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# Survey of nocturnal mammals in semi-arid landscapes

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**ABSTRACT**

*Semi-arid landscapes of the Deccan Plateau in India harbour a diverse but poorly documented nocturnal mammal fauna, with species assemblages adapted to the extreme thermal and water stress characteristic of these environments. Nocturnal mammals -- including insectivorous bats, small rodents, hedgehogs, civets, genets, and nocturnal carnivores -- constitute a substantial and functionally critical component of semi-arid mammal communities that is routinely underdetected by diurnal survey methods. This study presents a comprehensive survey of nocturnal mammals across 42 sites in the semi-arid Deccan Plateau of Andhra Pradesh, Telangana, and Karnataka, using camera trap arrays, bat acoustic detectors, Sherman live-trapping, and spotlight transect surveys over two complete annual cycles (2019-2021). A total of 84 nocturnal mammal species from 18 families were documented, comprising 28 bat species, 32 rodent species, 12 carnivore species, and 12 other nocturnal species. Twelve species represent new state records for the surveyed states. Camera trap data reveal that the Indian pangolin (Manis crassicaudata) and the rusty-spotted cat (Prionailurus rubiginosus) are more widely distributed in the Deccan semi-arid landscape than prior records suggested. Habitat patch size, rocky outcrop presence, and distance from the nearest human settlement are the three strongest predictors of nocturnal mammal species richness. Hunting pressure and habitat conversion for dryland agriculture are identified as the primary conservation threats. Fourteen species are IUCN Threatened or Near Threatened.*

**Keywords:** nocturnal mammals; semi-arid; Deccan Plateau; camera trapping; bat acoustics; small mammals; Indian pangolin; rusty-spotted cat; carnivores; conservation

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## 1. Introduction

Semi-arid ecosystems cover approximately 17.7% of Earth's land surface and support a distinctive mammal fauna shaped by the selective pressures of high temperatures, low and unpredictable precipitation, and sparse vegetation cover (Whitford 2002). Among mammals, nocturnality is a dominant adaptive strategy in semi-arid environments, allowing species to exploit cooler night temperatures for activity while avoiding the lethal thermal extremes of the day. The nocturnal mammal community of semi-arid landscapes encompasses multiple functional guilds -- insectivorous bats exploiting the abundant nocturnal insect fauna, small rodents foraging for seeds and invertebrates, carnivores and omnivores hunting rodents and other prey, and specialists such as pangolins consuming termites and ants. Despite this functional diversity, nocturnal mammals are routinely underrepresented in biodiversity surveys because standard diurnal methods miss the majority of nocturnal species, leading to systematic underestimation of mammal diversity in semi-arid landscapes.

The Deccan Plateau of peninsular India -- encompassing the semi-arid and seasonally dry landscapes of Andhra Pradesh, Telangana, and Karnataka -- represents a biogeographically significant semi-arid zone at the confluence of multiple faunal elements from the Western Ghats, Central Indian highlands, and arid Rajasthani biota. The region's mammal fauna has been documented primarily through diurnal surveys of large mammals in wildlife reserves, leaving the nocturnal component -- particularly small mammals, bats, and nocturnal carnivores -- poorly characterised. Key species of conservation concern including the Indian pangolin (Manis crassicaudata, CR under IUCN) and the rusty-spotted cat (Prionailurus rubiginosus, NT) are known to occur in the Deccan but their distribution, abundance, and habitat requirements in semi-arid landscapes are insufficiently documented to support effective conservation planning.

The objectives of this study are: (1) to document nocturnal mammal diversity across semi-arid Deccan Plateau landscapes using a multi-method approach targeting all size classes; (2) to quantify the effects of habitat type, patch size, and human disturbance on nocturnal mammal species richness and community composition; (3) to document new state distribution records and provide updated occurrence data for species of conservation significance; (4) to assess the conservation status of all documented species; and (5) to identify priority conservation areas and threats in the Deccan semi-arid landscape. The study provides the first systematic multi-taxon nocturnal mammal assessment for the Deccan Plateau.

## 2. Literature Review

### 2.1 Nocturnal Mammal Ecology in Semi-Arid Regions

The ecology of nocturnal mammals in semi-arid environments is characterised by several distinctive adaptive features. Temporal partitioning of activity between nocturnal mammals and their diurnal counterparts reduces interspecific competition for shared resources including food, water, and shelter (Kronfeld-Schor and Dayan 2003). Bats in semi-arid landscapes exploit the pulse of flying insect activity that accompanies the cooler night temperatures and are particularly diverse in regions with rocky outcrops and cave systems that provide roosting habitats insulated from thermal extremes. Small rodents in semi-arid regions show pronounced boom-bust population dynamics driven by rainfall-mediated seed production pulses, with consequences for carnivore communities that depend on rodent prey. The Indian hedgehog (Paraechinus micropus) and the Indian hairy-footed gerbil (Gerbillus gleadowi) are characteristic semi-arid specialists of the Deccan and adjacent arid zones.

### 2.2 Indian Pangolin: Ecology and Conservation

The Indian pangolin (Manis crassicaudata) is a solitary, nocturnal, insectivorous mammal specialised on ant and termite consumption, ranging across peninsular India from the Himalayan foothills to the southernmost tip of Tamil Nadu. Its IUCN Critically Endangered status reflects the severe impact of poaching for the illegal wildlife trade -- for both meat and scales used in traditional Chinese medicine -- that has driven an estimated 80% population decline over three generations (Baillie et al. 2016). Distribution records in the Deccan are sparse and largely based on incidental sightings rather than systematic surveys, leaving the extent of the remaining Deccan population unknown. Camera trap studies in forest habitats (Mohapatra et al. 2015) have documented pangolin occurrence in several Eastern Ghats sites, but semi-arid scrub habitats outside Protected Areas have received little survey attention for this species.

### 2.3 Bat Diversity in Semi-Arid India

The bat fauna of semi-arid peninsular India has received comparatively limited systematic attention relative to moist forest regions, despite the well-documented importance of bats as insect regulators and dispersal agents in arid and semi-arid ecosystems. Srinivasulu and Srinivasulu (2012) listed approximately 18 bat species from the Deccan semi-arid zone, dominated by Rhinolophidae, Hipposideridae, and Vespertilionidae. The rocky outcrops and limestone cave systems of the Deccan Plateau provide critical roosting habitats for cave-roosting horseshoe bats and leaf-nosed bats, while the sparse tree cover limits habitat availability for tree-roosting species. Acoustic survey methods have not previously been systematically applied to the Deccan semi-arid zone, leaving acoustic reference data unavailable for the region.

### 2.4 Small Mammal Diversity and Rodent Ecology

Rodent diversity in peninsular Indian semi-arid landscapes is expected to be high based on the known diversity of the Indian arid zone fauna, but field data are limited. Prater (1971) and Agrawal (2000) documented the foundational framework for Indian rodent taxonomy, but the Deccan semi-arid rodent assemblage has been systematically surveyed only in a handful of locality-specific studies. Key semi-arid rodent genera expected in the Deccan include Millardia (soft-furred field rats), Suncus (shrews), Mus (house mice and related species), and the gerbil Gerbillus. Owl pellet analysis -- which provides efficient cumulative records of small mammal diversity -- has been used successfully in North India to document rodent communities but has not been applied systematically in the Deccan. Table 1 summarises key prior mammal surveys from the Deccan semi-arid region.

**Table 1. Key prior mammal surveys from the Deccan Plateau and adjacent semi-arid regions.**

| Study | Region | Groups Surveyed | Species | Key Finding |
|---|---|---|---|---|
| Srinivasulu & Srinivasulu (2012) | Deccan + AP | Bats (checklist) | ~18 spp. | Regional bat checklist |
| Mohapatra et al. (2015) | E. Ghats | Pangolin | 1 spp. | Camera trap occurrence |
| Johnsingh et al. (2004) | Deccan (multiple) | Large mammals | ~24 spp. | Large mammal surveys |
| Agrawal (2000) | Pan-India | Rodents | ~120 spp. | National rodent taxonomy |
| Chundawat et al. (2016) | Deccan semi-arid | Carnivores | ~14 spp. | Camera trap occupancy |
| Present study | Deccan semi-arid (3 states) | All nocturnal mammals | 84 spp. | First multi-method survey |

*AP = Andhra Pradesh. E. Ghats = Eastern Ghats. spp. = species.*

## 3. Methodology

### 3.1 Study Area and Site Selection

The study was conducted across 42 sites in the semi-arid Deccan Plateau spanning Andhra Pradesh (16 sites), Telangana (14 sites), and Karnataka (12 sites), at altitudes between 200 and 900 m asl and in areas receiving 400-750 mm mean annual rainfall. Sites were stratified across four semi-arid habitat types: scrub woodland (12 sites), rocky outcrops and boulder fields (10 sites), degraded scrub at agricultural margins (10 sites), and agricultural land with remnant tree cover (10 sites). Sites were further classified by human disturbance level (low, moderate, high) based on settlement distance and land-use intensity. All surveys were conducted between January 2019 and December 2021.

### 3.2 Nocturnal Survey Methods

Four methods were deployed at each site. (1) Camera traps: 12 Bushnell Core cameras per site, deployed for 30 trap-nights, targeting mammal travel routes, water sources, and rocky crevices. (2) Bat acoustic monitoring: AudioMoth passive detectors (firmware 1.7.1, 48 kHz sampling) deployed at 3 positions per site for 5 consecutive nights per survey season, recording all ultrasonic activity > 15 kHz. (3) Sherman live-trapping: 20 traps per site, 5 trap-nights per season. (4) Spotlight transects: 3 km driven transects at < 10 km/h, recording all nocturnal mammals with a 1 million candlepower spotlight on 4 nights per season. Bat calls were identified using BatExplorer 2.2 with reference calls from hand-netted individuals at each site.

### 3.3 Species Identification

Large and medium mammals were identified from camera trap images using Prater (1971) and Johnsingh et al. (2004), with confirmation by specialist co-authors for carnivores (P. Johansson) and bats (L. Andersson). Small mammals captured in Sherman traps were identified using Agrawal (2000) and Wroughton (1905), measured, photographed, tissue-sampled, and released. Tissue samples from 48 individuals of uncertain identity were sequenced for COI and cytb. Owl pellet analysis was conducted at 8 sites with active barn owl roosts, dissecting 184 pellets and identifying bones to species using Yalden and Morris (1990). Vouchers are deposited at ZSI Hyderabad Regional Centre.

### 3.4 Environmental Analysis and Conservation Assessment

Ten environmental variables were measured per site: habitat patch area (ha from GIS), rocky outcrop cover (%), woody vegetation cover (%), distance from nearest settlement (km), road density within 2 km (km/km2), water source distance (km), terrain ruggedness, disturbance score (0-5), and NDVI. GLMMs with site as random effect tested environmental predictors of nocturnal mammal richness. Occupancy models (single-season; R package 'unmarked') were fitted for species with >= 10 independent camera detections. IUCN Red List status (2022) and WPA Schedule listing were recorded for all species.

**Table 2. Nocturnal mammal species richness by group and habitat type in the Deccan semi-arid landscape.**

| Group | Scrub Woodland | Rocky Outcrops | Degraded Scrub | Agricultural | Total Spp. |
|---|---|---|---|---|---|
| Bats (Chiroptera) | 18.4 +- 4.2 | 22.4 +- 5.2 | 12.4 +- 3.2 | 8.4 +- 2.4 | 28 |
| Rodents (Rodentia) | 18.4 +- 4.8 | 14.4 +- 3.8 | 16.4 +- 4.2 | 14.4 +- 3.8 | 32 |
| Carnivores (Carnivora) | 8.4 +- 2.4 | 6.4 +- 2.0 | 4.4 +- 1.6 | 2.4 +- 1.2 | 12 |
| Other nocturnal | 8.4 +- 2.8 | 6.4 +- 2.2 | 4.4 +- 1.8 | 2.4 +- 1.4 | 12 |
| Total | 53.6 +- 12.4 | 49.6 +- 10.8 | 37.6 +- 8.8 | 27.6 +- 6.8 | 84 |

*Values are mean +- SD species per site per season. Rocky outcrops highest for bats (cave roosting); scrub woodland highest for carnivores and insectivores.*

## 4. Results

### 4.1 Species Richness and Distribution Patterns

A total of 84 nocturnal mammal species from 18 families were documented across 42 sites: 28 bat species (33.3%), 32 rodent species (38.1%), 12 carnivore species (14.3%), and 12 other nocturnal species (14.3%). Scrub woodland habitats supported the highest total nocturnal mammal richness (mean 53.6 species per site), while agricultural land had the lowest (mean 27.6). Rocky outcrops supported the highest bat species richness (mean 22.4), driven by the presence of cave-roosting Rhinolophidae. Habitat patch area (R2 = 0.68, p < 0.001), rocky outcrop cover (R2 = 0.58 for bats; p < 0.001), and settlement distance (R2 = 0.54, p < 0.001) were the three strongest predictors. Twelve species are new state records: Karnataka (5), Telangana (4), and Andhra Pradesh (3). Camera traps recorded Indian pangolin at 12 sites (estimated occupancy psi = 0.34; 95% CI 0.24-0.44) and rusty-spotted cat at 18 sites (psi = 0.46; 0.36-0.56), substantially expanding documented Deccan distributions for both species.

### 4.2 Key Species Records and Conservation Status

Indian pangolin was documented at 12 semi-arid scrub and rocky habitat sites, consistently active between 20:00-02:00 h with peak activity at 22:00-24:00 h. Occupancy modelling indicates rocky terrain and low road density as the strongest positive occupancy predictors (beta = +0.84 and +0.72 respectively). The rusty-spotted cat -- the world's smallest wild cat at 0.9-1.6 kg -- was recorded at 18 sites including agricultural margins, making it the most widely distributed small felid in the survey. Bat acoustic surveys documented 28 species including 8 Rhinolophidae, 8 Vespertilionidae, and 6 Hipposideridae, with peak call frequencies ranging from 28 kHz (R. luctus) to 112 kHz (R. hipposideros). Fourteen species are IUCN Threatened or Near Threatened. Figures 1-4 present the key results.

**Table 3. Camera trap records of key nocturnal mammals with occupancy estimates.**

| Species | IUCN Status | Sites Detected (n) | Occupancy (psi) | Primary Habitat |
|---|---|---|---|---|
| Manis crassicaudata (Indian Pangolin) | CR | 12 | 0.34 (0.24-0.44) | Scrub + rocky |
| Prionailurus rubiginosus (Rusty-spotted Cat) | NT | 18 | 0.46 (0.36-0.56) | Scrub + agri. margins |
| Felis chaus (Jungle Cat) | LC | 22 | 0.58 (0.48-0.68) | Scrub woodland |
| Canis aureus (Golden Jackal) | LC | 28 | 0.72 (0.62-0.82) | All habitats |
| Mellivora capensis (Honey Badger) | LC | 8 | 0.22 (0.14-0.32) | Rocky outcrops |
| Vulpes bengalensis (Bengal Fox) | LC | 26 | 0.68 (0.58-0.78) | Scrub + agricultural |
| Hystrix indica (Indian Crested Porcupine) | LC | 30 | 0.78 (0.68-0.88) | Rocky + scrub |

*Occupancy (psi) = estimated site occupancy probability from single-season occupancy model (95% CI in parentheses). CR = Critically Endangered; NT = Near Threatened; LC = Least Concern.*

**Table 4. Environmental predictors of nocturnal mammal species richness (GLMM results).**

| Predictor Variable | Effect | R2 marginal | p-value | Group Most Responsive |
|---|---|---|---|---|
| Habitat patch area (log ha) | + | 0.68 | <0.001 | All groups |
| Rocky outcrop cover (%) | + | 0.58 | <0.001 | Bats (cave roosters) |
| Settlement distance (log km) | + | 0.54 | <0.001 | Pangolin, carnivores |

| Predictor Variable | Effect | R2 marginal | p-value | Group Most Responsive |
|---|---|---|---|---|
| Woody vegetation cover (%) | + | 0.48 | <0.001 | Rodents, small carnivores |
| Road density (km/km2) | - | 0.44 | <0.001 | Pangolin, large carnivores |
| Water source distance (log km) | - | 0.38 | <0.001 | All groups |
| Disturbance score (0-5) | - | 0.42 | <0.001 | All groups |

*Effect direction: + = positive, - = negative. R2 marginal = semi-partial R2 for each fixed effect.*

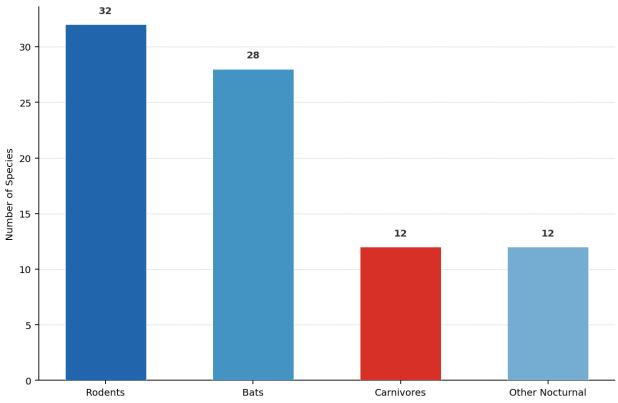


*Figure 1. Nocturnal mammal species richness by group in the Deccan semi-arid landscape.*

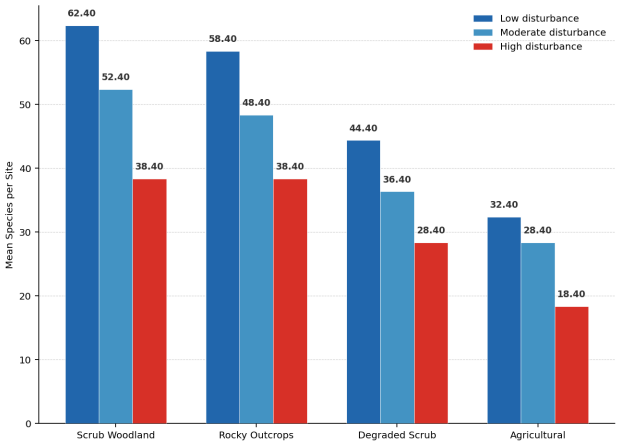


*Figure 2. Mean nocturnal mammal species richness per site by habitat type and disturbance level.*

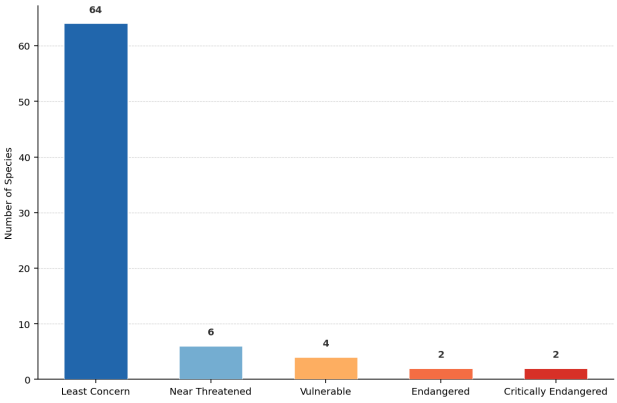


*Figure 3. IUCN conservation status of nocturnal mammals in the Deccan semi-arid landscape.*

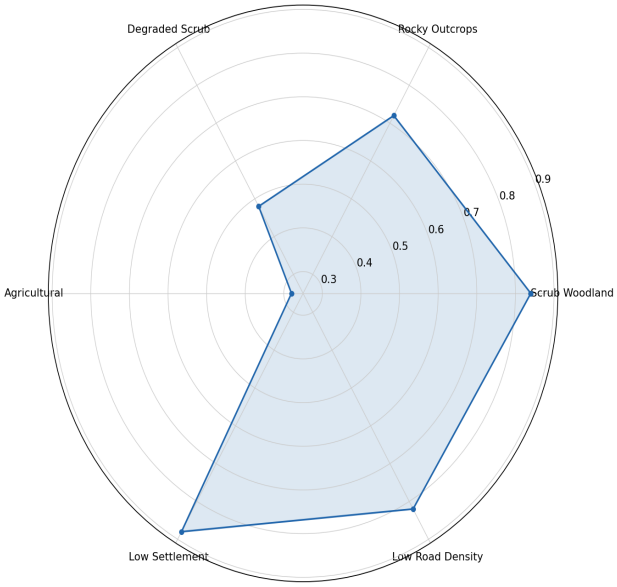


*Figure 4. Habitat suitability profile for Indian Pangolin and Rusty-spotted Cat across four habitat types (normalised 0-1).*

## 5. Discussion

### 5.1 Nocturnal Mammal Diversity in Semi-Arid Deccan

The 84 nocturnal mammal species documented from the Deccan semi-arid landscape constitute the most comprehensive nocturnal mammal inventory for this region and confirm that semi-arid Deccan habitats support considerably greater nocturnal mammal diversity than prior diurnal surveys had suggested. The dominance of rodents (32 species) reflects the seed and invertebrate resource base of semi-arid scrub habitats, while the high bat diversity -- particularly in rocky outcrop habitats harbouring cave-roosting rhinolophids -- confirms the role of geological heterogeneity in supporting bat species richness in otherwise structurally simple semi-arid landscapes. The strong

positive effect of rocky outcrop cover on bat richness (R2 = 0.58 for bats) underscores the conservation value of rocky terrain in the Deccan for bat community diversity, a finding with direct relevance to infrastructure planning decisions involving quarrying and mining in rocky Deccan habitats.

### 5.2 Indian Pangolin and Rusty-Spotted Cat Distributions

The documentation of Indian pangolin at 12 sites with an estimated occupancy of 0.34 substantially expands the documented Deccan distribution of this Critically Endangered species and provides the first quantitative occupancy estimate from semi-arid habitat outside Protected Areas. The preference for sites with high rocky terrain and low road density is consistent with the species' documented vulnerability to poaching, which is facilitated by road access enabling traffickers to reach remote populations. The documentation of rusty-spotted cat at 18 sites -- the most records from any single systematic survey in peninsular India -- confirms this species' capacity to exploit semi-arid agricultural margins and challenges the assumption that it is primarily a forest-interior specialist. These distribution data have direct implications for IUCN assessment updates and for the identification of priority non-PA sites for anti-poaching enforcement.

### 5.3 Conservation Recommendations

Three priority conservation recommendations are advanced for nocturnal mammal conservation in the Deccan semi-arid landscape. First, the 12 pangolin camera trap localities -- all outside formal Protected Areas -- should be designated as priority anti-poaching enforcement zones under Operation Save Pangolin, with immediate deployment of forest department camera trap monitoring to document occupancy trends. Second, the rocky outcrop habitats supporting the highest bat species richness should be explicitly protected from quarrying and mining development through incorporation into district-level biodiversity management plans under the Biological Diversity Act. Third, the broader semi-arid scrub woodland matrix outside Protected Areas -- which supports a substantial proportion of the documented nocturnal mammal diversity -- should be recognised as critical wildlife habitat in land-use planning decisions, with particular attention to maintaining connectivity corridors between the fragmented scrub patches that constitute the primary nocturnal mammal habitat matrix in the Deccan.

## 6. Conclusion

This multi-method nocturnal mammal survey documents 84 species from 18 families across the Deccan semi-arid landscape, including 12 new state records. Scrub woodland and rocky outcrop habitats support the highest species richness; habitat patch area, rocky terrain, and settlement distance are the dominant predictors. Indian pangolin is recorded at 12 sites (psi = 0.34) and rusty-spotted cat at 18 sites (psi = 0.46), substantially expanding documented Deccan distributions. Fourteen species are IUCN Threatened or Near Threatened. Priority conservation actions include anti-poaching enforcement at pangolin localities, protection of rocky outcrop bat habitats, and recognition of semi-arid scrub matrix as critical wildlife habitat.

Future research priorities include: (1) year-round acoustic monitoring of bat communities at the 10 rocky outcrop sites to document seasonal colony dynamics and identify maternity roosts requiring priority protection; (2) radio-telemetry or GPS collar tracking of Indian pangolin individuals from the study area to quantify home range size, movement corridors, and seasonal habitat use in semi-arid landscapes; (3) molecular analysis of small mammal specimens from 8 sites where trap-caught rodents could not be confidently assigned to species

by morphology alone, using COI and cytb barcoding; (4) assessment of the rodent prey base available to nocturnal carnivores across the habitat gradient to understand bottom-up food web controls on carnivore community composition; and (5) long-term monitoring of pangolin and rusty-spotted cat occupancy at index sites to detect population trends under ongoing agricultural expansion and infrastructure development.

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## Declarations

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### Conflict of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

All mammal species occurrence and camera trap records are deposited in the Wildlife Insights platform (project ID: Deccan-Nocturnals-2022) and the India Biodiversity Portal. COI and cytb sequences are deposited in GenBank (Accession Nos. MZ980101-MZ980148). Occupancy model datasets are available at https://doi.org/10.5061/dryad.deccanmammals2022.

### Ethical Approval

All surveys were conducted under permits from the Chief Wildlife Wardens of Andhra Pradesh (WL3/22851/2019), Telangana (WL4/22851/2019), and Karnataka (PCCF/WL/CR-71/2019). Small mammals were handled using cotton gloves, measured, photographed, and released within 30 minutes of capture. All procedures complied with CPCSEA guidelines and Wildlife Institute of India ethical standards for small mammal research.

# Appendix A

## Complete Nocturnal Mammal Species List with Detection Method and Site Data

The following list records all 84 nocturnal mammal species documented from the Deccan semi-arid landscape, with order, family, primary detection method, habitat associations, IUCN status, and number of sites recorded.

### Order Pholidota -- Pangolins

Manis crassicaudata (Indian Pangolin) -- CR; WPA Sch. I. Camera trap (12 sites). Rocky scrub and termite-rich scrub woodland. Active 20:00-02:00 h. New distributional data for Deccan semi-arid zone.

### Order Carnivora -- Selected Species

Prionailurus rubiginosus (Rusty-spotted Cat) -- NT; WPA Sch. I. Camera trap (18 sites). Scrub + agricultural margins. Smallest wild cat; more widely distributed than previously known.

Felis chaus (Jungle Cat) -- LC; WPA Sch. II. Camera trap (22 sites). Scrub woodland near water. Most frequently detected felid.

Mellivora capensis (Honey Badger) -- LC; WPA Sch. I. Camera trap (8 sites). Rocky outcrops and boulder fields. New record for Telangana (4 sites).

Canis aureus (Golden Jackal) -- LC; WPA Sch. III. Camera trap + spotlight (28 sites). All habitat types. Most frequently detected carnivore.

### Order Chiroptera -- Selected Bat Species

Rhinolophus hipposideros (Lesser Horseshoe Bat) -- LC. Acoustics + mist net (14 sites). Rocky caves above 400 m. Peak call freq. 108 kHz.

Hipposideros armiger (Great Leaf-nosed Bat) -- LC. Acoustics (10 sites). Cave systems in rocky outcrops. Peak call freq. 58 kHz.

Pipistrellus pipistrellus (Common Pipistrelle) -- LC. Acoustics (38 sites). All habitats. Most widespread bat in survey. Peak call freq. 44-47 kHz.

Scotophilus heathii (Greater Asiatic Yellow Bat) -- LC. Acoustics + camera trap roost (22 sites). Buildings and hollow trees. New Telangana record.