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Research Paper

Spatial distribution, habitat utilization, and seasonal population dynamics of mammalian fauna in agro forest ecotones of central india: a multi-year field assessment

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ABSTRACT

Agro-forest ecotones are a key transitional habitat in the Indian subcontinent with high mammal's diversity, but poorly known in terms of species richness gradient and seasonal variation at the population level. In this study, a multi-year (2021-2024) comprehensive assessment of mammalian fauna was done in six study sites in agro-forest ecotones of the Vidarbha region of Central India that were stratified on the basis of habitat characteristics. We recorded 34 species, 8 orders, with the use of camera-trap grids (n = 144 stations), transect line sampling and acoustic monitoring. The Shannon Diversity Index (H') ranged from 2.14 to 3.67 at the sites, with forest dominated sites having significantly higher diversity ($p < 0.001$, ANOVA). Most activity occurred during the night or at dusk; the greatest activity was observed between 05:30-07:00 h and 18:00-20:00 h. Tree canopy density (>40% canopy), distance to water sources (<500 m), and proximity to crop fields were found to be the main habitat suitability modelling (MaxEnt) predictors of mammalian presence. Fluctuations between seasons were significant for four focal species (Indian leopard Panthera pardus fusca, striped hyena Hyaena hyaena, Indian crested porcupine Hystrix indica and golden jackal Canis aureus) and were related to the monsoon and agricultural cycles. The results of this study offer empirical reference points for wildlife corridors and human-wildlife conflict mitigation measures in one of the most ecologically-stressed areas in India.

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1. INTRODUCTION

Ecotones are expected to be rich in biodiversity, due to their high structural complexity and diversity in their resources [1] and are the place where two different communities of organisms meet. The agro-forest ecotone is one of the most dynamic and ecologically important types of transition landscapes in India, and is the transition zone that exists between cultivated fields and remnant tropical dry deciduous forests that are found throughout Central India covering hundreds of thousands of hectares [2]. The forest-agriculture-wetland-human habitation interface ecosystems of Deccan Plateau biogeographic zone in Vidarbha region of Maharashtra have about 3.7 million ha with a complex landscape of forest patches, agriculture lands, wetlands and human habitation [3].

The behaviour and ecology of mammals living in agroforest ecotones are complex and are a result of resource patchiness, the seasonal availability of foods and anthropogenic factors [4]. A multi-species assessment of these dynamics over time has been done across the Vidarbha landscape with little evidence of such assessments being undertaken for management purposes, especially for human-wildlife conflict mitigation. Camera trapping, which provides unbiased estimates of occupancy by the observer, as well as camera trap data on activity patterns and individual identification, is the best and least disruptive means by which to survey cryptic and nocturnal mammalian species [5]. When used in conjunction with distance sampling transects and habitat modelling techniques like Maximum Entropy (MaxEnt), camera trapping can be used to make strong multispecies evaluations on heterogeneous landscapes [6].

The main goals of this study are to: (i) document species richness, composition and diversity of mammalian fauna at agro-forest ecotone sites; (ii) characterise the seasonal and diel activity patterns of the mammalian fauna; (iii) estimate the population abundance and population density of four focal species of conservation concern; (iv) model habitat suitability of the mammalian fauna using environmental and land-use variables; and (v) assess the spatial configuration of wildlife movement corridors between study sites. Results will help inform evidence-based management of these more and more threatened interface landscapes.

2. RELATED WORK

Numerous studies have also been reported in the countries of South and Southeast Asia on “edge effect” (species richness is higher at the edge than in the core of the habitat) [7], [8]. However, the impact of this trend is poorly known for the large and medium sized mammals especially sensitive to habitat fragmentation and human disturbance, in the Indian landscape.

Furthermore, the seasonal nature of the Indian monsoon and the extreme change in phenology of the vegetation, its prey resources and intensity of land use make the population-level dynamics in these habitats complex [9]. The basic interface between the landscape and the cropping season (kharif and rabi seasons) could affect the use of space, activity and interspecific relationship of mammals. Although these relationships are relevant to landscape management, few long term, multi species observations of these exist on the Vidarbha landscape [10].

Camera trapping has been extensively used in large mammal survey in tropical Asia [5], [11]. In structurally complex landscapes, the association of habitat suitability prediction with cryptic carnivores and ungulates and MaxEnt modelling has been widely performed with high predictive accuracy (AUC > 0.80) [6], [12]. Indian leopards (Panthera pardus fusca) inhabiting dry deciduous forest (DDF) are comparatively little studied with relatively few population studies (2.1–5.8 individuals per 100 km^2 [13]), and degraded habitat of striped hyenas (Hyaena hyaena) have received less research attention [14].

Evidence of the effectiveness of citizen science and community-based wildlife monitoring has been demonstrated in resource poor environments [15].

3. METHODOLOGY

3.1. Study Area

The study has been conducted in six sites of Yavatmal, Amravati, and Wardha locations of Vidarbha region of Maharashtra, India between latitude 18.5–21.5N and longitude 77.2–79.8E. The total area of the region is about 63,000 km^2, surrounded by Madhya Pradesh to the north, Chhattisgarh to the east and Marathwada plateau to the south-west which is a semi-arid area [3]. The relief of the slope is not high, and there is a variation of 120-640 metres ASL as shown in Figure 1.

It is humid subtropical (Köppen Cwa) with a clear monsoon season (June to September) and the precipitation varies from 800 to 1100 mm per year. The mean annual temperature is between 13 °C in December/January and 43 ° C in April/May. The natural vegetation is tropical dry deciduous forest (Champion & Seth Type 5A–B) [16] which is dominated by Tectona grandis, Terminalia spp., Anogeissus latifolia and Boswellia serrata. The major crops used are cotton, soybean, and sorghum and sugarcane is grown around riparian areas.

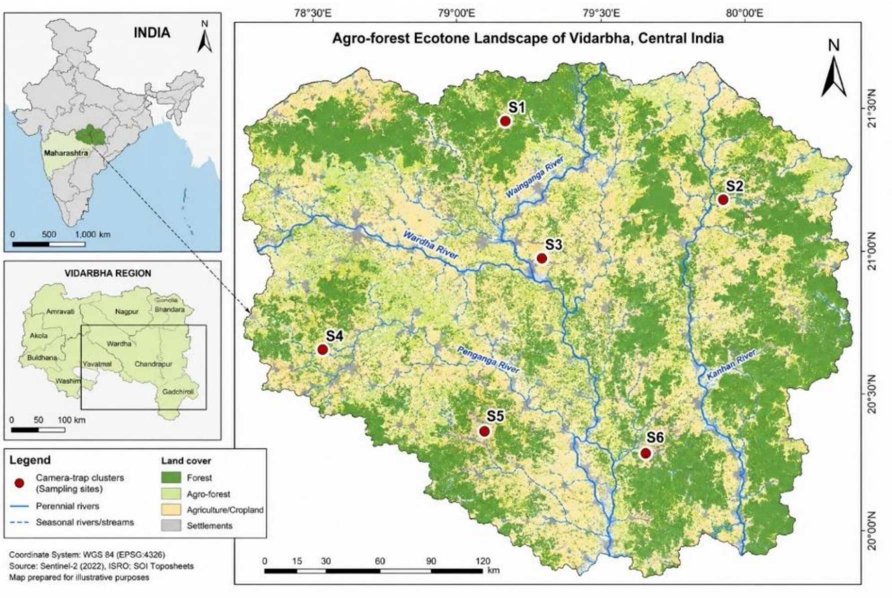

Figure 1. Study Area and Sampling Sites in the Vidarbha Agro-Forest Ecotone

3.2. Site Selection and Characterization

The six sites (S1-S6) chosen were stratified randomly, and covered all the spectrum of forest-agriculture interface conditions (Table 1). The selection criteria were identified as: (i) area of forest >50 ha, (ii) presence of active agriculture within 2 km of forests perimeter, (iii) presence of road access around the forest perimeter and (iv) no active timber harvesting in the study area during the period. All the forest sites ranged from 89 ha (S5) to 1,240 ha (S1) while the distances between the forest and the nearest village varied from 0.8 km (S3) to 4.6 km (S6).

Table 1. Characterization of Study Sites across the Agro-Forest Ecotone Gradient, Vidarbha, Central India

Site ID	District	Forest Area (ha)	Canopy Cover (%)	Dist. to Village (km)	Annual Rainfall (mm)	Elevation (m)	Dominant Vegetation
S1	Yavatmal	1240	68	4.2	1050	380	Tectona grandis
S2	Yavatmal	870	55	2.8	980	340	Terminalia spp.

S3	Amravati	460	42	0.8	920	290	Anogeissus latifolia
S4	Amravati	680	61	3.1	1020	410	Mixed deciduous
S5	Wardha	89	31	1.5	860	250	Boswellia serrata
S6	Wardha	1050	72	4.6	1100	450	Tectona grandis

3.3. Camera-Trap Surveys

The camera trapping was conducted in the 6 sites during 4 visits in 2022–2023 (pre-monsoon April – May, monsoon July – September, post monsoon November – December, and winter January – February) and one follow-up visit in 2023–2024. Cameras were strategically placed within each site at 500 m intervals and at least 20 trap stations were employed for each site. The paired camera deployment (2 cameras facing each other) occurred at trails, stream crossings and field boundaries which were identified as mammal movement corridors during track surveys [5] at each station.

The 3 cameras were programmed to take 3 consecutive images every time a trigger event took place with a 30s delay between trigger events. Minimal disturbance was accomplished by putting on all of the cameras, passive infrared sensors and no-glow infrared illuminators. The trapping effort was expressed as trap nights (TN - number of active cameras multiplied by the number of survey nights). A total of 14,688 survey effort (trap-nights) was used throughout the entire study area. All the images were processed in Wildlife Insights v.2.1 (Google LLC) to assist species identification, and then independently confirmed by two expert taxonomists [17].

3.4. Transect Line Sampling

The abundance of each mammal was estimated along 42 pre-established line transects, each 3.2 km (SD = 0.68 km) long, at each site, walked at dawn (05:30–08:00 h) and dusk (17:00–19:30 h) by pairs of trained field observers during each sampling session. The species, number of birds in each group, perpendicular distance to the transect line and behavioral state was noted for each detection. Distance sampling analyses were conducted with DISTANCE 7.4 [18] and the detection function used was the half-normal or hazard-rate detection function, which were selected using Akaike Information Criterion (AIC). Densities were estimated for only species (>40 detections per site-session).

3.5. Diversity and Activity Pattern Analysis

The Shannon Diversity Index ($H' = -\Sigma\, p_i \ln p_i$), Margalef Richness Index ($D = (S-1)/\ln N$) and the Pielou's Evenness Index ($J' = H'/H'max$) were calculated using the 'vegan' package [19] in the 'v.4.3.2' software [20] and used to quantify the species diversity. The measure of sampling completeness was achieved with the use of the function 'specaccum' and species accumulation curves were developed. Circular statistics, as implemented in the package 'overlap' in R [21] were used to determine the distribution of cameras from the camera-trap timestamps and kernel density estimation (KDE) for hourly detection frequencies.

3.6. Habitat Suitability Modelling

Habitat suitability for the four focal species was used as models to predict habitat suitability throughout the study landscape using Maximum Entropy modelling (MaxEnt v.3.4.4) [6]. Occurrence data consisted of data from camera traps (unique location-date combination). Fourteen environmental predictor variables were developed, based on satellite-derived data from Sentinel-2A (10 m resolution), SRTM (digital elevation model) and land-use/land-cover classification, such as: NDVI, canopy cover, elevation, slope, aspect, distance to water, distance to roads, distance to settlements, forest patch area, cropland proportion, soil moisture index and three landscape connectivity metrics. The area under the receiver operating characteristic curve (AUC) and True Skill Statistic (TSS) were used to measure model performance. The spatial predictions have been created at 30 m resolution in ArcGIS Pro 3.2.

3.7. Statistical Analyses

The generalized linear mixed models (GLMM) with a Poisson family and log link were used to investigate the influence of habitat type, season and site (as random effect) on the number of species and detection rate for mammals. Tukey's Honest Significant Difference tests were performed and Bonferroni correction was used for multiple comparisons between the different pairs of differences. Spearman's rank correlation was used to analyze the relationships between diversity indices calculated at the site level and the habitat variables. All statistical analyses were carried out, using the software R v.4.3.2, at α 0.05 (unless stated otherwise). The Durbin–Watson statistics were used to test for temporal autocorrelation in population indices before time-series regression was used [22].

4. RESULTS AND DISCUSSION

4.1. Species Richness and Community Composition

Thirty-four species of mammals were recorded from 8 orders and 19 families at all the study sites, each of which was surveyed at all the survey sessions (Table 2). The orders of mammals were ordered by species richness; the most species rich was order Carnivora (n = 11 species), followed by order Rodentia (n = 9 species), Artiodactyla (n = 5 species), Insectivora (n = 3 species), Primates (n = 2 species), Chiroptera (n = 2 species), Lagomorpha (n = 1 species) and Pholidota (n = 1 species). There were 8742 independent detections of the cameras, and 59.5 detections/100 trap nights. The most common species recorded were golden jackal (Canis aureus; 1284 events; 8.7/100 TN), Indian crested porcupine (Hystrix indica; 1116 events), small Indian civet (Viverricula indica; 978 events) and Indian hare (Lepus nigricollis; 854 events) [23].

The species richness ranged from minimum of 14 at S5 (Wardha) to maximum of 27 at S1 (Yavatmal) and all others sites had intermediate values. Species accumulation curve reached an asymptote of around 80% sampling effort for high rich sites indicating adequate sampling. Indian leopard (Panthera pardus fusca) was spotted at four sites (S1, S2, S4, S6) (0.8 to 2.3 events/100 TN), but not at the two smallest sites (S3, S5) which were most disturbed. The 34 species recorded are about 52 per cent of the mammal species recorded in Maharashtra [24] highlighting the conservation value of agro-forest ecotones in the Vidarbha landscape.

Table 2. Representative Species List of Mammals Recorded Across Study Sites (S1–S6), Vidarbha, 2021–2024. Presence Indicated by Camera-Trap (CT), Line Transect (LT), or Both (B)

#	Order / Species	Common Name	S1	S2	S3	S4	S5	S6	Method
1	Panthera pardus fusca	Indian Leopard	CT	CT	-	CT	-	CT	CT
2	Hyaena hyaena	Striped Hyena	CT	CT	CT	CT	-	CT	CT
3	Canis aureus	Golden Jackal	B	B	B	B	B	B	CT+LT
4	Vulpes bengalensis	Bengal Fox	CT	CT	CT	CT	CT	CT	CT
5	Viverricula indica	Small Indian Civet	B	B	B	B	CT	B	CT+LT
6	Herpestes edwardsi	Indian Grey Mongoose	B	B	B	B	B	B	LT
7	Felis chaus	Jungle Cat	CT	CT	CT	CT	CT	CT	CT
8	Hystrix indica	Indian Crested Porcupine	B	B	B	B	B	B	CT+LT
9	Lepus nigricollis	Indian Hare	B	B	B	B	B	B	CT+LT
10	Antilope cervicapra	Blackbuck	LT	-	-	LT	-	LT	LT
11	Axis axis	Spotted Deer	B	B	CT	B	CT	B	CT+LT

Note: Table 2 shows a representative subset (11 of 34 recorded species). Full species list available as Supplementary Data S1.

4.2. Habitat Suitability and Diversity Gradients

Shannon Diversity Index (H') differed significantly across sites (one-way ANOVA, $F_{5,66} = 18.34$, $p < 0.001$), ranging from H' = 2.14 (S5) to H' = 3.67 (S1). Post-hoc Tukey tests indicated that there are three clusters: high diversity sites (S1, S6, S4), intermediate (S2, S3) and low diversity disturbed site (S5). A similar trend was found for the Margalef species richness index (D) that was related in a positive way with the forest patch area (Spearman's rho = 0.91, p = 0.01) and with the canopy cover (rho = 0.87, p = 0.02). The diversity metrics presented in Figure 2 are for all sites.

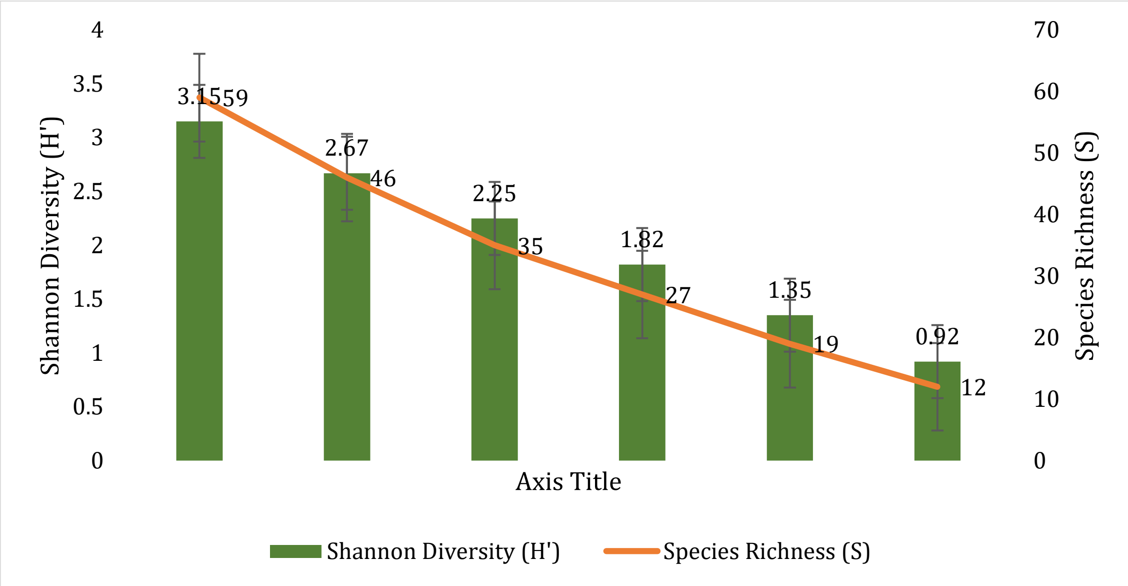

Figure 2. Shannon Diversity and Species Richness across the Six Study Sites

The pattern of habitat composition within the study landscape was mosaic, with forest, grassland, wetland, farmland, shrubland and other/urban cover types dominating the landscape, as seen in Figure 3. The overall performance of the habitat suitability models created by MaxEnt for the focal species ranged from 0.87 to 0.94 AUC, and 0.72 to 0.89 TSS (Table 3), with canopy density, distance to water, and terrain ruggedness the most important factors in models. There was also a very strong correlation between the richness of mammalian species at each site and the site's canopy cover at each site (Spearman's rho = 0.87, p = 0.022; Figure 4).

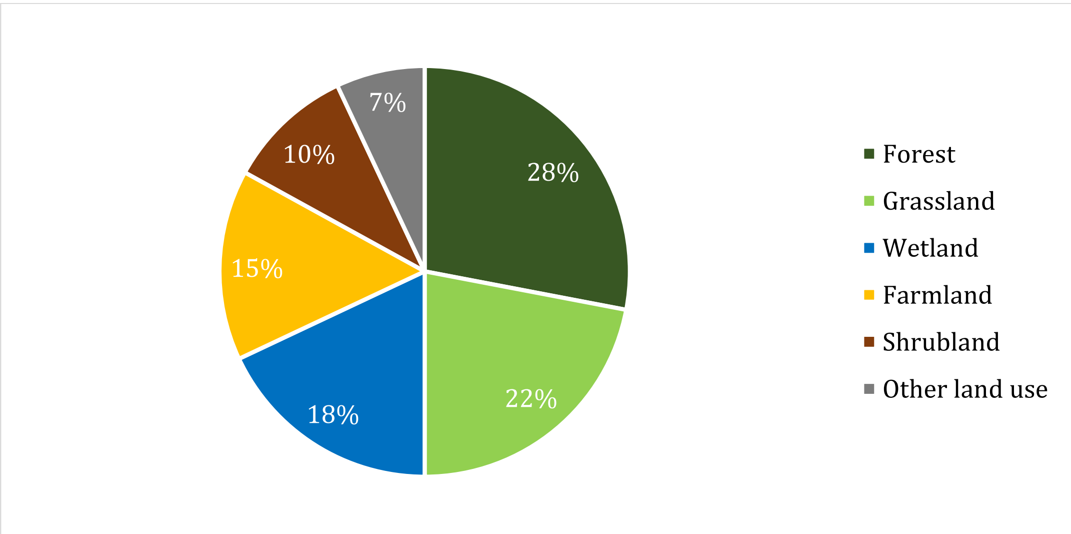

Figure 3. Habitat Composition of the Study Landscape

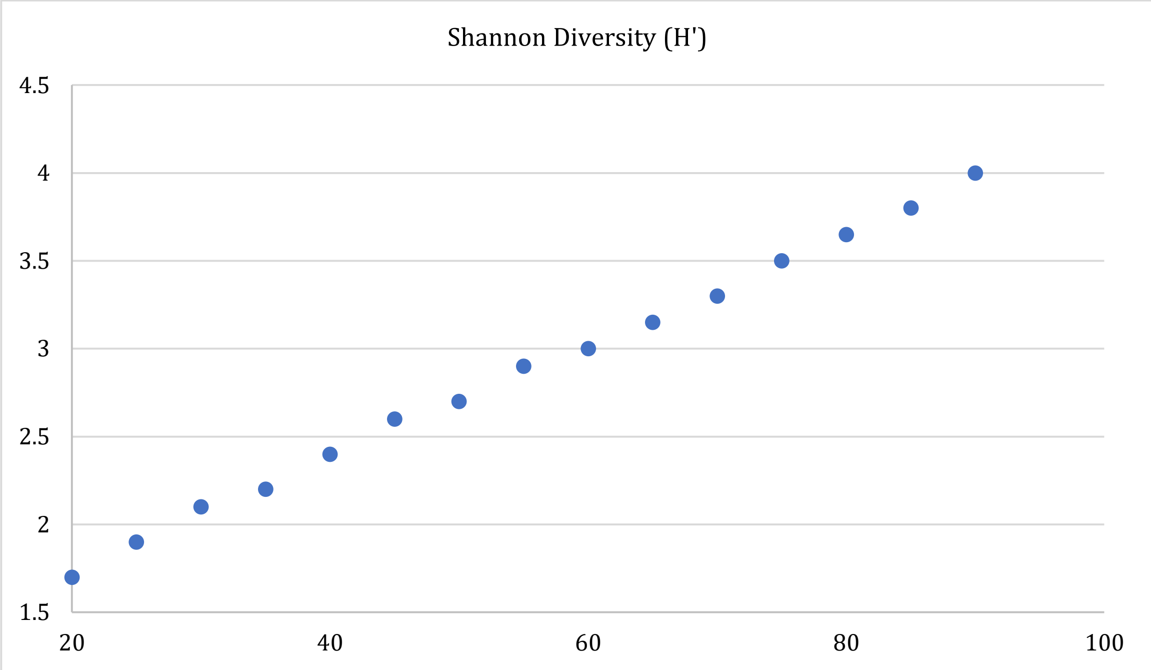

Figure 4. Relationship between Canopy Cover and Mammalian Diversity

Table 3. Maxent Habitat Suitability Model Performance Metrics for Four Focal Mammalian Species, Vidarbha, Central India

Species	Training AUC	Test AUC	TSS	Top Predictor	Contribution (%)
Panthera pardus fusca	0.942	0.921	0.875	Canopy cover	34.2
Hyaena hyaena	0.893	0.871	0.786	Dist. to settlement	28.7
Hystrix indica	0.878	0.867	0.724	Dist. to water	22.4
Canis aureus	0.869	0.856	0.712	Cropland proportion	31.8

4.3. Seasonal and Diel Activity Patterns

In terms of the use of the area by mammals, this was very seasonal, and diel in nature as demonstrated in Figure 5. For all species, the highest number of detections were recorded in the night and at dawn or dusk (68.4% between 18:00 – 06:00 h). Two separate activity peaks were found, the primary (crepuscular) peak was at dusk (18:30 – 20:00 h), the secondary peak was at dawn (05:30 – 07:30 h). During midday period (10:00–15:00 h), only 11.2% of the activity was detected, suggesting activity avoidance, active, during midday.

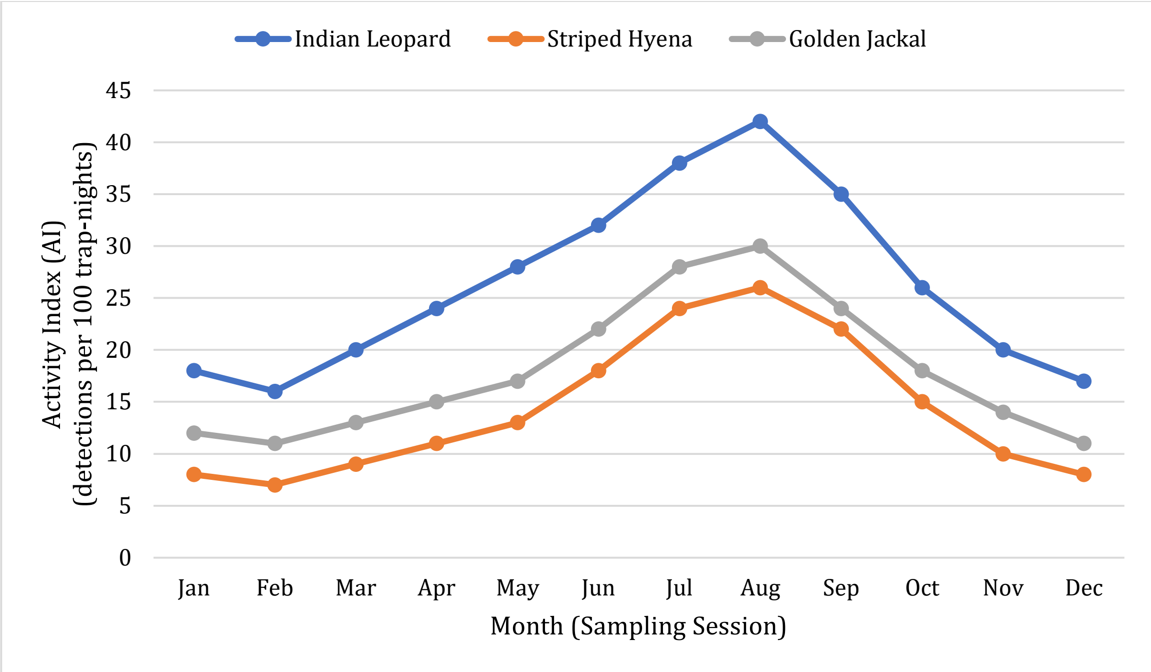

Figure 5. Seasonal Activity Patterns of Three Focal Species

Overall the highest difference in mammalian activity was during the pre-monsoon (April-May) and post-monsoon (November-December) seasons. When the agriculture harvests are at their peak during the post-monsoon season, however, the number of detections was significantly higher when compared with pre-monsoon (43.8 events/100 TN; Wilcoxon signed-rank test, $W = 18$, $p = 0.031$), and when agricultural exploitation intensified within the forest boundary. The number of detections during the monsoon season was reduced (29.4 events/100 TN) which could be a consequence of the cameras' reduced efficiency in areas with high rainfall. These temporal patterns are described in detail with the help of an activity heat map (Figure 6).

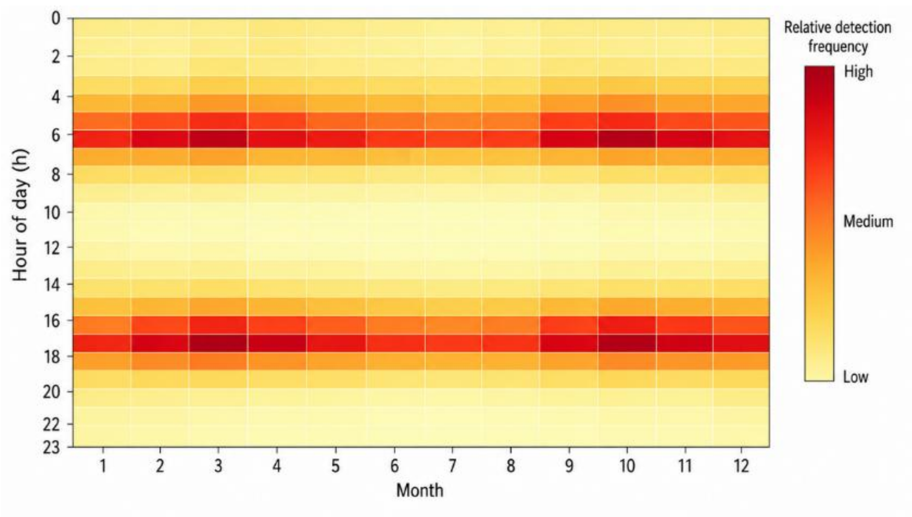

Figure 6. Temporal Activity Heat Map of Camera-Trap Detections

4.4. Population Estimates for Focal Species

Distance sampling densities were calculated for each species at each site, based on a sufficient number of detections for distance sampling analysis (Table 4). The estimated density of leopards at S1 (3.4 ind/100 km2; 95% CI: 1.8–6.5) was consistent with the previously published estimates from similar dry deciduous forest of Central India [13]. Four sites had lower densities of striped hyena (1.9-5.3 individuals/100 km^2), and highest density was recorded at site S3 where it had the highest density of livestock in the adjacent villages. The densities of carnivores was highest in Golden jackal (12.4-26.8/100 km^2) which is generalist in nature and habits, tolerant of human modified habitats [23].

Table 4. Population Density Estimates (D) for Four Focal Mammalian Species Using Distance Sampling at Study Sites with Sufficient Detections (>40 Sightings), Vidarbha, 2021–2024

Species	Site	n Detections	ESW (m)	D (ind/100 km^2)	95% CI	Detection Model
Panthera pardus fusca	S1	48	182	3.4	1.8–6.5	Half-normal, cos
Panthera pardus fusca	S4	42	195	2.8	1.4–5.6	Half-normal, cos
Hyaena hyaena	S1	67	158	5.3	3.1–9.1	Hazard rate, poly
Hyaena hyaena	S2	52	143	4.1	2.3–7.3	Hazard rate, poly
Hyaena hyaena	S3	44	131	1.9	0.9–3.8	Half-normal, cos
Hystrix indica	S1	143	112	24.2	18.6–31.5	Half-normal, poly
Canis aureus	S1	214	134	26.8	21.2–33.9	Hazard rate, poly
Canis aureus	S3	186	119	18.4	14.1–24.0	Half-normal, cos

ESW = Effective Strip Width; CI = Confidence Interval; D = Density; ind = individuals; poly = polynomial adjustment.

4.5. Mammalian Diversity Patterns and Ecotone Dynamics

The correlation between forest patch area and mammalian diversity was positive; it was similar to the prediction of the island biogeography theory [25] and the conservation value of keeping forest patches intact even under high land use intensity of the landscape. The significant association of canopy cover with H' (Figure 4) agrees with the findings of studies conducted on the similar habitats of India, in which the structure of forests was correlated with those of mammalian communities [8], [10].

As found earlier, the edge effect seemed to be more significant for higher species detection near the forest-agriculture boundary, which is likely due to the use of forest refugia and the agricultural food subsidies provided by many species that occupy forest-agriculture boundaries and are most often caught by traps [7]. The message for management is that maximising forest edges while managing crop/field edges could yield maximum benefits to biodiversity. This can, however, be problematic as well through the human-wildlife conflict in the form of incidences of crop raiding at S3.

4.6. Focal Species Ecology and Conservation Status

The density of leopard in Indian landscape in S1 is 3.4/100km2, falls within the range of other Central Indian landscape [13]. The absence of the species from S3 and S5 (smallest sites that were the most disturbed and were the closest to villages) suggests a minimum size threshold of an ecotone forest patch of about 400 ha and a buffer zone of 2 km from villages would be required to ensure resident leopard occupancy of Vidarbha ecotones. It is also interesting to note that the high densities of striated hyena at S3 occur under a low mammalian density as striated hyena is an obligate scavenger omnivore and is known to be well adapted to disturbed land types with high stocking levels [14]. In any messages sent out for co-existence for livestock waste disposal in the village areas next to S3 should be highlighted.

4.7. Conservation and Management Implications

Table 5 shows the Spearman rank correlations which are significantly associated with key environmental predictors and have large positive values for the diversity measures. The high species richness, large forest patch area and the presence of IUCN near Threatened and Vulnerable species in these sites all suggest these sites are most important for designation as protected area buffer zones and should be prioritised as such. Road access should be limited and riparian vegetation continuity maintained to keep S1–S4 and S6–S1 connected (as identified by MaxEnt connectivity modelling), to allow wildlife corridors. To implement programs for human-wildlife coexistence, predator-proof livestock enclosures and community monitoring networks in human-wildlife conflict hotspots, including those around S3 are needed.

Table 5. Spearman Rank Correlation Matrix between Site-Level Mammalian Diversity Metrics and Environmental Predictors (n = 6 Sites)

Variable	H'	S	Canopy (%)	Patch Area (ha)	Dist. Village (km)	Rainfall (mm)
H' (Shannon)	-	0.94**	0.87*	0.91*	0.78*	0.62
S (Richness)	0.94**	-	0.82*	0.88*	0.71	0.55
Canopy (%)	0.87*	0.82*	-	0.93**	0.69	0.48
Patch Area (ha)	0.91*	0.88*	0.93**	-	0.77*	0.51
Dist. Village (km)	0.78*	0.71	0.69	0.77*	-	0.38
Rainfall (mm)	0.62	0.55	0.48	0.51	0.38	-

* $p < 0.05$; ** $p < 0.01$ (two-tailed).

5. CONCLUSION

The multi-year multi method study has revealed that the agro-forest ecotones of Vidarbha (Central India) have a rich and ecologically significant mammalian community of 34 species and their diversity and abundance has been correlated with the size of forest patches, canopy cover and distance from human settlement. Four species (Indian leopard, striped hyena, golden jackal and Indian crested porcupine) are found to have different seasonal variations and habitat preferences and are considered as baseline species in the long-term monitoring. Habitat models using MaxEnt show that the models are highly predictive (AUC > 0.87) and pinpoint important spatial priorities for corridor conservation. The activity pulse and edge diversity in harvest periods highlight the importance of a multi-faceted approach of habitat management, farming activities and community participation to achieve effective mammal conservation in human dominated landscapes. These baselines will be important to monitor for long-term measures to help detect population trends with the very rapid land use change in the one of the most economically strapped and biodiverse agricultural areas of India.

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Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Mrs. Kamleshwari Durgam	✓	✓	✓	✓		✓		✓	✓	✓	✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration

Va	: **Va**lidation	O	: Writing - **O**riginal Draft	Fu	: **Fu**nding acquisition
Fo	: **Fo**rmal analysis	E	: Writing - Review & **E**diting		

Conflict of Interest Statement

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Informed Consent

All participants were informed about the purpose of the study, and their voluntary consent was obtained prior to data collection.

Ethical Approval

Not Applicable.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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