B3 – Kaleem; B4 – Sanjeev; B5 – Urigan; B6 – Durga; B7 – Ashok; B8 – Abinaya

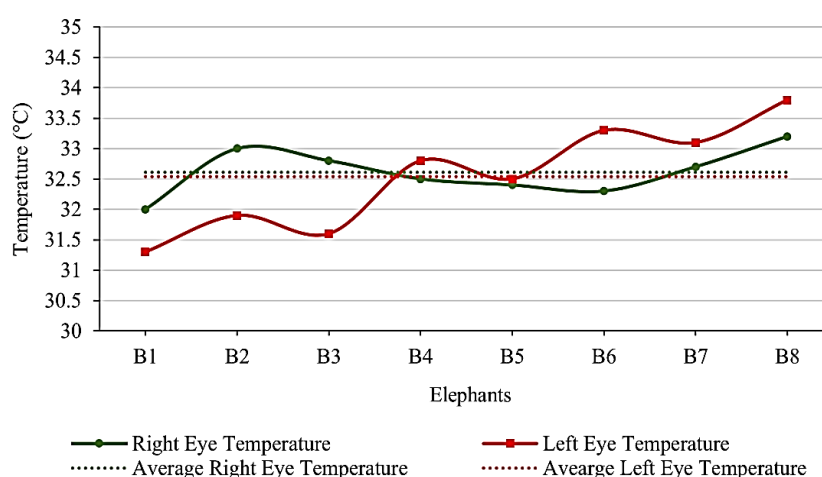


Figure 2. Variations in the right and left eye temperatures of elephants and the respective average values

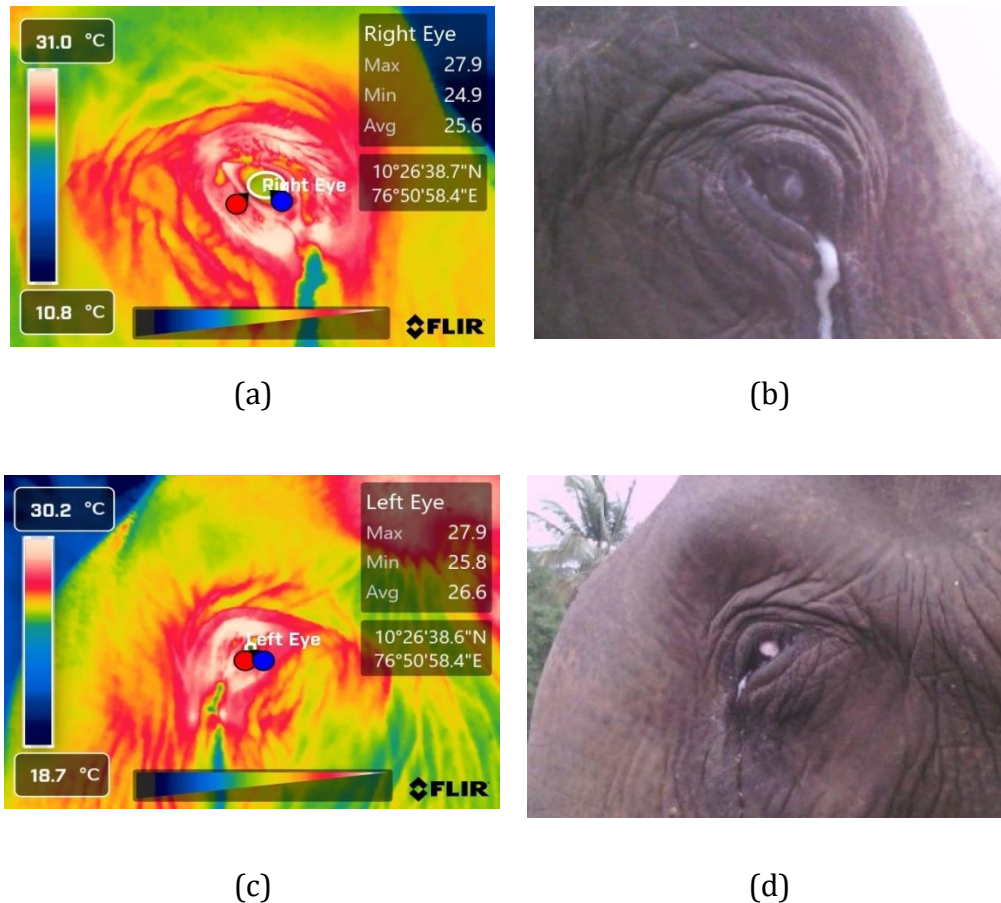


Figure 3. Elephant Sivagami: a & b - Right eye and c & d - Left eye

Thermograms of elephants suffering from ocular disorders were also recorded but not included in the above calculations. For example, Elephant Sivagami (Female, 74 years old) exhibited decreased radiation in both eyes compared to healthy elephants (Fig. 3). Both eyes appeared cloudy and opaque, with a white discharge present during the thermogram recording.

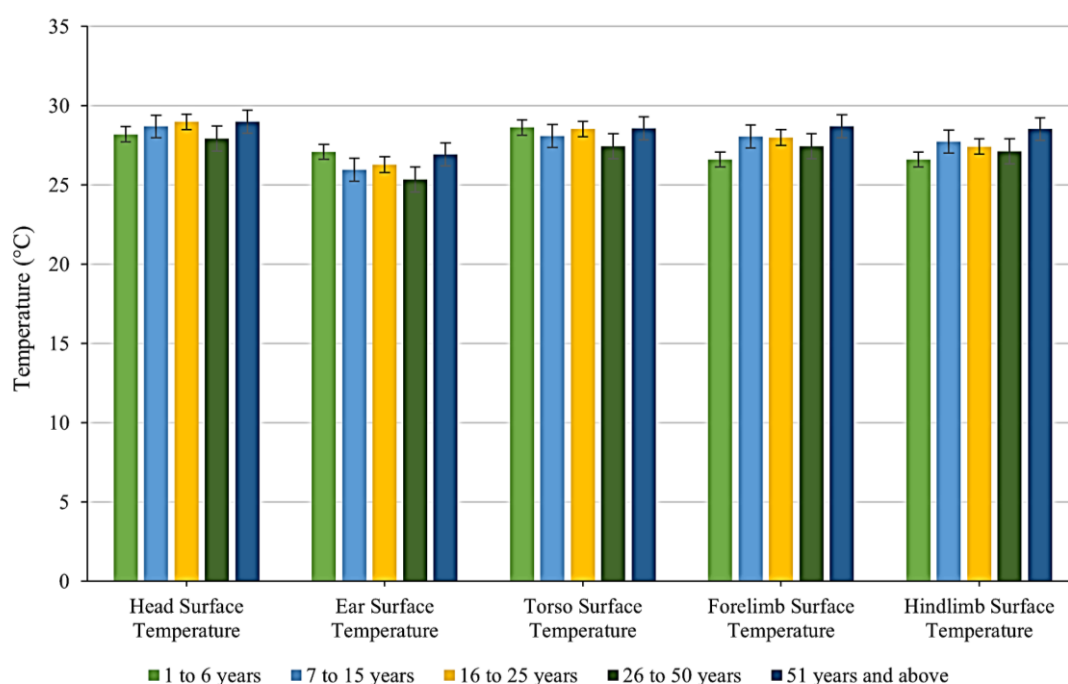
Age-wise comparison

Surface temperatures recorded in this study indicated no significant variation between male and female captive elephants at ATR and MTR. A comparison across different age groups was also conducted to assess age-related temperature differences. Elephants were classified into five groups: juvenile (1-6 years), sub-adult (7-15 years), young adult (16-25 years), adult (26-50 years), and senior adult (51+ years), based on modified references (Arivazhagan and Sukumar, 2008). Average surface temperatures listed in Table 3 and illustrated in Figure 4.

Table 3. Average surface temperatures of elephants housed at ATR and MTR classified according to different age groups.

Age groups	HST (°C)	EST (°C)	TST (°C)	FST (°C)	HLST (°C)
1 to 6 years (n = 2)	28.20	27.10	28.63	26.60	26.60
7 to 15 years (n = 8)	28.69	25.96	28.10	28.06	27.73
16 to 25 years (n = 8)	28.98	26.29	28.53	27.99	27.43
26 to 50 years (n = 11)	27.93	25.34	27.45	27.45	27.13
51 years and above (n = 6)	28.99	26.93	28.57	28.71	28.53

HST- Head Surface Temperature; EST- Ear Surface Temperature; TST- Torso Surface Temperature; FST- Forelimb Surface Temperature; HLST- Hind limb Surface Temperature

**Figure 4.** Average surface temperatures of different body parts corresponding to different age groups

Welch ANOVA and post hoc Dunnett's T3 multiple comparison test showed no statistically significant differences between body parts and age groups. While some studies suggest temperature differences between calves and adults (Lefebvre *et al.*, 2023; Weissenböck *et al.*, 2012), this study found no significant differences, possibly due to unequal sample sizes in the age groups.

Effect of Ambient Temperature on Thermographic Analysis

IRT captures radiation emitted by objects, so factors like direct sunlight can distort the thermal patterns of an animal. To mitigate this, thermograms in this study were taken early in the morning (6:00 A.M. to 9:00 A.M.) and late in the evening (4:00 P.M. to 7:00 P.M.), with elephants positioned in shade to acclimate before recording. High ambient temperatures at ERRC, ranging from 25°C to 43°C, contrasted with cooler ATR (15°C-22°C) and MTR (19°C-27°C), affected the accuracy of thermogram and made the elephants appear "cooler" (Fig. 5).

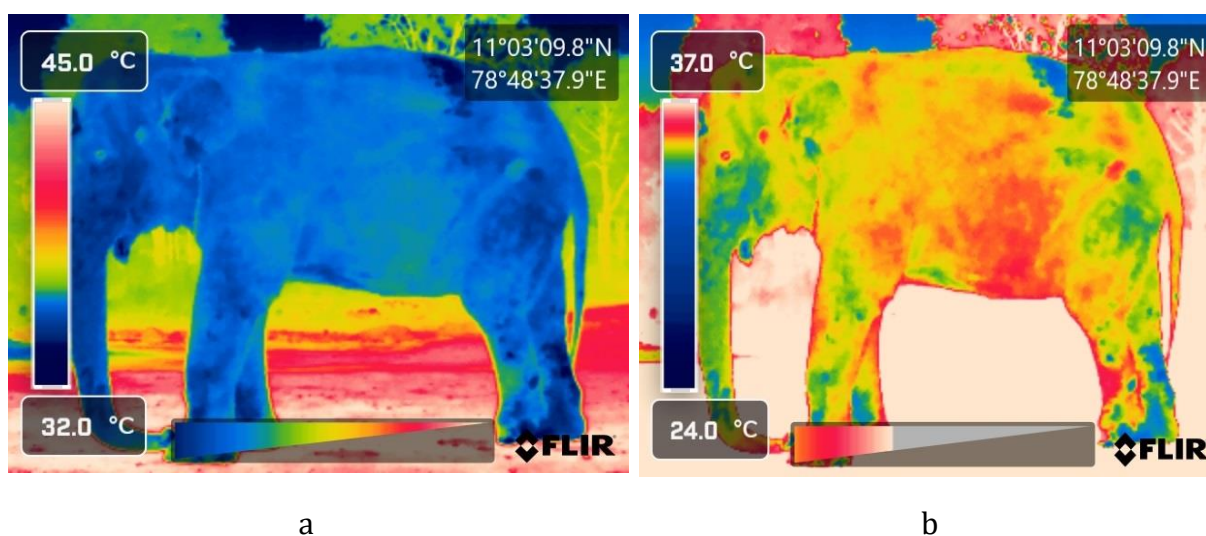


Figure 5. Thermograms of an elephant from ERRC. a - Temperature scale set by the instrument automatically based on the surroundings. Note the temperature scale and the high ambient temperature of the surroundings; b - Temperature scale manually adjusted to match the thermograms captured in ATR and MTR

Female elephants in ERRC showed higher surface temperatures than those at ATR and MTR, with averages indicating a 3.5 °C to 5.5 °C increase. While it is possible that the rescued and rehabilitated elephants of ERRC possess medical conditions like wounds and inflammations that might influence surface temperatures, it should be noted that for these reasons these elephants' surface temperatures were not included in the calculation of normal thermographic data (Table 1) and are presented here for the purpose of highlighting the effect that ambient temperature can have on thermograms (Table 4, Figure 6).

Table 4. Surface temperatures of elephants housed at ERRC with mean and standard deviation (n = 22)

Elephants	HST (°C)	EST (°C)	TST (°C)	FST (°C)	HLST (°C)
C1	31.30	28.70	30.65	30.90	29.90
C2	33.75	33.90	33.45	32.66	32.60
C3	30.45	31.10	31.35	30.70	30.80
C4	35.00	34.60	35.30	35.15	34.80
C5	31.25	28.80	30.25	31.90	31.00
C6	34.90	34.40	35.90	34.70	34.70
C7	30.25	30.10	29.60	30.75	30.50
C8	35.45	34.80	37.10	36.00	36.10
C9	31.30	29.60	31.55	30.90	31.10
C10	34.20	34.60	33.85	33.50	33.40
C11	31.25	28.10	31.05	30.05	29.50
C12	34.45	34.40	35.00	34.85	34.15
C13	30.60	29.40	30.50	31.25	30.60
C14	32.55	32.20	32.80	33.70	33.40
C15	28.40	27.00	28.40	28.20	28.20
C16	35.05	34.00	34.85	35.26	35.00
C17	29.80	29.40	29.46	28.10	27.50
C18	34.75	34.30	35.46	35.30	34.90
C19	28.90	28.80	29.66	29.40	29.65
C20	34.60	34.50	34.10	33.50	32.80
C21	27.35	26.00	27.52	27.65	28.26
C22	34.25	33.50	34.90	34.05	34.10
Mean	32.26	31.46	32.39	32.20	31.95
Standard Deviation	2.48	2.92	2.72	2.57	2.54

C1- Gomathi (A); C2-Gomathi (B); C3-Indhu (A); C4-Indhu (B); C5-Indira (A); C6-Indira (B); C7-Jainy (A); C8-Jainy (B); C9-Jayanthi (A); C10-Jayanthi (B); C11-Kirathi (A); C12-Kirathi (B); C13-Malachi (A); C14-Malachi (B); C15-Rupali (A); C16-Rupali (B); C17-Santhiya (A); C18-Santhiya (B); C19-Sumathi (A); C20-Sumathi (B); C19-Sumathi (A); C20-Sumathi (B); C21-Sundari (A); C22-Sundari (B)

HST-Head Surface Temperature; EST-Ear Surface Temperature; TST-Torso Surface Temperature; FST-Forelimb Surface Temperature; HLST-Hind limb Surface Temperature

A & B refer to thermograms recorded in the same elephant during different time periods

"Thermal loading," where surroundings retain sun radiation, can bias thermograms (Garner *et al.*, 1995). The camera adjusts the temperature scale based on detected radiation, which can oversaturate images if manually set to temperature ranges similar to ATR and MTR (~30 °C to 20 °C), affecting interpretation (Fig. 5). Thermographers must understand animal anatomy, physiology, and environmental

conditions, case in point being the elephants of ERRC whose temperatures reflect their environment and not thermoregulatory issues.

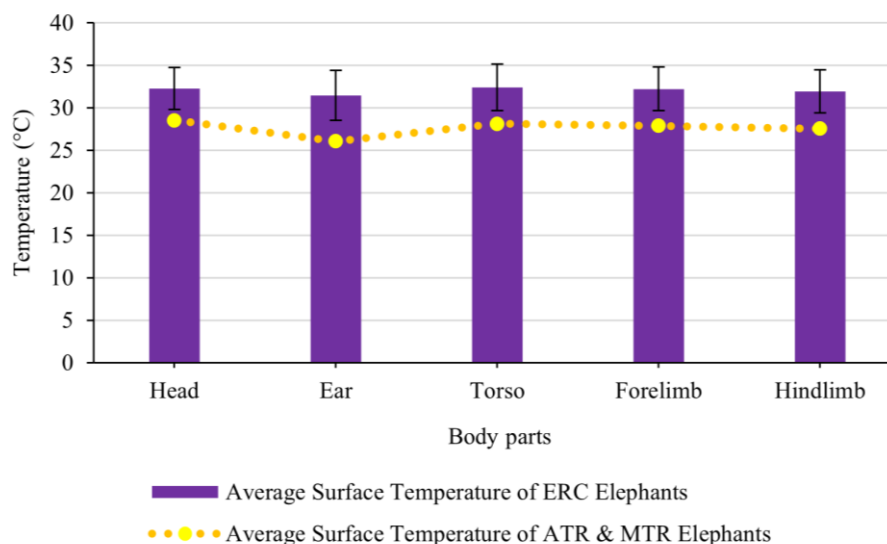


Figure 6. Variation in the average surface temperatures of elephants housed at ERRC (Mean±SD) and ATR & MTR

B) Identifying Surface Injuries and Foot Ailments

i) Inflammation

Inflammation induces physiological reactions such as vasodilation and increased blood vessel permeability at the inflammation site leading to heating and swelling (Kasper *et al.*, 2015) that are detectable by IRT, like the example shown in Figure 7.

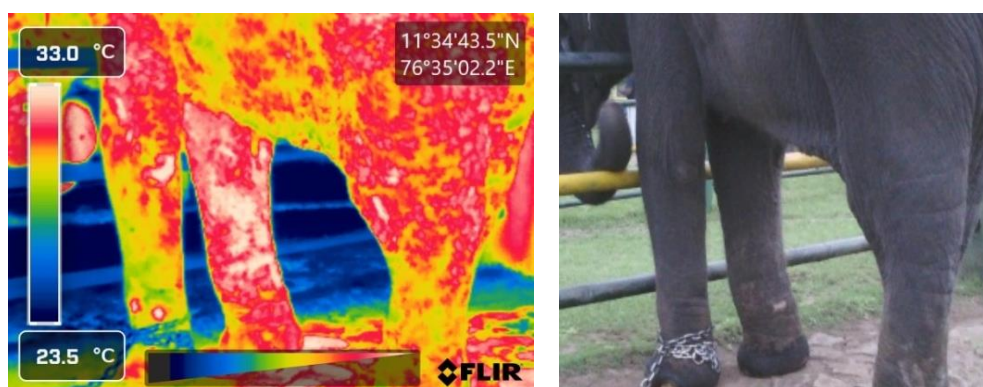


Figure 7. Elephant Masini: Right forelimb showing inflammation causing increased radiation

ii) Wounds

Healing of wounds involves an inflammatory phase, causing vasodilation of blood vessels and leakage of oedematous fluid into the tissue, causing swelling. These processes cause a localised increase in radiation (Kasper *et al.*, 2015), which can be visualised using IRT, examples shown in Figures 8 and 9.

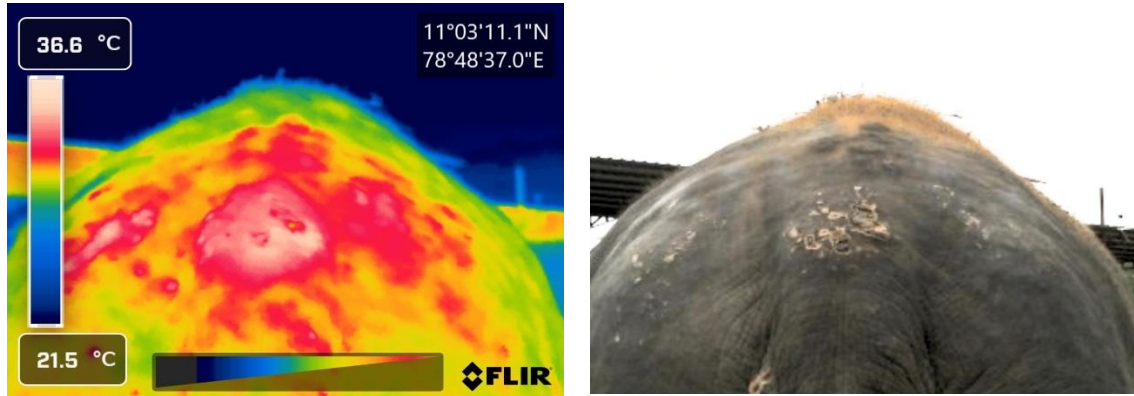


Figure 8. Elephant Malachi; wound at the base of tail region causing increased radiation

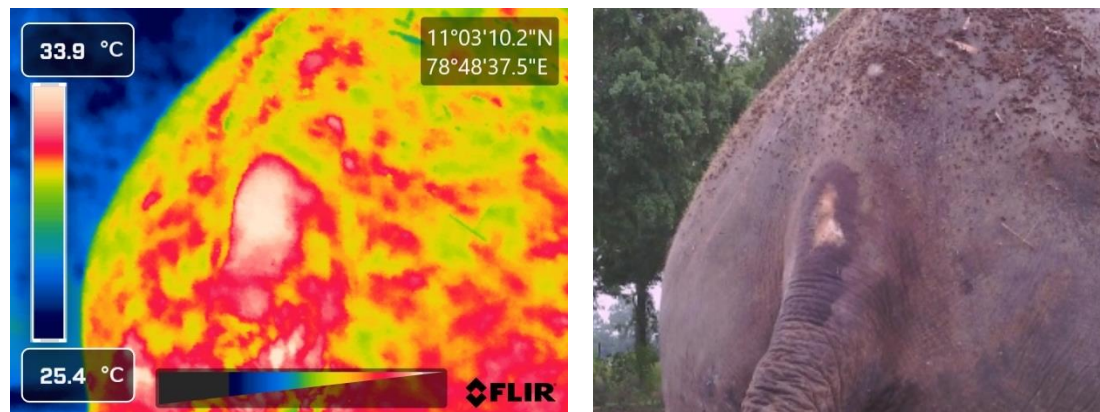


Figure 9. Elephant Kirathi: wound at the base of tail causing increased radiation

iii) Abscess

Abscesses progress through distinct stages: initial inflammation and pus pocket formation ('before ripe'), followed by maturation ('ripe' stage suitable for drainage), and finally healing, marked by decreased inflammation and new tissue formation (Baiu & Melendez, 2018; Bowman, 2022). Thermograms of surface-level abscesses before and after ripening are shown in Figures 10 and 11.

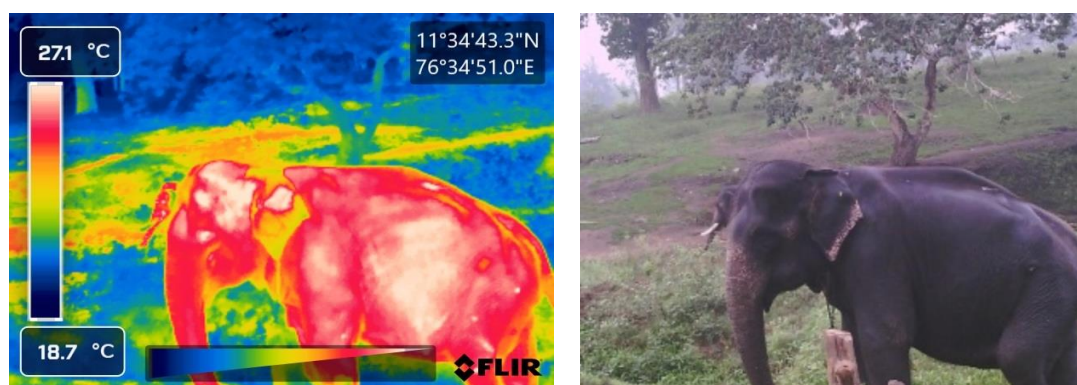


Figure 10. Elephant Kamatchi: ear abscess at ripe stage showing increased radiation

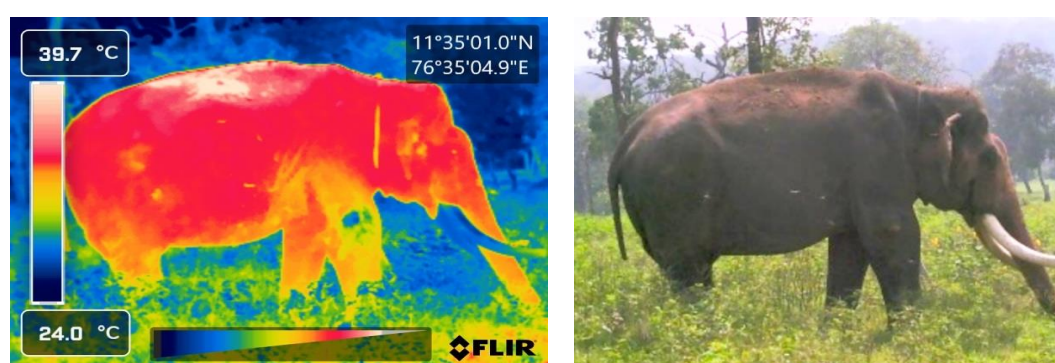


Figure 11. Elephant Anna: broken abscess in the right forelimb showing lower radiation

iv) Lameness and other Foot Ailments

In the wild, elephants' foot pads, which are generally thick and wrinkled on the bottom, cushion their steps and protect their sensitive foot structures from punctures. In captivity, elephants usually do not require as thick a pad for protection against environmental hazards. However, insufficient activity, unsuitable substrates, or irregular foot care can lead to overgrown, wounded, or infected footpads and nails. Such examples are shown in Figures 12 and 13.



Figure 12. Elephant Gomathi: withering observed in the right hind limb showing lower radiation

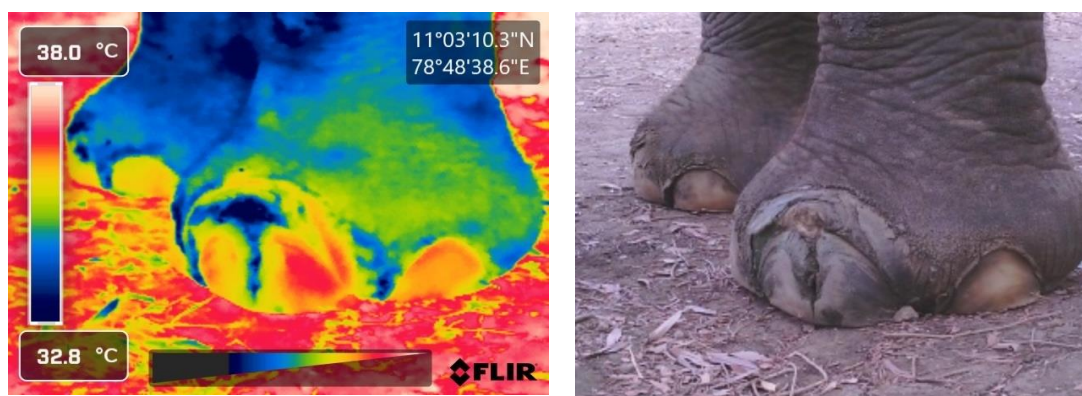


Figure 13. Elephant Gomathi: nail crack observed in the left forelimb, showing irregular radiation

CONCLUSION

Infrared thermography is a non-invasive technology ideal for monitoring wildlife, particularly captive elephants. Unlike smaller animals, elephants require multiple handlers for examination, making routine medical procedures challenging. While basic tests like blood and urine analyses are manageable, complex procedures such as endoscopy and radiography are difficult due to equipment limitations and the need for animal cooperation. Thermal cameras offer significant advantages: they provide real-time results, allow for distant observation without immobilization, and are portable. With proper training, thermograms can guide preliminary diagnoses and treatment planning, while stored data supports long-term medical documentation.

Effective use of infrared thermography requires basic operational training, knowledge of elephant anatomy and physiology, and consideration of environmental factors that may affect readings. Consistent monitoring is essential for meaningful results. Infrared thermography serves as a practical diagnostic tool for elephant management, requiring minimal prerequisites compared to other methods. Its immediate results and non-invasive nature make it valuable for both captive facilities and Reserved Forests, supporting elephant care and conservation efforts.

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14 BABESIOSIS: A THREAT FOR CAPTIVE WILD FELIDS – A CASE REPORT OF CAPTIVE LION (*PANTHERA LEO*) AT ARIGNAR ANNA ZOOLOGICAL PARK, CHENNAI, INDIA

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ABSTRACT

Haemoprotzoan infections, particularly babesiosis, cause significant health risks to captive wildlife, including felids. A survey was conducted from March 2023 to March 2024 to examine haematophagous infections in Zoo carnivores, by microscopic and molecular methods. This study reports the first molecular confirmation of *Babesia panickeri* infection in a captive lion (*Panthera leo*) at Arignar Anna Zoological Park, India. A blood sample was collected from the caudal vein of an unhealthy lioness named Jaya, who exhibited clinical signs consistent with infection, including lethargy and loss of appetite. Polymerase chain reaction targeting the 18S rRNA gene of *Babesia spp.* was performed using a genus-specific primer generating a 619 bp amplicon, confirming the presence of *Babesia spp.* The PCR product was purified and sequenced. Phylogenetic analysis was conducted using the Maximum Likelihood method and Tamura-Nei model; sample sequence showed a 96% bootstrap-supported relationship with *Babesia panickeri* which was recently isolated and described in Kerala, India. This finding showed the importance of molecular diagnostics in identifying haemoprotzoan infections in captive wildlife and possible potential cause due to tick vectors in disease transmission. Captive felids are particularly vulnerable to haemoprotzoan infections due to stress, a closed environment, and increased exposure to arthropod vectors. Effective management strategies, including improved diagnostic tools and vector control measures, are essential to mitigate the health risks of haemoprotzoan infections in captive felids.

Keywords: Haemoprotzoan, *Babesia*, wildlife, vectors

INTRODUCTION

Haemoprotozoan diseases are predominantly vector-borne in tropical and subtropical regions worldwide, including India (Salih *et al.*, 2015). Climatic conditions in the tropic region favour the survival and development of potential vectors, which is the foremost reason susceptible animals are affected (Velusamy *et al.*, 2014). Piroplasmids are tick-borne protozoan parasites that infect blood cells (erythrocytes, lymphocytes or other leukocytes) or endothelial cells of numerous wild and domestic vertebrates worldwide. They cause severe disease in livestock, dogs, cats, wild mammals and occasionally, humans. Piroplasmid infections are prevalent in wild carnivores worldwide, although there is limited information about their clinical and epidemiological importance.

There are currently nine recognised species of *Babesia*, two of *Theileria*, two of *Cytauxzoon* and one of *Rangelia* infecting captive and wild carnivores, including members of Canidae, Felidae, Mustelidae, Procyonidae, Ursidae, Viverridae, Hyaenidae and Herpestidae in the Americas, Eurasia and Africa (Alvarado-Rybak *et al.*, 2016). However, the number of piroplasmid species is likely higher than currently accepted due to the reported existence of DNA sequences that may correspond to new species and the need for studies on many host species and biogeographical areas. Indeed, many species have been recognised in the last few years with the advancement of molecular analyses. Disease and mortality have been documented in some wild carnivores, whereas other species appear to act as natural, subclinical reservoirs. Various factors (e.g. unnatural hosts, captive stress, habitat degradation, climate fluctuation or immunosuppression) have been associated with disease susceptibility to piroplasmid infections in some species in captivity. The hemoparasitic diseases are mainly vector-transmitted, with ticks or flies involved. A characteristic feature of many of these infections is that animals that recover from acute infection become carriers, creating a potential source of infection to healthy, susceptible populations (Callow, 1984). Hence, diagnosing these infections in carrier animals has great epidemiological significance as they are the sources of infection for the vectors (Das *et al.*, 2002).

Felids, including lions, are highly prone to haemoprotozoan infections due to their exposure to vector-borne parasites such as *Trypanosoma*, *Babesia* and *Cytauxzoon* (McDermid *et al.*, 2017; Sharma *et al.*, 2024; Green *et al.*, 2020). Since these protozoans

are transmitted through ticks and other haematophagous insects, captive wildlife is more vulnerable to these infections. Infected animals might have anaemia, fever, loss of appetite and some fatal systemic illness. Understanding those infections is important for wildlife conservation in ex-situ conditions like zoological parks. In this study, we have screened captive lions for haemoprotozoan disease.

MATERIALS AND METHODS

We collected a blood sample of an apparently unhealthy 12-year-old lioness named Jaya from Arignar Anna Zoological Park (AAZP). For the diagnosis, 2 ml of blood was drawn by venipuncture of the caudal vein through an 18G disposable syringe and collected in a tube containing EDTA (Shrivastav *et al.*, 2011). The blood sample was stored at 4 °C during transport and until processing.

Molecular screening

The primers used for molecular screening of *Babesia* spp. are listed in Table 1. Polymerase chain reaction was performed in a thermal cycler (Bio-Rad, USA). PCR was performed using the conditions mentioned in Table 2. PCR products were visualised using agarose gel electrophoresis. Positive samples were subjected to the gel purification method following the PCR Clean-up kit (QIAquick PCR Purification kit) protocol. The confirmation of the eluted product was done by agarose gel electrophoresis. Purified PCR products were sequenced using Applied Biosystems 3500 Series Genetic Analyzer.

Table 1. Primers used for amplification of the Partial 18S rRNA gene of *Babesia* spp

Primers	Sequence	Amplicon size	Reference
Ba103F	5' CCAATCCTGACACAGGGAGGTAGTGACA 3'	619 bp	Kledmanee <i>et al.</i> (2009)
Ba721R	5'CCCCAGAACCCAAAGACTTTGATTTCTCTCAAG 3'		

Table 2. PCR protocol for Partial 18S rRNA gene of *Babesia* spp.

Step		Temperature	Time
Initial denaturation		95°C	3 min.
30 cycles	Denaturation	94°C	45 sec.
	Annealing	60°C	45 sec.
	Extension	72°C	90 sec.
Final extension		72°C	10 min.

Bioinformatic analysis

Phylogenetic analysis was performed to identify the species. Sequences of other haemoprotozoan isolates were selected from GenBank, NCBI. The obtained sequences were aligned with downloaded sequences using the Cluster W programme of MEGA 11 software (Tamura *et al.*, 2021). The maximum likelihood method was used to interpret evolutionary history with 5000 bootstrap replications (Yang & de Angelis, 2013).

RESULTS AND DISCUSSION

In this study, the lion showed clinical signs of lethargy and anorexia, which are symptoms of Babesiosis. Polymerase chain reaction is considered as a confirmatory test for haemoprotozoan disease screening. Figure 1 shows the lion sample positive for *Babesia* spp. The *Babesia* genus-specific primers amplified a 619 bp product without spurious products from the genomic DNA. The primers did not amplify any negative control.

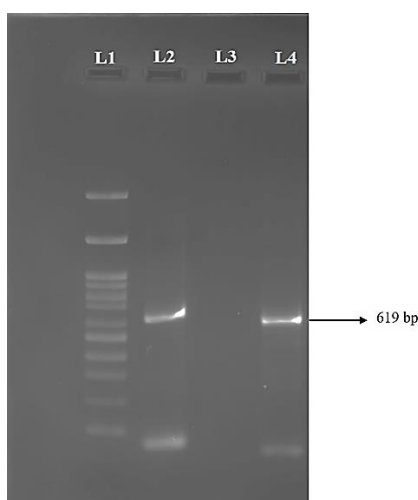


Figure 1. Gel image of Lioness – Jaya sample positive for *Babesia* spp. L1 – 100bp ladder; L2 – Positive control; L3 – Negative control and L4 – Lioness – Jaya sample

The phylogenetic analysis based on 18S rRNA gene sequences confirmed the taxonomic identity of the Jaya lion sample. The Maximum Likelihood (ML) tree and Tamura-Nei model, constructed with 5000 bootstrap replicates, demonstrated well-supported relationships among *Babesia* and *Theileria* species (Fig. 2). The Jaya lion sample clustered with *Babesia panickeri* (MN267560.1, Cat-Kerala, India) with strong bootstrap support (96%), confirming that it belongs to *Babesia panickeri* (Panicker *et*

al., 2020). This placement provides molecular evidence for its species identity, distinguishing it from other *Babesia* species in the analysis.

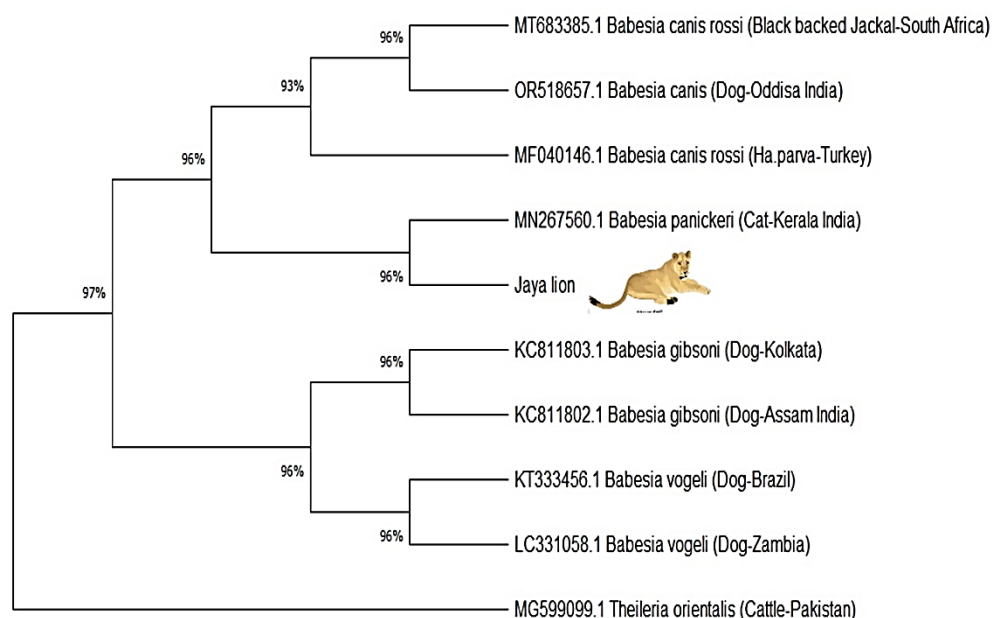


Figure 2. Phylogenetic tree constructed using MEGA11 with 5000 bootstraps replicated. Maximum likelihood tree shows the sample clustered with *Babesia panickeri*

Several reports of the increased reliability of molecular tools for diagnosing parasites of veterinary importance (McManus & Bowles, 1996). The DNA-based methods involve multiple steps, and the cost of setting up the laboratory equipment and purchasing assay reagents for the PCR-based detection methods are high. However, these methods are precious research tools for epidemiological studies and have been used to provide accurate epidemiological data for parasites from many different geographical locations (Singh, 1997). The epidemiology of parasitic diseases is changing, mainly because of changes in animal management and climatic conditions. These modifications can provoke an increase in the stock of vectors, an increase in the contact rate between animals and vectors, and an increase in the contact rate between animals and wild fauna. This results in likely modifications of the endemic situation, with a higher risk of clinical diseases (L'Hostis & Seegers, 2002). Tick control is the only effective way to control tick-borne diseases. This requires adequate knowledge of the tick vectors involved in transmitting each pathogen. There are only very few documented reports on the detection of pathogens in ticks in India. Research into vaccines, improved diagnostic tools, and more effective treatment options remain

ongoing to combat these diseases, especially considering their significant burden on global health, particularly in resource-limited settings.

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15 LIGHT MICROSCOPIC STUDIES OF SOME POLLEN MORPHOTYPES OF THE UPPER MONTANE NILGIRI FLORA

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ABSTRACT

The study of the microscopic features of the pollen grains, Palynology, provides robust inputs for understanding the flora when combined with the habits and habitats of the plants that yielded them. The present study investigates the pollen morphological features of a selection of 18 pollen taxa recovered from six surface soil samples from grasslands in the upper montane region of the Nilgiris, a biodiversity hotspot in the Western Ghats of India, characterized by alternate stable states (forests, grasslands and swamps). Samples were collected during January and March 2024, in the framework of the ongoing Nilgiri Archeological project. This Light Microscopic study focuses on identifying and classifying pollen morphotypes based on the morphological characteristics of the pollen wall, the exine that remains as a proxy of the plant that produced it, contributing to our understanding of the local vegetation and landscape dynamics. The qualitative and quantitative pollen morphological features observed were: aperture type, shape, size and exine ornamentation in a mix of arboreal (*Olea glandulifera*-t, *Meliosma*, *Dodonaea viscosa*, *Ilex*, *Ligustrum*, *Pinus*, *Rapanea*, *Daphniphyllum* and *Acacia*) and non-arboreal pollen taxa (*Justicia*-t, Apiaceae, *Impatiens*, *Artemisia*, Asteraceae (echinate), Asteraceae (fenestrate), Cyperaceae, Gentianaceae and Poaceae). In addition to helping identify the possible plant groups that produced them, the diversity of traits in the pollen morphotypes reflects adaptations of the plants to different ecological conditions providing some insights into pollen biology and their role in plant systematics. Site-specific variations in distribution of the pollen morphotypes within the dataset of surface samples presented are also briefly discussed in view of factors (e.g., edaphic, microclimatic, topographic and anthropogenic) affecting pollen deposition. As pollen remains one of the best-preserved plant proxies in past sedimentary deposits, critical insights into regional pollen

morphology holds the key to broader applications such as the interpretation of present and past vegetation structures, foraging preferences of pollinators like native honeybees and other similar applications.

Keywords: Pollen traits; climatic changes; palaeoecology; palaeoclimatology; vegetation reconstruction

INTRODUCTION

Pollen grains function as structures that house the male gametophyte in seed plants. The study of pollen morphology, termed Palynology, primarily focuses on the structure of the pollen walls rather than their internal features. The field of pollen analysis originated in 1916 with the investigation of Quaternary sedimentary deposits from lakes and bogs (Von Post, 1916; Birks & Berglund, 2018). Today, it remains a crucial tool for reconstructing past vegetation and environmental conditions. Pollen analysis can also be considered a remote sensing tool, capturing the historical and present composition of vegetation (Webb *et al.*, 1978; Lazar, 2025). Palynology has demonstrated additionally its value in the study of taxonomic groups and various scientific disciplines, as well as in a range of Quaternary applications, including palaeoecology, palaeoclimatology and archaeology (Macdonald, 1988; Bhagwat *et al.*, 2012; Anupama *et al.*, 2014a, 2014b; Clément *et al.*, 2024). Information obtained from pollen studies can offer insights into how natural vegetation has responded to human activities throughout history, as also to climatic and environmental changes (Prentice, 1988; Edwards & Macdonald, 1991). Pollen grains from various flowers exhibits unique characteristics in terms of shape, size and surface ornamentation (Wodehouse, 1959; Erdtman, 1966; Nayar, 1990; Tissot *et al.*, 1994)

Pollen grains typically possess apertures, which can be either elongated or circular, with variation in the number of apertures. The apertures may be elongated (colpi) or circular (pores) or a combination of both these (colporus). The apertures are prominent, often interrupting the fine structural patterns on the surface of the pollen grain. Aperture diversity is diverse across different taxa, families, species, and even within individual plants (Mignot *et al.*, 1994). Pollen wall patterns are diverse and often unique to individual species, making them valuable for taxonomic classification and forensic investigations (Szibor *et al.*, 1998). The exine, the outer layer of a living pollen grain, is divided into two distinct sublayers: an inner smooth layer (nexine) and an

outer sculptured layer (sexine). The chemically resilient outer layer is primarily composed of sporopollenin—a complex polymer with minor amounts of polysaccharides (Birks & Birks, 1980), resistant to decomposition, and preserved in various substrates like amber, lignite and anaerobic sediments such as peat deposits in both Quaternary and pre Quaternary sequences. The pollen grains of each plant species exhibit distinct features making them valuable for identifying plant species in fossil remains from various deposits and sites.

Detailed pollen descriptions are crucial, as understanding vegetation history relies heavily on pollen analysis. Pollen morphology often plays a significant role in plant taxonomy, often supporting the classification of specific families such as Arecaceae (Thanikaimoni, 1970) and Clusiaceae (Seetharaman, 1985). While taxonomists traditionally rely on phenotypic characteristics to identify plant species, pollen morphology too offers a reliable basis for plant species identification (Punt *et al.*, 2007; Rouhan & Gaudeul, 2021). In this context, while the Nilgiris region is renowned for its diverse range of flowering plants, comprehensive information on the pollen morphology and diversity of pollen taxa is limited (Vasanthy, 1988).

The present Light Microscopic study investigates the pollen morphological features of a selection of 18 of the pollen taxa recovered from six surface soil samples from grasslands in the upper montane region of the Nilgiris, a biodiversity hotspot in the Western Ghats of India. The six surface samples were collected between January and April 2024 in the framework of the ongoing Nilgiri Archeological project and their pollen content was extracted and examined under a Light Microscope. The focus is on identifying and classifying pollen morphotypes based on the morphological characteristics of the pollen. This was done in 18 out of a total of 45 pollen taxa found in the six surface sediments. The qualitative and quantitative pollen morphological features observed included aperture type, shape, size and exine ornamentation in a mix of arboreal (AP) and non-arboreal (NAP) pollen including some introduced plants such as *Pinus* and *Acacia* that currently dominate these landscapes (Table 1).

MATERIALS AND METHODS

Study area and Sampling

Sampling was carried out across multiple locations in Nilgiris, namely Tenth Mile (11°27'31.30"N; 76°37'11.40"E), Taranadu Mund (11°29'30.10"N; 76°37'12.30"E),

Aduthal Mund (11°29'10.10"N; 76°37'12.80"E), Muthnad Mund (11°26'51.80"N; 76°39'52.80"E), Seventh Mile (11°26'35.30"N; 76°38'19.10"E) and Ninth Mile (11°26'17.20"N; 76°37'44.00"E) (Fig. 1). These montane sites consist of alternate stable states (shola forests, grasslands and swamps) interspersed with plantations, primarily managed by the Toda community.



Figure 1. Location map of the study areas in Nilgiris (Source: Google Maps).

The vegetation comprises a mix of native (shola forest trees like *Ilex denticulata*, *Daphniphyllum neilgherrense*, *Michelia nilagirica*; different grass species of *Sisyrinchium*, *Eragrostis*, *Apluda*, and in limited pockets, *Eriochrysis rangachari* called “Avvul” by the Todas who favour it for the construction of their traditional roof; different species of sedges like *Cyperus* and *Fimbristylis* and swamp elements such as different species of *Impatiens*, *Eriocaulon* and *Xyris*.) and introduced and invasive taxa (like *Acacia* spp., *Eucalyptus* sp., and *Cestrum elegans*). Surface soil samples were collected from six distinct locations within grasslands with patches of remnant sholas overlapping within a radius of 1 km around the points of surface soil collection during the period of January and March 2024. The present landscape is characterized by an interruption of the

natural grasslands and marshlands with patches of trees and shrubs that have invaded it.

Sample preparation and microscopic analysis

The six surface soil samples collected as mentioned above were analyzed for their pollen content at the Laboratory of Palynology, French Institute of Pondicherry (IFP). To process the samples, after removal of silicates using 40% HF, acetolysis method (Erdtman, 1960) was followed to eliminate cellulose and other cellular materials obscuring the visibility of exine. For morphological examination, the acetolyzed pollen grains were mounted on glass slides using glycerin, covered with cover slips and sealed with DPX mountant. Light microscopy (LM) was conducted using an Olympus microscope with a $\times 40$ objective lens, while a $\times 100$ objective was employed for detailed pollen identification, and images were captured using relevant software installed with camera attachment. Each pollen grain was systematically examined, and key morphological traits including aperture type, shape, size and surface ornamentation were observed using reference collection and literatures (Faegri & Iversen, 1989). The size ranges and descriptions for the pollen morphotypes provided here are based on cross-checking with the appropriate reference pollen slides and then incorporating this knowledge in the studied samples. It also draws on measurements made on the same pollen taxa reported in other modern surface and quaternary studies (e.g., Anupama *et al.*, 2014a; Navya, 2020). It is of note that the list of selected pollen taxa comprises a mixed taxonomic hierarchy with *Dodonaea viscosa* at the species level and taxa like Poaceae and Cyperaceae at the family level; there are also pollen types such as *Justicia*-t (Anupama *et al.*, 2014a) and *Olea glandulifera*-t that may include members of other genera in Oleaceae like *Chionanthus* spp. in a different landscape.

RESULTS

A total of 45 distinct pollen taxa were identified during the light microscopic study of the six surface samples collected and analyzed as detailed above of which 20 were arboreal 23 non arboreal, one (*Croton*-t) was non-classified, and one remained unidentified (Fig. 2). Among the dominant plant taxa, Poaceae was the most prevalent, followed by Cyperaceae, Asteraceae (both echinate and fenestrate types), Gentianaceae, Apiaceae and *Olea glandulifera*-t, which were recorded in all study sites (Fig. 2). Most other taxa, such as *Artemisia*, *Justicia*-t, *Meliosma*, *Dodonaea viscosa*, and introduced

taxa like *Eucalyptus*, *Acacia* and *Pinus*, appeared less frequently in the soil pollen assemblages. Certain pollen taxa showed site-specific prominence or occurrences: *Impatiens* was recorded only at Aduthal Mund where *Ilex* was more seen; *Artemisia* appears only in both Aduthal Mund and Seventh Mile; *Acacia* and *Pinus* reach their respective maximum only in Tenth Mile; Gentianaceae was recorded in more numbers at Seventh Mile and Muthanadu Mandu.

For the detailed microscopic and morphological examination 18 pollen taxa highlighted by asterisks were selected to reflect the regional diversity of pollen morphotypes. The qualitative and quantitative pollen morphological features observed included aperture type, shape, size and exine ornamentation in a mix of 9 arboreal (AP) and 9 non arboreal pollen (NAP) (Table 1). Among the selected pollen taxa, three are from the Asteraceae family (Asteraceae (echinate) and Asteraceae (fenestrate) types; and *Artemisia*), and two are from Oleaceae (*Olea glandulifera*-t and *Ligustrum*). Others comprise taxa such as *Justicia*-t, *Acacia*, *Meliosma*, *Dodonaea viscosa*, *Rapanea*, *Impatiens*, *Daphniphyllum*, Poaceae, Cyperaceae, Gentianaceae, Apiaceae *Pinus* and *Ilex* that are distinct morphotypes from 13 distinct families (Table 1; Plates 1a, b).

Pollen morphology of the selected morphotypes (Plate 1a, b) exhibited variations across different plant species, displaying a wide range of characteristics related to exine ornamentation patterns, shape, size and aperture type. The majority of species produced pollen grains dispersed as monads, except for *Acacia*, which exhibited polyads. Shape diversity was also evident, with prolate, spheroidal, and oblate spheroidal forms being the most commonly observed. Apiaceae and *Justicia*-t pollen were primarily prolate, while *Artemisia*, Asteraceae (echinate) displayed a variety of forms, including prolate spheroidal, spheroidal and oblate spheroidal. Pollen from Poaceae and Asteraceae (fenestrate) were mostly spheroidal.

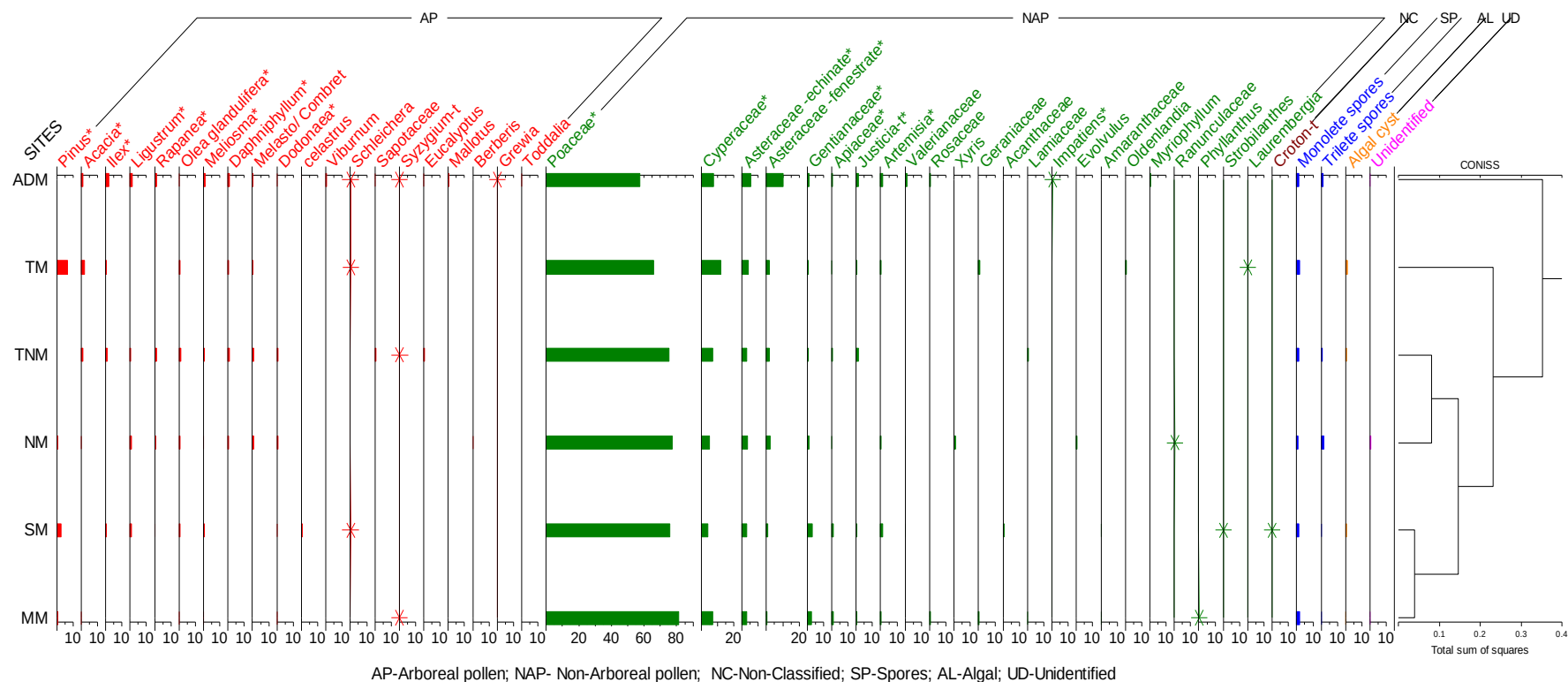


Figure 2. Frequency of occurrence of various pollen taxa (all 45 taxa/types excluding spores) retrieved from surface soil samples of six sites in the Nilgiris. The selected 18 pollen taxa are highlighted with asterisk (*).
 Sites: ADM - Aduthal Mund, TM - Tenth mile, TNM - Taranad mund, NM - Ninth mile, SM - Seventh mile, MM - Muthnad mund

Table 1. Morphological characters of selective (18) pollen taxa/traits chosen from various study sites at Nilgiris.

Sl. No	Family	Pollen Taxa	Group	Size μm (P)	Size μm (E)	Shape	Ornamentation	Aperture
1	Acanthaceae	<i>Justicia</i> -t	NAP	25-30	18-20	Prolate	Reticulate	3 Colporate/3 porate
2	Apiaceae	Apiaceae	NAP	40-45	15-18	Prolate	Reticulate	3 Colporate
3	Aquifoliaceae	<i>Ilex</i>	AP	30-35	22-25	Prolate	Clavate	3 Colporate
4	Balsaminaceae	<i>Impatiens</i>	NAP	15-22	25-35	oblate (Rectangular in polar view)	Reticulate	4 to 5 colpate
5	Asteraceae	<i>Artemisia</i>	NAP	20-28	15-25	Prolate spheroidal/ spheroidal/ oblate spheroidal	Microechinate	3 Colporate
6	Asteraceae	Asteraceae (echinate)	NAP	20-25	18-22	Prolate spheroidal/ spheroidal/ oblate spheroidal	Echinate	3 Colporate
7	Asteraceae	Asteraceae (fenestrate)	NAP	20-25	20-25	Spheroidal	Fenestrate	3 Colporate
8	Cyperaceae	Cyperaceae	NAP	28-40	25-35	Spheroidal-obovoid	Psilate	4 to 5 faintly aperturate
9	Euphorbiaceae	<i>Daphniphyllum</i>	AP	23-25	23-25	Prolate spheroidal/ spheroidal/ oblate spheroidal	Granulate	3 colpoidate
10	Gentianaceae	Gentianaceae	NAP	40-45	25-30	Prolate/ prolate spheroidal	Striato-reticulate	3 Colporate
11	Mimosaceae	<i>Acacia</i>	AP	40-42	35-38	Prolate/ prolate spheroidal (for the polyad)	Polyads	Polyaperturate
12	Myrsinaceae	<i>Rapanea</i>	AP	25-28	20-22	Prolate spheroidal/ Spheroidal	Granulate/Psilate	4 colpate
13	Oleaceae	<i>Ligustrum</i>	AP	30-35	25-30	Prolate spheroidal/ spheroidal/ oblate spheroidal	Reticulate	3 Colporoidate
14	Oleaceae	<i>Olea glandulifera</i> -t	AP	25-28	25-28	Prolate spheroidal/ spheroidal/ oblate spheroidal	Reticulate	4 Colporoidate
15	Pinaceae	<i>Pinus</i>	AP	65-80 (L)	35-45 (W)	Disaccate	Reticulate-granulate	Inaperturate
16	Poaceae	Poaceae	NAP	38-42	40-45	Spheroidal	Psilate	Monoporate
17	Sabiaceae	<i>Meliosma</i>	AP	35-40	35-38	Prolate-spheroidal	Reticulate	3 Colporate
18	Sapindaceae	<i>Dodonaea viscosa</i>	AP	35-40	33-36	Prolate spheroidal/ spheroidal/ oblate spheroidal	Granulate	3 Colporate

Other distinct morphologies included bisaccate grains in *Pinus* (Plate 1b (F)), spheroidal-obovoid in Cyperaceae (Plate 1a (H)), and oblate grains with a rectangular polar view in *Impatiens* (Plate 1a (D)). The dataset reveals a range of pollen sizes, with the size of the pollen axes varying across pollen morphotypes. The smallest pollen size ranges (~20-30 μm P, 18-22 μm E) among the chosen taxa were for Asteraceae (echinate) and *Justicia*-t, while *Pinus* has the largest pollen grains (65–80 μm P, 35–45 μm E), with bisaccate units that enhance wind dispersal. In contrast, Poaceae (grass) produce spheroidal pollen (38–42 μm P, 40–45 μm E), featuring a psilate surface and monoporate apertural condition.

Aperture types vary among the studied pollen grains. Poaceae exhibits monoporate condition (Plate 1b (G)), while Cyperaceae has 4–5 apertures (Plate 1a (H)). *Impatiens* displayed 4–5 colpate apertures (Plate 1a (D)). Composite aperture types were frequently recorded, with eight taxa—such as Gentianaceae, *Ilex*, and *Dodonaea viscosa*—showing 3-colporate pollen grains (Plate 1b (I)), while *Rapanea* had 4-colporate grains (Plate 1b (C)). Exine sculpture (ornamentation) also exhibited significant diversity. Reticulate exine was observed in six taxa, including Apiaceae, *Ligustrum* and *Olea glandulifera*-t. Striato-reticulate ornamentation was observed in Gentianaceae, while granulate exine was characteristic of *Daphniphyllum* and *Dodonaea viscosa*. This study shows that species from the family Asteraceae exhibited echinate (and microechinate), and fenestrate exine patterns. Additionally, clavate-type ornamentation was recorded in *Ilex*, while a generally psilate exine was observed in both Poaceae and Cyperaceae. Pollen grains from the family Pinaceae (*Pinus*) were found to be inaperturate with a unique bisaccate structure with a reticulate-granulate texture (Plate 1b (F)). To understand the different pollen types within a family, it is crucial to analyze many pollen grains, across different genera; species-level identification using only LM is rare but feasible, as with *Dodonaea viscosa* in this study.

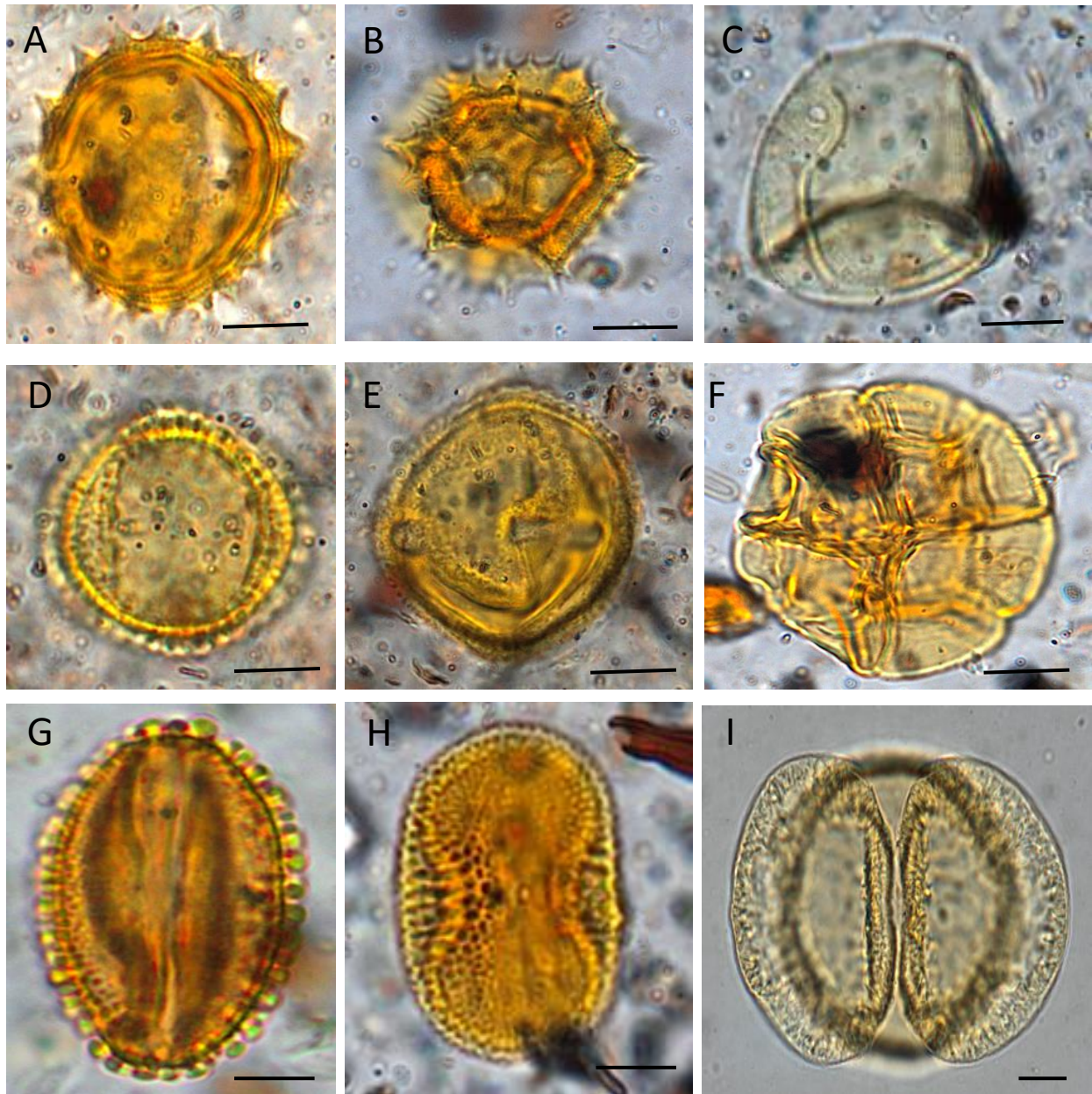


Plate 1a. LM images of some of the pollen taxa from the Nilgiris. A. *Justicia*-t, B. Apiaceae, C. *Ilex*, D. *Impatiens*, E. *Artemisia*, F. Asteraceae (echinate), G. Asteraceae (fenestrate), H. Cyperaceae, I. *Daphniphyllum* (Scale bar: 10 µm)

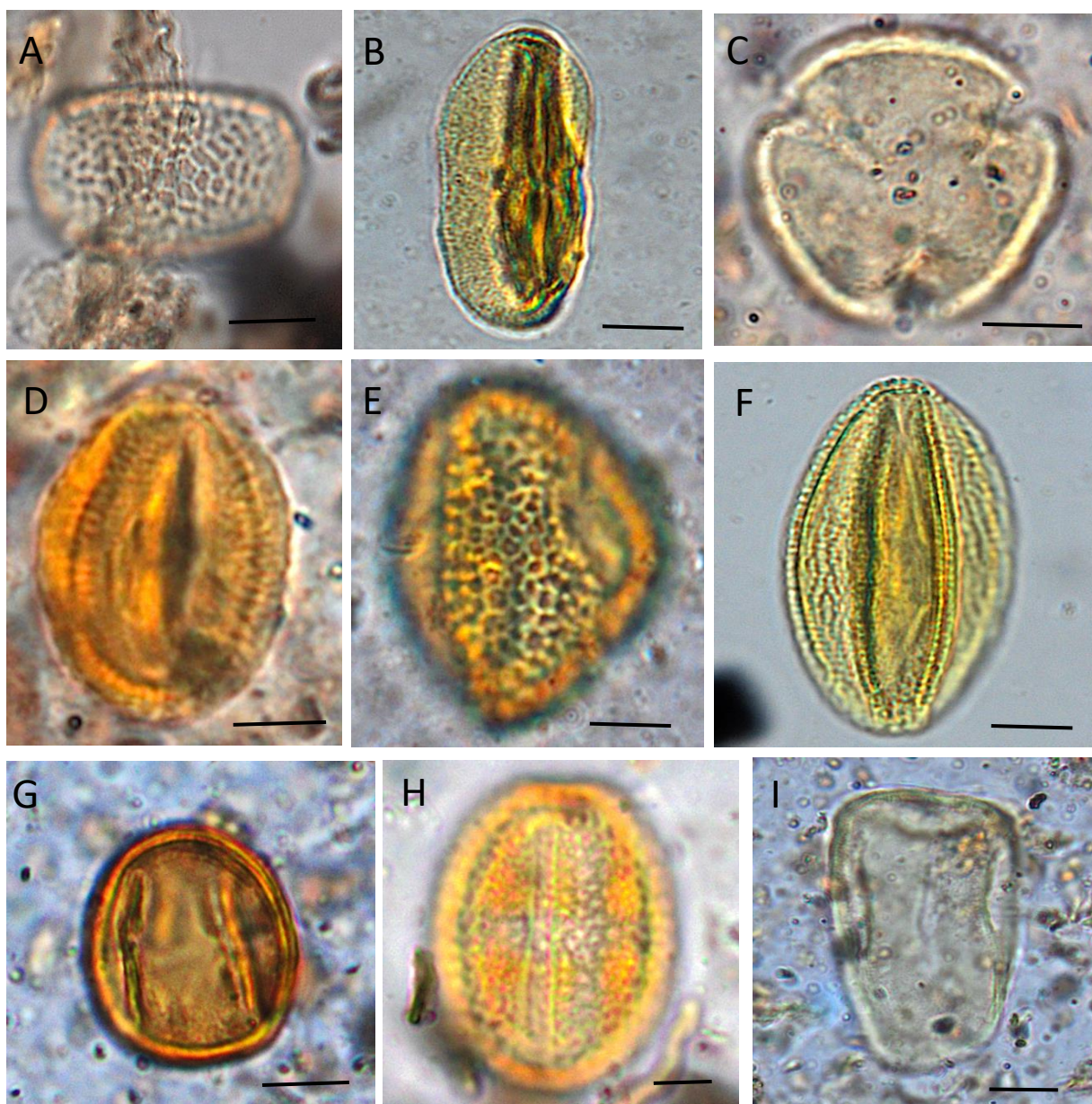


Plate 1b. LM images of some of the pollen taxa from the Nilgiris. A. Gentianaceae, B. *Acacia*, C. *Rapanea*, D. *Ligustrum*, E. *Olea glandulifera*-t, F. *Pinus*, G. Poaceae, H. *Meliosma*, I. *Dodonaea viscosa*. (Scale bar: 10 µm)

DISCUSSION

This study describes the pollen morphology of 18 pollen taxa from 15 families revealing variations in the nature and number of apertures, exine sculpturings, shapes and size. Certain pollen taxa, even when present in low frequencies, hold ecological significance as indicators of shola forest ecosystems. For instance, the genera *Ilex*, *Ligustrum*, *Rapanea* and *Impatiens* are commonly associated with hygrophilous environments and montane forests and we find their corresponding pollen taxa in most

of the studied sites. Pollen from the Apiaceae family are generally linked to cultivated vegetation, but in this landscape they are found mainly in the grasslands and frequently considered a relative “dryness” indicator along with other taxa like *Artemisia* (Sutra *et al.*, 1997).

Similarly, site-specific variations in pollen distribution such as the rare occurrence of *Impatiens* in only one site or the differences in proportions of Cyperaceae, Poaceae, *Artemisia* and Gentianaceae. *Pinus* and *Acacia* observed in this study suggest the potential influence of edaphic microclimatic topographic and anthropogenic factors on pollen deposition, which is crucial for accurately reconstructing past vegetation dynamics and assessing anthropogenic impacts on regional flora. Among these, it is of note that though introduced species of *Pinus* and *Acacia* (known to be invasive: Hiremath & Sundaram 2013) dominate this montane landscape currently, both in their sheer numbers and in their size too, neither taxon nor others such as *Eucalyptus* (not discussed here for morphology but included in Fig. 2) ever reach percentages over five. The case of low proportions of *Pinus* in our samples (only notable presence is at Tenth Mile) (Fig. 2) is intriguing in terms of its morphology. *Pinus* is a winged pollen and known to be transported over very long distances but its record again like *Acacia* is found in very small percentages. While pollen of *Acacia* are considered to be mostly entomophilous they have also been reported in surface samples elsewhere in India (Navya, 2020) and in Africa (Gaillard *et al.*, 2021). The advantage in this landscape for these introduced invasives is that they are able to tower over the native shola trees with the ability to disperse both pollen and seeds into the grasslands. Though preliminary, our finding that the pollen dispersal of these two species in the grassland samples seems limited could have implications for better managing the eradication of these species based on their dispersal mechanism.

As noted by Carvalho *et al.* (1999), species present with less than 1% may be due to limited pollen production, as observed in *Justicia-t*, *Daphniphyllum* and *Impatiens*. Some samples contained unidentified pollen taxa, highlighting challenges in determining the botanical origin of certain pollen grains. This difficulty is often attributed to gaps in our understanding of the pollen of the regional flora. Furthermore, pollen grains from distinct plant families may exhibit morphological similarities, as seen

in the common tricolporate, reticulate pollen taxa that are prevalent among dicotyledons.

Identifying pollen from soil samples can provide valuable insights into local and regional scale botanical composition even without extensive vegetation surveys. The present study shows that as many as 45 pollen taxa were recovered from only six study sites and that most of them correspond to the native shola grasslands and swamp formations found here as alternate stable states of vegetation. Work is ongoing in this project to extend the pollen morphological study to key montane forest taxa in the Nilgiris by continuing to collect both surface samples, sediment cores and whenever available pollen from native honeybee combs found nesting in tree hollows.

CONCLUSIONS

The first results from this ongoing study are promising in at least three ways: 1) they establish the capability of pollen analysis to serve as a potential remote sensing tool capturing a large assemblage of the native vegetation in this complex landscape even without a vegetation survey though such surveys are essential in the perspective to establish quantitative pollen-vegetation relationships here; 2) they provide tangible evidence that at least some of the introduced and invasive taxa (*Pinus* and *Acacia*) that currently overpower this montane landscape are not significant from a palynological angle providing an impetus to further research on their dispersal mechanism (Appendix 1) and subsequently their management and 3) the palynological imprint of the native vegetation reflecting much of its diversity even when recorded in lower proportions as distinctly identifiable morphotypes. These results are a direct consequence of an accurate identification of the regional pollen morphotypes emphasizing the need for more in-depth pollen morphological studies in this montane region with a complex vegetation distribution. Such pollen morphological studies can also yield additional valuable insights for taxonomic classification, while also contributing to phylogenetic studies that can help make the link with both the evolutionary and the environmental factors responsible. The dominance of tricolporate apertures in dicotyledons (eg: *Dodonaea viscosa*, Asteraceae (echinate), *Olea glandulifera*-t), monoporate and faint apertures in monocotyledons (Poaceae; Cyperaceae) align with established taxonomic patterns. These findings highlight the importance of pollen characteristics in plant

taxonomy and evolutionary research, emphasizing their role in understanding species relationships and adaptations.

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16 AN INVENTORY OF GRASS SPECIES IN THE NILGIRI TAHR (*NILGIRITRAGUS HYLOCRIUS*) HABITAT OF THE ANAMALAI TIGER RESERVE, TAMIL NADU, INDIA

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ABSTRACT

Grasslands are highly dynamic and important since they are sensitive to global warming and act as an important forage source for the endangered Nilgiri tahr (*Nilgiritragus hylocrius*). It is a natural habitat dominated by grasses and contains few trees and shrubs. The present study examined grass diversity within the habitat of the Nilgiri tahr in the Anamalai Hills. A total of 45 grass species under 26 genera have been identified in the study area. Notable species include *Arundinella mesophylla*, *Arundinella purpurea*, *Heteropogon contortus*, *Chrysopogon zeylanicus*, *Andropogon lividus*, *Themeda triandra*, *Themeda tremula*, *Tripogon bromoides* and *Eragrostis unioides*. All are unique and serve as an important food for the Nilgiri tahr. Forest fires, grazing, invasive species, and infrastructure development in the Nilgiri tahr habitats threaten forage grasses. The findings from this research will be valuable for the conservation of the shola grasslands species' presence in Nilgiri tahr habitat.

Keywords: Nilgiri tahr, Anamalai, grass species, forage species, *Arundinella*, *Andropogon*

INTRODUCTION

Grasses are natural and unique group of plants with remarkable diversity (Kabeer & Nair, 2009). Poaceae is one of the largest families of flowering plants, with 11,369 species under 720 genera (Clayton *et al.*, 2016) and have a significant role in sustaining the life of human beings and animals (Kabeer & Nair, 2009). In India, Poaceae is represented by 1,334 species under 261 genera (Karthikeyan, 2005). It is the fifth largest plant groups in flowering plants. Poaceae plants like rice, wheat and maize are important food sources. They also provide some other useful products like fodder, oils, house-building materials and lawn making materials (Jain, 1986).

Grass maintains natural ecosystem in addition to water quality, preventing floods, erosion, and drought. It is an essential sources of pleasure and subsistence like

meals, medication, and aesthetic sense and so on. A few grasses are directly or indirectly associated with the ascendance of the economic system of local communities (Ray & Sainkhediya, 2012).

Grass species plays a vital role in stabilizing soil, thus preventing erosion. Their fibrous root systems help to maintain soil structure and facilitates in water infiltration and aid in carbon sequestration. Many ubiquitous plant species support the diet of mountain ungulates, health and survival in harsh, high-altitude meadows. Studies on shola grasslands, especially in the Nilgiris tahr habitats, have been carried out by Davidar (1978), Rice (1988) and Mishra and Johnsingh (1998) at different times. Ganesan (2019-2020) and his research team conducted a plant survey at different locations in Anamalai hills, particularly shola grass species were identified and documented at grass hills National Park and in the book "Check list of flora and fauna of Anamalai hills".

Kabeer and Nair (2009) have reported 447 species (including 19 infra-specific taxa) in 136 genera in '*Flora of Tamil Nadu Grasses*'. As on date, detailed inventory list on the grass diversity of Grass Hills National Park of Anamalai Tiger Reserve (ATR) is available except few collections at Madras Herbarium (MH). Hence, the present study was carried out to highlight the shola grass diversity and low elevation grass species occurring in ATR, Tamil Nadu.

MATERIALS AND METHODS

Study area

The ATR is situated in the Anamalai sub-cluster of the Western Ghats mountain range in northwestern Tamil Nadu. It extends between the latitudes of 10°13'08" N and 10°33'27" N, and the longitudes of 76°49'02" E and 77°21'09" E. The study area and direct and indirect sighting locations of Nilgiri tahr is provided in figure 1. The reserve is situated at a varying altitude ranging from 280 m to 2545 MSL, and the annual mean temperature ranges from maximum of 28°C to a minimum of 13°C. The relative humidity in this hilly region varies between 50% and 90%. The South-West monsoon is major rainy season, contributing to 77% of the total annual rainfall. The various forest types represented in ATR as per the Champion and Seth (1968) classification are dry thorn forest, dry deciduous forest, dry savannah forest, moist deciduous forest, wet evergreen forests, montane grasslands and sholas. It has three National parks such as Karian shola,

Manjampatti, and Grass Hills. It is a potential habitat for Nilgiri tahr as well as a hotspot for the floral and faunal diversity in the southern Western Ghats. This pristine habitat harbours grasslands interspersed with shola forests, many rocky cliffs and plateaus adorned with perennial water source.

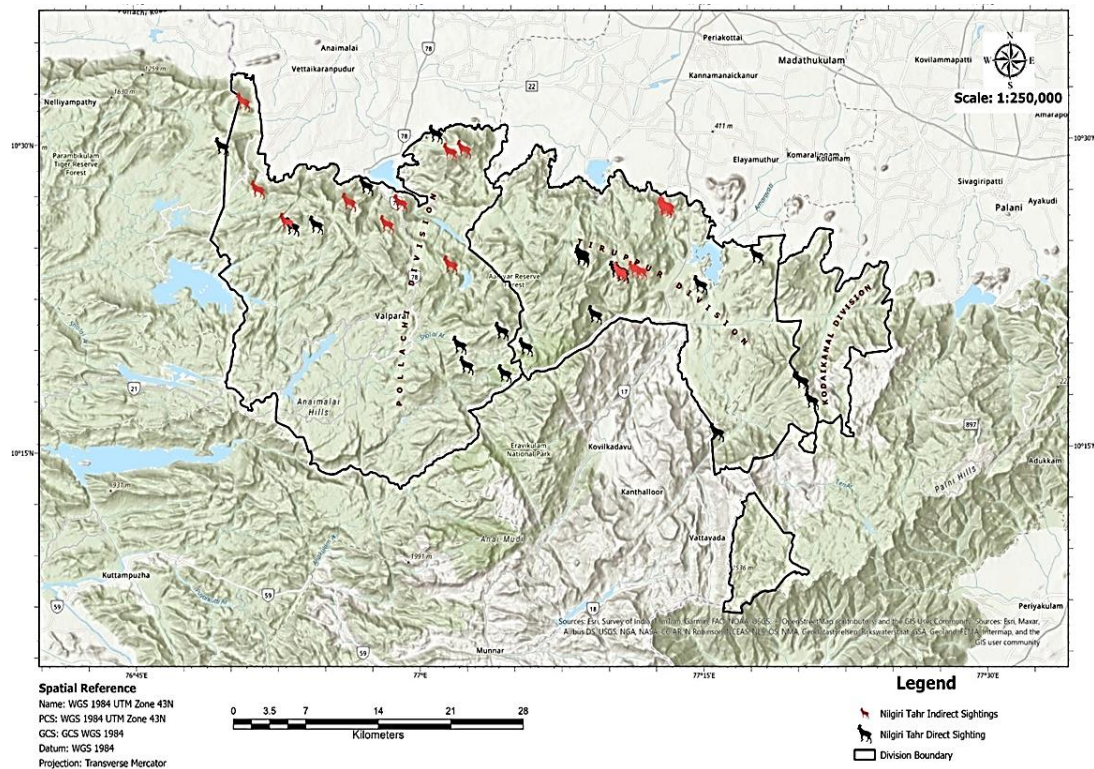


Figure 1. Map showing Nilgiri tahr direct and indirect sighting locations in Anamalai Tiger Reserve, Tamil Nadu

Floristic study

Intensive and extensive field explorations in Grass Hills National Park (GHNP), was carried out from June 2023 to May 2024. Exploration of vegetation type was carried in different seasons in Nilgiri tahr habitats of the study area. Different grass species samples have been collected with inflorescence for identification of species. During the fieldwork, plant morphology characters both vegetative structures like annual or perennial herb, stem, and leaf and reproductive structures like inflorescence and fruits were observed, recorded and documented. The collected plant specimens were carefully identified using regional and local floras (Fischer, 1921; Gamble, 1915-1936; Henry *et al.*, 1989; Kabeer & Nair, 2009). The specimens were also compared with reference specimens available at Madras Herbarium, Botanical Survey of India, Coimbatore and

Fischer's Herbarium (FRC), Coimbatore. The identified plant specimens are deposited at Project Nilgiri office, Forest campus, Coimbatore.

RESULTS AND DISCUSSION

Totally, 38 Nilgiri tahr habitats were identified in Tirupur and Pollachi divisions of Anamalai Tiger Reserve. The present study examined grass diversity within the habitats of the Nilgiri tahr in the Anamalai Hills. In this field study, 45 grass species belonging to 26 genera were identified and documented in the Nilgiri tahr habitats of the study area (Table 1). The following genera were abundant in Nilgiri tahr habitats: *Eragrostis* (5 species), *Arundinella* (4 species), *Tripogon* (4 species), *Themeda* (3) and *Ischaemum* (3) species. The Project Nilgiri tahr team and frontline field staff have continuously perambulated different places of the Anamalai Tiger Reserve. During the field survey, the team could identify some unique floral species in Nilgiri tahr habitat, such as *Andropogon lividus*, *Arundinella ciliata*, *Arundinella mesophylla*, *Arundinella purpurea*, *Chrysopogon zeylanicus*, *Eragrostis unioides*, *Eulalia phaeothrix*, *Tripogon pungens*, *Heteropogon contortus*, *Ischaemum indicum*, *Themeda triandra* and *Themeda tremula* species, which forms the prime food species of Nilgiri tahr (Fig. 2 & 3).

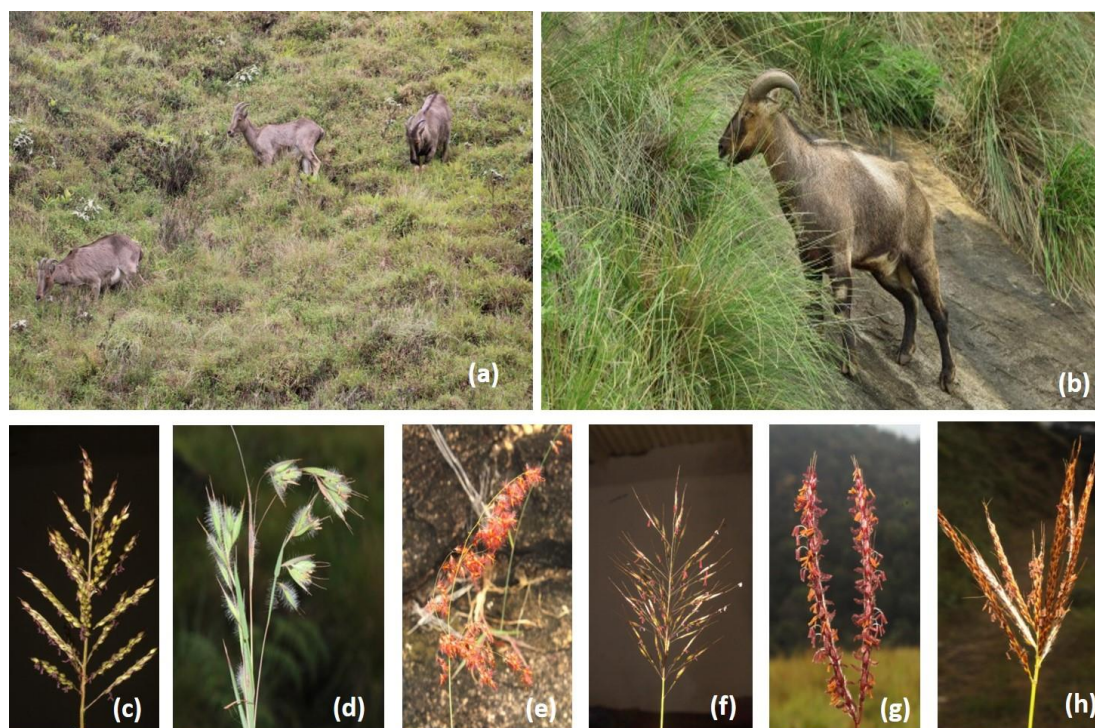


Figure 2. Food habits of the Nilgiri Tahr. Herd grazing at Koramparai area (a), *Garnotia elata* (b), *Arundinella purpurea* (c), *Themeda triandra* (d), *Melinis repens* (e), *Chrysopogon zeylanicus* (f), *Andropogon lividus* (g) and *Bothriochola pertusa* (h)

Table 1. Checklist of grass species in Anamalai Tiger Reserve

S. No	Botanical Name	Ecological status	Fl/Fr
1	<i>Andropogon lividus</i> Thwaites.	Common	Jun-Aug
2	<i>Andropogon polytychus</i> Steud.	Common	Oct-Dec
3	<i>Arundinella ciliata</i> (Roxb.) Nees ex Miq.	Common	Jun-Sep
4	<i>Arundinella mesophylla</i> Nees ex Steud.	Endemic	Jul-Dec
5	<i>Arundinella pumilla</i> (Hochst. Ex A. Rich.) Steud.	Common	Jun-Nov
6	<i>Arundinella purpurea</i> Hochst. Ex. Steud.	Common	Jun-Sep
7	<i>Bothriochola pertusa</i> (L.) A. Camus	Common	Jul-Dec
8	<i>Bothriochola foulkesii</i> (Hook) Henrard.	Common	Jun-Sep
9	<i>Bulbostylis densa</i> (Wall.) Hand.-Mazz.	Common	Jun-Sep
10	<i>Aristida setacea</i> Retz,	Common	Jun- Aug
11	<i>Garnotia elata</i> (Arn. Ex Miq).	Common	Jul-Oct
12	<i>Garnotia exaristata</i> Gould.	Rare	Jul-Oct
13	<i>Setaria pumila</i> (Poir) Roem. & Schult.	Common	Jul-Oct
14	<i>Chrysopogon hackelii</i> (Hook.f.) C.E.C. Fisch.	Endemic	Oct-Dec
15	<i>Chrysopogon zeylanicus</i> (Steud. Thwaites	Common	Aug-Dec
16	<i>Cenchrus ciliaris</i> L	Endemic	Aug-Dec
17	<i>Chloris barbata</i> Sw.	Endemic	Oct-Dec
18	<i>Cymbopogon citratus</i> (DC) Stepf.	Common	Aug-Dec
19	<i>Jansenella griffithiana</i> (C. Muell.) Bor	Common	Aug-Dec
20	<i>Agrostis peninsularis</i> Hook.f.	Common	Jun-Aug
21	<i>Dichanthium oliganthum</i> (Hochst. Ex Steud.) Cope	Endemic	Sep-Nov
22	<i>Helictotrichon virescens</i> (Nees ex Steud.) Henarrd	Common	Aug-Dec
23	<i>Eragrostis unioloides</i> (Retz.) Nees ex Steud.	Common	Jul-Nov
24	<i>Eragrostis atrovirns</i> (Desf.) Trin Ex Steud.Panicum	Common	Aug-Dec
25	<i>Eragrostis tenuifolia</i> (A.Rich) Hochst Ex Steud.	Common	Aug-Dec
26	<i>Eragrostis tenella</i> (L) P.Beauv. wx. Roem & Schult.	Common	Aug-Dec
27	<i>Eragrostiella bifaria</i> (Vahl) Bor	Common	Aug-Dec
28	<i>Eulalia phaeothrix</i> (Hack.) Kuntze	Common	Jun-Nov
29	<i>Ischaemum indicum</i> (Houtt.) Merr.	Endemic	Aug-Dec
30	<i>Ischaemum ciliare</i> Retz.	Common	Jun-Nov
31	<i>Ischaemum commutatum</i> Hack.	Common	Aug-Sep
32	<i>Apluda mutica</i> L	Common	Jul-Nov
33	<i>Eragrostis gangetica</i> (Roxb.) Steud.	Common	Aug-Nov
34	<i>Heteropogon contortus</i> (L) P. Beauv ex. Roem & Schult.	Common	Jul-Dec
35	<i>Isachne bourneorum</i> C.E.C Fisch.	Common	Aug-Dec
36	<i>Isachne globosa</i> (Thunb.) Kunzte	Common	June-Sep
37	<i>Melinis repens</i> (Willd.) Zizka	Common	May-Aug
38	<i>Themeda triandra</i> Forssk.	Common	Jun-Nov
39	<i>Themeda tremula</i> (Nees ex Steud.) Hack.	Common	Jun-Sep
40	<i>Themeda cymbaria</i> Hack	Common	Jun-Sep
41	<i>Tripogon ananthaswamianus</i> Sreek., V.J. Nair & N.C. Nair	Endemic	Jun- Nov
42	<i>Tripogon wightii</i> Hook. F.	Endemic	Jun- Nov
43	<i>Tripogon pungens</i> C.E.C Fisch.	Endemic	Aug- Dec
44	<i>Tripogon bromoides</i> Roem. & Schult.	Common	Jul- Sep
45	<i>Panicum gardneri</i> Thwaites	Common	Jul- Sep



Themeda tremula



Cyperus sanguinolentus



Cymbopogon citratus



Arundinella mesophylla



Tripogon pungens



Andropogon lividus



Chrysopogon hackelii



Garnotia elata



Arundinella pumilla



Jansenella griffithiana



Arundinella purpurea



Bothriochola pertusa

Figure 3. Grass diversity in the Nilgiri tahr habitat of the Anamalai Tiger Reserve, Tamil Nadu, India.

Further, the leaves and inflorescence of native herbs and shrubs such as *Anaphalis beddomei*, *Rhodomyrtus tomentosa*, *Impatiens scapiflora* and *Impatiens chinensis* were observed to be foraged by the Nilgiri tahr. The maximum numbers of grass species were identified at the elevation range between 1100 and 2300 MSL (Fig. 4). Rice (1988) has reported 38 important food species of Nilgiri tahr in Eravikulam National Park (ENP), which is adjacent to Grass Hills National Park.

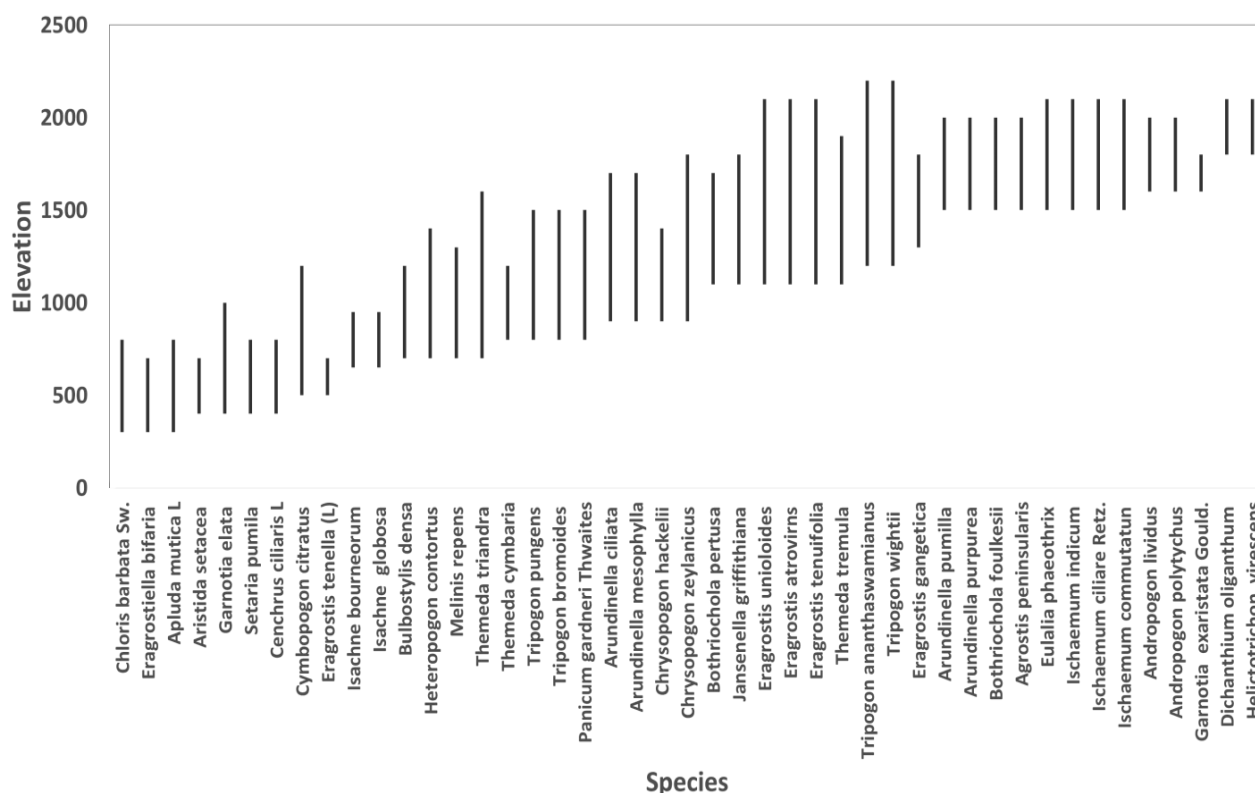


Figure 4. Elevation-based species distribution in the Nilgiri tahr habitat

Eravikulam National Park and Grass Hills National Park (GHNP), are the prime habitats of Nilgiri tahr, which is located on the inter-state boundary of Tamil Nadu and Kerala. Rice (1988) identified 38 plant species as food plants of the Nilgiri tahr in the nearby ENP. After 35 years of his description of the genera *Cyanotis* and *Lobelia*, we have identified two species in each genus, as specified. The plant species such as, *Lobelia nicotianifolia*, *Lobelia leschenaultiana*, *Cyanotis arachnoidea* and *Cyanotis pilosa* were recorded in the adjacent GHNP. These species were recorded in the regional plant book, management plan of ENP (2012-2022) and the Botanical Survey of India Herbarium Centre.

Mishra and Johnsingh (1998) have identified eight grass species, such as *Heteropogon contortus*, *Themeda triandra*, *Chrysopogon aciculatus*, which are common in the Nilgiri tahr habitats of the study area. The Nilgiri tahr's survival is intrinsically linked to the availability of these diverse food species and its quality. Although several reports documented the importance of Nilgiri tahr and its conservation, their ecological importance in the grassland ecosystem remains unexplored. The high-altitude dwelling Nilgiri tahr is not the only determinant of predator population dynamics, but also plays a significant role in validating ecological succession. Mishra and Johnsingh (1998) conducted survey in the Nilgiri tahr habitats 12 grasslands in the Anaimalai Hills recorded 22 species of grass species. Of these, the current study has recorded 12 species based on a survey conducted in ten places excluding the two places (Kerala areas) mentioned by Mishra and Johnsingh (1998). The comparison of grass species revealed that species such as *Heteropogon contortus*, *Themeda triandra*, *Eulalia phaeothrix*, *Arundinella mesophylla*, *Arundinella purpurea* and *Tripogon ananthaswamianus* were recorded common in the both sites.

CONCLUSION

The shola grasslands gained conservation priority because of the supporting to Nilgiri tahrs as homeland, habitat for diverse flora, fauna and major water catchment area. In the current study, 45 grass species belonging to 26 genera, which are the prime species of Nilgiri tahr were documented. This study enlightened the understanding of the Nilgiri tahr habitat. Till date, 45 grass species have been identified, which will be very useful for future research in the remaining areas of Tamil Nadu such as Srivilliputhur-Megamalai Tiger Reserve (SMTR), Kalakkad Mundanthurai Tiger Reserve (KMTR) and Mudumalai Tiger Reserve (MTR). In total, 25 grass species have been identified in Nilgiri tahr habitats as food species for Nilgiri tahr.

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17 FOUR ELUSIVE INDIAN MOSSES DISCOVERED IN THE WESTERN GHATS

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ABSTRACT

Bryophytes are the pioneers in colonizing a terrestrial habitat from an aquatic environment. Hence, they prefer to grow in moist habitats. They possess two morphologically distinct phases namely a diploid sporophyte which is dependent on a free-living haploid gametophyte. They are known as the amphibians of the plant kingdom since they require water to complete their life cycle. They prefer microclimatic niches and hence, about 90% of the bryophytes are forest dwellers, especially tropical rainforests, which possess a rich diversity of bryophytes owing to their diverse vegetation types and micro-habitats. The Western Ghats possess a high degree of endemism. About 60 genera, with 49 being unispecific, and 2015 species of flowering plants are endemic to Peninsular India. All the 60 genera and approximately 1600 species are endemic to the Western Ghats. About 150 species are localised endemics. Similarly, 190 species of mosses and 10 liverworts are endemic to the Western Ghats.

Palani Hills and Sirumalai Hills of the Western Ghats have been chosen for the present study. Sirumalai Hills are an eastward spur of the Palani Hills, approximately 15 km east as the crow flies. Barring the surveys by the Colonial Europeans, Palani Hills and Sirumalai Hills remain the least explored areas for bryophytes. Therefore, with a view to documenting the bryophytes of Palani Hills and Sirumalai Hills in the Western Ghats, surveys were conducted between 2023 and 2024, which resulted in the discovery of four endemic mosses, namely *Anoetangium walkeri*, *Dicranella macrospora*, *Isopterygium assamicum* and *Pinnatella limbata*. A detailed description, a distribution map and a photographic plate are provided for each species.

Keywords: Endemic, Gondwanaland, Palani hills, Sirumalai hills, Western Ghats, Tamil Nadu

INTRODUCTION

The 1,600 km long Western Ghats, running parallel to the West Coast, belong to the 250 million year-old Gondwanaland. The forests/vegetation types occurring here are relicts of those that existed millions of years ago and hence, they poses a high degree of endemism. About 60 genera, with 49 being unispecific, and 2015 species of flowering plants are endemic to Peninsular India (Gopalan & Henry, 2000). All the 60 genera and approximately 1600 species are endemic to the Western Ghats, which amounts to 75 % of the endemic species of Peninsular India. About 150 species are localised endemics (Henry *et al.*, 1984). However, studies on the mosses of the Western Ghats are far from adequate and hence, knowledge on their distribution and status remains inadequate.

Sirumalai Hills are an eastward spur of the Palani Hills, approximately 15 km east as the crow flies. Palani Hills were surveyed for mosses by Potier de la Varde (1922 - 1925), who described 40 species, followed by Foreau (1930, 1931, 1961 & 1964). Foreau, who listed 368 species from Palani Hills, included species from Sirumalai Hills as well. Barring these surveys, Palani Hills and Sirumalai Hills remain the least explored for bryophytes, and hence the present study has been taken up. While documenting the bryoflora of these two areas, four mosses, namely *Anoetangium walkeri* Broth, *Dicranella macrospora* Gangulee, *Isopterygium assamicum* (Mitt.) A. Jaeger and *Pinnatella limbata* Dixon were discovered. Incidentally, all four are endemic to India. Therefore, a detailed description, a distribution map and photographic plates are provided for each species to enlighten interested botanists.

MATERIALS AND METHODS

Study area

The study area encompasses the Palani Hills and Sirumalai Hills of the Western Ghats, Tamil Nadu.

Sample Collection

Documentation of bryophytes was made as soon as the monsoon rains ceased. Samples collected were dissected and observed under an Olympus SZ51 binocular stereomicroscope and photographs of relevant plant parts were taken using an Olympus BX43 compound research microscope. Identification was made following

monographs and recent publications and also by comparing with authentic specimens. Collected specimens are housed at the Herbarium of Scott Christian College, Nagercoil (SCCN).

Taxonomic treatment

1. *Anoetangium walkeri* Broth, Rec. Bot. Surv. India 1: 311. 1899; R.S. Chopra, Taxon. Indian Moss: 114. 1975; J. Lal, Checklist Indian Moss: 17. 2005; N. Aziz & Vohra, Pottiac. India: 19. 2008; Dandotiya & al., Arch. Bryol. 88: 26. 2011. - Type: India, Coorg (Kodagu), near Mercara (Madikeri), February, 1898, *T.L. Walker* 277 (CAL) (Fig. 1)

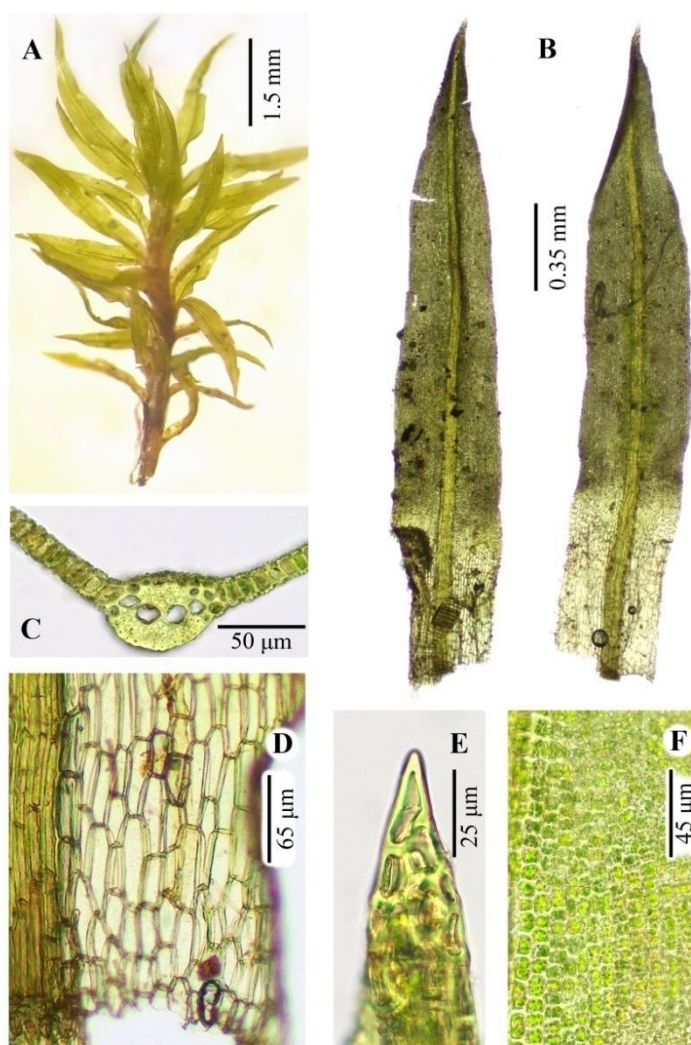


Figure 1. *Anoetangium walkeri* Broth: Plant (A), leaves (B), cross section of leaf (C), leaf basal cells (D), leaf apical cells (E) and leaf median cells (F) (D.T.T. Daniels 56)

Plants caespitose, 0.5–1.5 cm tall, brownish-green. Stems simple, brownish, 0.2–0.24 × 0.2–0.24 mm in cross section with a central strand. Leaves 1.5–2.8 × 0.3–0.4 mm, lanceolate, carinate, papillose-crenulate at margin, short-acuminate at apex; apical and median cells 4–8 × 6–8 µm, rounded-quadrate, multi-papillate, indistinct; basal ones incrassate, 16–65 × 8–16 µm, rectangular; costa ending just below apex to excurrent, brown. Sporophyte not seen.

Habitat: Terricolous, in mixed plantations, *ca* 1000 m.

Distribution: Sri Lanka and India: Western Ghats of Karnataka and Tamil Nadu (Dindigul).

Specimen examined: Western Ghats: Tamil Nadu, Dindigul District, Kodaikanal, C.S.I. Synod Guest House, *ca* 1000 m, 21.11.2024, *D.T.T. Daniels & A.E.D. Daniels 56.*

2. *Dicranella macrospora* Gangulee, Nova Hedwigia 8: 145. 1964 & Moss. E. India 1(2): 264, f. 121. 1971; J. Lal, Checklist Indian Moss: 47. 2005; Dandotiya & al., Arch. Bryol. 88: 19. 2011; A.E.D. Daniels & K.C. Kariyappa, Bryofl. Agasthyamalai BR.: 30. 2019; A.E.D. Daniels & P.M. Biju, Bryofl. S.-most E. Ghats, India: 18. 2022. - Type: India, Meghalaya, Khasia Hills, *Griffith s.n.* (BM) (Fig. 2)

Plants caespitose, pale green. Stems erect, branched or not, 0.3–1 cm tall, reddish-brown to orange-brown, 0.12–0.17 × 0.07–0.09 mm in cross section, ovate, 4–8 cells across, with a central strand. Leaves erectopatent to patent, 0.8–1.3 × 0.3–0.6 mm, lower ones shorter than the upper, falcate when dry, lanceolate, concave, sheathing at base, canaliculate, entire at margin, subulate, faintly toothed at apex; costa percurrent, brown; apical and median ones 8–26 × 4–8 µm, rhomboid; basal cells 13–24 × 3–7 µm, quadrate, rectangular; alar region indistinct. Sporophyte not seen.

Habitat: Terricolous, near roadside cuts, *ca* 1150 m.

Distribution: India: Northeast India (Meghalaya), E. Ghats and W. Ghats of Kerala and Tamil Nadu (Dindigul).

Specimen examined: Western Ghats: Tamil Nadu, Dindigul District, Sirumalai, Vellimalai, *ca* 1150 m, 31.07.2024, *Z.H. Williams 864.*

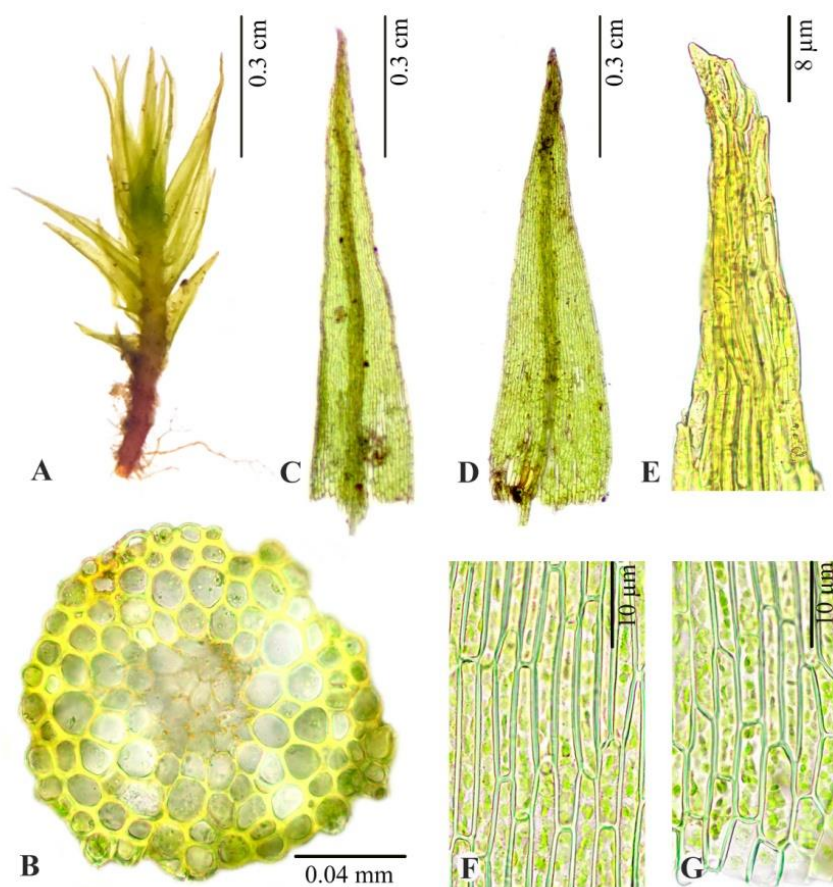


Figure 2. *Dicranella macrospora* Gangulee: Plant (A), cross section of stem (B), leaves (C & D), apical cells (E), median cells (F) and basal cells (G) (Z.H. Williams 864)

3. *Isopterygium assamicum* (Mitt.) A. Jaeger, Ber. Senckenberg. Naturf. Ges.: 432. 1878; Bruehl, Rec. Bot. Surv. India 13(1): 112. 1931; R.S. Chopra, Taxon. Indian Moss: 534. 1975; Gangulee, Moss. E. India 3(8): 1961, f. 1009. 1980; J. Lal, Checklist Indian Moss: 79. 2005; Dandotiya & al., Arch. Bryol. 88: 74. 2011; A.E.D. Daniels & al., Bryofl. Indira Gandhi Natl. Pk.: 265. 2018; A.E.D. Daniels & R.D.A Raja, Bryofl. Silent valley Natl. Pk.: 193. 2020. *Stereodon assamicus* Mitt, J. Proc. Linn. Soc., Bot. 1(Suppl.): 104. 1859. - Type: India, Assam, *Griffith s.n.* (BM) (Fig. 3)

Plants caespitose, green, glossy. Stems creeping, 0.7–3 cm long, 0.12–0.16 × 0.06–0.1 mm, ovate, without a central strand; cortical cells 2- or 3-layered, 3–10 × 2–6 μm, thick-walled; medullary ones 8–25 × 4–18 μm, thin-walled; branches irregularly pinnate, not complanate. Leaves patent, ovate-lanceolate, concave, 0.6–1.4 × 0.3–0.5 mm, narrow, almost smooth at margin, long-acuminate at apex, ecostate; cells linear-

rhomboid; apical cells $14-30 \times 4-8 \mu\text{m}$; median ones $20-45 \times 3-6 \mu\text{m}$; basal cells $18-40 \times 6-10 \mu\text{m}$; Sporophyte not seen.

Habitat: Lignicolous in degraded evergreen forests, ca 1350 m.

Distribution: India: Northeast India, E. Ghats of Tamil Nadu, and W. Ghats of Kerala and Tamil Nadu (Coimbatore and Dindigul).

Specimen examined: Western Ghats: Tamil Nadu, Dindigul District, Sirumalai, Thumbi cholai, ca 1350 m, 28.02.2023, A.E.D. Daniels & Z.H. Willaims 430.

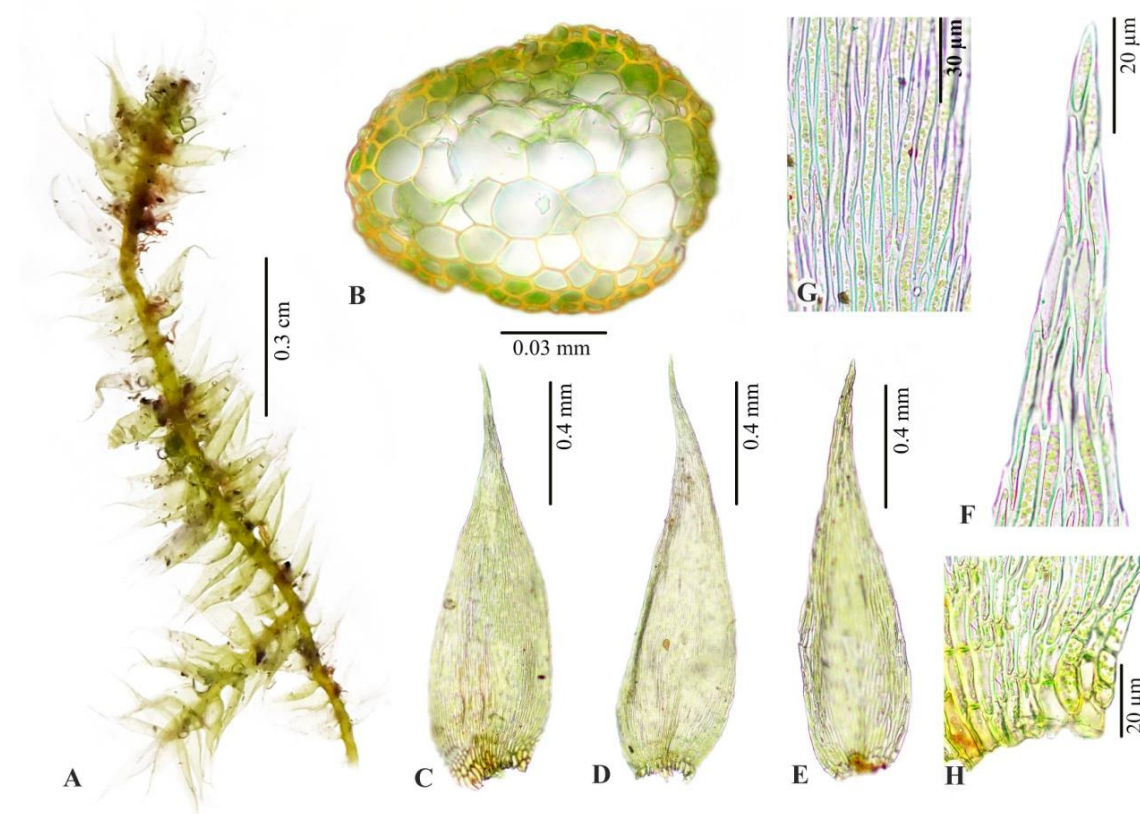


Figure 3. *Isopterigyium assamicum* (Mitt.) A. Jaeger: Plant (A), cross section of stem (B), leaves (C-E), apical cells (F), median cells (G) and basal cells (H) (A.E.D. Daniels & Z.H. Williams 430)

4. *Pinnatella limbata* Dixon, J. Indian Bot. 2: 184, f. 8. 1921; Blatt., J. Bombay Nat. Hist. Soc. 33: 875. 1929; Bruehl, Rec. Bot. Surv. India 13(1): 78. 1931; R.S. Raghavan & B.M. Wadhwa, Bull. Bot. Surv. India 10: 346. 1968; R.S. Chopra, Taxon. Indian Moss.: 375. 1975; Enroth, Acta Bot. Fennica 151: 59. 1994; J. Lal, Checklist Indian Moss.: 104. 2005; Dandotiya & al., Arch. Bryol. 88: 83. 2011; J.-P. Frahm & al., Arch. Bryol. 158: 9. 2013; U.

Schwarz, Trop. Bryol. 35: 50. 2013. - Type: India, Karnataka, N. Kanara, Sampkhand, on rocks in stream, October 1919, *Sedgwick s.n.* (BM) (Fig. 4)

Plants forming mats, robust, pale green. Primary stems creeping, 4–6 cm long, $0.19\text{--}0.48 \times 0.18\text{--}0.35$ mm in cross section, ovate, without a central strand; cortex 3- or 4-layered; cells $2\text{--}6 \times 1\text{--}3$ μm , thick-walled; medullary cells $6\text{--}8 \times 4\text{--}7$ μm , thin-walled; primary stem leaves appressed to stem, slightly decurrent, $0.8\text{--}1 \times 0.6\text{--}0.8$ mm, broadly ovate at base narrowing to a lingulate upper half, acute at apex; costa one, reaching a little below apex; secondary stems (stipe) erect, 2–3 cm tall, irregularly pinnate, $0.15\text{--}0.17 \times 0.13\text{--}0.16$ mm in cross section, more or less circular, without a central strand; cortex 3- or 4-layered; cells $3\text{--}5 \times 2\text{--}4$ μm , thick-walled; medullary ones $4\text{--}6 \times 2\text{--}5$ μm , thin-walled; leaves at the base of stipe cordate, $0.3\text{--}0.35 \times 0.23\text{--}0.45$ mm, broader than long, ecostate to faintly one-costate, faintly irregularly crenulate at margin; pseudoparaphyllia foliose, ovate-oblong, $0.13\text{--}0.22 \times 0.04\text{--}0.05$ mm, irregularly broad-toothed at margin, acuminate; leaves above the base erectopatent to patent, ovate-lanceolate, decurrent, $1.73\text{--}1.81 \times 0.6\text{--}0.67$ mm, sometimes inflexed on one side, faintly plicate, entire at base, irregularly toothed at margin above, unistratose, acute; leaf axillary hairs one or two per axil, uniseriate, $4\text{--}5\text{-celled}$, $120\text{--}150 \times 9\text{--}14$ μm ; leaf cells incrassate, ovate-quadrate to quadrate-hexagonal, faintly papillate at cell tip; apical cells $6\text{--}11 \times 4\text{--}8$ μm ; median ones $7\text{--}12 \times 5\text{--}7$ μm ; basal ones $10\text{--}48 \times 10\text{--}14$ μm , faintly porose; submarginal elongated cells $10\text{--}12 \times 6\text{--}7$ μm ; costa single, ending a little below apex, deuters and stereids well-developed, in 4 layers; branch leaves erectopatent to patent, ovate-lanceolate, decurrent, $1.5\text{--}1.72 \times 0.52\text{--}0.65$ mm, sometimes inflexed on one side, faintly plicate, entire at base, irregularly toothed at margin above, unistratose, acute; cells incrassate, ovate-quadrate to quadrate-hexagonal, faintly papillate at cell tip; apical cells $10\text{--}13 \times 5\text{--}8$ μm ; median ones $5\text{--}13 \times 4\text{--}6$ μm ; basal ones $13\text{--}22 \times 4\text{--}10$ μm , faintly porose; submarginal elongated cells $7\text{--}12 \times 5\text{--}7$ μm ; costa single, ending a little below apex, deuters and stereids well-developed, in 4 layers. Sporophyte not seen.

Habitat: Rupicolous in evergreen forests, ca 1400 m.

Distribution: Western Ghats of Karnataka, Kerala and Tamil Nadu (Dindigul).

Specimen examined: Western Ghats: Tamil Nadu, Dindigul Dist., Thumbi Cholai, ca 1400 m, 28.02.2023, A.E.D. Daniels & Z.H. Williams 497.

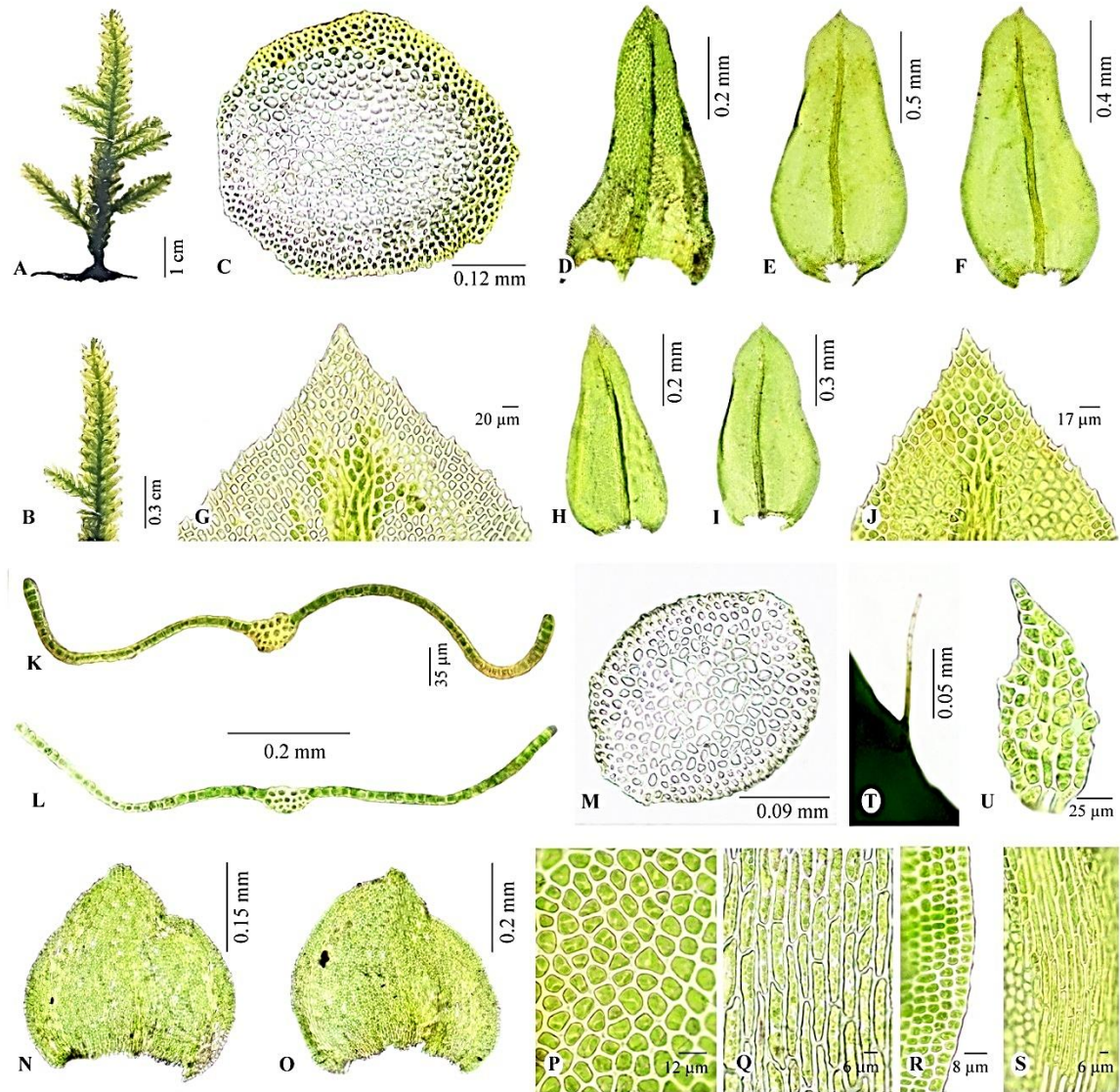


Figure 4. *Pinnatella limbata* Dixon. Plant (A), portion of plant (B), cross section of primary stem (C), primary stem leaf (D), secondary stem leaves (E & F), apical cells of secondary stem leaf (G), branch leaves (H & I), apical cells of branch leaf (J), cross section of secondary stem leaf (K), cross section of branch leaf (L), cross section of branch (M), leaves at the base of secondary stem (N & O), leaf median cells (P), leaf basal cells (Q), leaf marginal cells (R), bistratose layer in leaf (S), axillary hair (T), pseudoparaphyllium (U) (A.E.D. Daniels & Z.H. Williams 497)

The distribution map of all four endemic mosses in Tamil Nadu is given in the figure 5.

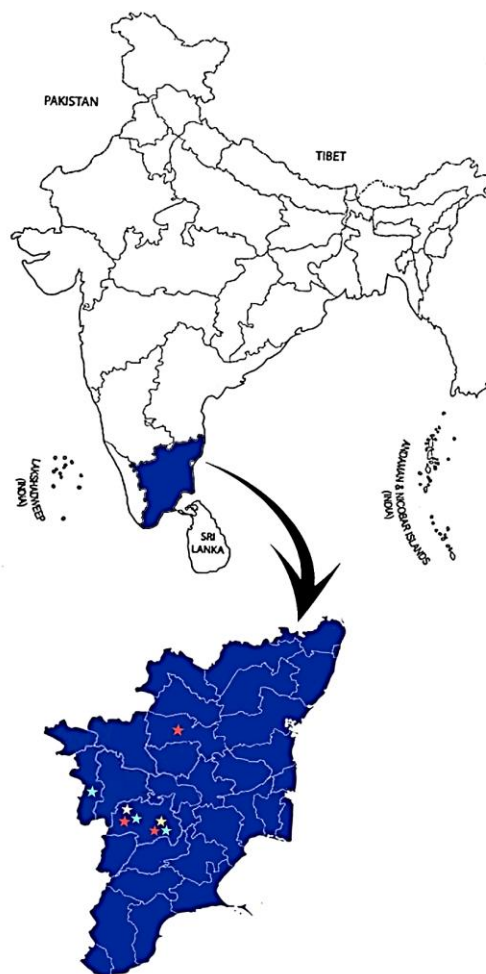


Figure 5. Distribution map of the four endemic mosses in Tamil Nadu

- ☆ *Anoectangium walkeri* Broth.
- ★ *Dicranella macrospora* Gangulee
- ★ *Isopterygium assamicum* (Mitt.) A. Jaeger
- ★ *Pinnatella limbata* Dixon

DISCUSSION

The four endemic mosses *Anoectangium walkeri* of Pottiaceae, *Dicranella macrospora* of Dicranaceae, *Isopterygium assamicum* of Hypnaceae and *Pinnatella limbata* of Neckeraceae were found to grow as terricolous forms in mixed plantations and open roadside cuts, as lignicolous forms in degraded evergreen forests and as rupicolous forms in evergreen forests, respectively. Of these, *Pinnatella limbata* is a narrow endemic restricted to the southern Western Ghats only. The *Anoectangium*

walkeri is distributed in the southern Western Ghats and Sri Lanka as well. The Southern Western Ghats and Sri Lanka are treated as one biodiversity hotspot (Gunawardene *et al.*, 2007). *Dicranella macrospora* and *Isopterygium assamicum* are distributed in both Northeast India and Peninsular India. This disjunct distribution is hard to explain. One probability is due to inadequate floristic studies. From the present observation, it may be concluded that *Dicranella macrospora* and *Isopterygium assamicum* are highly adaptable species and therefore can colonize even in open and exposed habitats. But, *Anoetangium walkeri* and *Pinnatella limbata* prefer more humid habitats such as evergreen forests. This indicates that evergreen forests need to be conserved in order to protect delicate forest-dwelling species such as these.

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18 ILLEGAL CANNABIS CULTIVATION IN TAMIL NADU: AN ANALYSIS OF PATTERNS AND SPATIAL DISTRIBUTION

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ABSTRACT

Drugs and Psychoactive substances have been deeply connected with human civilization since its evolution. Cannabis (*Cannabis sativa*) and its derivatives are widely consumed by people around the world after alcohol. A survey conducted by the Ministry of Social Justice and Empowerment, Government of India, showed that around 3.1 crore Indians (2.8% of the Indian population) are users of cannabis products. Cannabis cultivation is carried out extensively in many countries around the world. Despite its extensive cultivation, limited literature is available on its cultivation, distribution, and consumption at the global level and no sufficient studies have been carried out at the micro level on these aspects. The present study aimed to investigate the cultivation patterns of cannabis and to establish the spatial distribution of cannabis cultivation in the district of Theni, Tamil Nadu. Data were collected from 100 forest personnel (n=100) and farmers (n=56) by the interview schedule and ethnographic method from January to October 2024. Field interviews revealed that only a limited number of forest personnel actively monitor these regions, with their primary focus being on cannabis-related issues. Encroachment into forest lands, particularly during the rainy season and land preparation periods, poses a significant challenge. Cannabis cultivators employ various techniques to grow the plant, leveraging the remoteness and dense vegetation of forest areas. The findings indicate an urgent need for targeted interventions to address these challenges. It is recommended that forest personnel receive enhanced training and awareness about cannabis cultivation techniques to improve detection and prevention. Appointing special land surveyors in each district to protect forest boundaries could help curb encroachment. As historically, the communities in the study area used cannabis as a local remedy for ailments such as diarrhoea, body pain, wound pain, and infertility, creating awareness about the harmful effects of cannabis cultivation is essential to reduce its prevalence.

Keywords: Cannabis cultivation; farmers; enforcement agencies; spatial distribution

INTRODUCTION

Illegal cannabis cultivation is a global phenomenon. In many countries, cannabis has long been cultivated illegally and continues to be so. While cannabis is native to Asia, its precise origin has not yet been identified (Chouvy, 2019). Historically, its diffusion extended over a vast area, from the Caspian Sea basin to the southern Himalayas, and further into China and western Siberia, where the Altai valleys still contain wild cannabis (Crescini, 1971). Archaeological findings confirm that cannabis was first domesticated in northern China around 5000–6000 years ago. It was cultivated as early as 5000–4000 BC, presumably used for textile fibre production. Also, cannabis fibre was used in papermaking, and the world's oldest surviving example of paper, discovered in China and dating back to the first century BC, was made entirely from hemp¹ fibres (Lu & Clarke, 1995). The earliest Chinese treatise on agriculture, written during the Northern Wei dynasty (AD 386–534), also refers to hemp as one of the country's main crops (Yu, 1987).

In India, cannabis was used for ritual and medicinal purposes even before the Christian era. The term "bhang²" is mentioned in the Atharva Veda (2000–1400 BC). Sanskrit texts from the seventh or sixth century BC also refer to cannabis as a medicinal plant. Beyond Asia, caravans³ introduced cannabis to Africa, where various tribes used it in religious rituals. In some cases, the plant was considered sacred. While cannabis became dominant in the East, flax remained the major crop in Europe and North Africa. Cannabis eventually spread to Egypt, though there is no evidence that it was used in mummy wrappings. Traces of cannabis cultivation have reportedly been found along the banks of the Nile. However, its true expansion occurred around the seventh century AD, first reaching Syria and then Egypt, where it was used as a narcotic (Mignoni, 1999). As a result, Egypt played a key role in classifying cannabis as a drug during discussions at the United Nations. The Single Convention on Narcotic Drugs, 1961 formally classified cannabis alongside hard drugs.

¹ A plant in the botanical class of *Cannabis sativa* grown specifically for industrial and consumable use.

² An edible preparation made with a paste, from the leaves of the cannabis plant, mixed with water and served with milk.

³ A group of merchants, pilgrims, or travelers traveling together, often on a trade expedition to hostile regions.

Although cannabis has been considered a narcotic for centuries, its formal recognition as such in international law gained traction in the early 20th century. Several key events contributed to this classification:

1. **Early Prohibition Efforts (Early 1900s):** In the early 20th century, cannabis was widely used, but its recreational use began to be stigmatized. Harry Anslinger, the first commissioner of the Federal Bureau of Narcotics (1930–1962), played a major role in criminalizing cannabis in the U.S. He claimed that cannabis use was linked to violence, addiction, and mental illness, despite limited scientific evidence.
2. **The Marihuana Tax Act of 1937:** This U.S. law effectively made cannabis illegal by imposing heavy taxes on its production and sale. Anslinger played a significant role in the passage of this act, aligning cannabis with other narcotic drugs like opiates and cocaine.
3. **The Single Convention on Narcotic Drugs (1961):** This international treaty sought to combat drug trafficking by regulating the production and distribution of narcotics. It formally listed cannabis as a narcotic substance, imposing strict controls on its cultivation and distribution in most countries.

Harry Anslinger's campaign in the 1930s played a pivotal role in shaping the argument that cannabis should be classified as a narcotic. His efforts, along with international treaties like the 1961 Single Convention, cemented cannabis' classification as an illicit drug worldwide.

Historically, large-scale commercial cannabis production has been associated with countries such as Mexico. Other countries with long traditions of cannabis cultivation, including India, Nepal, and Jamaica, also contribute significantly to global production (Leggett, 2006). However, there is very little field-based research on illegal cannabis cultivation. Only a few geographers have studied illegal drug crops, and even fewer have focused on them over the long term. Illegal drug crop cultivation has been a geographic concern for a long time, yet field-based studies on illegal cannabis and other illicit crops remain rare in academic research.

Cannabis is the world's most widely cultivated and consumed illegal drug, but significant knowledge gaps remain in its research. Research on illegal cannabis

cultivation in the Global South⁴ is particularly scarce. Little is known about cultivation practices in major producing countries like Afghanistan, Albania, India, Lebanon, and Mexico, despite their crucial roles in supplying regional and global markets (Clarke, 1998). Moreover, the nature of illegal cannabis cultivation is changing. Since very few scholars conduct on-location research on cannabis cultivation, the researchers in the present study have adopted a field-based approach, focusing on the Theni district in Tamil Nadu, India.

MATERIALS AND METHODS

The authors of the present study wanted to understand the various factors associated with the illegal cannabis cultivation in Tamil Nadu, focusing on four districts—Dindigul, Madurai, Virudhunagar, and Theni. These districts were chosen because they were consistently referred to as prominent sites of concern by experts (law enforcement officials, social workers, and researchers) familiar with the region's agricultural and law enforcement landscapes. However, the study focused only on Theni district, because the majority of the past cases of cannabis cultivation were found in this district, making it a key area for a more in-depth analysis of the issue. The researchers sought permission from the Tamil Nadu Forest Department, which led to the mandatory presentation of the proposed study before its Research Technical Committee. After addressing the committee's suggestions, the Tamil Nadu Forest Department granted the necessary approval for the study.

The researchers employed a mixed-methods approach, combining both qualitative and quantitative techniques. Additionally, ethnographic methods⁵ were used to understand the ground realities, while GPS technology enabled the precise recording of cultivation sites. Secondary data were sourced from case files in the forest department. Four research instruments were developed for data collection: (1) gathering cannabis cultivation details from forest personnel, (2) existing case file data, (3) mapping latitude and longitude coordinates of cultivation sites from forest personnel, and (4) interviewing farmers involved in cannabis cultivation. Key variables examined in the study included demographic details, cultivation methods, soil types,

⁴ A term used to describe countries in Africa, Asia, Latin America, and Oceania that are less developed economically and socially.

⁵ A qualitative research method that involves collecting data about a group or culture through observation and interviews.

irrigation practices, harvesting techniques, distance from human settlements, and perspectives on legalisation. The researchers also reviewed legal provisions, enforcement actions, and outcomes.

During the pilot study, meetings with forest officials indicated that the number of current cannabis cultivation cases across the four districts was minimal, with most cases being registered several years ago. However, the researchers identified Theni district as historically significant for cannabis cultivation, which led to its selection for in-depth study. Theni consists of two zones: forest⁶ and wildlife⁷. Specific ranges—Bodinayakanur, Cumbum West, Uthamapalayam (forest zone), and Gudalur, Cumbum East, Varusanadu, and Megamalai (wildlife zone)—were chosen based on past case records and the inputs of forest officials. The researchers also engaged with local officers and conducted range-level meetings to refine the research methodology.

The finalized research methodology contained both structured and narrative-style questions⁸. Methodology-1 included 50 items, methodology-2 had 27 items, methodology-3 contained one item, and methodology-4 featured 101 items. Data collection involved visits to the selected ranges, interviews with forest personnel, and a thorough review of case files, with each case review taking 30 to 45 minutes. For the present research, the authors interviewed 100 forest personnel in the Theni District, of which only 37 forest personnel were familiar with the cannabis plant, while 63 had never encountered it during their service. Site visits to previous cannabis cultivation areas required extensive travel, sometimes involving overnight stays in the forest. Data gathering was intensive, lasting all day along, with some areas requiring multiple-day explorations due to rugged terrain and dense vegetation.

For identifying the farmers, the researchers adopted the snowball sampling method⁹ to identify the sample and the ethnographic method for collecting information on illegal cannabis cultivation. Several days of visits to the village involved general conversations in tea shops, areas where people gathered, and individuals at the village

⁶ Forest zone has six ranges namely, Andippatti, Periyakulam, Bodinayakkanur, Theni, Cumbum West, and Uthamapalayam.

⁷ Wildlife zone has six ranges namely, Kandamanur, Chinnamanur, Gudalur, Cumbum East, Varusanadu, and Megamalai.

⁸ Narrative style questions are open-ended and focus on exploring the experiences of participants. They are designed to uncover the “why” and “how” behind a particular phenomenon.

⁹ Snowball sampling is a non-probability sampling technique in which the samples have traits that are rare to find and the research participants are asked to assist researchers in identifying other potential subjects.

level. Once trust was established, the researchers gradually introduced the study's aspects. After that, the villagers provided details about farmers who had cultivated cannabis in the previous years. Based on this information, the researchers visited the villages, introduced themselves, and explained the study's objective. Some participants immediately agreed and participated in the survey, while others suggested specific locations for the researchers to visit, where information could be obtained from the participants. Each interview lasted at least one hour and fifteen minutes. At the beginning of the study, several participants were reluctant to participate. The researcher had to make frequent requests before the participants agreed to join the study.

The present study collected both qualitative and quantitative data from forest personnel, farmers, and case files. The collected data was analysed using the Statistical Package for Social Sciences (SPSS) version 29.0¹⁰, for both qualitative and quantitative data through descriptive statistics to determine the frequency and percentage. For qualitative data, the researcher developed keywords for thematic analysis¹¹, which was also further analysed using descriptive statistics to calculate the frequency and percentage.

RESULTS

The forest personnel reported having frequently observed mono-cropping¹² practices among farmers, while a small percentage reported seeing mixed-cropping¹³ methods. Farmers, on the other hand, practiced both mono-cropping and mixed-cropping, particularly with crops such as sugarcane, cotton, banana, corn, pigeon pea (thuvurai), beans, avarai, chickpea, and flowers (saamanthi). Interestingly, while farmers only mentioned a limited number of mixed crops, forest personnel were familiar with several mixed-crop varieties. Due to this reality on the ground, the researchers found that forest personnel gathered information at the field level. However, this knowledge was mostly held by a few personnel nearing retirement, while several others lacked awareness of mixed crops and cropping patterns at the field level.

¹⁰ Statistical Package for Social Sciences is a statistical software package used for data analysis, with version 29.0 being a recent release, offering features like improved messaging and usability of Workbooks

¹¹ A research method that helps identify and interpret patterns in qualitative data.

¹² A farming method where the same crop is grown repeatedly in the same field over many years.

¹³ A farming technique where multiple crops are grown on the same land at the same time.

Table 1. Type of soil used for cannabis cultivation (Values in parentheses are percentage values)

Type of Soil	Forest Personnel (n=37)	Farmer (n=56)
Black Soil	5 (13.5)	0
Forest Soil/Mountain Soil	26 (70.3)	56 (100)
Laterite Soil	1 (2.7)	0
Red Soil	5 (13.5)	0

From Table 1 it can be found that both forest personnel and farmers agreed that cannabis cultivation yields high in certain soils. Several respondents (farmers – 100%; forest personnel – 70.3%) identified forest and mountain-based soils as ideal, while a limited number mentioned black soil.

This finding suggested that, in previous years, many illegal cultivators had chosen forest areas for cannabis cultivation. Field visits to previously destroyed illegal cannabis cultivation sites, along with interviews with respondents, revealed that past cultivators had carefully selected their locations. These cultivators typically chose areas deep inside forests, particularly in hilly regions. Often, the cultivation sites were located in valleys at high altitudes, requiring cultivators to cross one or two mountains, ensuring that the location remained hidden from view. The researchers also found that cultivators selected sites with frequent water sources, large rocks or caves nearby, and areas where animals were unlikely to cross. Additionally, the soil in these locations appeared distinct, being highly coloured and rich in nutrients.

The respondents (farmers and forest personnel) noted that the cannabis plant requires ample sunlight for high yield and pest prevention. Once the cultivators finalised a location, they cleared the forest land by removing various plants and trees and cutting tree branches to allow sunlight to penetrate. This method made it difficult for forest personnel to locate cultivation sites unless they received specific leads. Even with leads, identifying the exact location remained challenging. To overcome this, the authors of the present research observed that personnel would climb the tallest trees or reach the top of mountains using binoculars for surveillance, making detection easier. Otherwise, identifying illegal cannabis cultivation was highly complicated.

Table 2. Type of irrigation used for cannabis cultivation (Values in parentheses are percentage values)

Type of irrigation	Forest personnel (n=37)	Farmer (n=56)
Field Sprinkler	2 (5.4)	30 (53.6)
Used Pipelines (Falls or Upper Area water)	33 (89.2)	0
Drip	1 (2.7)	0
Never Noticed	1 (2.7)	0

Several farmers employed irrigation methods to distribute water to cannabis plantations. They used small black pipelines similar to drip irrigation systems, fixing them to waterfalls or upper water sources. These pipelines were often concealed with forest debris, buried in small pits, or covered with soil, making them difficult to detect. In some cases, farmers constructed small irrigation canals to direct water to the cultivation area, these results are represented in Table 2. The researchers found that illegal cultivators also used man-made water storage solutions, such as underground plastic-covered tanks or plastic barrels, to secure water for irrigation.

During discussions, all respondents indicated that they used the pit method¹⁴ for cultivation. The cleaned area was highly organized, with pits spaced every 2, 3, 4, 5, or 6 feet. This method allowed the plants to grow tall and yield a high quantity during the harvesting period. Cannabis plants were propagated from seeds, and some cultivators used an interesting technique to test seed viability. They placed seeds in water, discarding any that floated, as these were considered damaged. The researchers found that seeds were often purchased from individuals who had previously cultivated cannabis. In some cases, buyers and sellers operated within the region.

Cultivators distributed seeds in each pit, with some opting for a small-area mother bed concept. After growing for 10 to 20 days, seedlings were transplanted, with each pit containing a minimum of 3 to 6 saplings. Alternatively, cultivators directly sowed 5 to 10 seeds per pit. The plants were spaced at least 4 to 10 cm apart. Farmers used compost such as bone powder, chicken, cow, goat, and bat manure during cultivation. Additionally, they applied chemical pesticides and fertilizers like urea, potassium, DAP, ROGU, and FACTAMFOS. Growth promoters, such as peanut/groundnut

¹⁴ A method of planting crops in pits, which can be used for a variety of crops.

cake and neem cake, were used in specific seasons to enhance yield. The researchers found that seasonal growth promoters altered the plant's colour and contributed to higher production during harvest.

Table 3. Number of times, the cannabis plants have to be watered (Values in parentheses are percentage values)

Times to be watered	Forest personnel (n=37)	Farmer (n=56)
Daily once	9 (24.3)	14 (25)
Daily twice	19 (51.4)	36 (64.3)
Weekly thrice	4 (10.8)	6 (10.7)
Never Noticed	5 (13.5)	0

From the Table 3 it can be found that, the respondents mentioned cannabis plants were watered once or twice during the cloudy season, while in other climate conditions, they were watered up to three times a week. Most farmers cultivated cannabis on plots smaller than one acre, with only a few cultivating on 2 to 5-acre plots. The researchers noted that clearing large portions of forest land took several days, increasing the risk of detection. Frequent movements in and out of the village made it easier for locals to notice large-scale cultivation. As a result, cultivators preferred keeping their operations small, often restricting their plots to less than one acre.

From Table 4, it can be found that all respondents, including farmers and a few forest personnel, stated that cannabis plants emit a distinct smell. Interestingly, this smell becomes noticeable only after 4 to 6 months. Cultivators identified male, female, and "transgender" plants. Male plants produced flowers, and once flowering began, these plants were removed from the cultivation area. Female plants did not flower, allowing cultivators to distinguish them within three months. Occasionally, some plants would flower later in the cycle—these were referred to as transgender plants. The researchers learned that some cultivators removed these plants entirely, while others only removed the flowering parts. This technique was used to produce high-quality, seedless cannabis.

Table 4. Crop Period between Germination and Harvest (Values in parentheses are percentage values)

Crop Period	Forest personnel (n=37)	Farmer (n=56)
11 to 12 months	2 (5.4)	3 (5.4)
9 to 10 months	0	4 (7.1)
7 to 8 months	4 (10.8)	11 (19.6)
4 to 6 months	30 (81)	38 (67.9)
3 months	1 (2.7)	0

After six months, the cannabis plants were harvested. The authors of the present research also found that farmers determine the right time for harvesting by observing several indicators, including leaf shedding, colour changes, cola growth, and the presence of gel-like substances on the plant. These observations guided farmers in choosing the optimal harvest time.

Suggestions from the research

The researchers have observed that several forest personnel were unaware of the illegal cultivation of cannabis. Due to lack of knowledge, many of the personnel could not identify the cannabis plant in the field. On several occasions, during routine visits to the forest, the personnel were uncertain whether they had encountered the cannabis plant or not. Due to network issues, the forest personnel could not utilize technologies like Google Lens¹⁵ in the field. An annual practical-based training at the district level would help personnel identify the plant within their jurisdiction. Most importantly, the older and more experienced Anti-Poaching Watchers (APWs) are familiar with the illegal cannabis cultivation methods and related mechanisms at the village level. Given the situation on the ground, the forest personnel could significantly benefit from understanding the realities of the situation.

Based on field visit observations, the researchers have found that the forest department strictly adheres to procedures and implements them at the ground level. Several previously destroyed areas are now being rehabilitated into the Shola Forest¹⁶. However, many younger forest personnel show little interest in learning about the history of illegal activities, building relationships with informers, or cooperating with stakeholders and senior officers in their work areas. Due to a lack of interest, the

¹⁵ To identify leaves by taking a picture of the leaf and using the app to search for matches.

¹⁶ A patch of stunted tropical montane forest found in valleys amid rolling grassland in South India

personnel are not aware of key information at the field level and, as a result, are less equipped to prevent crimes and illegal activities in their jurisdictions.

The forest personnel cover vast areas, but due to a manpower shortage, many fear entering the deeper sections of the forest. Additionally, many of the illegal operators are armed. This situation makes it rare for personnel to conduct raids in the designated areas. Furthermore, in wildlife ranges, the movement of animals in these areas complicates the tasks of the personnel. Apart from these, the forest personnel also face numerous challenges, such as a lack of inter-departmental cooperation, technical issues, and delays in approvals from stakeholder departments. Despite these challenges, joint patrols are occasionally conducted.

The crime/illegal activities occurring within the forest area are often considered a form of transnational organized crime. Establishing a special unit with well-equipped personnel in sensitive areas could improve prevention mechanisms at the field level. Encroachment is another significant issue that was observed during the present study. Forest personnel have taken various preventive measures, but due to a lack of manpower and the remote locations of certain areas, encroachment on forest land continues. Especially during the rainy season, many people encroach on the forest and set up temporary shelters. Personnel often struggle to track these movements, and when they do take action, encroachers often claim ownership of the land. To address this, a special revenue officer should be appointed in each district or sensitive area for land surveys. In case of issues, a swift land survey should be conducted to enforce regulations. This would significantly help preserve forests across regions.

According to several forest personnel, if illegal cultivation is detected within forest limits, the department issues memos to the concerned personnel, which creates a negative response. As a result, the personnel often hesitate to report illegal activities up the chain of command. In contrast, when police personnel identify illegal cannabis cultivation, they are recognized for their service and receive medals. To motivate forest personnel, a similar recognition system could be implemented, where personnel receive medals for identifying and reporting illegal activities. This would not only encourage personnel but also enhance their professional standing.

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19 IDENTIFICATION AND CHARACTERIZATION OF SOUTH INDIAN MAMMAL HAIR USING TRICHO-TAXONOMIC ANALYSIS

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ABSTRACT

The identification and characterization of mammalian hair using trichotaxonomic analysis are crucial for advancing wildlife conservation and forensic science. In this study, hair samples from eight mammalian species housed at Arignar Anna Zoological Park, Chennai, Tamil Nadu, were analyzed to establish species-specific characteristics from March, 2024 to August, 2024. Using well-established methodologies such as gelatin smear preparation, DPX mounting and stereomicroscopy, the study examined medullary and cuticular characteristics under 10x and 100x magnifications. The analysis revealed distinct morphological features, including medulla patterns, cuticle scale variations, and structural differences, enabling species differentiation. Additionally, the study emphasized the importance of developing a comprehensive identification key for mammalian hair, contributing to a reference database for South Indian mammals. This research provides significant insights into biodiversity studies and forensic science, enabling species identification from hair samples through non-invasive methods. The findings contribute to a foundational understanding that can be utilized in future biodiversity monitoring and wildlife conservation efforts. Results underscore the utility of trichotaxonomy in understanding biodiversity, predator-prey relationships by scat analysis, and aiding in wildlife crime investigations. To experiment with portable solutions, hair samples from the deer family were also observed using a foldscope (paper microscope), showcasing its potential as a field-friendly tool for on-site analyses. However, this was done on an experimental basis. Integrating traditional taxonomic methods with innovative technologies paves the way for enhanced species management and conservation strategies.

Keywords: Trichotaxonomy, mammalian hair, species identification, biodiversity conservation, forensic science, south Indian mammals.

INTRODUCTION

Tricho-taxonomy, the microscopic analysis of hair structure, serves as a critical tool in wildlife conservation and forensic investigations (Debeljak *et al.*, 2016; Bahuguna, 2010). Unlike DNA analysis, tricho-taxonomy offers a non-destructive, cost-effective approach that can be utilized even with limited or precious samples, making it particularly valuable in the context of wildlife crime where identifying species and individuals is paramount (Miller *et al.*, 2019). This study focused on the tricho-taxonomic analysis of mammals at Arignar Anna Zoological Park, Chennai, Tamil Nadu, contributing to the broader efforts of conserving India's diverse and endangered mammalian species.

India, as a biodiversity hotspot, is home to over 400 mammal species, with many facing threats from habitat loss, poaching, and human-wildlife conflict (Hedge *et al.*, 2017; Karanth *et al.*, 2017). Tricho-taxonomy plays a crucial role in wildlife crime investigations by enabling rapid and accurate species identification through hair analysis (Teerink, 1991; Kaur *et al.*, 2021). The unique characteristics of hair, particularly the cuticle and medulla, are employed for species identification, individual differentiation, and understanding ecological interactions (Kaur *et al.*, 2021; Teerink, 1991).

The findings will have significant implications for combating wildlife crime, where such forensic methods can aid in tracing and preventing illegal activities. By integrating traditional taxonomic methods with modern forensic science, this study underscores the importance of a multidisciplinary approach to wildlife conservation. The integration of tricho-taxonomy with Foldscope technology offers a non-invasive and cost-effective approach for field analysis (Patel *et al.*, 2015). The results are expected to inform future conservation strategies, improve management practices within zoological parks, and contribute to global efforts in safeguarding endangered species. Ultimately, this tricho-taxonomic exploration hopes to inspire a deeper appreciation for the intricate biological details that play a critical role in the survival and conservation of mammalian species.

MATERIALS AND METHODS

Study Area

Arignar Anna Zoological Park, Vandalur, Chennai, Tamil Nadu, India, is a large ex-situ conservation centre for wild animals, particularly threatened and endangered species of the Western and Eastern Ghats. The Zoo has a research plan, with prioritized species and specific areas of concern for research, and has implemented a Zoo Information Management System for efficient management of animal records and conservation efforts. The Zoo has been successful in promoting conservation education and has received recognition for its educational programs.

Hair sample collection

"Hair samples of various mammalian species were collected at Arignar Anna Zoological Park, Chennai, Tamil Nadu, by zookeepers under the supervision of the Zoo veterinarian and biologist, ensuring minimal disturbance to the animals. The samples were then analyzed for cuticle and medullary characteristics. Proper permission for hair sample collection was obtained from the Principal Chief Conservator of Forests & Chief Wildlife Warden, Chennai (WL5(A)/34438/2023 03/2024). The sample collection was conducted over one week in March 2024. Animals' enclosures were observed and areas in which shed hairs are frequently found were identified. These could be locations where they rest, groom, or scratch against objects (Miller *et al.*, 2019). Using a brush, the hair samples were separated from the soil and dirt.

Microscopic observations

Cuticle observation: Samples were treated with 70% ethanol for 5 minutes to remove dirt and stickiness. About 0.2 gm of gelatin was mixed with 10 ml hot distilled water until dissolved for preparing the gelatin solution. The gelatin solution was smeared onto a glass slide and the hair samples of all the mammalian species were carefully placed on the smear without disturbing the gelatin. Then this was allowed to sit overnight to dry. The hair was picked from the dried gelatin using a forceps carefully and observed under the microscope (Bahuguna, 2010). The 10x and 100x lenses were used to observe the

distinctive features of cuticle patterns of the hair samples and photographs were taken for each prepared slide.

Medullary observation: Samples were treated with 70% ethanol for 5 minutes to remove dirt and stickiness. The hair samples were then air dried and cut into small pieces to immerse in Xylene solution for 24-48 hours depend on the thickness of the hair sample. Then the hair sample was air dried and mounted on the glass slides with DPX and covered with coverslip. This was let dry for another 28 hours (Bahuguna, 2010).

A Stereo Microscope (Magnus CH-20i TR. LED Magcam Trinocular Microscope) used to visualize the features of hair samples at 10x and 100x magnification for viewing medulla of the hair. Structure and visible features like vacuoles were examined.

Foldscope observation: The Foldscope, a portable paper microscope, was tested in a laboratory setting to evaluate its potential field applications for rapid microscopic analysis of hair samples. Hair samples were placed on prepared slides, and observations were made directly using the Foldscope. Images of medulla, root, and cuticle regions were captured using a mobile phone camera. The Foldscope provided an accessible and cost-effective alternative for field-based hair identification, particularly in remote locations where traditional microscopy is not feasible. It proved useful for preliminary assessments, allowing researchers to make on-the-spot observations before conducting further laboratory analysis.

RESULTS

Tables 1 and 2 and Figures 1 to 10 present the tricho-taxonomic characteristics of the eight selected mammalian species.

Table 1 Cuticular and medulla characteristics of Golden jackal, Indian wolf, Dhole, Asiatic lion, Indian leopard and striped hyena

a) Golden Jackal, <i>Canis aureus</i>			
<u>Cuticular characteristics</u>			
Region	Scale margin	Scale Distance	Scale pattern
Proximal	Smooth	Distant	Broad petal
Medial	Crenate	Near	Irregular wave
Distal	Crenate	Near	Irregular wave
<u>Medulla characteristics</u>			
Composition	Structure	Pattern	Margins
Multicellular	Wide medulla with vacuoles	Continuous	Irregular
b) Indian wolf, <i>Canis lupus indica</i>			
<u>Cuticular characteristics</u>			
Region	Scale margin	Scale Distance	Scale pattern
Proximal	Rippled	Near	Irregular wave
Medial	Crenate	Near	Irregular wave
Distal	Crenate	Near	Irregular wave
<u>Medulla characteristics</u>			
Composition	Structure	Pattern	Margins
No cell visible	Simple and Wide medulla	Continuous	Straight
c) Dhole, <i>Cuon alpinus</i>			
<u>Cuticular characteristics</u>			
Region	Scale margin	Scale Distance	Scale pattern
Proximal	Smooth	Distant	Regular wave
Medial	Crenate	Near	Irregular wave
Distal	Crenate	Near	Irregular wave
<u>Medulla characteristics</u>			
Composition	Structure	Pattern	Margins
Multicellular	Wide medulla with vacuoles	Continuous	Irregular
d) Asiatic Lion, <i>Panthera leo</i>			
<u>Cuticular characteristics</u>			
Region	Scale margin	Scale Distance	Scale pattern
Proximal	Smooth	Near	Regular wave
Medial	Crenate	Near	Irregular wave
Distal	Rippled	Close	Irregular wave
<u>Medulla characteristics</u>			
Composition	Structure	Pattern	Margins
No cell visible	Simple and narrow medulla	Continuous	Irregular
e) Indian leopard, <i>Panthera pardus fusca</i>			
<u>Cuticular characteristics</u>			
Region	Scale margin	Scale Distance	Scale pattern
Proximal	Smooth	Distant	Regular mosaic
Medial	Smooth	Near	Regular wave
Distal	Crenate	Close	Irregular wave
<u>Medulla characteristics</u>			
Composition	Structure	Pattern	Margins
No cell visible	Wide medulla with vacuoles	Continuous	Irregular
f) Striped hyena, <i>Hyaena hyaena</i>			
<u>Cuticular characteristics</u>			
Region	Scale margin	Scale Distance	Scale pattern
Proximal	Smooth	Near	Regular wave
Medial	Crenate	Near	Irregular wave
Distal	Crenate	Close	Irregular wave
<u>Medulla characteristics</u>			
Composition	Structure	Pattern	Margins
Multicellular	Wide and simple medulla	Continuous	Irregular

Table 2. Cuticular and medulla characteristics of hairs of Royal Bengal tiger, white tiger and melanistic tiger (*Panthera tigris*)

a) Royal Bengal Tiger, <i>Panthera tigris</i>			
<u>Cuticular characteristics</u>			
Region	Scale margin	Scale Distance	Scale pattern
Proximal	Smooth	Near	Regular wave
Medial	Rippled	Near	Irregular wave
Distal	Crenate	Close	Irregular wave
<u>Medulla characteristics</u>			
Composition	Structure	Pattern	Margins
No cell visible	Simple and narrow medulla	Continuous	Irregular
a) White Tiger, <i>Panthera tigris</i>			
<u>Cuticular characteristics</u>			
Region	Scale margin	Scale Distance	Scale pattern
Proximal	Smooth	Near	Regular wave
Medial	Rippled	Near	Irregular wave
Distal	Crenate	Close	Irregular wave
<u>Medulla characteristics</u>			
Composition	Structure	Pattern	Margins
No cell visible	Simple and narrow medulla with vacuoles	Continuous	Irregular
a) Melanistic tiger, <i>Panthera tigris</i>			
<u>Cuticular characteristics</u>			
Region	Scale margin	Scale Distance	Scale pattern
Proximal	Smooth	Near	Regular wave
Medial	Crenate	Near	Irregular wave
Distal	Rippled	Close	Irregular wave
<u>Medulla characteristics</u>			
Composition	Structure	Pattern	Margins
No cell visible	Simple and narrow medulla	Continuous	Irregular

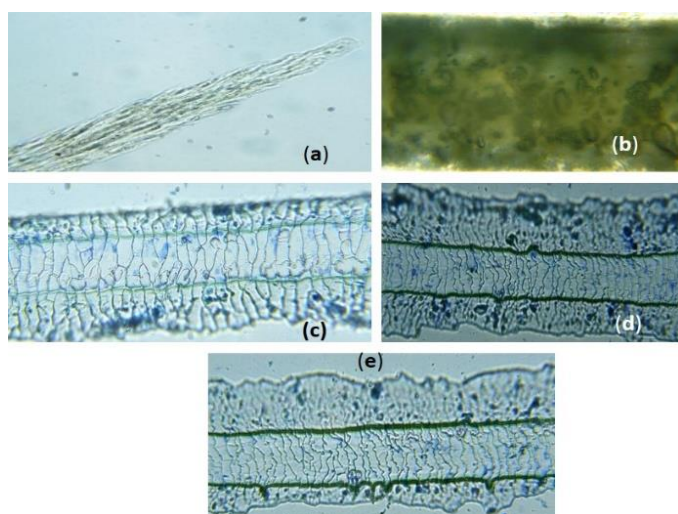


Figure 1. Cuticular and medulla characteristics of Golden jackal, *Canis aureus*: (a) root structure, (b) medulla structure, (c) cuticle structure (proximal region), (d) cuticle structure (medial region) and (e) cuticle structure (distal region)

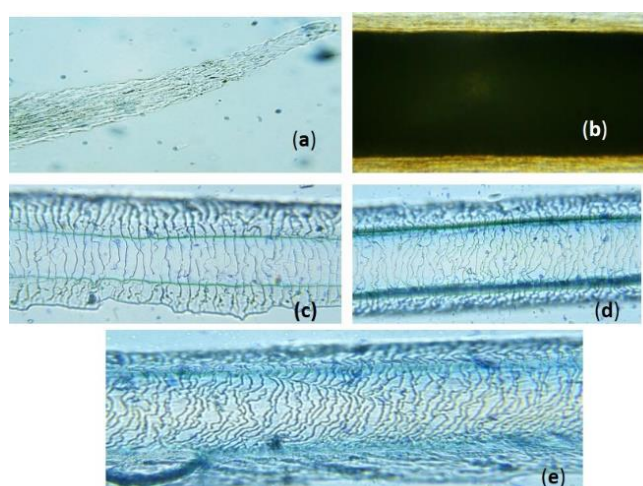


Figure 2. Cuticular and medulla characteristics of Indian wolf, *Canis lupus indica*: (a) root structure, (b) medulla structure, (c) cuticle structure (proximal region), (d) cuticle structure (medial region) and (e) cuticle structure (distal region)

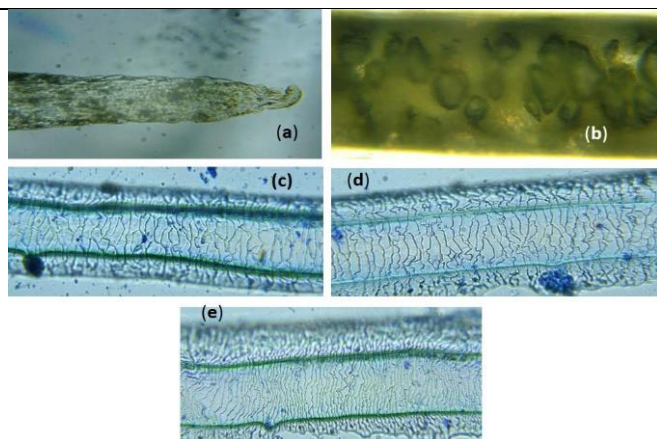


Figure 3. Cuticular and medulla characteristics of Dhole, *Cuon alpinus*: (a) root structure, (b) medulla structure, (c) cuticle structure (proximal region), (d) cuticle structure (medial region) and (e) cuticle structure (distal region)

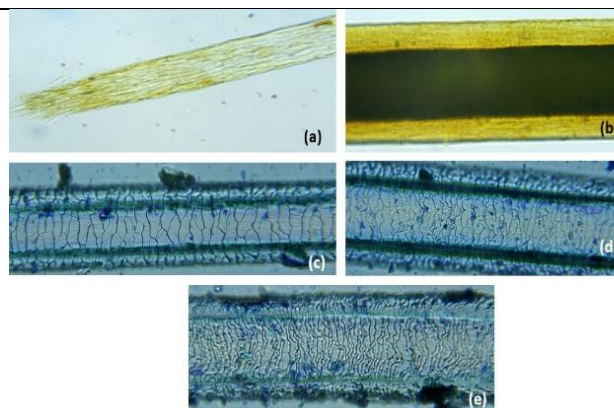


Figure 4. Cuticular and medulla characteristics of Asiatic lion (*Panthera leo*): (a) root structure, (b) medulla structure, (c) cuticle structure (proximal region), (d) cuticle structure (medial region) and (e) cuticle structure (distal region)

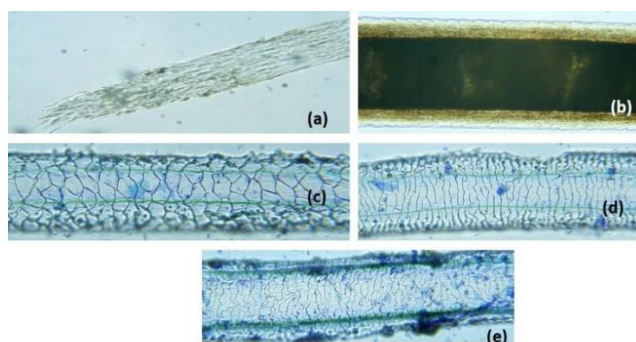


Figure 5. Cuticular and medulla characteristics of Indian leopard, *Panthera pardus fusca*: (a) root structure, (b) medulla structure, (c) cuticle structure (proximal region), (d) cuticle structure (medial region) and (e) cuticle structure (distal region)

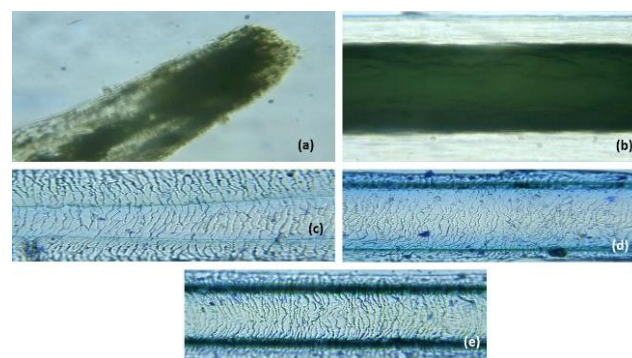


Figure 6. Cuticular and medulla characteristics of striped hyena (*Hyaena hyaena*): (a) root structure, (b) medulla structure, (c) cuticle structure (proximal region), (d) medulla structure and (e) cuticle structure (distal region)

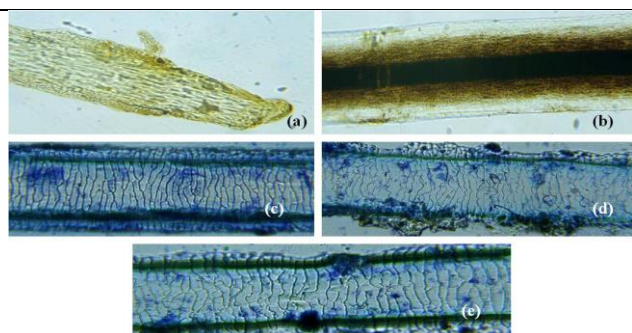


Figure 7. Cuticular and medulla characteristics of hairs of Royal Bengal tiger: (a) root structure, (b) medulla structure, (c) cuticle structure (proximal region), (d) cuticle structure (medial region) and (e) cuticle structure (distal region)

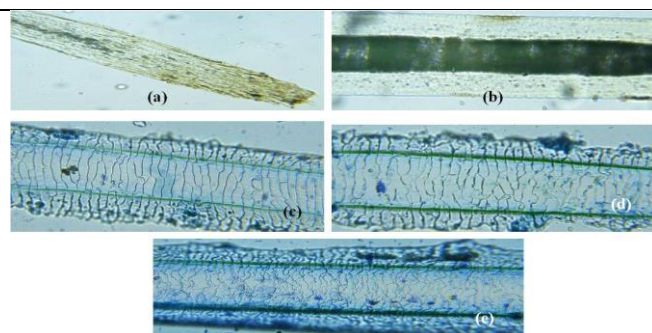


Figure 8. Cuticular and medulla characteristics of hairs of Royal Bengal tiger: (a) root structure, (b) medulla structure, (c) cuticle structure (proximal region), (d) cuticle structure (medial region) and (e) cuticle structure (distal region)

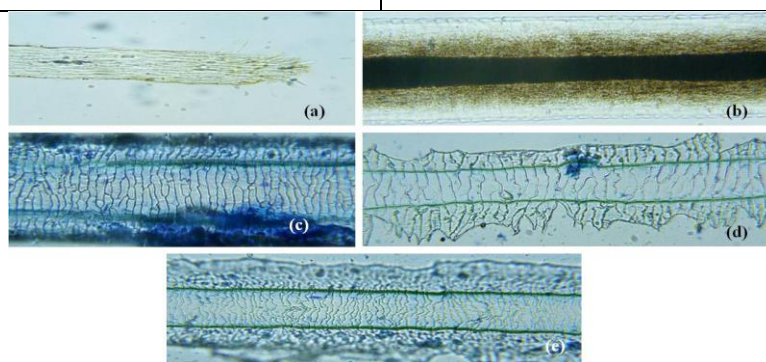


Figure 9. Cuticular and medulla characteristics of hairs of Royal Bengal tiger: (a) root structure, (b) medulla structure, (c) cuticle structure (proximal region), (d) cuticle structure (medial region) and (e) cuticle structure (distal region)

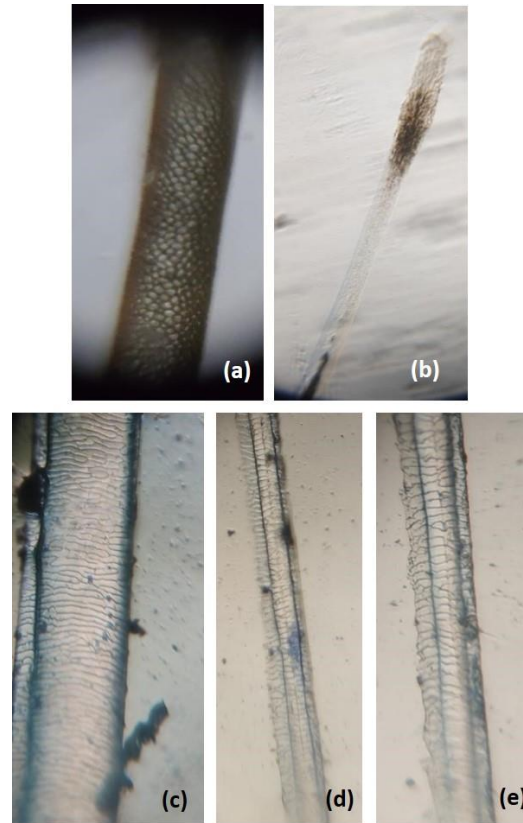


Figure 10. Foldscope images of medulla (a), root (b), cuticle proximal region (c), cuticle medial (d), and cuticle distal region (e) of the hair of barking deer (*Muntiacus muntjak*), captured using a mobile phone in a laboratory setting.

DISCUSSION

The examination of hair morphology across mammalian species provides valuable insights into evolutionary adaptations, ecological niches, and conservation needs. The Golden Jackal, Indian Wolf, and Dhole exhibited distinct medulla and cuticular patterns, facilitating species identification and forensic applications (Nigam *et al.*, 2019). Similarly, variations in Royal Bengal tiger, White tiger, and Melanistic tiger suggested that the coat color differences do not significantly alter hair morphology, reinforcing the role of trichotaxonomy in wildlife crime investigations (Kshirsagar *et al.*, 2021). Species such as the Asiatic lion, Indian leopard, and striped hyena displayed species-specific hair characteristics, reflecting their ecological adaptations and evolutionary history (Sharma *et al.*, 2016; Kale & Vats, 2019). These findings emphasized the importance of tricho-taxonomic keys for species classification and conservation.

Tricho-taxonomic keys provide a systematic approach for non-invasive species identification, crucial in ecology, conservation biology, forensic science, and wildlife management. Advances in microscopy and imaging technologies have further enhanced the accuracy and efficiency of this method, enabling finer-scale species differentiation. This study contributed to the development of a comprehensive reference key for South Indian mammals, supporting wildlife conservation and forensic investigations. The integration of tricho-taxonomy with emerging technologies strengthens efforts in species monitoring and biodiversity preservation.

The Foldscope, a portable paper microscope, played a key role in the present study, showcasing its potential for on-site hair analysis in the field. Its use was explored as a practical solution for field-based species identification, particularly in remote areas where traditional microscopy is not feasible. The Foldscope enabled the observation of medulla, root, and cuticle regions of hair samples, providing a cost-effective and accessible alternative for preliminary assessments. Its portability makes it a valuable tool for researchers and conservationists working in the field, allowing for rapid species identification and enabling timely interventions. As demonstrated by previous studies (Kumar & Soni, 2019; Patel & Singhal, 2020), the Foldscope has been successfully employed in various ecological and biodiversity research applications, making it an excellent complement to traditional taxonomic methods. This technology is particularly valuable in remote locations where traditional lab-based methods may not be feasible (Wehling *et al.*, 2019). While DNA-based methods offer high accuracy in species identification, tricho-taxonomy serves as an efficient and practical preliminary screening tool (Bahuguna, 2010), allowing for rapid species identification and supporting conservation efforts by enabling quicker responses to wildlife crime and human-wildlife conflict situations. This integration of Foldscope microscopy with trichotaxonomy has the potential to enhance species management and conservation strategies, providing researchers with a versatile tool for wildlife monitoring and forensic investigations in the field (Singh & Thomas, 2018; Wong & Nair, 2017).

CONCLUSION

Tricho-taxonomy technique enables researchers in rapid and accurate identification of mammalian species and is utilized in wildlife crime investigations. The

present study provides valuable reference for species identification of eight mammalian species, which is vital for forensic and conservation purposes. Integration of tricho-taxonomy with Foldscope technology offers a non-invasive and cost-effective approach for field analysis of hairs. The Foldscope, a portable and affordable microscope, enables field biologists and conservationists to conduct on-site hair analysis, bridging the gap between laboratory research and on-ground wildlife monitoring. Thus, the combination of tricho-taxonomy and Foldscope technology holds promise as an invaluable resource for wildlife conservation, monitoring biodiversity, and assisting in forensic investigations. Further research and widespread adoption of this method can contribute significantly to the protection and conservation of mammal species in India and beyond.

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AUTHOR INDEX

- Abinaya, R. **78, 99**
Anagha Biju **58**
Anand, M. **7**
Anita Varghese **133**
Anugrah Jayesh **58**
Anupama, K. **221**
Arulraj Rajappa **257**
Aruna, S. **78**
Ashokkumar, M. **119**
Ashwin Vishwanathan **66**
Ben, C.P. **246**
Bindu, K. **177**
Daniels, A.E.D. **246**
Daniels, D.T.T. **246**
Divya, D. **214**
Eswaran, D. **197**
Ganesan, M.G. **38, 119, 237**
Ganesh Ram, K. **119, 237**
Glenn Baldwin, **21**
Gopi, G.V. **165**
Goyal, S.P. **165**
Honnavalli N. Kumara, **177**
Jayashree Ratnam, **66**
Jose Benjamin Thomas, **257**
Ramesh, K., **148**
Kanishkar, A., **78**
Kumar, K., **197**
Lazar, J., **221**
Madeswaran, R., **197**
Manigandan, K., **119, 237**
Manimozhi, A., **38**
Mathesan, R., **133**
Nazia, A., **270**
Nesan, T., **119, 237**
Nisha Bhakat, **66**
Panda, U.S., **7**
Pandiya Rajan, R.S., **7**
Paul Blanchflower, **21**
Pavinkumar, P., **78**
Praisys M. Shaju, **58**
Prasad, S., **221**
Pratim Roy, **133**
Priyanka, S., **119**
Radhika Rajasree, S. R., **58**
Rajasivam, M., **270**
Rajeshkumar, N., **119, 237**
Rangesh, K., **7**
Ranjithkumar, V., **78**
Rohit Naniwadekar, **177**
Sajeevan, M.K., **99**
Sandhya, P., **214**
Sanjana Vadakke Kuruppath, **148**
Santhoshkumar, S., **78**
Sathishkumar, S., **38**
Senbagapriya, S., **38, 197**
Shilpa Bevoor, **165**
Siva Ranjani, S., **197, 214**
Sivasankaran, A., **21**
Sowjanya, V.L., **38**
Sridhar, K., **214**
Srinivasan Murugesan, **257**
Subbaiyan, B., **119, 237**
Udhayan, A., **38, 197, 214**
Vandana Kannan, **133**
Varun Kher, **148, 165**
Vasanthakumari, D., **214**
Vijay Ramesh, **133**
Vishnu, P., **58**
Vivek Ramachandran, **66**
Williams, Z.H., **245**

PROCEEDINGS
4 th Annual Research Conference



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