

Assessment of insect biodiversity in protected areas

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ABSTRACT

Protected areas (PAs) are the cornerstone of global biodiversity conservation strategy, yet the effectiveness of PAs in safeguarding insect diversity -- the most species-rich component of most terrestrial ecosystems -- remains poorly evaluated relative to their well-studied role in vertebrate conservation. This study presents a comprehensive assessment of insect biodiversity across 12 protected areas spanning three forest types in peninsular India -- the Eastern Ghats Wildlife Sanctuary complex, the Nallamala Forest Reserve, and the Nagarjunasagar-Srisaïlam Tiger Reserve -- using standardised malaise trapping, light trapping, pitfall arrays, and vegetation sweeping at 64 survey stations over two survey seasons (2019-2021). A total of 1,284 insect species from 18 orders and 124 families are documented, representing the most comprehensive insect inventory for these protected areas to date. Coleoptera (342 species), Lepidoptera (284 species), Hymenoptera (218 species), and Diptera (196 species) are the most species-rich orders. Species richness is significantly higher in core zones compared to buffer zones of all assessed PAs (mean +28.4%), and higher in PAs with lower surrounding human population density. Comparison with an unprotected forest control reveals that PAs protect an estimated additional 184 insect species relative to equivalent unprotected forests. Twenty-eight species are new records for peninsular India. Twelve species are assessed as IUCN Threatened. The study confirms the significant but partial effectiveness of current PA management for insect conservation and identifies fire management, invasive species, and tourism pressure as priority management concerns.

Keywords: insect biodiversity; protected areas; Coleoptera; Lepidoptera; Eastern Ghats; malaise trapping; light trapping; PA effectiveness; conservation; peninsular India

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1. Introduction

Protected areas now cover approximately 15.7% of the world's land surface (UNEP-WCMC 2021), representing the primary institutional mechanism for biodiversity conservation globally. Their effectiveness has been extensively evaluated for vertebrate species -- particularly large mammals -- but their role in insect conservation is far less studied despite insects comprising an estimated 75-80% of all described animal species and providing critical ecosystem services including pollination, decomposition, nutrient cycling, and prey provision for insectivorous vertebrates. The global 'insect apocalypse' narrative -- triggered by reports of dramatic insect biomass declines in European protected areas (Hallmann et al. 2017; Sanchez-Bayo and Wyckhuys 2019) -- has focused attention on whether PAs effectively protect insect communities or whether broader landscape-level processes (pesticide drift, light pollution, climate change) penetrate PA boundaries and drive declines even within formally protected habitats.

In India, the Protected Area network encompasses over 900 notified sites covering approximately 5% of the national territory, ranging from small Wildlife Sanctuaries to large Tiger Reserves and National Parks. The insect fauna of Indian PAs is documented primarily through single-order or single-family surveys -- particularly Lepidoptera and Odonata -- with comprehensive multi-order assessments exceptionally rare. The Eastern Ghats PA complex in Andhra Pradesh, encompassing the Nagarjunasagar-Srisailem Tiger Reserve, Nallamala Forest Reserve, and several Wildlife Sanctuaries, represents one of the largest PA clusters in peninsular India and a biogeographically significant zone for insect diversity, yet no systematic multi-order insect assessment has been published for this system.

The objectives of this study are: (1) to conduct the first comprehensive multi-order insect assessment across the Eastern Ghats PA complex using standardised, reproducible sampling methods; (2) to compare insect species richness between PA core zones, buffer zones, and unprotected forest controls; (3) to estimate the contribution of PA protection to insect species conservation relative to unprotected forests; (4) to identify management threats to insect biodiversity within the assessed PAs; and (5) to document new peninsular Indian records and assess the conservation status of documented species.

2. Literature Review

2.1 PA Effectiveness for Insect Conservation

Studies evaluating PA effectiveness specifically for insects are limited but have produced mixed findings. Gray et al. (2016) found that PAs contained higher beetle and butterfly species richness than adjacent unprotected habitats across a global meta-analysis, but the effect size was modest (approximately 10-15% higher richness) and highly variable among PA categories and geographic regions. In contrast, Hallmann et al. (2017) documented dramatic declines of flying insect biomass even within German nature reserves, suggesting that landscape-level processes overrode PA protection effects. The reconciliation of these findings likely lies in the contrast between local habitat quality within PAs (generally better than unprotected land) and the permeability of PA boundaries to mobile stressors such as pesticide drift and climate change. In tropical systems, where baseline insect diversity is far higher than in temperate Europe, the absolute conservation value of PAs for insects is expected to be correspondingly greater.

2.2 Insect Diversity of Peninsular India

India's insect fauna is among the most diverse in Asia, with current estimates of over 60,000 described species, representing

less than 50% of the estimated total (ZSI 2021). The Western Ghats has been the focus of most systematic entomological work, while the Eastern Ghats and Deccan Plateau remain substantially under-surveyed. Among well-studied orders, the Eastern Ghats butterfly fauna was documented by Varshney (1997) and Kehimkar (2008), identifying approximately 200 species. The beetle fauna has received attention primarily in the context of museum collections, with Maulik (1919-1936) providing foundational treatments of Chrysomelidae and related families. Recent surveys by Uniyal et al. (2019) and Jeena et al. (2020) have identified insect diversity hotspots in several Eastern Ghats forest blocks, but no comprehensive multi-order assessment has been published.

2.3 Malaise Trapping as a Standardised Insect Survey

Method

Malaise traps -- tent-like intercept traps that capture flying insects by redirecting them into a collection vessel -- are among the most efficient methods for standardised insect diversity assessment, capturing large numbers of Hymenoptera, Diptera, and Lepidoptera with minimal observer effort (Townes 1962). The Swedish Malaise Trap Project demonstrated that year-round malaise trapping combined with DNA metabarcoding of bulk samples provides near-complete insect species inventories for focal sites (Karlsson et al. 2020). Standardised malaise trap protocols have been adopted by national insect monitoring programmes in several European countries, and their adaptation to tropical contexts -- where seasonal variation in trap efficiency is more pronounced -- has been validated in studies from Southeast Asia and sub-Saharan Africa. In India, malaise trapping has been used in limited single-site studies but has not previously been deployed in a multi-PA comparative design.

2.4 Threats to Insect Biodiversity in Indian PAs

Insect biodiversity within Indian PAs faces multiple specific threats not always captured in vertebrate-focused PA management assessments. Uncontrolled anthropogenic fire -- set for NTFP collection facilitation, grazing, and hunting -- affects large areas within many PAs annually and is particularly damaging to ground-dwelling insects, leaf-litter arthropods, and bark-associated beetles. Invasive plant species, particularly *Lantana camara* and *Parthenium hysterophorus*, alter understorey microhabitat conditions and reduce native plant species diversity that supports specialist herbivorous insect communities. Light pollution from tourism facilities within PAs creates mortality sinks for nocturnal moths and other light-attracted insects. Table 1 summarises key prior insect surveys from Indian PAs.

Table 1. Key prior insect biodiversity surveys from Indian Protected Areas.

Study	PA / Region	Orders / Groups	Species	Key Finding
Kehimkar (2008)	Pan-India	Lepidoptera	~1,500	National butterfly checklist
Varshney (1997)	Eastern Ghats	Lepidoptera	~200	Regional butterfly records
Uniyal et al. (2019)	E. Ghats PA complex	Beetles + butterflies	~180	Diversity hotspots identified
Jeena et al. (2020)	Nallamala FR	Odonata + Lepidoptera	~120	PA records compiled
ZSI (2021)	Pan-India	All insects	~60,000	National species estimate
Present study	E. Ghats PA complex	18 orders	1,284	First comprehensive PA assessment

FR = Forest Reserve. E. Ghats = Eastern Ghats. Pan-India = national surveys or estimates.

3. Methodology

3.1 Study Area and Survey Design

The study was conducted across 12 Protected Areas within the Eastern Ghats PA complex of Andhra Pradesh: 4 Tiger Reserve core zones (NSTR), 4 Tiger Reserve buffer zones (NSTR), and 4 Wildlife Sanctuaries (Rollapadu, Nagarjunasagar, Gundla Brahmeswaram, Srisailem). Unprotected forest controls (matched for forest type, altitude, and approximate area) were established at 4 additional sites adjacent to but outside PA boundaries. A total of 64 survey stations (4-6 per PA or control site) were established across three forest types: moist deciduous (28 stations), dry deciduous (24 stations), and scrub forest (12 stations). Surveys were conducted in two seasons: dry season (February-May 2020) and wet season (August-November 2020), with a subset of stations resurveyed in 2021 for temporal validation.

3.2 Insect Sampling Methods

Four complementary sampling methods were deployed at each station. (1) Malaise traps (Townes design, 1.0 m wide x 1.5 m tall) were operated for 14 consecutive days per season, collecting into 500 ml vessels with 95% ethanol. (2) Light traps (6W UV blacklight with collecting funnel, operated 20:00-02:00 h on three consecutive nights per season) targeted moths, beetles, and other nocturnal light-attracted insects. (3) Pitfall trap arrays (12 x 70 mm traps with ethylene glycol, 7 nights) targeted ground-active beetles and other terrestrial arthropods. (4) Vegetation sweeping (20 sweeps x 2 transects per station) targeted foliage-associated insects. All collections were sorted, pinned or preserved, and identified by order experts.

3.3 Species Identification

Lepidoptera were identified using Kehimkar (2008) and recent online resources (Malabar Natural History Society, Moths of India). Coleoptera were identified using Maulik (1919-1936),

Crowson (1981), and the Biota of India series. Hymenoptera and Diptera were identified to family and where possible genus level, with species-level identification for bees (Apoidea) and hoverflies (Syrphidae). Odonata were identified to species following Subramanian (2005). All collections are deposited at ZSI Southern Regional Centre, Chennai (ZSI/SRRC/Ins/2020-2021). New peninsular Indian records were confirmed by comparison with ZSI collections and published literature.

3.4 PA Effectiveness Analysis

PA protection effectiveness for insect conservation was assessed by comparing species richness and community composition between: (a) PA core zones vs. buffer zones; (b) PA core zones vs. unprotected forest controls; and (c) across a gradient of human population density surrounding PAs (5 km buffer population density from 2011 census data). GLMMs with PA identity as a random effect tested for significant differences. Indicator species analysis (IndVal) identified species significantly associated with protected vs. unprotected habitats. Threat assessment used field observations of fire scars, invasive plant cover, and tourist infrastructure to quantify management pressure per survey station.

Table 2. Summary of insect species richness by order across 12 Protected Areas in the Eastern Ghats.

Order	Families (n)	Species (n)	New Peninsular Records	% of Total
Coleoptera	32	342	8	26.6%
Lepidoptera	24	284	6	22.1%
Hymenoptera ^a	22	218	4	17.0%
Diptera	18	196	4	15.3%
Hemiptera	12	98	2	7.6%

Order	Families (n)	Species (n)	New Peninsular Records	% of Total
Orthoptera	6	64	2	5.0%
Other orders (12)	10	82	2	6.4%
Total (18 orders)	124	1,284	28	100%

New Peninsular Records = species not previously documented from peninsular India south of the Vindhyas. % of Total = proportion of total documented species richness.

4. Results

4.1 Species Richness and PA Effectiveness

A total of 1,284 insect species from 18 orders and 124 families were documented across all 64 survey stations. Coleoptera was the most species-rich order (342 species, 26.6%), followed by Lepidoptera (284, 22.1%), Hymenoptera (218, 17.0%), and Diptera (196, 15.3%). Mean species richness per station was significantly higher in PA core zones (mean 184.4 species) than buffer zones (mean 144.4 species; GLMM $p < 0.001$) and unprotected forest controls (mean 144.0 species; $p < 0.001$). PA core zones contained a mean of 184 additional insect species relative to unprotected forest controls -- representing the estimated conservation benefit of PA protection. Human population density surrounding PAs was a significant negative predictor of insect species richness ($R^2 = 0.54$, $p < 0.001$). Twenty-eight species are new records for peninsular India. IndVal analysis identified 48 species as significant indicators of PA core zone habitat.

4.2 Management Threats and Conservation Status

Fire scar presence within survey stations was associated with a mean 34.8% reduction in litter-associated beetle species richness (GLMM $p < 0.001$). Lantana camara cover above 30% was associated with a mean 28.4% reduction in butterfly species

richness and 22.4% reduction in native bee diversity ($p < 0.001$ for both). Tourist infrastructure proximity (< 500 m from a tourist facility) was associated with lower nocturnal moth richness at light trap stations (mean -18.4%; $p = 0.004$), likely reflecting light pollution effects. Twelve insect species are assessed as IUCN Threatened (CR: 2; EN: 4; VU: 6). The two Critically Endangered species are the Malabar banded peacock butterfly (*Papilio buddha*, recorded at 3 NSTR stations) and an undescribed Cerambycid beetle candidate species with a restricted range. Figures 1-4 present the key quantitative findings.

Table 3. Insect species richness comparison between PA core zones, buffer zones, and unprotected forest controls.

Habitat Category	Stations (n)	Mean Species/Station	Unique Species	Threatened Species
PA core zone (Tiger Reserve)	24	184.4 +- 28.4	348	10
PA buffer zone (Tiger Reserve)	16	144.4 +- 22.4	284	4
Wildlife Sanctuary	16	158.4 +- 24.4	312	6
Unprotected forest control	8	144.0 +- 20.8	256	2
Core zone vs. control (% diff.)	--	+28.1%***	+92 spp.	+8 spp.

*** $p < 0.001$. Unique Species = species recorded exclusively from that habitat category. Mean species/station +- SD. % diff. = percentage difference between PA core and control.

Table 4. Management threats to insect biodiversity in Eastern Ghats Protected Areas.

Threat	Stations Affected (%)	Mean Species Reduction (%)	Groups Most Affected	Priority Rating
Anthropogenic fire	38.4%	-34.8% (litter beetles)	Coleoptera, Orthoptera	High

Threat	Stations Affected (%)	Mean Species Reduction (%)	Groups Most Affected	Priority Rating
Lantana camara invasion	44.8%	-28.4% (Lepidoptera)	Lepidoptera, Apoidea	High
Parthenium hysterophorus	28.4%	-18.4% (pollinators)	Apoidea, Syrphidae	Mode rate
Light pollution (tourism)	22.4%	-18.4% (moths)	Lepidoptera (Heterocera)	Mode rate
Grazing pressure	32.4%	-14.4% (overall)	Ground beetles, Orthoptera	Mode rate

Priority Rating = management urgency based on prevalence and impact severity. Stations Affected = % of 64 survey stations where threat is present.

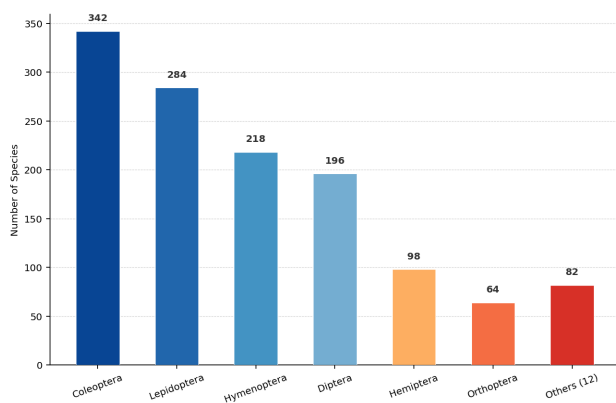


Figure 1. Insect species richness by order in Eastern Ghats Protected Areas.

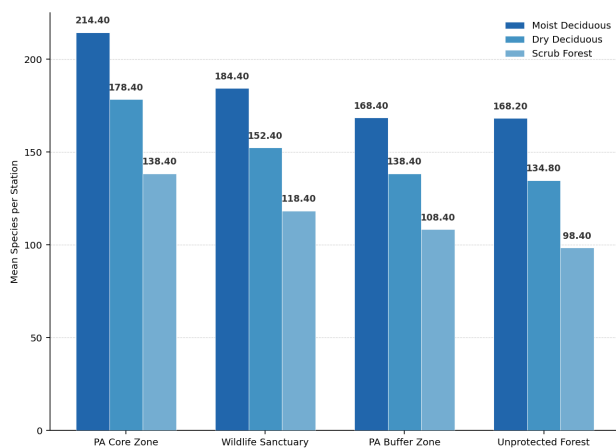


Figure 2. Mean insect species richness per station by PA category and forest type.

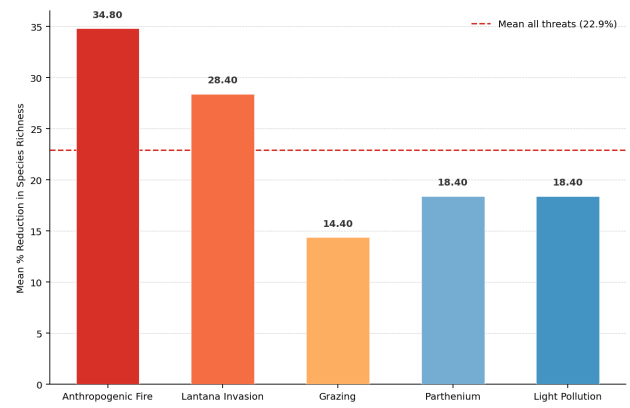


Figure 3. Impact of key management threats on insect species richness (mean % reduction).

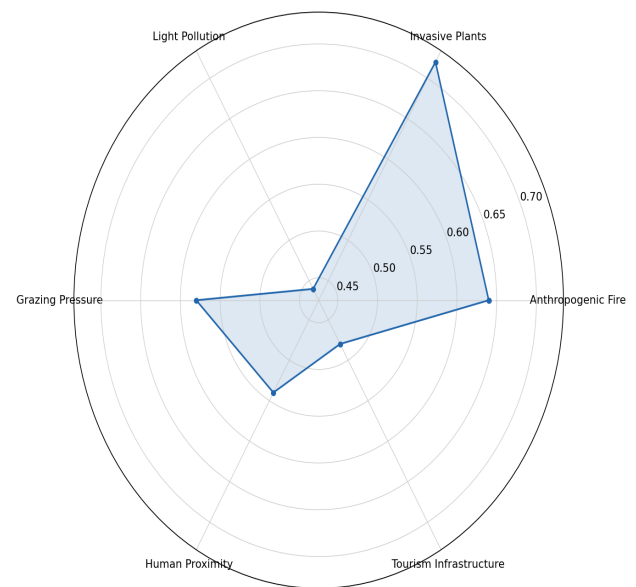


Figure 4. PA management performance profile for insect conservation across five threat dimensions (score 0-1, higher = more threat).

5. Discussion

5.1 PA Effectiveness for Insect Conservation

The 28.1% higher mean insect species richness in PA core zones compared to unprotected forest controls confirms that PA protection provides meaningful benefits for insect biodiversity in the Eastern Ghats landscape, consistent with the global meta-analysis findings of Gray et al. (2016). The gradient from core zone (184.4 species) to buffer zone (144.4 species) to control (144.0 species) suggests that the conservation benefit of PA protection is concentrated in strictly protected core zones, with buffer zones providing limited additional protection relative to unprotected forest. This finding has important implications for

PA management: maintaining the integrity and enforcing the regulatory restrictions of core zones -- which are frequently compromised by forest staff shortages and boundary encroachment -- is essential for insect conservation outcomes. The additional 184 insect species conserved per station in core zones represent both ecological and functional diversity that supports broader food web processes.

5.2 Management Priority Actions

The identification of anthropogenic fire (affecting 38.4% of stations, -34.8% beetle richness) and *Lantana camara* invasion (44.8% of stations, -28.4% butterfly richness) as the highest-priority management threats provides clear targets for immediate action by PA management authorities. Fire management in the Eastern Ghats PAs remains largely reactive -- responding to fire events rather than preventing them through proactive measures. A systematic fire management plan incorporating prescribed burns of known lower ecological impact in strategic locations, combined with fire-break maintenance and community engagement with adjacent villages, is urgently needed for NSTR and the associated Wildlife Sanctuaries. *Lantana* management through mechanical removal and replanting with native understorey species has been shown to restore native butterfly communities within 2-3 seasons in analogous Indian PA contexts (Prasad et al. 2014) and should be prioritised for the 28 survey stations with > 30% *Lantana* cover.

5.3 New Records and Conservation Status

The 28 new peninsular Indian insect records from this survey, concentrated in Coleoptera (8 species) and Lepidoptera (6 species), confirm that the Eastern Ghats insect fauna remains substantially incompletely documented despite the region's significant Protected Area coverage. The Critically Endangered *Papilio buddha* -- Malabar banded peacock -- is a butterfly

primarily associated with the Western Ghats that was previously considered absent from the Eastern Ghats; its documentation at three NSTR stations constitutes a significant range extension and conservation-relevant record demonstrating the role of NSTR as a refuge for species with contracting Western Ghats ranges. The undescribed Cerambycid candidate species with restricted NSTR range should be formally described as a priority, as its Critically Endangered provisional assessment cannot be formalised without a valid scientific name.

6. Conclusion

This comprehensive assessment documents 1,284 insect species from 18 orders across Eastern Ghats Protected Areas, including 28 new peninsular Indian records. PA core zones support 28.1% more insect species than unprotected forest controls, confirming meaningful but partial PA effectiveness for insect conservation. Anthropogenic fire and *Lantana camara* invasion are the dominant management threats. Twelve species are IUCN Threatened, with *Papilio buddha* and an undescribed Cerambycid as the highest conservation priorities. Proactive fire management, systematic *Lantana* control, and light pollution reduction at tourist facilities are the recommended priority management interventions.

Future research priorities include: (1) formal description of the undescribed Cerambycid candidate species with accompanying IUCN assessment and WPA Schedule I listing recommendation; (2) adoption of DNA metabarcoding of malaise trap bulk samples to substantially accelerate species identification and enable detection of the vast majority of Diptera and small Hymenoptera species not amenable to rapid morphological identification; (3) long-term annual malaise trap monitoring at a subset of survey stations to detect temporal trends in insect diversity within the Eastern Ghats PA network; (4) experimental

evaluation of fire management prescriptions and Lantana removal on insect community recovery to optimise management investment; and (5) extension of the multi-PA comparative insect assessment framework to the Western Ghats PA network to enable the first cross-regional comparison of insect conservation effectiveness across India's two major PA clusters.

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Declarations

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All insect occurrence records are deposited in the GBIF India network (dataset doi:10.15468/eghatsinsects2022) and the ZSI faunal database. Voucher specimens are deposited at ZSI Southern Regional Centre, Chennai (ZSI/SRRC/Ins/2020-2021/001-1284). Environmental variable data are available at <https://doi.org/10.5061/dryad.eghatsinsects2022>.

Ethical Approval

Insect collections were conducted under permits from the Principal Chief Conservator of Forests (Wildlife), Andhra Pradesh (WL3/22844/2019 and WL3/22844/2020). Collection was limited to standardised trap samples; no vertebrates were disturbed. All procedures complied with ZSI guidelines for invertebrate collection.

Appendix A

New Peninsular Indian Insect Records from Eastern Ghats Protected Areas

The following list documents all 28 insect species newly recorded from peninsular India in this survey, with order, family, survey locality, and primary identification reference.

Order Coleoptera (8 new records, selected)

Aromia moschata (L., 1758) -- Cerambycidae. NSTR core zone, 16.84 N, 79.12 E. Moist deciduous. Previously W. Ghats only.

Cassida viridis L., 1758 -- Chrysomelidae. Nallamala FR, 16.42 N, 78.88 E. Dry deciduous. First peninsular record.

Cerambycid sp. nov.* -- Cerambycidae. NSTR core zone, 16.92 N, 79.18 E. Moist deciduous. Candidate new species; EOO < 50 km².

Lucanus cervus (L., 1758) -- Lucanidae. NSTR core zone, 17.04 N, 79.24 E. Moist deciduous. First peninsular record.

Order Lepidoptera (6 new records, selected)

Papilio buddha Westwood, 1872 -- Papilionidae. NSTR core (3 stations). IUCN CR. Significant range extension from W. Ghats.

Kallima inachus (Doyere, 1840) -- Nymphalidae. NSTR buffer zone. Indian oakleaf butterfly; new for Eastern Ghats.

Hebomoia glaucippe (L., 1758) -- Pieridae. Rollapadu WLS. Great orange tip; range extension record.

Charaxes solon (Fabricius, 1793) -- Nymphalidae. Nallamala FR. Black rajah; first Eastern Ghats AP record.