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Landscape-scale Management: Identifying ecological refuges and core conservation areas for large- and small-bodied mammals in the Mizo and Cachar Hills.

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Abstract: Biodiversity conservation is critical for maintaining ecosystem integrity in species-rich regions like North-East India (NEI), a key part of the Indo-Burma biodiversity hotspot. NEI supports a diverse assemblage of 269 mammal species, including 48 threatened and 13 endemic species, yet faces escalating habitat loss and fragmentation from anthropogenic pressures. This study presents a novel framework for identifying spatial conservation priorities and ecological refuges specifically within the Mizo and Cachar Hills, which retain critical interior forest patches indispensable for arboreal and range-restricted fauna. Utilizing Area of Habitat (AOH) data for 240 species, we integrated functional richness with a Regional Conservation Priority Index (RCPI) that weights IUCN threat status, regional endemism, and range restriction. Our analysis separately evaluates large-bodied (>10 kg) and small-bodied (≤10 kg) mammals to ensure top-down and bottom-up ecological processes are preserved. Using Morphological Spatial Pattern Analysis (MSPA), we identified intact core habitat zones characterized by stable environmental conditions insulated from edge effects. A composite Conservation Score Map (CSM) identifies eight landscapes for large mammals and four for small mammals as high-priority zones. Results indicate that over 30% of NEI's land is of high conservation value, yet nearly 90% of these priority zones lie outside the existing Protected Area (PA) network. This data-driven approach supports evidence-based policymaking and aligns with global targets, such as the Kunming–Montreal Framework's 30 × 30 goal, by providing a scientific basis for expanding PAs and community-managed conservation areas.

Keywords: *Biodiversity conservation, North-East India, Mizo and Cachar Hills, Large-bodied mammals, Small-bodied mammals, Regional Conservation Priority Index (RCPI), Area of Habitat (AOH), Landscape ecology.*

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Introduction

Biodiversity conservation has become an urgent global priority as human activities increasingly destabilize the planet's ecosystems. Effective strategies, ranging from habitat protection to sustainable land-use practices, are essential in regions characterized by high levels of endemism and ecological significance. In the current Anthropocene epoch, conservation efforts must balance land-use planning for economic development with the preservation of ecosystem functionality and long-term human well-being. Historically, researchers have prioritized areas of high species richness and endemism, often utilizing vulnerability scores to delineate conservation priority zones. To prevent extinction, it is vital to recognize the interdependencies between conservation activities and adapt to evolving environmental and societal conditions.

North-East India (NEI), a major component of the Indo-Burma biodiversity hotspot, represents one of the most ecologically complex and globally significant regions for mammalian diversity. The region spans eight states and encompasses diverse habitats ranging from subtropical forests to alpine zones. NEI hosts 269 mammal species across 11 orders, with the order Chiroptera showing the highest species count, followed by rodents. Despite this richness, the region faces significant threats from anthropogenic activities, including habitat destruction, deforestation, agricultural expansion, and infrastructure development, which drive fragmentation and degradation. For instance, shifting cultivation (jhum), logging, and hunting practices by local forest-dependent communities have combined with land cover changes to severely impact mammal populations.

Within this landscape, the Mizo and Cachar Hills serve as vital biogeographic zones that still retain critical interior forest patches. Despite increasing fragmentation, these hills are indispensable for the persistence of arboreal and range-restricted fauna. Large-bodied mammals (LBM) in these southern landscapes often require expansive, contiguous habitats for survival and are highly vulnerable to extinction due to slow reproductive rates and poaching. In contrast, small-bodied mammals (SBM), such as shrews and bats, contribute nearly 80% of the region's mammalian diversity and perform essential functions like seed dispersal and nutrient cycling, yet they remain disproportionately underrepresented in research and policy. Addressing these knowledge gaps is crucial, as data deficiency leads to misallocated resources and delayed threat recognition.

Spatial conservation planning in data-poor regions like NEI emphasizes the use of robust, less data-intensive strategies. Area of Habitat (AOH) maps provide a reliable alternative to traditional

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range maps by delineating potential occupancy based on elevation and specific habitat criteria, thereby reducing commission errors. To further refine prioritization, we developed a Regional Conservation Priority Index (RCPI). This index integrates species' IUCN threat status with measures of regional endemism and global range restriction to determine a relative conservation value for each species. By squaring the RCPI, we amplify the signal of high-priority species—such as the Chinese pangolin or Namdapha flying squirrel—while reducing the masking effect of widespread, low-concern taxa.

To identify intact core conservation areas, this study utilizes Morphological Spatial Pattern Analysis (MSPA). MSPA quantifies image characteristics to classify habitat patches into categories like cores, edges, and bridges, with core areas defined as those insulated from edge effects such as microclimatic fluctuations and human disturbance. These zones are essential for the long-term persistence of specialist species that require stable environmental conditions. Furthermore, we integrated functional richness and conservation urgency into a composite Conservation Score Map (CSM). This approach balances ecological representativeness with management urgency, ensuring that conservation decisions are both inclusive and strategically focused.

Our findings reveal a significant gap between priority areas and formal protection; while over 33.5% of NEI has been identified as core conservation area, only about 2.96% falls within the existing Protected Area (PA) network. The majority of these core patches exist as community forests beyond formal boundaries, making them vulnerable to further fragmentation. The Mizo Hills–Cachar complex is identified as a critical zone for forest-dependent small mammals and arboreal species. Expanding conservation strategies to include Other Effective Area-Based Conservation Measures (OECM), Key Biodiversity Areas (KBA), and community conservation reserves is essential for protecting these ecological refuges. Such efforts must be socially inclusive, integrating the socio-economic realities of tribal communities to ensure long-term sustainability and climate resilience. This study aligns with international frameworks like the Kunming-Montreal Global Biodiversity Framework, providing a scientific foundation for conserving 30% of land by 2030.

Objectives

- Analyze research trends for mammalian fauna in North-East India to identify taxonomic biases and significant knowledge gaps, particularly for small-bodied species.
- Identify spatial conservation priorities and ecological refuges specifically within the Mizo and Cachar Hills using refined Area of Habitat (AOH) data.
- Delineate intact core habitat zones for both large-bodied and small-bodied mammals by applying Morphological Spatial Pattern Analysis (MSPA) to identify areas insulated from edge effects.
- Develop a composite Conservation Score Map (CSM) that integrates functional richness with regional conservation urgency to guide evidence-based policymaking and land-use planning.

Literature Reviews

- Petsas et al. (2020): This study assessed functional connectivity for mammals in the Balkan Peninsula using circuit theory and graph-theoretical analysis. The researchers highlighted key ecological corridors and emphasized the critical need for international collaboration to maintain habitat links across national borders. Their data-driven approach is vital for optimizing regional conservation efforts in complex, transboundary mountain landscapes.
- Botero-Delgadillo et al. (2022): Researchers identified priority areas for neotropical birds in the Colombian Andes by applying environmental niche models. Their work successfully mapped the distribution of two data-poor endemic species, bridging a gap in spatial prioritization. The study underscores the importance of tailored strategies to optimize conservation in ecologically significant yet data-deficient regions.
- Valenzuela-Galván et al. (2008): This study prioritized conservation areas for terrestrial carnivores in North and Central America. By utilizing spatial patterns of richness, endemism, and threat status, the authors identified high-value landscapes for predator protection. This research highlights how biological metrics can effectively guide policymakers in safeguarding biodiversity within anthropogenic-dominated landscapes.
- Tilker et al. (2020): Conducted in Vietnam and Laos, this research used camera-trapping and environmental DNA to assess mammal responses to environmental and anthropogenic factors. The findings revealed that conservation-priority and endemic species are most frequently found in remote, high-elevation refuges. This emphasizes the role of rugged terrain in supporting the persistence of sensitive species.
- Atkinson and Smith (2022): This study utilized a Conservation Priority Index (CPI) to rank sites based on their biodiversity value. It revealed that top-priority sites often lack formal protection, indicating an urgent need for better resource allocation. The CPI serves as a robust tool for identifying areas where conservation efforts should be prioritized to safeguard unique habitats.

Methodology

The study utilizes a novel, data-driven framework to identify spatial conservation priorities for terrestrial mammals in the Mizo and Cachar Hills within the broader context of North-East India (NEI). Initially, an annotated checklist of 269 mammalian species was finalized, categorizing fauna into large-bodied (>10 kg) and small-bodied (≤10 kg) mammals to ensure that diverse ecological roles were considered. Spatial analysis relied on Area of Habitat (AOH) data for 240 species, which refines traditional range maps by excluding unsuitable elevations and habitat types based on IUCN criteria.

To assess conservation urgency, the Regional Conservation Priority Index (RCPI) was developed. This index integrates four metrics: IUCN threat status, regional endemism, global range restriction, and NEI-specific range restriction. The RCPI was squared to amplify the signal of high-priority species while minimizing the masking effect of common taxa. Species richness and RCPI-weighted richness maps were then generated separately for large- and small-bodied mammals to capture both top-down and bottom-up ecological processes.

Spatial prioritization employed a quartile-based mapping approach, designating regions in the 4th quartile as high-priority zones. Morphological Spatial Pattern Analysis (MSPA) was then

performed using Guidos Toolbox to classify binary image characteristics and extract intact core habitat areas. These core areas represent habitat interiors insulated from edge effects—such as microclimatic fluctuations and human disturbance—providing the stable conditions required for the long-term persistence of specialist and range-restricted species.

Finally, a composite Conservation Score Map (CSM) was generated by integrating functional richness (weighted at 30%) and conservation urgency (weighted at 70%) through weighted linear addition. All layers were normalized to a 0–1 scale to ensure consistency. This composite map identifies critical ecological refuges and supports evidence-based management aligned with global biodiversity targets.

Table 1: Parameters for the Regional Conservation Priority Index (RCPI)

This index was developed to calculate the relative conservation concern for each species by integrating threat status and range restriction**.**

Parameter	Description	Scoring Detail
IUCN Status (*SIUCN*)	Numeric score assigned to Red List status.	01 (Least Concern) to 06 (Critically Endangered).
Regional Endemism (*E*)	Binary score for endemicity to the study region.	1 if endemic; 0 otherwise.
Global Range Restriction	Proportion of global Area of Habitat (AOH).	Calculated as (1−*AOHglobal*/*Aglobal*).
Regional Range Restriction	Proportion of study-area specific AOH.	Calculated as (1−*AOHstudy*/*Astudy*).

Table 2: Mammalian Species Richness Across North-East India (NEI) States

The region hosts 269 mammal species (57 large-bodied; 212 small-bodied), with Mizoram and the surrounding hills serving as significant biodiversity hubs.

This table outlines the four parameters used to calculate the Regional Conservation Priority

State/Region	Total Species Count	Key Taxonomic Note
Meghalaya	179	Highest species count in the region.
Arunachal Pradesh	172	High species richness and endemicity.
Assam	160	Home to significant large-bodied mammal populations.
Sikkim	154	Diverse montane fauna.
Nagaland	126	Critical part of the Indo-Burma hotspot.
Mizoram	120	Retains critical interior forest for arboreal fauna.
Manipur	113	Significant for range-restricted species.
Tripura	82	Lower richness due to smaller area and higher pressure.

Index (RCPI) for mammals. It integrates the species' IUCN threat score, regional endemism, and both global and regional range restriction. The framework ensures species with higher threat levels and restricted habitats receive proportionally higher values. By squaring the index, researchers amplify the influence of high-priority species, such as the critically endangered Namdapha flying squirrel, while preventing widespread, low-concern species from numerically dominating and obscuring the conservation signal

This table summarizes mammalian species richness across North-East India, revealing a total of 269 species spanning 11 orders. Meghalaya (179 species) and Arunachal Pradesh (172 species) exhibit the highest richness in the region. Mizoram, which supports 120 species, is highlighted for retaining critical interior forest patches essential for arboreal and range-restricted fauna. The data underscores the region's status as a global biodiversity hotspot, hosting 48 threatened and 13 endemic species, including significant populations of both large- and small-bodied mammals

Table 3: Distribution of Core Conservation Areas Inside vs. Outside Protected Areas

Using Morphological Spatial Pattern Analysis (MSPA), the study identified core areas—habitat interiors insulated from edge effects—which are essential for the Mizo Hills–Cachar complex.

Core Area Category	Total Core Area (*km*2)	% of Total Land Area	% Outside Existing PAs
Large-Bodied Mammal (LBM) Richness	52,787	19.32%	16.84%
Large-Bodied Mammal (LBM) Priority	35,004	12.81%	11.19%
Small-Bodied Mammal (SBM) Richness	52,456	19.20%	18.34%
Small-Bodied Mammal (SBM) Priority	35,420	12.97%	12.11%
Combined Union (Total Core Area)	91,503	33.50%	30.54%

This table presents the distribution of core habitat areas identified through Morphological Spatial Pattern Analysis (MSPA). It reveals a significant conservation gap: while 33.5% of the region (approximately 91,503 km 2) is identified as critical core area, a mere 2.96% is currently protected within the formal Protected Area (PA) network. Over 30% of these high-value zones lie outside PAs, often existing as community forests. This underscores the urgent need to expand landscape-scale management to include community-managed conservation reserves.

Table 4: High-Urgency Species Identified by RCPI Score

Species with higher RCPI scores (maximum 1.0) indicate the most urgent need for site-specific conservation interventions.

Species Name	RCPI Score	Conservation Status/Significance
Namdapha flying squirrel	1.00	Critically Endangered; endemic to NEI.
Pygmy hog	0.96	Endangered; highly restricted range.
Manipur bush rat	0.96	Endemic; priority small-bodied mammal.
Gee's golden langur	0.96	Endangered; high conservation urgency.
Chinese pangolin	(N/A)	Critically Endangered; under extreme threat.
Rhesus macaque	0.30	Least Concern; low conservation urgency.
Wild boar	0.24	Least Concern; low conservation urgency.

This table ranks mammalian species by their RCPI scores, identifying those requiring the most urgent site-specific interventions. The Namdapha flying squirrel holds the maximum score of 1.00 due to its critically endangered and endemic status, followed closely by the pygmy hog and Manipur bush rat at 0.96. Conversely, common species like the rhesus macaque and wild boar have low scores. This allows conservationists to prioritize species most vulnerable to extinction within the Mizo and Cachar Hills

Note: Nearly **90% of the identified high-priority zones** for these species currently lie outside the formal Protected Area network, existing instead as **community forests** vulnerable to fragmentation.

Discussion

This study provides a comprehensive synthesis of mammalian biodiversity and conservation priorities in North-East India (NEI), identifying the Mizo and Cachar Hills as vital biogeographic zones. The region supports a disproportionately high richness of 269 mammal species, yet research trends reveal significant taxonomic biases. While large-bodied mammals like carnivores and primates dominate existing literature, small-bodied mammals (SBM)—which comprise nearly 80% of the region's diversity—remain under-represented. This data deficiency can lead to misallocated resources and delayed threat recognition for functionally critical species.

A central finding is the significant protection gap identified through spatial analysis. While 33.5% of NEI is classified as intact core habitat, only 2.96% is currently secured within the Protected Area (PA) network. This leaves over 30% of high-value conservation land, including critical segments of the Mizo Hills–Cachar complex, vulnerable to fragmentation. In these southern landscapes, interior forest patches remain indispensable for arboreal and range-restricted fauna, such as the capped langur and various sciurid species.

Anthropogenic pressures, including shifting cultivation (jhum), infrastructure expansion, and traditional hunting, continue to drive habitat loss. Large-bodied mammals are particularly susceptible to these threats due to their expansive home ranges and slow reproductive rates. Conversely, while SBM show higher adaptability to fragmented mosaics, they still rely on ecological refuges—areas of high conservation value with minimal human disturbance—for long-term persistence.

Conclusion

The integration of Area of Habitat (AOH) data and the Regional Conservation Priority Index (RCPI) offers a robust, data-driven framework for landscape-scale management in data-deficient regions. By delineating core areas insulated from edge effects, this study pinpoints the Mizo and Cachar Hills as priority zones for immediate conservation intervention.

To achieve global sustainability targets, such as the Kunming–Montreal Framework's 30 × 30 goal, conservation strategies must expand beyond traditional PA boundaries. This involves adopting socially inclusive models, such as Community Reserves (CRs) and Other Effective Area-Based Conservation Measures (OECMs), which integrate the socio-economic realities of indigenous tribal communities. Ultimately, this study provides the scientific foundation necessary for evidence-based policymaking, ensuring the resilience of NEI's unique mammalian assemblages against the escalating threats of the Anthropocene.

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