sciendo

Raptor Journal 2025, 19: 45–59. DOI: 10.2478/srj-2025-0006
©Raptor Protection of Slovakia (RPS)

Abundance, taxonomic and functional diversity of raptors along aridity gradient and habitat types in Rajasthan, India

Abundacia, taxonomická a funkčná diverzita dravcov pozdĺž graditenu sucha a typov biotopov v Rádžastáne, India

Rounak CHOUDHARY, Vivek SHARMA, Pawan SINGH, Ekta SHEKHAWAT, Subroto DUTTA, Praveen MATHUR, Saba KHAN, Mayank SHARMA & Aayushi MEENA

Abstract: Birds of prey and their community structure can serve as indicators of ecosystem conditions. In this study, we analysed abundance, taxonomic and functional diversity and their variability across different levels of aridity and habitats. We recorded 43 species of raptors belonging to five families of three orders, and their taxonomic diversity was relatively uniform across the aridity gradient and habitat types. Black kite (*Milvus migrans*) and shikra (*Accipiter badius*) were the most abundant species across Rajasthan, while the long-eared owl (*Asio otus*) was the rarest. From the perspective of functional diversity, our findings suggest that the Thar Desert, being the most extreme and dry environment, supports species with specialised traits that allow them to survive harsh conditions. Results also indicate that lifestyle, beak length, tarsus length, and body mass combinations represent unique functional traits influenced by varying climatic (aridity) and ecological conditions (habitats). Understanding these functional relationships is critical for raptor conservation, particularly in arid landscapes where habitat fragmentation and food abundance fluctuations may impact species persistence.

Abstrakt: Dravé vtáky a štruktúra ich spoločenstva môžu slúžiť ako indikátory stavu ekosystému. V tejto štúdii sme analyzovali početnosť, taxonomickú a funkčnú diverzitu dravcov a ich variabilitu pozdĺž gradientu sucha a v rôznych tipov biotopov. Zaznamenali sme 43 druhov dravých vtákov patriacich do piatich čeľadí troch radov. Ich taxonomická diverzita bola relatívne uniformná, tak v rámci gradientu sucha ako aj typov biotopov. Haja tmavá (*Milvus migrans*) a jastrab šikra (*Accipiter badius*) boli najpočetnejšími druhmi v celom Rádžastáne, zatiaľ čo myšiarka ušatá (*Asio otus*) bola najvzácnejšia. Z hľadiska funkčnej diverzity naše zistenia naznačujú, že púšť Thar, ktorá je najextrémnejším a najsuchším prostredím, podporuje druhy so špecializovanými vlastnosťami, ktoré im umožňujú prežiť v drsných podmienkach. Výsledky tiež naznačujú, že kombinácie životného štýlu, dĺžky zobáka, dĺžky tarsusu a telesnej hmotnosti predstavujú jedinečné funkčné znaky ovplyvnené rôznymi klimatickými (aridita) a ekologickými podmienkami (biotop). Porozumenie týchto funkčných vzťahov je kľúčové pre ochranu dravcov, najmä v suchých územiach, kde fragmentácia biotopov a kolísanie množstva potravy môžu ovplyvniť prezistenciu druhov.

Key words: birds of prey, functional traits, predators, owls, scavengers, conservation

Rounak Choudhary, Ekta Shekhawat, Subroto Dutta, Praveen Mathur, Mayank Sharma, Aayushi Meena, Department of Environmental Science (Centre for Excellence), Maharshi Dayanand Saraswati University, Ajmer (305009), Rajasthan, India, E-mail: rounakchoudhary17@gmail.com.
Vivek Sharma, Saba Khan, Department of Zoology, Maharshi Dayanand Saraswati University, Ajmer (305009), Rajasthan, India.
Pawan Singh, Department of Zoology, Samrat Prithviraj Chouhan Government College, Ajmer (305001), Rajasthan, India.

Acknowledgements: Acknowledgements: We are grateful to the Department of Science and Technology (DST), Ministry of Science and Technology, Government of India, for funding the research under DST-INSPIRE fellowship programme. Next, we thank Filip Tulis for his helpful comments on earlier manuscript drafts.

Introduction

The term 'raptor' refers to avian species from the Accipitriformes, Cathartiformes, Falconiformes, and Strigiformes orders (McClure et al. 2019), and they are the top avian predators in most terrestrial environments around the World (McClure et al. 2018). Raptors are renowned for their hunting abilities, which include using a sharp cutting edge with a hooked bill, strong and powerful legs for grasping their prey, acute eyesight, speed, and flight strength (Bildstein 2017). Raptors are further classed as predators and scavengers based on their role in the ecosystem (Donázar 2016). Predators play an essential role in ecosystem structure and function by controlling prey populations. In contrast, scavengers ensure the flow of nutrients in the food chain and prevent disease spread by feeding on dead organisms. Raptors are more vulnerable to anthropogenic pressures and extinction than other bird species (O'Bryan et al. 2022) as they occur at low population densities due to occupying high trophic levels and have slow life histories (Owens and Bennett 2000; Sergio et al. 2008). Their threats include, e.g., climate change (Iknayan and Beissinger 2018), electrocution (Lehman 2001; Kouba et al. 2021), habitat alterations (Bildstein 2006) and intentional or unintentional poisoning (Oaks et al. 2004; Brochet et al. 2017).

Aridity plays a fundamental role in shaping landscape habitat characteristics, influencing vegetation structure, water availability, soil composition, and species distribution. At broader spatial scales, bird communities in arid-semiarid environments are thought to be generally independent of habitat structure, with climatic variables having a greater influence (Rotenberry 1978; Naranjo & Raitt 1993; Kaboli et al. 2006). Aridity and land cover heterogeneity may impact bird food resources, affecting species diversity and richness in a particular area (Lorenzón et al. 2016). Communities in these landscapes ought to consist of species with survival abilities.

Along the aridity gradient, environmental filtering is strong and favours species with specific survival traits for drought and heat tolerance (Díaz et al. 1998; Joseph et al. 2014). As a result, functional diversity is often reduced because only a limited set of functional traits enables survival under such conditions. Although direct studies on aridity are limited, research indicates that aridity is generally associated with lower species diversity, especially in tropical regions (Hawkins et al. 2003; Oliveira et al. 2022). Furthermore, studies suggest that bird functional diversity can decline more rapidly than species richness, indicating that functionally distinct species are often lost first (Flynn et al. 2009; Luck et al. 2013). Although these findings primarily come from studies on land-use change, they imply that similar patterns could also occur along aridity gradients.

The diversity of raptors is linked to several environmental factors (Voskamp et al. 2017), with habitat type and seasonality playing key roles in shaping community dynamics (Morrison et al. 2006). Habitat structure and heterogeneity significantly influence the species richness and abundance of raptor communities by providing varied foraging opportunities, nesting sites, and perching structures (White 1974; Thiollay 2006). Different habitat types support distinct assemblages of raptors depending on their hunting strategies, dietary preferences, and nesting requirements (Guisan et al. 2017; Morrison 2012). These differences affect taxonomic diversity and shape raptors' functional diversity by promoting species' coexistence with different ecological roles and adaptations. Therefore, understanding how raptor communities respond to habitat characteristics is essential for effective habitat management and conservation planning (Thiollay 2006; Morrison 2012).

So, evaluating taxonomic and functional diversity in relation to the aridity gradient and habitat should provide insights into the mechanisms by which species losses or additions that have specific functional features affect ecosystem functioning (Kremen 2005). Therefore, functional diversity is defined as a component of biodiversity that describes the degree of functional differences between species (e.g., how organisms use resources) and measures the distribution and range of the organisms' effects on the ecosystem. It considers redundancy and complementarity among co-occurring species, which determine the stability and efficiency of ecological processes (Diaz & Cabido 2001; Petchey & Gaston 2006). On the other hand, activities such as agriculture have been shown to help some raptor species by creating new niches with increased prey availability and visibility for hunting across larger areas (Grande et al. 2018).

For the conservation and management of raptors, it is crucial to understand their distribution in environmental space, which essentially requires baseline information on their occurrence. In this study, we assessed and described raptors' abundance and taxonomic and functional diversity observed over two years along an aridity gradient in open, closed and mosaic habitats.

Materials and Methods

Study area

Our study was conducted in Rajasthan, India's largest state, within the arid and semi-arid biogeographic zones (Fig. 1A).

Limited water resources, scarce arable land, high evapotranspiration, sparse vegetation, rodent infestations, and the lack of perennial rivers mark Rajasthan's arid environment. The prevailing climate types include dry temperate, warm semi-dry temperate, and temperate sub-humid, with summer precipitation in some areas. The region's natural vegetation consists of grasslands and desert scrublands, while agriculture and rangelands dominate the land cover (Fig. 1B). Large portions of the Thar Desert have been altered by human activity, with agriculture exerting significant pressure on native plant communities. Northern tropical thorn forests (Champion & Seth 1968) characterise the rolling arid landscape, featuring particularly the following species: *Acacia capparis*, *Acacia catechu*, *Acacia senegal*, *Anogeissus pendula*, *Azadirachta indica*, *Butea monosperma*, *Prosopis cineraria* and invasive *Prosopis juliflora*. The study area spans 0.342 million square kilometres, located between 23.4° and 29.7° N latitude and 69.3° and 78.3° E longitude. The arid and semi-arid zones harbour more than 450 bird species (Sharma et al. 2013). The Aravalli Hills separate these zones, acting as a natural climatic and ecological barrier that influences vegetation and wildlife distribution. These zones form a distinct aridity gradient, shaping the region's environment and fauna. Rajasthan's arid region includes the Thar Desert, characterised by low and variable rainfall (100–400 mm per year), high temperatures, and sandy terrain. In comparison, the semi-arid region of Rajasthan receives significantly more rainfall (400–800 mm) and features a more diverse mosaic of grasslands, scrublands, dry deciduous woods, and agricultural fields. The aridity gradient in Rajasthan spans about 800 km (Fig. 1C).

Data Collection

Raptors' diversity was recorded from November 2022 to January 2025. All 36 sampling locations were distributed across Rajasthan's aridity gradient to ensure representation of diverse habitats. All study zones were surveyed at least five times during different seasons (summer, monsoon and winter). Transect surveys were conducted during peak raptor activity periods: mornings from 07:00–11:00 and evenings from 16:00 till sunset (Bunn et al. 1995; Vergara 2010; Tiwari et al. 2023). Multiple observation points and transects of varying lengths were established within the sampling locations. Transect placement followed a semi-random approach, considering accessibility in hilly and forested regions. Road transects spanned 3–20 km and were conducted in a vehicle at a maximum speed of ~50 km/h. Line transects, ranging from 0.1 to 3 km, were walked on foot. Observation points were strategically placed to

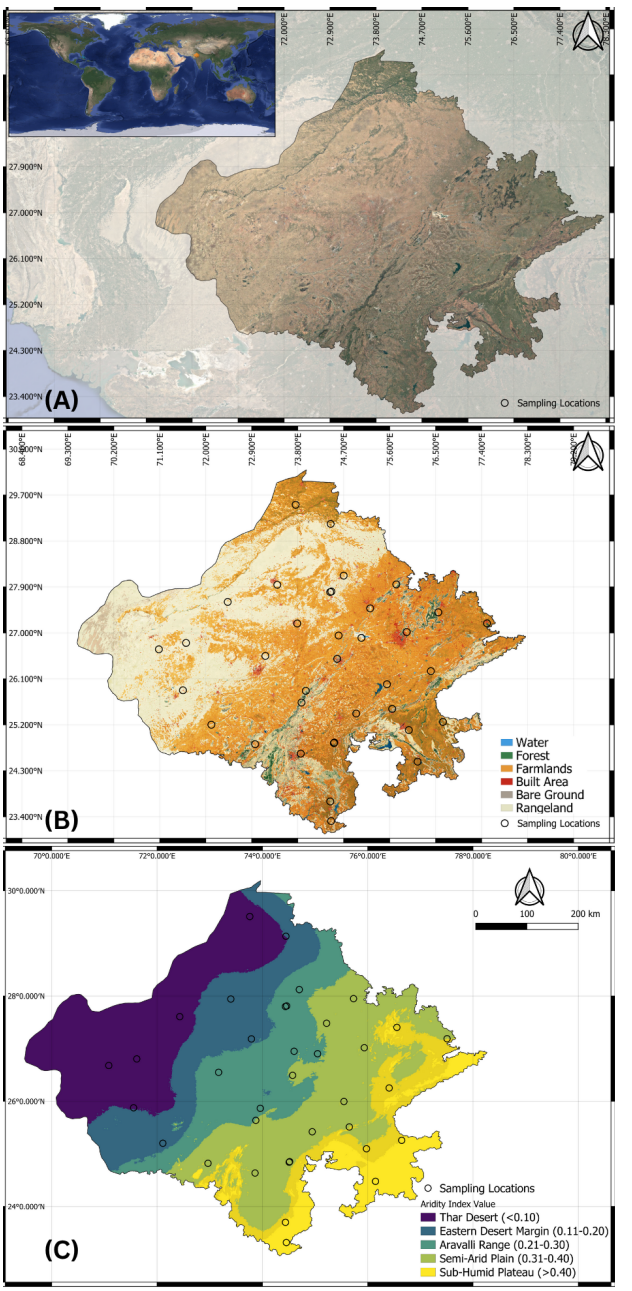


Fig. 1. Map of study area highlighting Rajasthan on a global map (A), habitat types with sampling locations (B), and Aridity Index Value across the study area (C; defined as the ratio of precipitation to potential evapotranspiration).

Obr. 1. Mapa študovanej oblasti s vyznačením Rádžastánu na globálnej mape (A), typy biotopov v spolu so vzorkovacími lokalitami (B) a Indexu suchosti v študovanej oblasti (C; definovaná ako pomer zrážok k potenciálnej evapotranspirácii).

count flying raptors within a 1–2 km radius and to monitor vultures feeding on carcasses. Occasional sightings near designated sampling locations were also included in the analysis. Raptors were identified in the field based on morphological characteristics and behaviour (Naoroji 2006). Unidentified individuals were photo-documented for later confirmation.

During surveys, each raptor sighting was classified into two levels: 1. habitat categories: Open habitats (represented grasslands, wetlands, rangelands, etc.), Closed habitats (closed-canopy woodlands, forests, etc.) and Mosaic habitats (heterogeneous habitats dominated by farmlands) (Fig. 1B) and 2. five aridity zones: Thar Desert (<0.10 Aridity Index Value – AIV, see below for details), Eastern Desert Margin (0.11–0.20 AIV), Aravalli Hills (0.21–0.31 AIV), Semi-Arid Plain (0.31–0.40 AIV) and Sub-Humid Plateau (>0.40 AIV) (Fig. 1C). Aridity zones were defined by Aridity Index Value (AIV) as the ratio of precipitation to potential evapotranspiration. For classification and visualisation of aridity index across Rajasthan, we used high-resolution (30 arc-seconds) global raster climate data (Zomer & Trabucco 2019).

We used species richness as an indicator of taxonomic diversity. For selected functional traits, we used the AVONET dataset (Tobias et al. 2022), which contains bird species' morphological and ecological data and the EltonTraits 1.0 dataset for Raptor activity attributes (Wilman et al. 2014) (Table 1).

For alpha functional diversity analysis we used multiple indices including Functional Dispersion (FDis) that measures trait dispersion within the community (Laliberté & Legendre 2010), Functional Richness (FRic) reflects the volume of functional space occupied by species (Cornwell et al. 2006; Villéger et al. 2008), representing the breadth of trait diversity, Functional Divergence (FDiv) assesses how species are distributed relative to the center of the functional space (Villéger et al. 2008), Functional Evenness (FEve) describes how evenly species are distributed in trait space (Villéger et al. 2008), Functional Specialisation (FSpe) indicates the degree to which species are functionally specialised (Bellwood et al. 2006, Mouillot et al. 2013), Functional Mean Pairwise Distance (FMPD) calculates the average functional distance between all possible species pairs in the community (Weiher et al. 1998), Functional Mean Nearest Neighbour Distance (FNND) measures how functionally unique each species is relative to its closest neighbour (Weiher et al. 1998) and Functional Originality (FOri) that quantifies the uniqueness of species traits within a community (Mouillot et al. 2013).

We used the Jaccard Dissimilarity index for beta functional diversity analysis, which measures the total functional dissimilarity between two communities (Chao et al. 2019). To gain deeper insight into the source of functional dissimilarity, the total Jaccard dissimilarity can be partitioned into two components: Jaccard Turnover and Jaccard Nestedness (Baselga 2012). The turnover quantifies the extent to which functional dissimilarity arises from replacing or substituting functional traits between communities. A high turnover value indicates that functional differences are primarily due to different species performing different ecological roles in the two communities. In contrast, nestedness measures the part of functional dissimilarity that results from differences in trait richness. A high nestedness value suggests that the observed dissimilarity is not due to species replacement but rather the loss or absence of specific functional traits in one of the communities. The alpha and beta functional diversity analysis was performed using the "mFD" package (Magneville et al. 2022).

Tab. 1. Functional traits of raptors used in the analysis of functional diversity.
Tab. 1. Funkčné znaky dravcov použitých v analýze funkčnej diverzity.

Trait	Range	Description
Beak Length (mm)	17.9–87.8	Beak morphology reflects feeding specialisation.
Beak Depth (mm)	10–39.8	
Tarsus Length (mm)	25.6–134.2	The tarsus length (lower leg segment) influences perching, prey capture, and locomotion.
Hand Wing Index (HWI)	27.4–57.8	HWI reflects wing shape and flight efficiency.
Tail Length (mm)	74.2–371	Tail length affects flight agility and manoeuvrability.
Mass (g)	112–9798	Body mass influences metabolic rate, energy demands, and predation risk.
Habitat	Forest-Grassland-Human Modified-Rock-Shrubland-Wetland-Woodland	Habitat preference defines niche specialisation.
Niche	Aquatic Predator-Invertivore-Omnivore-Scavenger-Vertivore	The trophic niche determines a raptor's role in ecosystem functioning.
Lifestyle	Aerial-Generalist-Insessorial-Terrestrial	Lifestyle categorise hunting strategies.
Activity Period	Diurnal-Nocturnal	Diurnal raptors rely on daylight for hunting, while nocturnal species have specialised adaptations like silent flight and enhanced night vision, affecting their ecological role and competition.

Data analysis

Principal Coordinates Analysis was performed following the approach of Gower (1966), using the vegan package (Oksanen et al. 2025) to explore patterns of functional diversity in raptor communities along the aridity gradient. To statistically test the influence of variables on trait composition, we conducted Permutational Multivariate Analysis of Variance using the vegan package with 999 permutations, based on the Euclidean distance matrix. The analysis was based on functional traits of the species. We used species abundance and raptor-traits data to measure different functional diversity indices. The taxonomic composition was assessed using Euclidean distance-based clustering of species traits using the stats package in R software (R Core Team 2024). Species diversity was evaluated as species richness using rarefaction and extrapolation curves generated with the iNEXT package (Hsieh et al. 2024). We used Spearman's rank correlation to assess the strength and direction of monotonic relationships between aridity and each functional diversity index. All analyses were performed using R software (R Core Team 2024).

Results

Rank-abundance of raptors

A total of 1,182 individuals were recorded during the study, specifically 156 in the landscape of the Thar Desert (13.2%), 213 in the Eastern Desert Margin (18%), 244 in the Aravalli Hills (20.6%), 330 in the Semi-arid Plains (27.9%), and 239 in the Sub-humid Plateau (20.2%).

In the context of habitat, in open habitats 485 (41%), in closed habitats 413 (34.9%), and in mosaic habitats (having a mix of open and closed habitats along with farmlands) 284 (24%) individuals were recorded. The most abundant species were black kite (*Milvus migrans*; 12.9%), shikra (*Accipiter badius*; 9.3%), Egyptian vulture (*Neophron percnopterus*; 8.9%), spotted owlet (*Athene brama*; 8.7%) and Eurasian griffon vulture (*Gyps fulvus*; 5.8%). In comparison, the short-eared owl (*Asio flammeus*; 0.3%), black eagle (*Ictinaetus malaiensis*; 0.2%) and long-eared owl (*Asio otus*; 0.1%) were the rarest species (Fig. 2).

Species richness

A total of 43 raptor species were recorded during the study in Rajasthan. No marked differences in species richness were observed between habitats. Closed habitats like forests and woodlands exhibit the highest species richness (40 species), followed closely by open habitats like rangelands (39 species), while mosaic habitats like farmlands support fewer species (37 species) (Appendix 1). Species richness was highest in the Semi-arid Plains (41 species), while the other zones exhibited comparable values (36–38 species), suggesting relatively uniform raptor diversity across the aridity gradient (Appendix 2).

Functional Diversity

Principal Coordinates Analysis (PCA) shows the multidimensional trait space of 43 raptor species recorded in Rajasthan based on morphological and ecological traits (Fig. 3). The first two Principal Coordinates Analysis axes

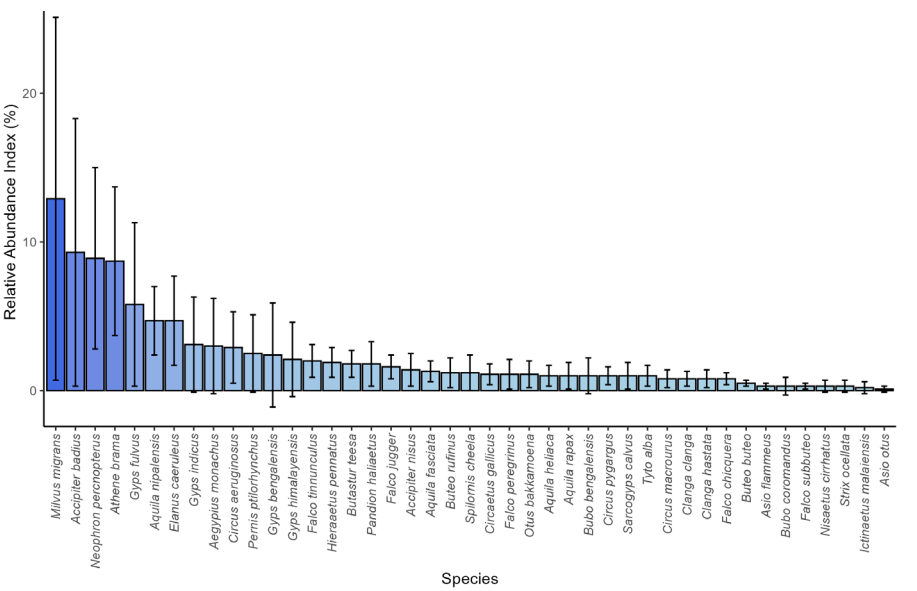


Fig. 2. Relative abundance of raptors (% ± SD) of species recorded in Rajasthan.
Obr. 2. Relatívna abundancia dravcov (% ± SD) druhov zaznamenaných v Rádžastáne.

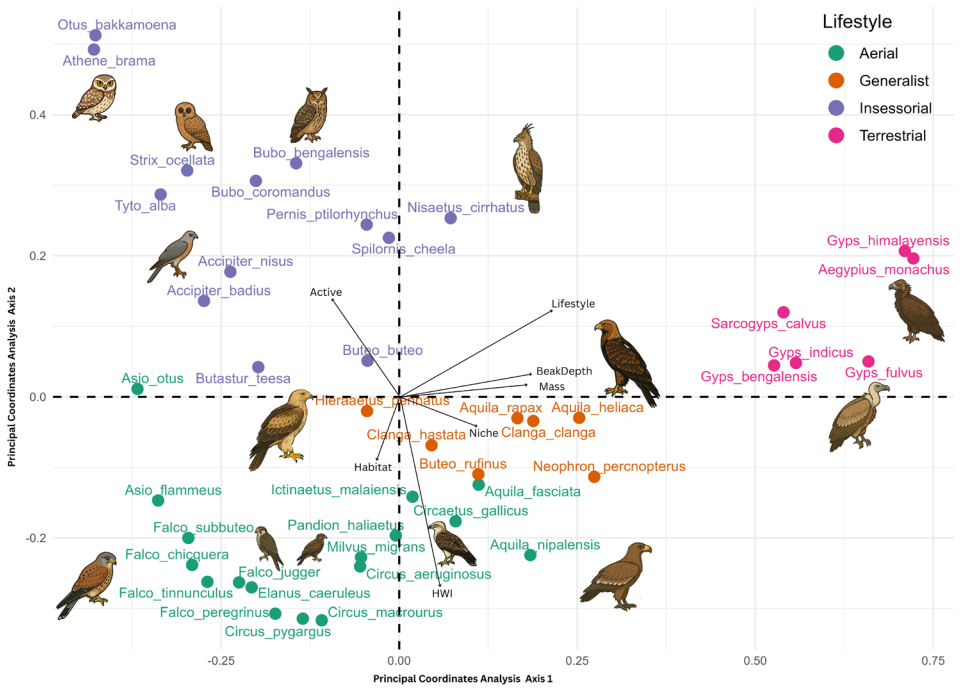


Fig. 3. PCA analyses of the multidimensional traitspace of raptors (n = 43 species) in Rajasthan.
Obr. 3. PCA analýza viacrozmerného priestoru znakov dravcov (n = 43 druhov) v Rádžastáne.

explained 25.72% and 15.31% of the total trait variation, respectively. Permutational Multivariate Analysis of Variance results showed that habitat ($R^2 = 0.646$, $F = 23.77$, $p = 0.023$) and lifestyle ($R^2 = 0.518$, $F = 10.24$, $p = 0.001$) explained the highest variation in the raptor trait space among ecological factors. Among morphological traits, beak length ($R^2 = 0.453$, $F = 34.08$, $p = 0.001$), tarsus length ($R^2 = 0.428$, $F = 30.80$, $p = 0.001$), and body mass ($R^2 = 0.424$, $F = 30.25$, $p = 0.001$) were the strongest predictors of trait differentiation. The analysis showed distinct functional clustering, with large-bodied, terrestrial scavengers such as vultures occupying the positive end of Axis 1, while smaller, aerial foragers such as falcons are positioned toward the negative axis (Fig. 3).

Functional diversity metrics showed distinct ecological patterns across the aridity gradient (Table 2). The Thar Desert have high functional dispersion and divergence (FDis = 0.702; FDiv = 0.829), suggesting strong ecological differentiation and specialisation among species, but low functional evenness and originality (FEve = 0.634; FOri = 0.337), indicating trait clustering and limited uniqueness. In contrast, the Eastern Desert Margin and Semi-arid Plains showed the highest functional richness (FRic = 0.919 and 0.923), indicating a broad range of ecological roles, along with relatively high originality (FOri = 0.390 and 0.373), respectively, suggesting a mix of specialists and unique species. The Aravalli Range displayed high evenness (FEve = 0.729) but lower dispersion (FDis = 0.585) and specialisation (FSpe = 0.486), pointing to functional redundancy and dominance of generalist traits. The Sub-humid Plateau had the lowest functional richness (FRic = 0.745) and generally moderate values across other metrics, implying reduced ecological differentiation and a more uniform trait structure. Overall, arid regions tended to support more specialised and divergent raptor communities, while mesic zones hosted more functionally redundant and generalist assemblages. Raptor communities differed across habitats in their ecological roles. Closed habitats had the highest functional dispersion (FDis = 0.663), indicating a wider range of traits due to complex vegetation and diverse prey, while mosaic habitats had lower dispersion (FDis = 0.593), suggesting functional redundancy. Functional divergence remained high in closed (FDiv = 0.812) and farmlands mosaic (FDiv = 0.820) habitats, showing distinct trait differences among species (Table 2).

We have not found a significant correlation between aridity and functional evenness (Spearman's rank correlation: $\rho = 0.7$, $p = 0.2$), and functional mean pairwise distance (Spearman's rank correlation: $\rho = -0.6$, $p = 0.3$).

Tab. 2. Functional diversity metrics across different landscapes (classified by aridity index).
Tab. 2. Ukazovatele funkčnej diverzity klasifikované podľa indexu suchosti a typu biotopu.

Landscape	Aridity Index Value	Species Richness	Functional Dispersion	Functional Mean Pairwise Distance	Functional Mean Nearest Neighbour Distance	Functional Evenness	Functional Richness	Functional Divergence	Functional Originality	Functional Specialisation
Thar Desert	<0.10	36	0.702	0.724	0.34	0.634	0.81	0.829	0.337	0.623
Eastern Desert Margin	0.11-0.20	38	0.622	0.687	0.396	0.642	0.919	0.792	0.39	0.567
Aravalli Hills	0.21-0.30	36	0.585	0.613	0.382	0.729	0.766	0.804	0.363	0.486
Semi-Arid Plains	0.31-0.40	41	0.583	0.638	0.379	0.651	0.923	0.802	0.379	0.491
Sub-Humid Plateau	>0.40	37	0.638	0.657	0.377	0.659	0.745	0.814	0.366	0.519
Habitat Type										
Open		39	0.637	0.661	0.382	0.616	0.919	0.769	0.37	0.53
Closed		40	0.663	0.672	0.337	0.667	0.806	0.812	0.337	0.542
Mosaic		37	0.593	0.638	0.423	0.638	0.706	0.82	0.416	0.499

Dissimilarity, Turnover and Nestedness

The Jaccard dissimilarity values (Table 3) showed that the Thar Desert had the most distinct raptor species composition, with high dissimilarity from the Sub-humid Plateau (0.4) and Aravalli Range (0.394), but was most similar to the adjacent Eastern Desert Margin (0.119). The Eastern Desert Margin showed moderate dissimilarity with the Aravalli Range (0.294) and the Semi-arid Plains (0.150), reflecting its intermediate position. Jaccard turnover was highest between the Thar Desert and the Aravalli Range (0.366) and the Sub-humid Plateau (0.357), indicating major species replacement along the aridity gradient. Nestedness was highest between the Semi-arid Plains and Sub-humid Plateau (0.193), suggesting partial species retention. In contrast, nestedness between the Eastern Desert Margin and Semi-arid Plains was negligible (0.003), indicating compositional differences were driven by turnover rather than species loss.

Discussion

The recorded birds of prey abundances offer important context for interpreting their distribution patterns and functional structure across the Rajasthan landscape. The high abundance of generalist species like black kites and shikras is consistent with patterns observed in a previous study of the arid landscape of Rajasthan (Tiwari et al. 2021). We recorded the highest abundance in open habitats; such habitats can offer raptors enhanced foraging efficiency due to greater visibility (Sergio et al. 2005; Eduardo et al. 2007). In contrast, the least abundance of raptors was found in mosaic habitats. These often represent transitional or fragmented zones, where human disturbance, edge effects, or resource unpredictability may reduce habitat quality for certain raptors (Butet et al. 2022).

Previous research has documented the Indian subcontinent as home to a diverse raptor assemblage (Baker

Tab. 3. Pairwise comparisons of the raptors across the landscapes of Rajasthan.
Tab. 3. Párové porovnania dravcov v krajine Rádžasthánu.

Index	Jaccard Dissimilarity				Jaccard Turnover				Jaccard Nestedness			
	Thar Desert	Eastern Desert Margin	Aravalli Hills	Semi-Arid Plain	Thar Desert	Eastern Desert Margin	Aravalli Hills	Semi-Arid Plain	Thar Desert	Eastern Desert Margin	Aravalli Hills	Semi-Arid Plain
Eastern Desert Margin	0.119				0				0.119			
Aravalli Hills	0.394	0.294			0.366	0.165			0.028	0.129		
Semi-Arid Plain	0.239	0.15	0.266		0.14	0.147	0.125		0.099	0.003	0.141	
Sub-Humid Plateau	0.4	0.315	0.128	0.193	0.357	0.168	0.104	0	0.043	0.147	0.024	0.193

1928; Ali & Ripley 1978; 1983; 1987; Naoroji 2006; Naoroji & Sangha 2013). Today, more than 112 raptor species are found in India (Praveen & Jaypal 2024). We recorded 43 raptor species across different aridity zones of Rajasthan. Previous studies documented 35 species in Rajasthan (Tiwari et al. 2023) and 30 species specifically in the Jaisalmer District of the Thar Desert (Bora et al. 2023). Additionally, recent records from citizen science platforms have reported the presence of over 60 raptor species in Rajasthan (eBird 2025). Among recorded raptors, white-rumped vulture (*Gyps bengalensis*), Indian vulture (*Gyps indicus*), and red-headed vulture (*Sarcogyps calvus*) are classified as Critically Endangered. Others, like the steppe eagle (*Aquila nipalensis*) and Egyptian vulture, are classified as Endangered, four species are listed as Vulnerable, and five as Near Threatened according to the International Union for Conservation of Nature Red List (IUCN 2025).

No marked differences in raptor species richness were found across the study area's aridity zones and habitats. Carrete et al. (2009) noted that raptor species richness has been shown to decline with increasing habitat modification resulting from anthropogenic activities. While habitat degradation generally negatively impacts raptors, certain species may benefit from heterogeneous landscapes and low-intensity agriculture, as these conditions create new ecological niches with increased prey availability and improved hunting visibility (Fleming & Bateman 2018). However, numerous threats contribute to raptor population declines, including habitat destruction (McClure et al. 2018), poisoning (Green et al. 2004; Green et al. 2022; Ogada et al. 2012), electrocution (Lehman et al. 2007; Kouba et al. 2021), free-ranging dogs (Gompper et al. 2014), destruction of nesting sites and the broader effects of climate change. Particularly in Rajasthan, the expansion of renewable energy infrastructure, including wind and solar farms in the Thar Desert, has introduced high-tension power lines, significantly impacting raptor populations (Uddin et al. 2021). Further, free-ranging dogs are increasingly recognised as a major threat to vultures and large raptors in the arid landscape of Rajasthan.

The functional diversity of raptors in Rajasthan suggests ecological groupings based on morphological traits (beak length, tarsus length, and body mass), habitat, and lifestyle adaptations. These groupings highlight how different species partition ecological roles, showcasing variations in hunting strategies, flight morphology, and habitat preferences. Raptors in the region thus can be broadly categorised into four functional groups: scavengers, aerial hunters, perch-and-ambush predators, and generalists. Scavenging vultures like white-rumped vulture, Eurasian griffon vulture, Himalayan vulture (*Gyps himalayensis*), Indian vulture, cinereous vulture (*Aegypius monachus*), and red-headed vulture are distinctly separated from active hunters due to their obligate dependence on carrion and soaring flight adaptations (Selva et al. 2019). Vultures exhibit specialised adaptations, including longer wingspans for efficient soaring, reduced tarsus length, and robust beaks for tearing carrion, which reinforce their functional separation from other raptors (Campbell 2015; Negro and Galvan 2018).

The members of the aerial hunting guild, which comprises falcons like peregrine falcon (*Falco peregrinus*), common kestrel (*Falco tinnunculus*), red-necked falcon (*Falco chicquera*), *Accipiter* species like Eurasian sparrowhawk (*Accipiter nisus*), shikra and kites like black kite, black-winged kite (*Elanus caeruleus*), are adapted for high-speed pursuits, possessing shorter wingspans, high aspect ratio wings, and sharp talons to capture agile prey (Spaar 1997; Dunne and Karlson 2017). Harriers like pallid harrier (*Circus macrourus*), western marsh harrier (*Circus aeruginosus*) demonstrate functional similarities to other aerial hunters but differ in their preference for open grasslands and wetlands, using low-altitude gliding to detect prey. Eagles like the steppe eagle, tawny eagle (*Aquila rapax*) and larger *Buteo* species adopt a mixed hunting strategy, alternating between soaring flight and perch hunting, displaying intermediate wing morphology suited for both gliding and short bursts of speed.

Particular species exhibit unique ecological adaptations at the extremes of the functional space. The Egyptian vulture's opportunistic feeding behaviour and ability to exploit a wide range of food resources, including small vertebrates and human refuse, differentiate it from obligate scavengers (Di Vittorio et al. 2017). In contrast, the piscivorous diet of osprey (*Pandion haliaetus*) and its specialised hunting technique, characterised by reversible outer toes and spiny foot pads, place it outside terrestrial raptors' primary clustering (Clancy 2005). This functional trait differentiation facilitates species' resource partitioning and hierarchical feeding interactions (Byrne et al. 2019). Five of the ten monitored traits, i.e., beak depth, hand-wing index, tail length, niche and activity period, had no significant influence on functional trait differentiation. Key traits, i.e., beak length, tarsus length, and body mass, exhibit co-variation, reflecting their role in shaping predatory efficiency. Raptors with longer tarsi and shorter wings are adapted for manoeuvrable hunting in cluttered habitats

(Ward et al. 2002), while those with larger body mass and longer wings specialise in soaring flight and long-distance travel (Duriez et al 2014). The alignment of these traits reinforces the structured functional diversity observed among Rajasthan's raptor assemblage. The observed patterns of functional diversity emphasise the ecological specialisation and niche differentiation among raptors in Rajasthan. While some species exhibit functional redundancy, ensuring ecosystem stability, others occupy highly specialised roles, making them vulnerable to environmental changes.

The Jaccard dissimilarity across different arid regions highlighted how raptor species composition changes along the aridity gradient. Species composition in the Thar Desert, the most arid area in this study, was quite distinct from that of more humid regions. The Eastern Desert Margin acted as a transitional zone, similar to the Thar Desert. The Aravalli Range and the Semi-arid plains allowed species from both arid and semi-arid regions to coexist. However, its higher dissimilarity with the Sub-humid Plateau indicated that aridity changes led to species composition alterations. The Jaccard turnover values further support these patterns, with the highest species replacement occurring between the Thar Desert and Aravalli Range and Sub-humid Plateau, indicating an almost complete shift in species composition along with the climate transition from extreme arid to mesic conditions.

The Jaccard nestedness reveals patterns of species loss along the aridity gradient. The highest nestedness occurs between the Semi-arid Plains and Sub-humid Plateau, indicating that many species in the Semi-arid Plains persist in the Sub-humid Plateau, though some disappear as conditions become wetter. In contrast, nestedness is extremely low between the Eastern Desert Margin and the Semi-arid Plains. This implies that species differences arise mainly from species turnover rather than a stepwise loss, reinforcing the Eastern Desert Margin's role as a species-rich ecological corridor. This area is special since the Eastern Desert Margin has such low nestedness. It's not just a transition zone but a mixing ground where many species from both arid and semi-arid areas coexist. Additionally, transitional zones, such as the Eastern Desert Margin and Semi-Arid Plains, are crucial in maintaining species diversity by mitigating biodiversity loss and facilitating gradual species shifts (Smith et al. 2001). Semi-arid and sub-humid zones require conservation strategies to prevent species loss, as nestedness patterns indicate a gradual decline in biodiversity rather than species replacement.

Closed habitats supported the most functionally diverse raptor communities, with species occupying more specialised roles and maintaining an even functional distribution. This may reflect the ecological complexity of closed habitats such as forests and woodlands, which offer various environments for species ranging from canopy-dwelling raptors to understory hunters (Hussin & Francis 2001). Open habitats like rangelands exhibited the highest functional richness, as they accommodate various ecological strategies, including scavengers and large aerial foragers (O'reagain & Schwartz 1995). Habitat heterogeneity is essential in sustaining functional diversity (Alsterberg et al. 2017), highlighting the value of conserving a mix of open and closed habitats. Fragmentation of forested areas could reduce functional specialisation, impacting species that depend on specific structural features or prey types (Dos Anjos et al. 2019). Similarly, the degradation of open habitats may affect species with unique functional traits, such as scavengers and wide-ranging hunters (Pringle et al. 2019). Protecting diverse habitat types can therefore support the long-term ecological balance of raptor communities and help maintain the variety of roles they play within ecosystems. Tailored conservation approaches may be beneficial for arid areas to address their unique species compositions.

The observed functional diversity of raptors has critical conservation implications. Raptors with high functional redundancy may help buffer against species loss, as other functionally similar species could partially compensate for declines. However, functionally unique species, particularly specialist scavengers and piscivores, are more vulnerable to environmental changes and habitat degradation.

The observed clustering of raptor species suggested that conservation efforts should prioritise preserving functional diversity rather than focusing solely on species richness (Cadotte et al. 2011). Protecting key habitats that support different raptor guilds, such as open plains for falcons, wetlands for harriers and ospreys, and forested patches for *Accipiter* species, is essential for maintaining ecosystem stability (Mundy 1995; Donázar et al. 2016).

References

Ali S & Ripley SD 1978: Handbook of the birds of India and Pakistan. Oxford University Press.

Ali S & Ripley SD 1983: Handbook of the birds of India and Pakistan: Together with those of Bangladesh, Nepal, Bhutan and Sri Lanka. Oxford University Press.

Ali S & Ripley SD 1987: Compact handbook of birds of India and Pakistan. Oxford University Press.

Alsterberg C, Roger F, Sundbäck K, Juhanson J, Hulth S, Hallin S & Gamfeldt L 2017: Habitat diversity and ecosystem multifunctionality—The importance of direct and indirect effects. Science Advances: 3(2), e1601475. DOI: 10.1126/sciadv.1601475

Baker E 1928: The fauna of British India (Birds), vol. 5, 2nd ed., London: Taylor & Francis

Baselga A 2012: The relationship between species replacement, dissimilarity derived from nestedness, and nestedness. Global Ecology and Biogeography: 21, 1223-1232. DOI: 10.1111/j.1466-8238.2011.00756.x

Bellwood DR, Wainwright PC, Fulton CJ & Howy AS 2006: Functional versatility supports coral reef biodiversity. Proceedings of the Royal Society B: 273, 101–107. DOI: 10.1098/rspb.2005.3276

Bildstein, KL: 2017 Raptors: the curious nature of diurnal birds of prey. Cornell University Press. DOI: 10.1111/jofo.12230

Bora N, Mitra U, Mohan A, Bishnoi P, Khan M & Narwade SS 2023: Notes on threatened raptors seen during a landscape survey in Jaisalmer district, Thar desert, Rajasthan. Journal of the Bombay Natural History Society 120 (1).

Brochet AL, Vav Den Bossche W, Jones VR, Arnardottir H, Damoc D, Demko M, Driessens G, Flensted K, Gerber M, Ghasabyan M, Gradinarov D, Hansen J, Horvath M, Karlonas M, Krogulec J, Kuzmenko T, Lachman L, Lehtiniemi T, Lorge P, Lotberg U, Lusby J, Ottens G, Paquet JY, Rukhaia A, Schmidt M, Shimmings P, Stipnieks A, Sultanov E, Vermouzek Z, Vintchevski A, Volke V, Willi G & Butchart SHM 2017: Illegal killing and taking of birds in Europe outside the Mediterranean: assessing the scope and scale of a complex issue. Bird Conservation International: 1–31. DOI:10.1017/S0959270917000533

Bunn AG, Klein W & Bildstein KL 1995: Time-of-day effects on the numbers and behaviour of non-breeding raptors seen on roadside surveys in eastern Pennsylvania, Journal of Field Ornithology 66 (4): 544–552.

Butet A, Rantier Y & Bergerot B 2022: Land use changes and raptor population trends: A twelve-year monitoring of two common species in agricultural landscapes of Western France. Global Ecology and Conservation 34: e02027. DOI: 10.1016/j.gecco.2022.e02027

Byrne ME, Holland AE, Turner KL, Bryan AL & Beasley JC 2019: Using multiple data sources to investigate foraging niche partitioning in sympatric obligate avian scavengers. Ecosphere 10(1): e02548. DOI:10.1002/ecs2.2548

Cadotte MW, Carscadden K & Mirotchnick N 2011: Beyond species: functional diversity and the maintenance of ecological processes and services. Journal of Applied Ecology 48(5): 1079-1087. DOI:10.1111/j.1365-2664.2011.02048.x

Campbell MON 2015: Vultures: their evolution, ecology and conservation. CRC Press. DOI:10.1201/b18638

Carrete M, Tella JL, Blanco G & Bertellotti M 2009: Effects of habitat degradation on the abundance, richness and diversity of raptors across Neotropical biomes. Biological Conservation 142(10): 2002-2011. DOI:10.1016/j.biocon.2009.02.012

Champion HG & Seth S K 1968: A revised survey of the forest types of India. Manager of publications, Delhi.

Chao A, Chiu CH, Villéger S, Sun IF, Thorn S, Lin YC, Chiang JM & Sherwin WB 2019: An attribute-diversity approach to functional diversity, functional beta diversity, and related (dis)similarity measures. Ecological Monographs: 89(2), e01343. DOI: 10.1002/ecm.1343

Clancy GP 2005: Feeding behaviour of the Osprey *Pandion haliaetus* on the north coast of New South Wales. Corella 29(4): 91-96.

Cornwell WK, Schwilk DW & Ackerly DD 2006: A trait-based test for habitat filtering: convex hull volume. Ecology: 87, 1465–1471. DOI:10.1890/0012-9658(2006)87[1465:ATTFHF]2.0.CO;2

Di Vittorio M, Lopez-Lopez P, Cortone G & Luiselli L 2017: The diet of the Egyptian vulture (*Neophron percnopterus*) in Sicily: Temporal variation and conservation implications. Vie et milieu - Life and environment 67(1): 7–14.

Diaz S & Cabido M 2001: Vive la difference: Plant functional diversity matters to ecosystem processes. Trends in Ecology & Evolution 16(11): 646–655. DOI:10.1016/S0169-5347(01)02283-2

Díaz S, Cabido M & Casanoves F 1998: Plant functional traits and environmental filters at a regional scale. Journal of Vegetation Science: 9, 113–22. DOI:10.2307/3237229

Donázar JA, Cortés-Avizanda A, Fargallo J A, Margalida A, Moleón M, Morales-Reyes Z & Serrano D 2016: Roles of raptors in a changing world: from flagships to providers of key ecosystem services. Ardeola 63(1): 181-234. DOI:10.13157/arla.63.1.2016.rp8

Donázar JA, Cortés-Avizanda A, Fargallo JA, Margalida A, Moleón M, Morales-Reyes Z, Moreno-Opo R, Pérez-García JM, Sánchez-Zapata JA, Zuberogoitia

I & Serrano D 2016: Roles of raptors in a changing world: from flagships to providers of key ecosystem services. Ardeola: 63(1), 181–234.

Dos Anjos L, Bochio GM, Medeiros HR, Almeida BDA, Lindsey BRA, Calsavara LC, Ribeiro MC & Domingues Torezan JM 2019: Insights on the functional composition of specialist and generalist birds throughout continuous and fragmented forests. Ecology and Evolution: 9(11), 6318–6328. DOI: 10.1002/ece3.5209

Dunne P & Karlson K T 2017: Birds of prey: hawks, eagles, falcons, and vultures of North America. Houghton Mifflin Harcourt.

Duriez O, Kato A, Tromp C, Dell'Omo G, Vyssotski AL, Sarrazin F & Ropert-Coudert Y 2014: How cheap is soaring flight in raptors? A preliminary investigation in freely-flying vultures. PloS one 9(1): e84887.

eBird 2025: eBird: An online database of bird distribution and abundance. eBird, Cornell Lab of Ornithology, Ithaca, New York. Retrieved February 02, 2025, from http://www.ebird.org.

Eduardo C, Carvalho A & Marini MÂ 2007: Distribution patterns of diurnal raptors in open and forested habitats in south-eastern Brazil and the effects of urbanization. Bird Conservation International 17(4): 367–380. DOI: 10.1017/S0959270907000822

Fleming PA & Bateman PW 2018: Novel predation opportunities in anthropogenic landscapes. Animal behaviour 138: 145–155. DOI: 10.1016/j.anbehav.2018.02.011

Flynn DFB, Gogol-Prokurat M, Nogeire T, Molinari N, Richers BT, Lin BB, Simpson N, Mayfield MM & DeClerck F 2009: Loss of functional diversity under land use intensification across multiple taxa. Ecological Letters 12: 22–33. DOI: 10.1111/j.1461-0248.2008.01255.x

Gompper ME 2014: Free-ranging dogs and wildlife conservation. Oxford University Press, USA. DOI: 10.1093/acprof:osobl/9780199663217.001.0001

Gower JC 1966: Some distance properties of latent root and vector methods used in multivariate analysis. Biometrika, 53(3,4),325–338, DOI: 10.1093/biomet/53.3-4.325

Grande JM, Orozco-Valor PM, Liébana MS & Sarasola JH 2018: Birds of prey in agricultural landscapes: The role of agriculture expansion and intensification. Birds of prey: biology and conservation in the XXI century: 197–228. DOI: 10.1007/978-3-319-73745-4_9

Green RE, Newton IAN, Shultz S, Cunningham AA, Gilbert M, Pain D J & Prakash V 2004: Diclofenac poisoning as a cause of vulture population declines across the Indian subcontinent. Journal of Applied Ecology 41(5): 793–800. DOI: 10.1111/j.0021-8901.2004.00954.x

Green RE, Pain DJ & Krone O 2022: The impact of lead poisoning from ammunition sources on raptor populations in Europe. Science of the Total Environment 823: 154017. DOI: 10.1016/j.scitotenv.2022.154017

Guisan A, Thuiller W & Zimmermann NE 2017: Habitat Suitability and Distribution Models: With Applications in R. Cambridge University Press.

Hawkins BA, Field R, Cornell HV, Currie DJ, Gue´gan J-F, Kaufman DM, Kerr JT, Mittelbach GG, Oberdorff T, O'Brien EM, Porter EE & Turner JRG 2003: Energy, water, and broad-scale geographic patterns of species richness. Ecology: 84, 3105–17. DOI: 10.1890/03-8006

Hsieh TC, Ma KH & Chao A 2024: iNEXT: iNterpolation and EXTrapolation for species diversity. R package version 3.0.1

Hussin MZB & Francis CM 2001: The Effects of Logging on Birds in Tropical Forests of Indo-Australia. In The Cutting Edge, Columbia University Press: pp. 193–212.

Iknayan KJ & Beissinger SR 2018: Collapse of a desert bird community over the past century driven by climate change. Proceedings of the National Academy of Sciences: 115 (34), 8597–8602. DOI: 10.1073/pnas.180512311

IUCN 2025: The IUCN Red List of Threatened Species. Version 2025-1. Retrieved April 04, 2025, from https://www.iucnredlist.org..

Joseph GS, Seymour CL, Cumming GS, Cumming DHM & Mahlangu Z 2014: Termite mounds increase functional diversity of woody plants in African savannas. Ecosystems: 17, 808–19.

Kaboli M, Guillaumet A & Prodon R 2006: Avifaunal gradients in two arid zones of central Iran in relation to vegetation, climate and topography. Journal of Biogeography 33: 133–144. DOI: 10.1111/j.1365-2699.2005.01379.x

Kouba M, Slobodník R & Chavko J 2021: Post-fledging dependence period, dispersal movements and temporary settlement areas in saker falcons (*Falco cherrug*). Raptor Journal 15: 75–87. DOI: 10.2478/srj20210005

Kremen C 2005: Managing ecosystem services: What do we need to know about their ecology? Ecology Letters 8(5): 468–479. DOI: 10.1111/j.1461-0248.2005.00751.x

Kumar S, Sohil A, Kichloo MA & Sharma N 2022: Landscape heterogeneity affects diurnal raptor communities in a sub-tropical region of northwestern Himalayas, India. PLoS ONE 17(4): e0246555. DOI: 10.1371/journal.pone.0246555

Laliberté E & Legendre P 2010: A distance-based framework for measuring functional diversity from multiple traits. Ecology: 91, 299–305. DOI: 10.1890/08-2244.1

Lehman RN 2001: Raptor electrocution on power lines: current issues and outlook. Wildlife Society Bulletin: 29, 804–813.

Lehman RN, Kennedy PL & Savidge JA 2007: The state of the art in raptor electrocution research: a global review. Biological conservation 136(2): 159–174. DOI: 10.1016/j.biocon.2006.09.015

Lorenzón RE, Beltzer AH, Olguin PF & Ronchi-Virgolini AL 2016: Habitat heterogeneity drives bird species richness, nestedness and habitat selection by individual species in fluvial wetlands of the Paraná River, Argentina. Austral ecology 41: 829–841. DOI: 10.1111/aec.12375

Luck GW, Carter A & Smallbone L 2013: Changes in bird functional diversity across multiple land uses: interpretations of functional redundancy depend on functional group identity. PLOS ONE: 8(5), e63671. DOI: 10.1371/journal.pone.0063671

Magneville C, Loiseau N, Albouy C, Casajus N, Claverie T, Escalas A, Leprieur F, Maire E, Mouillot D & Villéger S 2021: mFD: an R package to compute and illustrate the multiple facets of functional diversity. Ecography 2022(1): e05904 (ver. 1.0). DOI: 10.1111/ecog.05904

McClure CJ, Schulwitz SE, Anderson DL, Robinson BW, Mojica EK, Therrien JF & Johnson J 2019: Commentary: defining raptors and birds of prey. Journal of Raptor Research 53(4): 419–430. DOI: 10.3356/0892-1016-53.4.419

McClure CJ, Westrip JR, Johnson JA, Schulwitz SE, Virani MZ, Davies R & Butchart SH 2018: State of the world's raptors: Distributions, threats, and conservation recommendations. Biological Conservation 227: 390–402. DOI: 10.1016/j.biocon.2018.08.012

Mouillot D, Graham NAJ, Villéger S, Mason NWH & Bellwood DR 2013: A functional approach reveals community responses to disturbances. Trends in Ecology & Evolution: 28: 167–177. DOI: 10.1016/j.tree.2012.10.004

Morrison ML, Marcot BG & Mannan RW 2006: Wildlife-habitat relationships: Concepts and applications. 3rd ed. Island Press, Washington, DC.

Mundy DL 1995: The thematic use of raptors as a focus for environmental studies and conservation programs. Prescott College.

Naoroji R & Sangha HS 2013: Status and distribution of raptors in Rajasthan. In Faunal heritage of Rajasthan, India: 357–409. New York: Springer. DOI: 10.1007/978-1-4614-0800-0

Naoroji R 2006: Birds of Prey of the Indian Sub-continent, 1–690. Uttar Pradesh: Om Books International. DOI: 10.3356/0892-1016-43.2.172

Naranjo LG & Raitt RJ 1993: Breeding bird distribution in Chihuahuan desert habitats. Southwest. Nat. 38: 43–51. DOI: 10.2307/3671643

Negro JJ & Galván I 2018: Behavioural ecology of raptors. Birds of Prey: Biology and conservation in the XXI century: 33-62. DOI: 10.1007/978-3-319-73745-4

O'Bryan CJ, Allan JR, Suarez-Castro AF, Delsen DM, Buij R, McClure CJ & Kissling WD 2022: Human impacts on the world's raptors. Frontiers in Ecology and Evolution 10: 624896. DOI: 10.3389/fevo.2022.624896

O'reagain PJ & Schwartz J 1995: Dietary selection and foraging strategies of animals on rangeland: Coping with spatial and temporal variability. In International Symposium on the Nutrition of Herbivores, Vol. 4: pp. 419–424.

Oaks JL, Gilbert M, Virani MZ, Watson RT, Meteyer CU, Rideout BA, Shivaprasad HL, Ahmed S, Chaudhry MJI, Arshad M, Mahmood S, Ali A & Khan AA 2004: Diclofenac residues as the cause of vulture population decline in Pakistan. Nature: 427, 630–633.

Ogada DL, Keesing F & Virani M Z 2012: Dropping dead: causes and consequences of vulture population declines worldwide. Annals of the New York Academy of Sciences 1249(1): 57–71. DOI: 10.1111/j.1749-6632.2011.06293.x

Oksanen J, Simpson G, Blanchet F, Kindt R, Legendre P, Minchin P, O'Hara R, Solymos P, Stevens M, Szoecs E, Wagner H, Barbour M, Bedward M, Bolker B, Borcard D, Carvalho G, Chirico M, De Caceres M, Durand S, Evangelista H, FitzJohn R, Friendly M, Furneaux B, Hannigan G, Hill M, Lahti L, McGlinn D, Ouellette M, Ribeiro Cunha E, Smith T, Stier A, Ter Braak C, Weedon J & Borman T 2025: vegan: Community Ecology Package. R package version 2.6-10.

Oliveira ACPD, Nunes A, Oliveira MA, Rodrigues RG & Branquinho C 2022: How do taxonomic and functional diversity metrics change along an aridity gradient in a tropical dry forest? Frontiers in Plant Science: 13, 923219. DOI: 10.3389/fpls.2022.923219

Owens IPF & Bennett PM 2000: Ecological basis of extinction risk in birds: Habitat loss versus human persecution and introduced predators. Proceedings of the National Academy of Sciences: 97, 12144–12148. DOI: 10.1073/pnas.200223397

Petchey OL & Gaston KJ 2006: Functional diversity: Back to basics and looking forward. Ecology Letters 9(6): 741–758. DOI: 10.1111/j.1461-0248.2006.00924.x

Praveen J & Jayapal R 2024: Taxonomic updates to the checklists of birds of India and the South Asian region. Indian Birds 20 (6): 165–169.

Pringle S, Chiweshe N, Steward PR, Mundy PJ & Dallimer M 2019: Rapid redistribution of agricultural land alters avian richness, abundance, and functional diversity. Ecology and Evolution: 9(21), 12259–12271.

R Core Team 2024: R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org

Rotenberry JT 1978: Components of avian diversity along a multifactorial climatic gradient. Ecology 59: 693–699. DOI: 10.2307/1938772

Selva N, Moleón M, Sebastián-González E, DeVault TL, Quaggiotto MM, Bailey DM & Margalida A 2019: Vertebrate scavenging communities. Carrion ecology and management: 71-99.

Sergio F, Caro T, Brown D, Clucas B, Hunter J, Ketchum J, McHugh K & Hiraldo F 2008: Top predators as conservation tools: ecological rationale, assumptions, and efficacy. Annual Review of Ecology, Evolution, and Systematics: 39, 1–19. DOI: 10.1146/annurev.ecolsys.39.110707.173545

Sergio F, Newton I & Marchesi L 2005: Top predators and biodiversity. Nature 436(7048): 192–192. DOI: 10.1038/s41598-019-44159-6

Sharma BK, Kulshreshtha S, Sharma SK, Lodha RM, Singh S, Singh M & Sharma N 2013: Physiography and biological diversity of Rajasthan. In Faunal Heritage of Rajasthan, India: General Background and Ecology of Vertebrates. New York, NY: Springer New York:

Smith TB, Kark S, Schneider CJ, Wayne RK & Moritz C 2001: Biodiversity hotspots and beyond: the need for preserving environmental transitions. Trends in Ecology & Evolution: 16(8), 431. DOI: 10.1016/S0169-5347(01)02149-4

Spaar R 1997: Flight strategies of migrating raptors; a comparative study of interspecific variation in flight characteristics. Ibis 139(3): 523-535.

Thiollay JM 2006: The decline of raptors in West Africa: long-term assessment, human pressure and role of protected areas. Ibis 148: 240–254. Tiwari G, Pandey P, Kaul R, Lee H & Singh R 2023: Time-of-day bias in diurnal raptors in arid region of Rajasthan. Acta Ecologica Sinica 43(3): 545-559. DOI: 10.1016/j.chnaes.2022.07.005

Tiwari G, Pandey P, Kaul R, Lee H & Singh R 2021: Comparison of point and roadside transect methods to evaluate the abundance and richness of diurnal raptors in the arid region of Rajasthan. PLoS ONE 16(12): e0259805. DOI: 10.1371/journal.pone.0259805

Tobias JA, Sheard C, Pigot AL, Devenish AJM, Yang J, Sayol F & Neate-Clegg MHC 2022: AVONET: morphological, ecological and geographical data for all birds. Ecology Letters 25 (3): 581–597. DOI: 10.1111/ele.13898/

Vergara P 2010: Time-of-day bias in diurnal raptor abundance and richness estimated by road surveys, Revista catalana d'ornitologia 26: 22–30.

Villéger S, Mason NWH & Mouillot D 2008: New multidimensional functional diversity indices for a multifaceted framework in functional ecology. Ecology: 89, 2290–2301. https://doi.org/10.1890/07-1206.1

Weiher E, Clarke GDP & Keddy PA 1998: Community assembly rules, morphological dispersion and the coexistence of plant species. Oikos: 81, 309–322. DOI: 10.2307/3547051

Voskamp A, Baker DJ, Stephens PA, Valdes PJ & Willis SG 2017: Global patterns in the divergence between phylogenetic diversity and species richness in terrestrial birds. J Biogeogr 44: 709–721.

Ward AB, Weigl PD & Conroy RM 2002: Functional morphology of raptor hindlimbs: implications for resource partitioning. The Auk 119(4): 1052-1063.

White CM 1974: Current problems and techniques in raptor management and conservation. Transactions of the North American Wildlife Conference 39: 301–312.

Wilman H, Belmaker J, Simpson J, Rosa CDL, Rivadeneira MM, Jetz W 2014: EltonTraits 1.0: species-level foraging attributes of the world's birds and mammals. Ecology 95 (7): 2027. DOI: 10.6084/m9.figshare.c.3306933.v1

Zomer R & Trabucco A 2019: Global Aridity Index and Potential Evapotranspiration (ET0) Database: Version 3. figshare. Dataset. DOI: 10.6084/m9.figshare.7504448.

Received: 8.4.2025
Accepted: 31.7.2025

Appendix 1. Abundance and relative abundance of raptors in three different habitat categories in Rajasthan.
Príloha 1. Abundacia a relatívna abundacia dravcov v troch rôznych typoch biotopov v Rádžastáne.

Species	Open		Closed		Mosaic		Total	
	n	%	n	%	n	%	n	%
Accipiter badius	15	3.1	65	15.7	30	10.6	110	9.3
Accipiter nisus	8	1.7	5	1.2	3	1.1	16	1.4
Aegypius monachus	32	6.6	3	0.7	1	0.4	36	3.0
Aquila fasciata	3	0.6	11	2.7	1	0.4	15	1.3
Aquila heliaca	9	1.9	2	0.5	1	0.4	12	1.0
Aquila nipalensis	30	6.2	20	4.8	5	1.8	55	4.7
Aquila rapax	8	1.7	2	0.5	2	0.7	12	1.0
Asio flammeus	2	0.4	1	0.2	0	0	3	0.3
Asio otus	1	0.2	0	0	0	0	1	0.1
Athene brama	20	4.1	70	17	13	4.6	103	8.7
Bubo bengalensis	8	1.7	3	0.7	1	0.4	12	1.0
Bubo coromandus	0	0	4	1	0	0	4	0.3
Butastur teesa	7	1.4	13	3.2	1	0.4	21	1.8
Buteo buteo	2	0.4	3	0.7	1	0.4	6	0.5
Buteo rufinus	10	2.1	2	0.5	2	0.7	14	1.2
Circaetus gallicus	2	0.4	10	2.4	1	0.4	13	1.1
Circus aeruginosus	22	4.5	4	1	8	2.8	34	2.9
Circus macrourus	9	1.9	0	0	1	0.4	10	0.8
Circus pygargus	8	1.7	1	0.2	3	1.1	12	1.0
Clanga clanga	8	1.7	1	0.2	1	0.4	10	0.8
Clanga hastata	2	0.4	5	1.2	2	0.7	9	0.8
Elanus caeruleus	40	8.3	5	1.2	10	3.5	55	4.7
Falco chicquera	6	1.2	2	0.5	1	0.4	9	0.8
Falco jugger	15	3.1	1	0.2	3	1.1	19	1.6
Falco peregrinus	3	0.6	8	1.9	2	0.7	13	1.1
Falco subbuteo	3	0.6	0	0	0	0	3	0.3
Falco tinnunculus	14	2.9	2	0.5	8	2.8	24	2.0
Gyps bengalensis	5	1	20	4.8	3	1.1	28	2.4
Gyps fulvus	38	7.8	12	2.9	19	6.7	69	5.8
Gyps himalayensis	15	3.1	3	0.7	7	2.5	25	2.1
Gyps indicus	7	1.4	21	5.1	9	3.2	37	3.1
Hieraaetus pennatus	6	1.2	12	2.9	4	1.4	22	1.9
Ictinaetus malaiensis	0	0	2	0.5	0	0	2	0.2
Milvus migrans	55	11.3	23	5.6	75	26.4	153	12.9
Neophron percnopterus	49	10.1	12	2.9	44	15.5	105	8.9
Nisaetus cirrhatus	0	0	3	0.7	1	0.4	4	0.3
Otus bakkamoena	1	0.2	9	2.2	3	1.1	13	1.1
Pandion haliaetus	8	1.7	6	1.5	7	2.5	21	1.8
Pernis ptilorhynchus	4	0.8	21	5.1	5	1.8	30	2.5
Sarcogyps calvus	4	0.8	7	1.7	1	0.4	12	1.0
Spilornis cheela	1	0.2	11	2.7	2	0.7	14	1.2
Strix ocellata	0	0	4	1	0	0	4	0.3
Tyto alba	5	1	4	1	3	1.1	12	1.0
Total	**485**	**100**	**413**	**100**	**284**	**100**	**1182**	**100**
Total Species	**39**		**40**		**37**		**43**	

Appendix 2. Abundance and relative abundance of raptors in five different aridity zones in Rajasthan.
Príloha 2. Abundacia a relatívna abundacia dravcov v piatich rôznych zónach sucha v Rádžastáne.

Species	Thar Desert		Eastern Desert Margin		Aravalli Hills		Semi-Arid Plains		Sub-Humid Plateau		Total	
	n	%	n	%	n	%	n	%	n	%	n	%
Accipiter badius	4	2.6	7	3.3	18	7.4	54	16.4	27	11.3	110	9.3
Accipiter nisus	1	0.6	2	0.9	7	2.9	4	1.2	2	0.8	16	1.4
Aegypius monachus	18	11.5	11	5.2	0	0	3	0.9	4	1.7	36	3.1
Aquila fasciata	1	0.6	3	1.4	5	2.1	4	1.2	2	0.8	15	1.3
Aquila heliaca	4	2.6	4	1.9	2	0.8	1	0.3	1	0.4	12	1
Aquila nipalensis	12	7.7	15	7	16	6.6	9	2.7	3	1.3	55	4.7
Aquila rapax	5	3.2	4	1.9	2	0.8	1	0.3	0	0	12	1
Asio flammeus	1	0.6	1	0.5	1	0.4	0	0	0	0	3	0.3
Asio otus	0	0	1	0.5	0	0	0	0	0	0	1	0.1
Athene brama	12	7.7	9	4.2	25	10.3	37	11.2	20	8.4	103	8.7
Bubo bengalensis	0	0	2	0.9	7	2.9	2	0.6	1	0.4	12	1
Bubo coromandus	0	0	0	0	0	0	3	0.9	1	0.4	4	0.3
Butastur teesa	4	2.6	5	2.4	5	2.1	6	1.8	1	0.4	21	1.8
Buteo buteo	2	1.3	1	0.5	1	0.4	1	0.3	1	0.4	6	0.5
Buteo rufinus	4	2.6	5	2.4	4	1.6	1	0.3	0	0	14	1.2
Circaetus gallicus	2	1.3	1	0.5	3	1.2	5	1.5	2	0.8	13	1.1
Circus aeruginosus	1	0.6	3	1.4	8	3.3	15	4.6	7	2.9	34	2.9
Circus macrourus	1	0.6	3	1.4	4	1.6	1	0.3	1	0.4	10	0.9
Circus pygargus	1	0.6	3	1.4	4	1.6	3	0.9	1	0.4	12	1
Clanga clanga	4	2.6	2	0.9	2	0.8	1	0.3	1	0.4	10	0.9
Clanga hastata	1	0.6	1	0.5	1	0.4	2	0.6	4	1.7	9	0.8
Elanus caeruleus	5	3.2	9	4.2	22	9	12	3.6	7	2.9	55	4.7
Falco chicquera	2	1.3	3	1.4	2	0.8	1	0.3	1	0.4	9	0.8
Falco jugger	3	1.9	5	2.4	5	2.1	5	1.5	1	0.4	19	1.6
Falco peregrinus	1	0.6	1	0.5	6	2.5	4	1.2	1	0.4	13	1.1
Falco subbuteo	1	0.6	1	0.5	0	0	1	0.3	0	0	3	0.3
Falco tinnunculus	3	1.9	6	2.8	8	3.3	5	1.5	2	0.8	24	2
Gyps bengalensis	1	0.6	2	0.9	0	0	6	1.8	19	8	28	2.4
Gyps fulvus	20	12.8	32	15	10	4.1	5	1.5	2	0.8	69	5.8
Gyps himalayensis	10	6.4	12	5.6	1	0.4	1	0.3	1	0.4	25	2.1
Gyps indicus	6	3.9	5	2.4	4	1.6	2	0.6	20	8.4	37	3.1
Hieraaetus pennatus	2	1.3	2	0.9	6	2.5	6	1.8	6	2.5	22	1.9
Ictinaetus malaiensis	0	0	0	0	0	0	2	0.6	0	0	2	0.2
Milvus migrans	2	1.3	4	1.9	36	14.8	65	19.7	46	19.3	153	12.9
Neophron percnopterus	15	9.6	43	20.2	8	3.3	14	4.2	25	10.5	105	8.9
Nisaetus cirrhatus	0	0	0	0	1	0.4	2	0.6	1	0.4	4	0.3
Otus bakkamoena	1	0.6	1	0.5	3	1.2	6	1.8	2	0.8	13	1.1
Pandion haliaetus	1	0.6	1	0.5	4	1.6	9	2.7	6	2.5	21	1.8
Pernis ptilorhynchus	1	0.6	1	0.5	6	2.5	15	4.6	7	2.9	30	2.5
Sarcogyps calvus	3	1.9	1	0.5	0	0	3	0.9	5	2.1	12	1
Spilornis cheela	0	0	0	0	3	1.2	6	1.8	5	2.1	14	1.2
Strix ocellata	0	0	0	0	1	0.4	2	0.6	1	0.4	4	0.3
Tyto alba	1	0.6	1	0.5	3	1.2	5	1.5	2	0.8	12	1
Total	**156**	**100**	**213**	**100**	**244**	**100**	**330**	**100**	**239**	**100**	**1182**	**100**
Total Species	**36**		**38**		**36**		**41**		**37**		**43**	