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Article

Avian and Mammalian Diversity and Abundance in Jhalana Reserve Forest, Jaipur, India

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Abstract: We utilized camera traps to assess animal diversity, relative abundance, and anthropogenic activities in the Jhalana Reserve Forest (JRF), located amidst Jaipur, with a population of 3.9 million people. Between November 2017 and November 2019, camera traps were strategically deployed in both the tourist zone and peripheral areas, capturing 16,328 photos. This study represents the first comprehensive baseline assessment of animal diversity in JRF, documenting a total of 39 species, including 18 bird species, 14 mammals, and six domestic species, alongside human activity. Among the 14 mammal species, seven were carnivores. Notably, we identified 25 individual Indian leopards (*Panthera pardus fusca*) during 2017-2018, comprising 8 males and 17 females, highlighting the leopard as the apex predator in JRF. Concurrently, domestic animals accompanied by humans were observed within JRF. However, rigorous conservation efforts and patrols by the Rajasthan Forest Department resulted in a notable decline in human intrusion, reducing from 28.0% in 2017-18 to 3.9% in 2018-2019, with domestic animal activity reaching zero in the latter period. Consequently, the relative abundance of wildlife species increased during the study period of 2018-2019, underscoring the positive impact of conservation strategies implemented by authorities. Our findings affirm that camera traps effectively establish baseline data, assess animal diversity, and evaluate relative abundance in reserve forests situated within human-dominated landscapes. This study provides critical insights to inform the development and implementation of conservation strategies in similar protected areas.

Keywords: Diversity; avian; mammalian; Species abundance

Introduction

The study of biodiversity and ecological dynamics holds paramount importance in understanding and preserving our natural world. In this light, documenting species richness and species abundance becomes a critical tool for ecological research and conservation efforts. With the advent of technology, camera traps have emerged as an invaluable asset in this realm, offering insights into the lives of elusive and nocturnal wildlife that would otherwise remain hidden from our eyes [1]. Species diversity, distribution, and population abundance are strongly influenced by changes in habitat and its use over time [2,3]. Effective monitoring of species planning and implementation of conservation strategies, as well as understanding the demographics of wildlife are critical [4]. The Jhalana reserve forest represents a unique ecosystem that has yet to be thoroughly explored and understood. The significance of this study lies not only in its novelty but also in its potential to uncover unprecedented data regarding species distribution, human intrusion patterns, and the prey base for apex predators like leopards within this relatively new reserve. Through a comprehensive two-year survey employing camera traps, this research aims to illuminate the

intricate tapestry of life that thrives in the shadows of Jhalana, offering critical insights that could guide future conservation strategies and enhance our understanding of species dynamics in newly established protected areas.

The deployment of camera traps across various ecosystems has revolutionized the field of wildlife research and conservation, offering unparalleled insights into the behaviors, distributions, and populations of myriad species, often with a focus on elusive and nocturnal animals. This methodological advancement is well-documented in the literature, with studies highlighting its efficacy in recording species occurrences— a cornerstone of biodiversity surveys essential for determining species distribution and informing the International Union for Conservation of Nature (IUCN) status [5]. Furthermore, photographic capture-recapture techniques facilitated by camera traps have become a gold standard in estimating the abundance and density of several secretive large carnivores, including leopards [6–8], striped hyenas (*Hyaena hyaena*)[9–12], tigers (*Panthera tigris*)[8,13,14], snow leopards (*P. uncia*)[15], and jaguars (*P. onca*)[16]. Beyond their application in the study of mammalian fauna [17–19], camera traps have also proven effective in documenting avifauna within various habitats, including forests and grasslands [20,21].

Despite the widespread application and success of camera traps in diverse environments and for various species, a noticeable gap persists in the baseline data available for certain areas, notably the Jhalana reserve forest (JRF). Established in 2017, Jhalana has remained relatively unexplored from a scientific standpoint, lacking comprehensive data that could inform conservation efforts and enhance our understanding of its ecological dynamics [22]. This absence of baseline data represents a critical knowledge gap, underscoring the necessity of this study to employ camera traps within the reserve. By doing so, we aim to not only contribute to filling this gap but also to provide a foundation upon which future research and conservation strategies can be built, tailored to the unique environmental and biological context of the Jhalana reserve forest.

JRF is located in the heart of Jaipur city in north-western India, and is a northern tropical dry deciduous forest type. Apart from a limited number of species-specific studies on spiders [23], gray langurs (*Presbytis entellus*)[24], vegetation [25], forest ecosystem services [26], and our studies on the leopard population (*Panthera pardus fusca*), [22,27–32], no further studies have been conducted to document the species richness of JRF. Leopards have existed for centuries in this small island habitat, now surrounded by 3.9 million people in Jaipur's urban areas. However, there is no systematic documentation of the diversity of birds and mammals and the associated abundance in the JRF. The paucity of data on the ecology and wildlife of the JRF prompted us to conduct a baseline study on local wildlife diversity.

After studying the geography and climatic conditions, we discovered that there are no perennial streams, wells, or other natural water sources in the JRF. The only water sources available are artificial waterholes created by the Rajasthan Forest Department and the local nature lovers, villagers, and tourists. Wildlife has been observed to be water dependent and concentrate at these artificial waterholes. We set up camera traps at all of these waterholes and in the outlying areas. It is known that the frequency of revisiting specific camera stations is a consequence of site fidelity [33].

At the heart of our investigation into the ecological dynamics of the Jhalana Reserve Forest (JRF) lies a series of focused research questions aimed at elucidating the biodiversity and anthropogenic impacts within this relatively unexplored sanctuary. Our primary research objectives are twofold: first, to assess the diversity of animal species and their relative abundance within the reserve; and second, to investigate the extent and nature of human activities impacting this ecosystem. Complementing these objectives is an evaluation of the efficacy of camera trap methodology in capturing comprehensive photographic records of the species residing in JRF, thus providing a robust framework for generating essential baseline data.

Our hypothesis posits that the camera trap method serves as an effective tool not only for cataloguing animal diversity and their relative abundance but also for recording human intrusion in reserve forests situated within human-dominated landscapes. We anticipate that the insights gleaned from our study will furnish the forest department with valuable data to inform and refine strategies

aimed at rewilding, curtailing human intrusion, and bolstering the prey base for the leopards of Jhalana.

To address our research aims, we employed a rigorous methodological framework leveraging commercially manufactured Cuddeback camera traps (X-Change Color Model 1279), strategically deployed across the reserve from November 2017 to November 2019. This approach was tailored to the specific ecological characteristics and challenges of the semi-arid region of Northwest India where JRF is located. Notably, the reserve's lack of perennial water sources, which concentrates species activity around artificial waterholes, guided our stratified deployment of cameras at these critical sites to maximize record yield.

Our approach is underscored by its novelty and comprehensiveness - representing the first exhaustive study of its kind within JRF. By covering all locations within the reserve and compiling data without disturbing the wildlife, our study stands as a pioneering effort in the conservation and understanding of this unique ecosystem. Furthermore, our methodological choices — informed by the proven efficacy of camera traps in various studies and tailored to the specific context of JRF — directly address the previously identified gap in baseline data.

In aligning our study with these objectives, we anticipate providing foundational insights that will significantly contribute to the conservation and management strategies for Jhalana Reserve Forest, drawing on our extensive, novel dataset to elucidate not only the patterns of wildlife diversity and distribution but also the intricate interplay between these natural inhabitants and human activities within the reserve.

Methods

Study Area

The study was conducted from November 2017 to November 2019 at Jhalana Reserve Forest (JRF), located at $26^{\circ}51'N$ $75^{\circ}49'E$, 516 meters above sea level (ASL), in the southeast corner of Jaipur city, India (Figure 1).

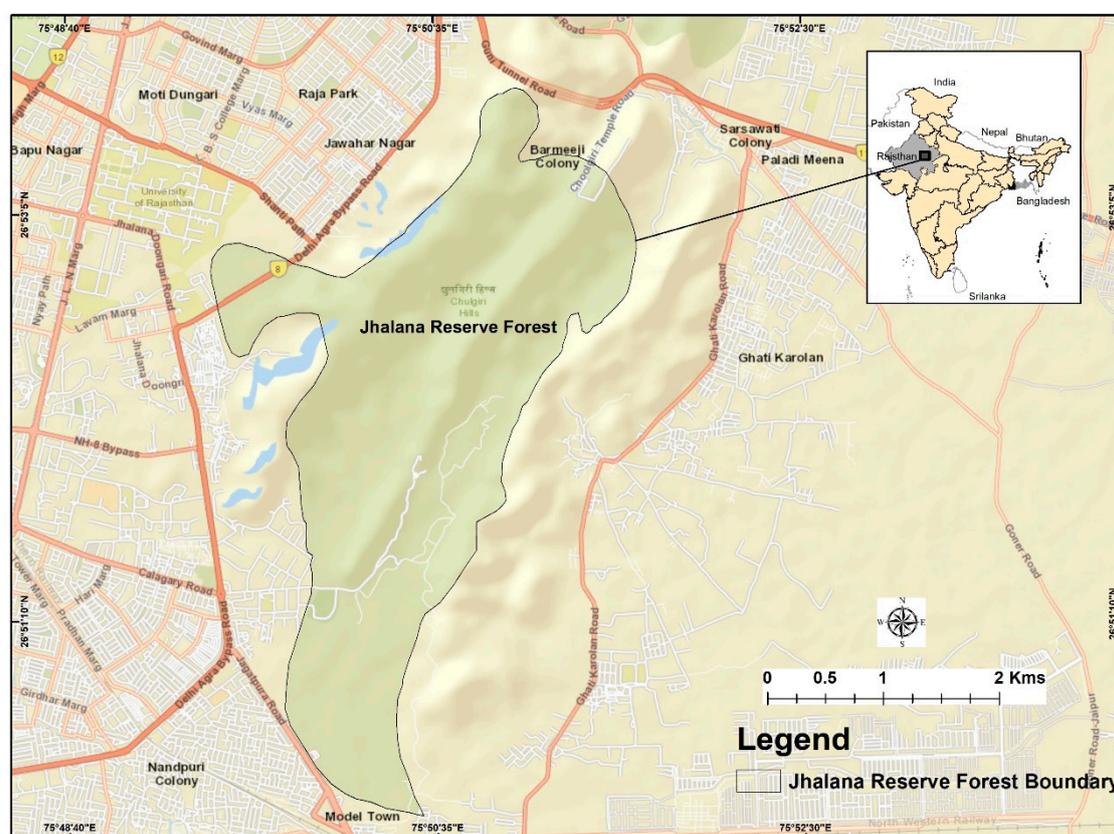


Figure 1. The location of Jhalana Reserve Forest in Rajasthan State, northwestern India.

JRF was declared a Reserve Forest in 1961 under the provisions of the Rajasthan Forest Act, 1953, encompassing a total area of 29 km². In 2017, it was designated as a leopard reserve. During the 1980s, the main valley was planted with *Acacia tortilis* and *A. senegal*. Most ephemeral streams flow in a south-westerly direction, while higher elevations in the north form low, flat hills. Elevations in the plains range from 280 meters in the south to 530 meters in the northeast. JRF lacks defined buffer or core areas, and a 2-meter-high wall with a 3-meter-high fence separates the forest area from surrounding neighborhoods and villages.

JRF is characterized by a semi-arid tropical dry deciduous forest. Tourist access is permitted through jeep safaris on three designated routes. Due to the continuous interface between the forest and human habitats, and its recent designation as a forest reserve, human encroachments into the reserve are common, as are wildlife incursions into adjacent villages and urban areas.

Field Methods

We utilized commercially manufactured Cuddeback cameras (X-Change Color Model 1279) equipped with motion sensors. No bait or lure was used to attract wildlife at any site [34]. The cameras were set with a minimum time delay of 15 seconds between captures. Each recording period lasted two weeks, and each camera was assigned a unique identification number. A total of 21 cameras were deployed, all of which recorded the date and time of each photo (Figure 2). Overexposed images with distorted perspectives and lack of clarity were discarded (N=89, 0.55%) and not included in our analyses.



Figure 2. An example of documentation with camera traps of Indian Leopard (*Panthera pardus fusca*) and Striped Hyena (*Hyaena hyaena*) at a Nilgai (*Boselaphus tragocamelus*) carcass.

The cameras were deployed in an optimally stratified manner. Cameras within the reserve were left untouched during the capture cycles, while cameras on the periphery were removed during the

day and reinstalled at night to prevent theft or damage. Cameras were installed at a height of 45 to 50 cm above the ground to cover access routes to the waterholes. In the outlying areas, camera traps were enclosed in boxes securely attached to iron bars to ensure safety. The trap locations were mapped using a GPS device.

We recorded the number of species (mean \pm SD), their abundance, distribution, and human activities. Individual leopards were identified based on their facial markings to estimate their abundance [22]. Of the 39 species recorded in the study area, 10 wildlife species were classified as gregarious (two or more individuals in one photo, Table 1), and the remaining 29 were classified as solitary. Since photographs of gregarious species indicate higher species abundance estimates and wider distribution [35], we recorded one data point per photograph when more than one individual of the same species was observed.

Table 1. Camera-trapped species in the JRF along with their photographic records and relative abundance (%) during 2017-2019 (in descending order). Species with (*) are gregarious species.

Common Name	Scientific Name	Family	N 2017_2018	N 2018_2019	Relative	Relative
					Abundanc e	Abundanc e
					2017_2018	2018_2019
Birds						
INDIAN PEAFOWL*	<i>Pavo cristatus</i>	Phasianidae	3047	1579	24.62	39.94
JUNGLE BABBLERS*	<i>Turdoides striata</i>	Leothricidae	9	334	0.07	8.45
RUFOUS TREEPIE*	<i>Dendrocitta vagabunda</i>	Corvidae	3	310	0.02	7.84
RED VENTED BULBUL*	<i>Pycnonotus cafer</i>	Pycnonotidae	3	308	0.02	7.79
RED WATTLED LAPWING	<i>Vanellus indicus</i>	Charadriidae	1	62	0.01	1.57
BLUE ROCK PIGEON*	<i>Columba livia</i>	Columbidae	3	64	0.02	1.62
GREY FRANCOLIN	<i>Francolinus pondicerianus</i>	Phasianidae	8	10	0.06	0.25
CATTLE EGRET	<i>Bubulcus ibis</i>	Ardeidae	7	10	0.06	0.25
EURASIAN COLLARED DOVE	<i>Streptopelia decaocto</i>	Columbidae	0	7	0.00	0.18
GREATER COUCAL	<i>Centropus sinensis</i>	Cuculidae	4	5	0.03	0.13
SHIKRA	<i>Accipiter badius</i>	Accipitridae	2	5	0.02	0.13
WHITE THROATED KINGFISHER	<i>Halcyon smyensis</i>	Alcedinidae	19	2	0.15	0.05
BRAHMINY STARLING*	<i>Sturnia pagodarum</i>	Sturnidae	0	1	0.00	0.03
CINEROUS TIT	<i>Parus cinereus</i>	Paridae	0	1	0.00	0.03
BLACK DRONGO	<i>Dicrurus macrocerus</i>	Dicruridae	0	1	0.00	0.03
JACOBIN CUCKOO	<i>Clamator jacobinus</i>	Cuculidae	0	1	0.00	0.03
INDIAN EAGLE OWL	<i>Bubo bengalensis</i>	Strigidae	2	1	0.02	0.03
LONG LEGGED BUZZARD	<i>Buteo rufinus</i>	Accipitridae	4	0	0.03	0.00
Mammals						

NILGAI*	<i>Boselaphus tragocamelus</i>	Bovidae	3377	622	27.29	15.73
LEOPARD	<i>Panthera pardus fusca</i>	Felidae	473	188	3.82	4.76
SMALL INDIAN CIVET	<i>Viverricula indica</i>	Viverridae	10	100	0.08	2.53
INDIAN CRESTED PORCUPINE	<i>Hystrix indica</i>	Hystriidae	178	60	1.44	1.52
BENGAL FOX	<i>Vulpes bengalensis</i>	Canidae	295	48	2.38	1.21
STRIPED HYENA	<i>Hyaena hyaena</i>	Hyaenidae	328	30	2.65	0.76
BLACK NAPED HARE	<i>Lepus nigricollis</i>	Leporidae	427	30	3.45	0.76
GOLDEN JACKAL	<i>Canis aureus</i>	Canidae	0	7	0.00	0.18
SAMBAR DEER*	<i>Rusa unicolor</i>	Cervidae	7	6	0.06	0.15
INDIAN MONGOOSE	<i>Herpestes edwardsii</i>	Herpestidae	8	5	0.06	0.13
INDIAN HEDGEHOG	<i>Paraechinus micropus</i>	Erinaceidae	1	1	0.01	0.03
SPOTTED DEER*	<i>Axis axis</i>	Cervidae	157	0	1.27	0.00
GRAY LANGUR	<i>Semnopithecus</i>	Pteropodidae	1	0	0.01	0.00
FRUIT BAT	<i>Pteropus giganteus</i>	Pteropodidae	1	0	0.01	0.00
Domestic Animals						
DOMESTIC CAT	<i>Felis catus</i>	Felidae	2	0	0.02	0.00
CATTLE	<i>Bos taurus</i>	Bovidae	449	0	3.63	0.00
GOATS	<i>Capra aegagrus hircus</i>	Bovidae	48	0	0.39	0.00
DOMESTIC HORSE	<i>Equus caballus</i>	Equidae	18	0	0.15	0.00
FERAL DOG	<i>Canis lupus familiaris</i>	Canidae	10	0	0.08	0.00
DOMESTIC PIG	<i>Sus scrofa domesticus</i>	Suidae	2	0	0.02	0.00
Human						
HUMANS*	<i>Homo sapiens</i>	Hominoidea	3470	155	28.04	3.92
Total			12374	3953	100	100

To understand the impact of designating the area as a reserve forest, the study was conducted over two consecutive years.

Statistical Analysis

Field data points collected from camera traps were used to compute the Abundance and Shannon Diversity Index at the geolocations of the camera traps. These values were then mapped using inverse distance weighted (IDW) interpolation. The geolocations varied annually based on changes in camera trap locations and waterholes.

Statistical comparisons were performed using R version 4.3.3. For this analysis, random points (N>100) were collected each year across the visible study area. Additional mapping processes were conducted using the QGIS 3.34 spatial environment.

Results

Over the study period from 2017 to 2019, a total of 16,328 photos were captured across 23,208 trap hours, averaging 0.7 (\pm 0.31 SD) images per hour. We recorded 39 species, including 18 bird species, 14 mammal species, 6 domestic animal species, and humans (Table 1). The relative abundance (\pm SD) for each species was derived from the number of photographic records. There were notable differences in taxonomic groups between the two study years: birds accounted for 25.15%

and 68.33% of observations, respectively; mammals for 42.53% and 27.75%; domestic animals were only documented in 2017-2018, comprising 4.28% of observations; and humans were documented 28.04% in 2017-2018 and 3.92% in 2018-2019.

The Indian peafowl (*Pavo cristatus*) was the most frequently observed species, accounting for 24.6% of sightings in 2017-2018 and 39.9% in 2018-2019, followed by nilgai (*Boselaphus tragocamelus*) at 27.3% and 15.7%, humans (*Homo sapiens*) at 28.0% and 3.9%, and Indian leopards (*Panthera pardus fusca*) at 3.8% and 4.8%.

Among the 14 mammal species, we observed seven carnivores, four artiodactyls, one rodent, one hedgehog, and one primate. Some species likely present in the reserve were not recorded due to low numbers or their absence in the areas where cameras were deployed. Eighteen bird species were photographed at waterholes, with jungle babblers (*Turdoides striata*), rufous treepies (*Dendrocitta vagabunda*), red-vented bulbuls (*Pycnonotus cafer*), red-wattled lapwings (*Vanellus indicus*), and blue rock pigeons (*Columba livia*) being some of the notable observations. Raptors such as the shikra (*Accipiter badius*), Indian eagle owl (*Bubo bengalensis*), and long-legged buzzard (*Buteo rufinus*) were also recorded.

Among wild carnivores, the Indian leopard, striped hyena, Bengal fox (*Vulpes bengalensis*), golden jackal (*Canis aureus*), small Indian civet (*Viverricula indica*), and Indian mongoose (*Herpestes edwardsii*) were observed. Herbivores frequently recorded included nilgai, chital (*Axis axis*), sambar deer (*Rusa unicolor*), and black-naped hare (*Lepus nigricollis*). Other vertebrates such as the crested porcupine (*Hystrix indica*) and fruit bat (*Pteropus giganteus*) were also present, along with the gray langur (*Semnopithecus entellus*), the only primate recorded.

Domestic animals documented included cattle (*Bos taurus*), goats (*Capra aegagrus hircus*), feral dogs (*Canis lupus familiaris*), cats (*Felis catus*), and domestic pigs (*Sus scrofa domesticus*), with grazing activity observed primarily in the peripheral areas. Human activity, divided into villagers, forestry officers, and ecotourism, was recorded within the reserve. Human presence decreased from 28.4% in the first year to 3.92% in the second year of the study.

We observed an increase in the relative abundance of several wildlife species in 2018-2019 compared to 2017-2018, including the Indian peafowl, rufous treepie, jungle babbler, red-vented bulbul, Indian leopard, and small Indian civet. Over the two-year period, 661 images of leopards were captured, identifying 25 individual leopards (8 males and 17 females).

Of the 39 species recorded, two were classified as "Vulnerable" (Indian leopard, sambar deer), one as "Near Threatened" (striped hyena), and the remaining 36 as "Least Concern" according to the IUCN Red List [36].

The abundance maps for 2017-2018 showed higher abundance density in the southern and southwestern parts of the study area, whereas in 2018-2019, the abundance density was more evenly distributed across the north and south parts (Figure 3a, b).

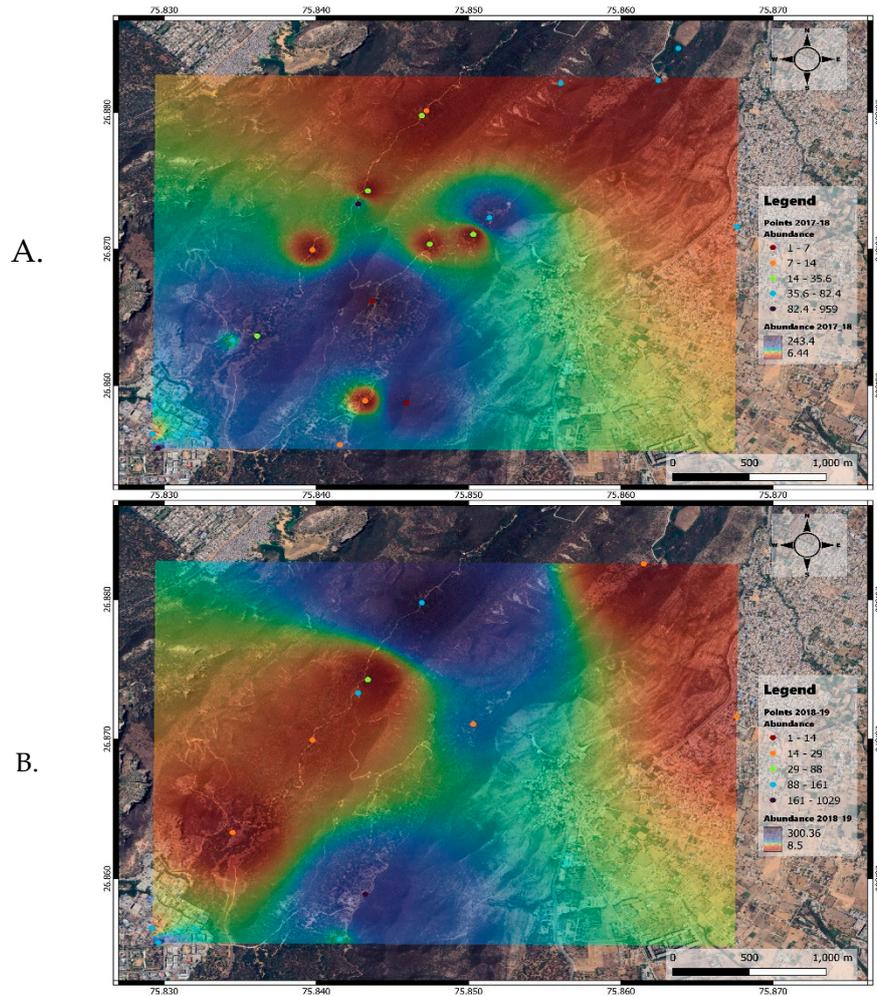


Figure 3. Abundance heat maps of the study years: A. 2017-2018, and B. 2018-2019.

There was no significant difference in abundance between the two years ($p = 0.27$; Figure 4).

The Shannon diversity index maps indicated higher diversity in the northern and central parts of the study area in 2017-2018, while in 2018-2019, diversity was higher in the southern, central, and southeastern parts (Figure 5a, b).

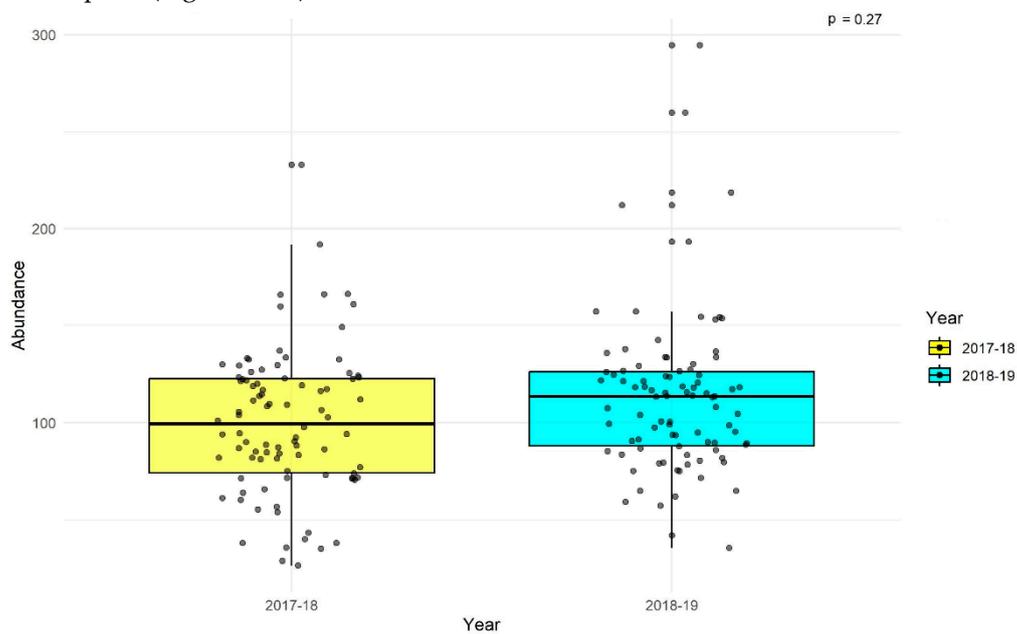


Figure 4. Year-wise comparison of species abundance using p-values for Jhalana Reserve Forest, Jaipur, India.

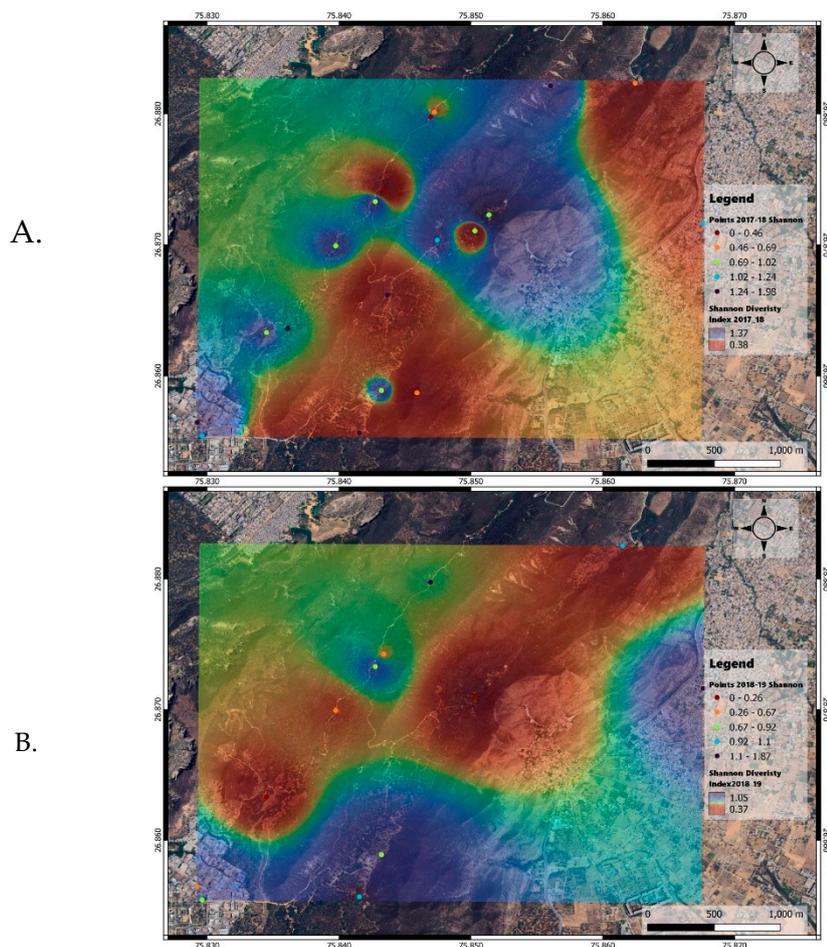


Figure 5. Shannon diversity index heat map for the years 2017-2018 (A) and 2018-2019 (B) in Jhalana Reserve Forest, Jaipur, India.

There was a significant difference in Shannon diversity index values between the two years ($p < 0.01$; Figure 6). This change in diversity has implications for the prey community of the apex predator, the Indian leopard, and the resource dependence of other species, likely influenced by changes in waterhole locations.

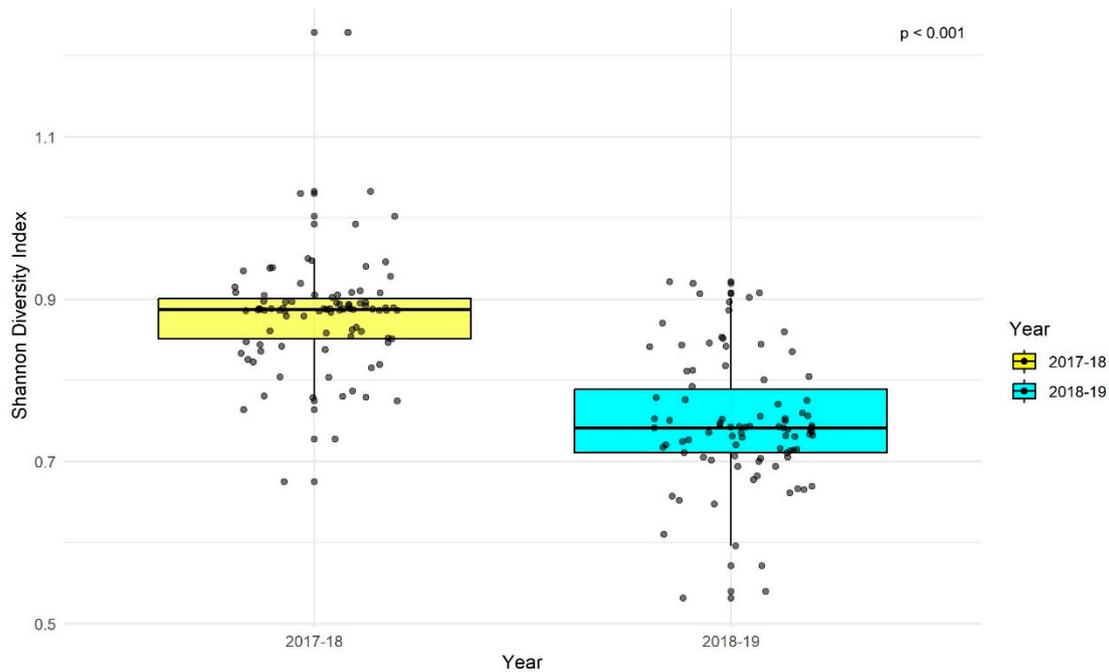


Figure 6. Year-wise comparison for study periods 2017-2018 and 2018-2019 of Shannon diversity index using p-values for Jhalana Reserve Forest, Jaipur, India.

Discussion

This study is the first to scientifically document the species richness within the JRF, capturing both wildlife and anthropogenic activities to understand the implications of declaring JRF as India's first leopard reserve. Despite the semi-arid, human-exploited landscape, JRF hosts seven carnivore species, although wild herbivores are not naturally present. These findings are consistent with camera trap studies in human-dominated landscapes, such as those in Maharashtra [37].

In the absence of tigers and wolves (*Canis lupus pallipes*), the leopard serves as the apex predator in JRF. Our results align with those of Karanth and Sunquist [38] and Reddy et al. [39], who noted that leopards thrive where large or medium-sized prey and competitors like tigers or dholes (*Cuon alpinus*) are absent. Leopards were photographed at all camera traps and were well distributed throughout the reserve and surrounding areas. Specific observations included a male leopard with an injury in December 2017, who later recovered. Unlike other studies [37,40], we captured both flanks and facial markings of leopards, enabling individual identification of 17 females and 8 males [22]. We recorded three females with cubs, indicating a resident and reproductive population, akin to findings by Athreya et al. [37].

The diet composition of JRF leopards shows a dependence on human-associated and domestic animals such as feral dogs, cats, goats, and cattle [28]. Domestic animals constituted 89% of the leopards' prey. A survey in Jaipur city reported 36,850 domestic dogs [41], a significant prey source for leopards. Camera trap data corroborate these findings with numerous images of domestic animals within JRF.

Eighteen villages surround JRF, and the local community relies on the forest for livelihood, engaging in activities such as grazing and firewood collection, leading to frequent human-wildlife interactions. The Rajasthan Forest Department's vigilance has reduced human activity within the reserve from 28.04% in 2017-18 to 3.9% in 2018-19 (Table 1), resulting in increased relative abundance of dominant wildlife species in 2018-19 (Table 1). This supports O'Brien and Kinnaird's [5] assertion that camera traps are effective for monitoring ground-dwelling birds and other wildlife, though they may underrepresent arboreal species.

Striped hyenas, Bengal foxes, and small Indian civets were commonly observed and well-distributed in JRF. Golden jackals and Indian mongooses were occasionally spotted at waterholes.

Hyenas were frequently seen near the southeastern border, close to human habitations. The construction of a 3-meter high wall on the reserve's border in 2018 by the Rajasthan Forest Department has reduced domestic animal intrusions to zero in 2018-19, though leopards can still traverse the fence.

A 2018 survey indicated 90% support for conservation efforts [27]. However, as domestic livestock is a significant food source for carnivores in human-modified habitats [28,42,43], conservation strategies must balance human and wildlife needs. Our results show that integrating wildlife into human-modified landscapes while considering human tolerance is crucial [44]. Research should extend beyond reserve boundaries to include adjacent areas, particularly in JRF where urban neighborhoods are contiguous with the forest.

Forest workers are primarily active in central JRF, involved in activities such as road construction, tree planting, water tanker transport to waterholes, and ecotourism route maintenance. Ecotourism, regulated since June 2017 under "Project Leopard," has contributed to human presence but is managed to minimize wildlife disturbance. Electric vehicles have been introduced to reduce noise impact [31].

Several studies highlight the effects of ecotourism on wildlife behavior, including changes in feeding, hormonal responses, habituation, predation, and reproductive success [45–48]. Further research on the impact of tourism in JRF will aid in developing responsible tourism policies. Continuous monitoring of species richness is vital for tracking protected and endangered species [49,50].

Our study demonstrates that camera trapping is an effective method for estimating and recording the animal diversity of the Jhalana Reserve Forest (JRF). The findings reveal that human-dominated landscapes can sustain and support a consortium of predators, and wildlife in JRF shares resources with humans outside the reserve forest. Various conservation measures undertaken by the Rajasthan Forest Department have significantly reduced human intrusion, leading to an increase in the relative abundance of wildlife species in the JRF. Camera traps have proven to be an essential tool for ongoing monitoring of vulnerable and near-threatened species in JRF, and this approach can be valuable in other human-shared protected areas to assess the status of wildlife amidst anthropogenic activities. Our results underscore the importance of integrating wildlife into human-modified landscapes while considering human tolerance and the necessity of extending research beyond reserve boundaries to include adjacent areas.

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Consent to participate: Agreed by all authors

Consent for publication: Agreed by all authors

Data Availability Statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Conflicts of Interest: The authors declare that they have no conflict of interest.

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