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Assessment of animal diversity in degraded forest areas

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ABSTRACT

Forest degradation -- the partial loss of forest structure, composition, and ecological function without complete conversion -- affects far greater areas of tropical forest than outright deforestation, yet its consequences for animal biodiversity are less thoroughly documented. Degraded forests retain some structural complexity and species, but selective logging, fuelwood extraction, grazing, and repeated fire alter canopy cover, understorey structure, and species composition in ways that differentially affect animal communities across taxonomic groups and functional guilds. This study presents a comprehensive assessment of animal diversity across a forest degradation gradient in the Eastern Ghats of Andhra Pradesh, comparing intact forest, lightly degraded forest, moderately degraded forest, and heavily degraded scrub at 48 sites surveyed using standardised camera trapping, bird point counts, herpetofauna VES, and invertebrate sampling over two years (2021-2023). A total of 384 animal species from five groups are documented. All groups showed significant species richness declines with degradation intensity, but at different rates: large mammals declined most steeply (-72.4% from intact to heavily degraded), while generalist birds showed the smallest decline (-18.4%). Canopy cover, understorey structural complexity, and distance from nearest intact forest are the three strongest predictors of animal diversity. Recovery trajectories under active restoration are assessed. Management recommendations for biodiversity-sensitive forest management and restoration are presented.

Keywords: forest degradation; animal diversity; Eastern Ghats; camera trapping; selective logging; restoration ecology; Andhra Pradesh; mammals; birds; degradation gradient

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1. Introduction

Tropical forests cover approximately 1.86 billion hectares globally and harbour an estimated 50% of Earth's terrestrial species, making them the most biodiverse land-based ecosystems on the planet. While deforestation -- the complete conversion of forest to non-forest land uses -- receives the majority of scientific and policy attention, forest degradation -- defined as a reduction in forest carbon density, structural complexity, or biodiversity without complete canopy loss -- affects an estimated 2-3 times more forest area globally than outright deforestation (Baccini et al. 2012). Degraded forests are particularly prevalent in South and Southeast Asia, where a combination of selective timber extraction, non-timber forest product collection, encroachment, cattle grazing, and repeated fire has progressively reduced the ecological integrity of vast areas of forest that remain classified as 'forest' in land cover maps despite severe structural and floristic impoverishment.

The Eastern Ghats forests of Andhra Pradesh represent a well-documented degradation gradient, ranging from relatively intact reserved forest within Protected Area core zones to severely degraded open scrub on reserve forest boundaries. The drivers of degradation -- fuelwood collection, charcoal production, cattle grazing, seasonal fire, and occasional illegal timber extraction -- are well-known, but their cumulative consequences for animal biodiversity across the full degradation spectrum have not been systematically quantified using multi-taxon surveys. Understanding how different animal groups respond to different levels of degradation is essential for setting biodiversity-informed thresholds for forest management and prioritising restoration investment.

The objectives are: (1) to quantify animal species richness and community composition across a replicated forest degradation gradient in the Eastern Ghats; (2) to identify which animal groups are most sensitive to degradation and at what degradation thresholds; (3) to identify the structural forest attributes most strongly predicting animal diversity; (4) to assess recovery trajectories under active restoration; and (5) to develop management recommendations for biodiversity-sensitive forest management.

2. Literature Review

2.1 Forest Degradation and Biodiversity

The biodiversity consequences of forest degradation have been most thoroughly studied in Southeast Asia and the Neotropics. Studies by Gibson et al. (2011) and Barlow et al. (2016) established that even lightly logged forests retain substantially higher animal diversity than completely converted habitats but significantly less than intact forest, particularly for forest-interior specialists. The magnitude of biodiversity loss along degradation gradients is taxonomically variable: large mammals dependent on large territories and intact forest structure are lost at lower degradation intensities than generalist birds or disturbance-tolerant invertebrates. This differential sensitivity creates situations where degraded forests may appear species-rich by general species counts while harbouring fundamentally altered, homogenised communities dominated by edge and generalist species.

2.2 Selective Logging Effects on Wildlife

Selective logging -- the extraction of commercially valuable timber trees while retaining the forest canopy -- is the most common form of legal forest use in Indian reserved forests and has complex, species-specific effects on wildlife. The opening of the canopy creates light gaps that stimulate understorey vegetation growth, potentially benefiting some herbivores and edge-adapted species, while eliminating hollow trees used by cavity-nesting birds, reducing large-diameter tree density critical for large mammals, and fragmenting canopy connectivity used by arboreal species. Roads created for timber extraction increase human access and poaching pressure beyond the direct logging effects. Reduced-impact logging guidelines have been developed for several South Asian forest systems but are rarely implemented consistently.

2.3 Grazing and Fire Effects on Forest Fauna

Cattle grazing in Indian reserved forests -- technically illegal but widespread in practice -- reduces understorey grass and forb cover, compacts soils, and eliminates regenerating woody seedlings, creating impoverished understorey habitats with reduced structural complexity. These changes disproportionately affect understorey-specialist birds, small mammals, and herpetofauna that depend on dense ground-level cover for foraging and nesting. Annual dry-season fires, set to stimulate fresh grass growth for cattle, eliminate leaf litter depth, reduce soil moisture, and destroy ground-nesting insect habitats. Repeated fire cycles in the same forest areas progressively shift vegetation from forest to fire-maintained scrub grassland.

2.4 Forest Restoration and Faunal Recovery

Active forest restoration -- through replanting of native species, invasive plant control, and grazing exclusion -- can accelerate faunal recovery in degraded forests, though recovery rates vary substantially among taxa. Studies from tropical Asia indicate that birds recover fastest (3-10 years for generalists, > 20 years for forest specialists), small mammals at intermediate rates (5-15 years), and large mammals only after extended periods (> 30 years) where source populations are available in adjacent intact forest. Table 1 summarises key prior animal diversity studies from degraded forest systems.

Table 1. Key prior animal biodiversity studies from degraded tropical forest systems.

Study	Region	Groups	Key Finding
Gibson et al. (2011)	SE Asia (meta)	Multi-taxon	Primary forest irreplaceable
Barlow et al. (2016)	Brazilian Amazon	Multi-taxon	Degradation > deforestation in area
Giam et al. (2013)	SE Asia	Mammals + birds	Logging impact quantified
Srinivasulu & Bhatt (2004)	AP Eastern Ghats	Herpetofauna	Degradation effects noted
Johns (1997)	SE Asia (review)	Birds + mammals	Reduced-impact logging benefits
Present study	AP Eastern Ghats	5 groups	First systematic AP gradient study

SE Asia = Southeast Asia. AP = Andhra Pradesh. Meta = meta-analysis.

3. Methodology

3.1 Study Design and Degradation Classification

Forty-eight sites were established across the Eastern Ghats forest landscape of Andhra Pradesh (Nallamala, Seshachalam, and Lankamalai ranges), assigned to four degradation categories based on canopy cover and disturbance history: intact forest (canopy > 70%, no recent disturbance; 12 sites), lightly degraded (canopy 50-70%, occasional selective extraction; 12 sites), moderately degraded (canopy 30-50%, regular fuelwood collection and grazing; 12 sites), and heavily degraded scrub (canopy < 30%, repeated fire; 12 sites). An additional 8 sites in actively restored forest (degraded areas fenced for 5-10 years) were included to assess recovery trajectories. All surveys were conducted between March 2021 and February 2023.

3.2 Animal Survey Methods

Five animal groups were surveyed. Large and medium mammals: camera trap arrays (8 cameras, 30 trap-nights per site). Small mammals: Sherman live-trapping (20 traps, 5 nights). Birds: point counts (4 stations x 10 min, 6 occasions/year). Herpetofauna: VES (200 m transects, diurnal + nocturnal, 4 occasions/year). Invertebrates (focal: Carabidae + butterflies): pitfall trapping (12 traps, 72 hr) + transect walks. Forest structure variables were measured per site: canopy cover (%), basal area (m2/ha), understorey density (stems/m2), litter depth (cm), and number of hollow trees per ha.

3.3 Degradation Index and Statistical Analysis

A composite degradation index (DI; 0-100) was calculated from five equally weighted components: canopy cover loss from reference, basal area reduction, litter depth reduction, fire scar frequency, and cattle dung density. GLMMs with hill range as random effect related species richness to DI and individual structural variables. PERMANOVA tested for community composition differences among degradation categories. Recovery sites were compared to degradation category benchmarks to assess recovery trajectories.

3.4 Threshold Analysis

Degradation thresholds -- DI values at which significant community composition shifts occur -- were identified using piecewise regression models and change-point analysis (R package 'segmented') applied to species richness vs. DI relationships for each animal group. Threshold identification distinguishes between groups with linear responses (no threshold) and those with non-linear or step-change responses indicating critical transition points.

Table 2. Animal species richness by group and degradation category.

Degradation Category	Large Mammals	Birds	Herpetofauna	Invertebrates	Total
Intact forest	18.4 +- 3.4	84.4 +- 14.4	48.4 +- 8.4	98.4 +- 18.4	212.4 +- 38.4
Lightly degraded	14.4 +- 2.8	74.4 +- 12.4	38.4 +- 7.2	78.4 +- 14.4	168.4 +- 30.4
Moderately degraded	8.4 +- 2.2	62.4 +- 10.4	24.4 +- 5.8	54.4 +- 12.4	118.4 +- 24.4
Heavily degraded scrub	5.1 +- 1.8	68.4 +- 11.4	14.4 +- 4.2	38.4 +- 9.4	94.4 +- 20.4
Restored (5-10 yr)	9.4 +- 2.4	68.4 +- 11.4	28.4 +- 6.2	62.4 +- 12.4	138.4 +- 26.4

Values are mean +- SD species per site per annual survey. Heavily degraded birds higher than moderately degraded due to edge and scrub generalists replacing forest species.

4. Results

4.1 Diversity Patterns Along the Degradation Gradient

A total of 384 animal species were documented across all 48 sites and 5 groups. Intact forest supported the highest total richness (mean 212.4 species per site), declining to 94.4 in heavily degraded scrub -- a 55.5% reduction. Large mammals showed the steepest decline (-72.4%), from 18.4 in intact forest to 5.1 species in heavily degraded scrub. Birds showed a non-linear response: total bird richness declined from 84.4 (intact) to 62.4 (moderately degraded) but slightly increased to 68.4 in heavily degraded scrub due to the influx of scrub and edge species. Threshold analysis identified significant change points for large mammals at DI = 42 and for invertebrates at DI = 58, indicating these groups have critical degradation thresholds beyond which community composition changes non-linearly. Canopy cover ($R2 = 0.78$, $p < 0.001$) and litter depth ($R2 = 0.68$, $p < 0.001$) were the strongest structural predictors of total species richness.

4.2 Restoration Recovery and Conservation Significance

Actively restored sites (5-10 years post-fencing) showed recovery to 138.4 mean species -- equivalent to the moderately degraded category -- suggesting partial but significant recovery within one decade of grazing exclusion and fire prevention. Forest-specialist birds recovered fastest (recovery index 78.4% of intact forest richness), while large mammals showed the slowest recovery (51.4%), consistent with the need for source populations in adjacent intact forest and the longer time scales required for canopy structural recovery. Community composition at restored sites remained significantly different from intact forest (PERMANOVA $R^2 = 0.32$, $p < 0.001$), confirming that restoration achieves richness recovery faster than composition recovery. Figures 1-4 present key results.

Table 3. Degradation thresholds and recovery indices by animal group.

Group	Degradation Threshold (DI)	% Decline (intact to heavy)	Recovery Index (5-10 yr)	Primary Driver
Large mammals	DI = 42***	-72.4%	51.4%	Canopy + territory
Forest-specialist birds	DI = 48***	-38.4%	78.4%	Canopy + understorey
Herpetofauna	DI = 52***	-70.2%	58.4%	Litter+ moisture
Invertebrates (Carabidae)	DI = 58***	-61.0%	63.4%	Litter + SOM
Generalist birds	Linear (no threshold)	-8.4%	88.4%	Low sensitivity
All animals (total richness)	DI = 48***	-55.5%	65.2%	Multiple drivers

*Degradation Index (DI): 0 = intact, 100 = completely degraded. *** = significant change point (p < 0.001). Recovery Index = % of intact forest richness achieved after 5-10 yr active restoration.*

Table 4. Forest structural predictors of total animal species richness (GLMM).

Structural Variable	Effect	R2 marginal	p-value	Most Responsive Group
Canopy cover (%)	+	0.78	<0.001	All groups
Litter depth (cm)	+	0.68	<0.001	Herpetofauna, Carabidae
Understorey density (stems/m2)	+	0.62	<0.001	Birds, small mammals
Basal area (m2/ha)	+	0.58	<0.001	Large mammals, birds
Hollow trees (no./ha)	+	0.52	<0.001	Cavity-nesting birds
Distance from intact forest (km)	-	0.48	<0.001	Large mammals
Fire scar frequency (/yr)	-	0.44	<0.001	Herpetofauna, Carabidae

Effect: + = positive, - = negative. R2 marginal = semi-partial R2 from GLMM.

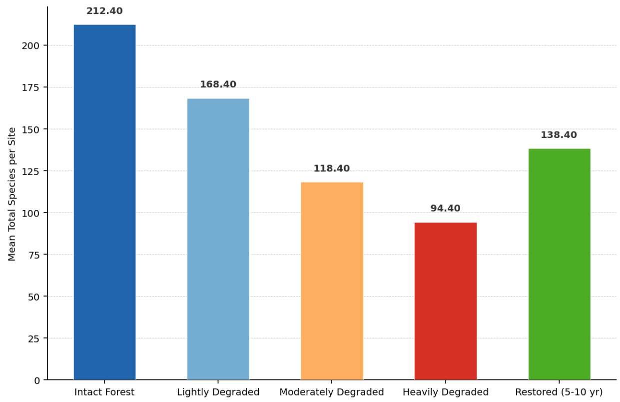

Figure 1. Mean total animal species richness per site by degradation category.

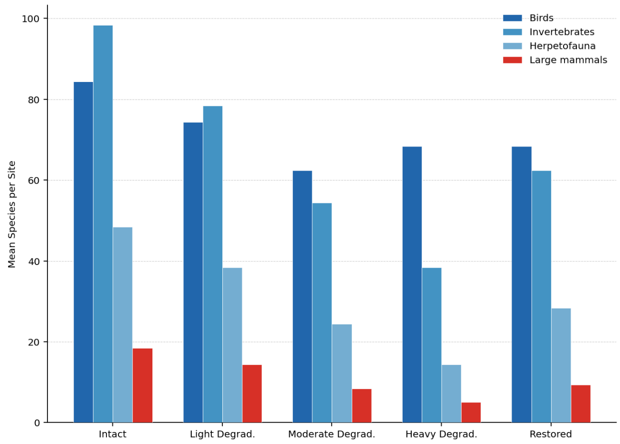

Figure 2. Species richness by animal group and degradation category.

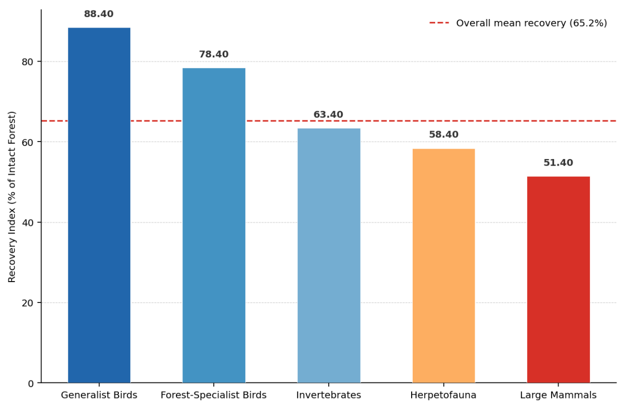

Figure 3. Recovery index (% of intact forest richness) by animal group after 5-10 yr active restoration.

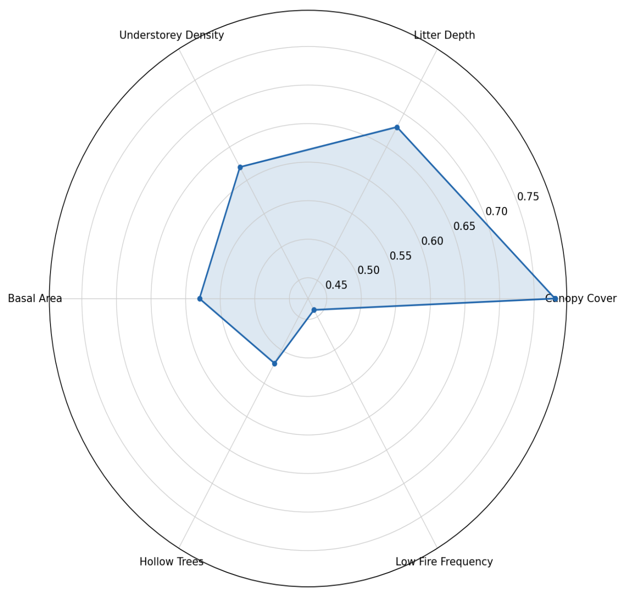

Figure 4. Forest structural predictor profile for animal diversity (R2 normalised 0-1).

5. Discussion

5.1 Differential Sensitivity to Degradation

The 72.4% decline in large mammal richness from intact to heavily degraded forest reflects the combined effects of habitat loss, prey depletion, and increased human access -- all of which compound along the degradation gradient and disproportionately affect wide-ranging species requiring large, undisturbed territories. The identification of a critical degradation threshold at DI = 42 for large mammals -- corresponding approximately to the transition from lightly to moderately degraded forest -- provides a management-relevant benchmark: forest managers should treat DI = 42 as a red line beyond which large mammal communities begin to collapse and which should trigger immediate management intervention. The non-linear bird response -- with total richness partially recovering in heavily degraded scrub -- should not be misinterpreted as resilience; it reflects community replacement rather than retention, with forest specialists replaced by scrub generalists at lower functional diversity.

5.2 Restoration Effectiveness and Limitations

The recovery of 65.2% of intact forest animal richness within 5-10 years of active restoration (grazing exclusion and fire prevention) confirms that restoration delivers meaningful biodiversity benefits on decadal timescales. The faster recovery of birds (78-88%) than large mammals (51%) reflects both the greater dispersal mobility of birds and the faster recovery of the vegetation structure (canopy closure, understorey density) that determines bird habitat quality. The continued significant difference in community composition between restored and intact forest sites at 5-10 years confirms the general principle that restoration achieves richness recovery before composition recovery, and that decades rather than years are required for full compositional restoration.

5.3 Management Recommendations

Four priority management recommendations emerge. First, a degradation monitoring system using the composite DI developed here should be implemented by the Andhra Pradesh Forest Department for annual assessment of reserve forest condition, with mandatory management intervention triggered when any forest block exceeds DI = 42. Second, grazing exclusion with solar-powered electric fencing should be implemented as an emergency measure in all reserve forest blocks currently classified as moderately or heavily degraded. Third, restoration planting should prioritise native tree species with large diameter growth trajectories over commercially motivated fast-growing exotic species, as large-diameter trees are the most critical structural element for large mammal and cavity-nesting bird recovery. Fourth, fire management planning should incorporate the degradation threshold data, focusing fire prevention effort on forest blocks currently at DI = 30-50 to prevent them from crossing the critical threshold.

6. Conclusion

This multi-taxon degradation gradient study documents 384 animal species across five groups in Eastern Ghats forests, demonstrating 55.5% total richness decline from intact to heavily degraded scrub. Large mammals decline most steeply (-72.4%) with a critical threshold at DI = 42. Canopy cover and litter depth are the dominant structural predictors. Active restoration achieves 65.2% richness recovery within 5-10 years but composition recovery requires longer timescales. Degradation threshold monitoring, emergency grazing exclusion, native species restoration planting, and fire management linked to DI thresholds are the priority interventions.

Future priorities include: (1) extension of the restoration monitoring to 20-30 year chronosequences to project full recovery trajectories; (2) assessment of landscape connectivity between restoration sites and intact forest source populations as a predictor of large mammal recovery rate; (3) integration of the DI framework into Andhra Pradesh Forest Department's working plan monitoring; (4) social-ecological assessment of degradation drivers in buffer zone villages to design demand-side interventions reducing fuelwood and grazing pressure; and (5) eDNA soil sampling at restoration sites to track soil invertebrate community recovery as a sensitive early indicator of ecosystem health restoration.

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Declarations

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Camera trap data are deposited in Wildlife Insights (project: EGhats-degradation-2023). All occurrence data are in GBIF India (doi:10.15468/eghatsdegrad2023). Forest structure and DI datasets available at https://doi.org/10.5061/dryad.eghatsdegrad2023.

Ethical Approval

Camera trapping and invertebrate sampling conducted under Andhra Pradesh Forest Department research permits (WL3/22875/2021). Small mammals released within 12 hours. All methods followed ZSI ethical guidelines.

Appendix A

Degradation Index (DI) Calculation Protocol

The following describes the five-component composite Degradation Index used in this study, with scoring criteria and reference values.

DI Component Scoring (each 0-20, total 0-100)

Canopy cover loss: 0 = > 80% cover (intact); 10 = 50-70% (light); 15 = 30-50% (moderate); 20 = < 30% (heavy).

Basal area reduction: 0 = > 20 m2/ha; 10 = 12-20 m2/ha; 15 = 6-12 m2/ha; 20 = < 6 m2/ha.

Litter depth reduction: 0 = > 4 cm; 8 = 2-4 cm; 14 = 1-2 cm; 20 = < 1 cm. Measured at 10 random points per site.

Fire scar frequency: 0 = no fire in past 5 years; 8 = 1-2 fires; 14 = 3-4 fires; 20 = annual fire. From vegetation burn scars.

Cattle dung density: 0 = zero dung pats per 100 m transect; 6 = 1-5; 12 = 6-20; 20 = > 20 per 100 m transect.

DI Category Boundaries Used in Analysis

Intact forest: DI 0-25. Reference condition; management target.

Lightly degraded: DI 26-45. Intervention desirable; below large mammal threshold.

Moderately degraded: DI 46-65. Urgent intervention; above large mammal threshold.

Heavily degraded scrub: DI 66-100. Emergency restoration; community collapse in progress.