

## Spatial Distribution and Species Diversity of Hornbills in the Protected Areas of the Terai Region of Uttar Pradesh, India

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### ABSTRACT

Hornbills (Family: Bucerotidae) are ecologically important frugivorous birds that contribute significantly to long-distance seed dispersal, forest regeneration, and the maintenance of tropical forest ecosystems. Despite their ecological significance, baseline information on the distribution and diversity of hornbill species in the protected areas of the Terai region of Uttar Pradesh remains limited. The present study assessed the distribution, abundance, and species diversity of Indian Grey Hornbill (*Ocyrceros birostris*) and Oriental Pied Hornbill (*Anthraceroceros albirostris*) across four protected areas of the Terai region, namely Pilibhit Tiger Reserve, Katarniaghat Wildlife Sanctuary, Sohagi Barwa Wildlife Sanctu-

ary, and Bakhira Bird Sanctuary. Field surveys were conducted using random surveys and point count methods. Species diversity was evaluated using Simpson's Index (D), Simpson's Diversity Index (1-D), Simpson's Reciprocal Index (1/D), Shannon–Wiener Diversity Index (H'), and Shannon Equitability Index (EH). The Indian Grey Hornbill was recorded from all four protected areas and exhibited greater overall abundance than the Oriental Pied Hornbill, which was absent from Bakhira Bird Sanctuary during the study period. Among the surveyed protected areas, Katarniaghat Wildlife Sanctuary recorded the highest species diversity (Shannon–Wiener Diversity Index,  $H' = 0.67$ ) and species evenness ( $EH = 0.96$ ), whereas Bakhira Bird Sanctuary exhibited the lowest diversity because only one hornbill species was recorded. Comparative analyses demonstrated clear variation in hornbill diversity and community composition among the protected areas. The observed differences in species occurrence and diversity indicate that hornbill assemblages vary across protected landscapes of the Terai region and suggest that habitat characteristics influence community composition. The study provides baseline ecological information on the distribution and diversity of hornbill species in the protected areas of Uttar Pradesh and establishes a scientific foundation for future ecological monitoring, habitat assessment, and conservation planning within the Terai landscape.

**Keywords** Hornbill diversity, *Ocyrceros birostris*, *Anthraceroceros albirostris*, Protected areas, Terai arc landscape, Biodiversity conservation.

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## INTRODUCTION

Hornbills (Family: Bucerotidae) are among the most ecologically significant frugivorous birds inhabiting the tropical and subtropical forests of Africa and Asia (Pawar, P. *et al.* 2021). They play a fundamental role in long-distance seed dispersal, thereby contributing to forest regeneration, plant recruitment, and the maintenance of ecosystem structure. Owing to this ecological function, hornbills are widely recognized as the “farmers of the forest” (Nigam, R. *et al.* 2026).

India supports nine hornbill species (Rana, K. *et al.* 2025) occupying diverse forest ecosystems, where their occurrence is closely associated with mature forests containing fruiting trees and suitable nesting cavities. Among these, the Indian Grey Hornbill (*Ocyrceros birostris*) and Oriental Pied Hornbill (*Anthraceroceros albirostris*) are widely distributed across northern India, including the Terai landscape of Uttar Pradesh (Ram, M. *et al.* 2025). Their distribution is strongly influenced by habitat quality, vegetation composition, food availability, and the presence of large cavity-bearing trees required for breeding (Pradhan, K. *et al.* 2024).

The Terai region of Uttar Pradesh forms an important component of the Terai Arc Landscape (TAL), one of South Asia’s globally significant biodiversity landscapes (Wee, S. Q. *et al.* 2024). The region comprises tropical moist deciduous forests, riverine forests, wetlands, and grasslands that support a rich assemblage of flora and fauna. However, increasing anthropogenic pressures, habitat fragmentation, land-use change, and degradation of natural forests have the potential to alter habitat suitability for hornbill populations (Sarkar and Talukdar 2023).

Despite the ecological importance of hornbills, systematic information on their distribution and diversity within the protected areas of the Terai region remains limited (Aik and Perumal 2017). Most previous investigations have been concentrated in the Western Ghats and Northeast India (Madhu, N. *et al.* 2026), leaving a substantial knowledge gap regarding hornbill ecology in northern India. Reliable baseline information on species distribution and diversity is therefore essential for understanding habitat use

and supporting conservation planning in the Terai landscape.

The present study aimed to (I) document the abundance and spatial distribution of Indian Grey Hornbill and Oriental Pied Hornbill across four protected areas of the Terai region of Uttar Pradesh; (II) evaluate species diversity using standard biodiversity indices; and (III) compare hornbill community structure among Pilibhit Tiger Reserve, Sohagi Barwa Wildlife Sanctuary, Katarniaghat Wildlife Sanctuary, and Bakhira Bird Sanctuary. The findings provide baseline ecological information that may assist future monitoring programmes and habitat-based conservation strategies for hornbills within the Terai landscape.

## MATERIALS AND METHODS

### Study area

The present study was conducted in four protected areas of the Terai region of Uttar Pradesh, India, namely Pilibhit Tiger Reserve (PTR), Katarniaghat Wildlife Sanctuary (KGWS), Sohagi Barwa Wildlife Sanctuary (SBWS), and Bakhira Bird Sanctuary (BBS) (Fig 1). The Terai region forms the northernmost belt of Uttar Pradesh along the Indo–Nepal border and constitutes an integral part of the Terai Arc Landscape (TAL), one of South Asia’s globally significant biodiversity landscapes. The region is characterized by tropical moist deciduous forests, riverine forests, wetlands, grasslands, and riparian ecosystems that support high floral and faunal diversity, including several ecologically important avian species such as hornbills.

The climate of the region is tropical monsoonal, with distinct summer, monsoon, and winter seasons. The southwest monsoon provides the majority of the annual rainfall, sustaining diverse vegetation communities, mature forest stands, and freshwater ecosystems that provide essential feeding, nesting, and breeding habitats for hornbill species.

The selected protected areas encompass both forest- and wetland-dominated ecosystems, representing a broad range of ecological conditions within the Terai landscape. This selection enabled a comparative

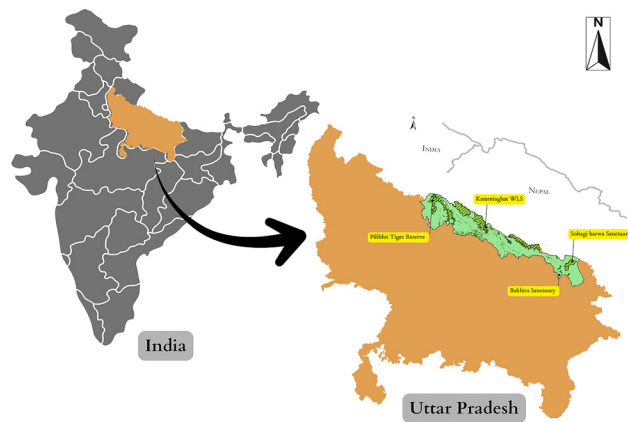


**Fig 1.** Study Area Map of 4 Protected Areas of the Uttar Pradesh Terai Region

assessment of hornbill distribution, abundance, and species diversity across contrasting habitat types. Detailed geographic, ecological, and habitat characteristics of each study area are summarized in Table 1, while their locations are illustrated in Fig 1. Together,

these protected areas provide a representative framework for evaluating hornbill community composition and generating baseline ecological information for biodiversity monitoring and conservation planning in the Terai region of Uttar Pradesh.

**Table 1.** Geographic, ecological and habitat characteristics of the protected areas surveyed for hornbill distribution and species diversity in the Terai region of Uttar Pradesh, India.

| Study Area                             | District                | Approximate Geographic Coordinates* | Protected Area (km <sup>2</sup> ) | Dominant Habitat                                                             | Major Vegetation Type                                                      | Altitude (m a.s.l.) | Recorded Hornbill Species                                                                      |
|----------------------------------------|-------------------------|-------------------------------------|-----------------------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------------|---------------------|------------------------------------------------------------------------------------------------|
| Pilibhit Tiger Reserve (PTR)           | Pilibhit & Shahjahanpur | 28°18'–28°42' N; 79°40'–80°05' E    | ~730                              | Tropical moist deciduous forest, grasslands and riverine habitats            | <i>Shorea robusta</i> (Sal)-dominated forests with mixed deciduous species | ~150–200            | Indian Grey Hornbill ( <i>O. birostris</i> ), Oriental Pied Hornbill ( <i>A. albirostris</i> ) |
| Katerniaghat Wildlife Sanctuary (KGWS) | Bahraich                | 27°41'–28°24' N; 81°48'–82°24' E    | ~551                              | Tropical moist deciduous forest, floodplains and riverine ecosystem          | Sal forests, mixed deciduous forests and riparian vegetation               | ~120–180            | Indian Grey Hornbill ( <i>O. birostris</i> ), Oriental Pied Hornbill ( <i>A. albirostris</i> ) |
| Sohagi Barwa Wildlife Sanctuary (SBWS) | Maharajganj             | 27°10'–27°30' N; 83°20'–83°45' E    | ~428                              | Moist deciduous forest with grasslands and riparian patches                  | Sal forests interspersed with mixed deciduous vegetation                   | ~100–150            | Indian Grey Hornbill ( <i>O. birostris</i> ), Oriental Pied Hornbill ( <i>A. albirostris</i> ) |
| Bakhira Bird Sanctuary (BBS)           | Sant Kabir Nagar        | 26°53'–26°58' N; 82°45'–82°55' E    | ~29                               | Freshwater wetland, marshes, agricultural interface and scattered tree cover | Wetland vegetation with peripheral mixed tree species                      | ~80–90              | Indian Grey Hornbill ( <i>O. birostris</i> )                                                   |

## Study design

The present study was conducted to assess the distribution, abundance, and species diversity of hornbills across four protected areas of the Terai region of Uttar Pradesh, India, namely Pilibhit Tiger Reserve (PTR), Katarniaghat Wildlife Sanctuary (KGWS), Sohagi Barwa Wildlife Sanctuary (SBWS), and Bakhira Bird Sanctuary (BBS). A comparative field-based survey design was adopted to document the occurrence and relative abundance of Indian Grey Hornbill (*O. birostris*) and Oriental Pied Hornbill (*A. albirostris*) under different habitat conditions.

## Field surveys

The study was conducted by adopting random sampling and point count technique (Gregory, R. D. *et al.* 2004). Nearly 50 km stretch was covered in each day survey and presence of hornbills either sighted or reported was being recorded. The observations were made with the help of CASON Professional 8×40 HD, 10X ZOOM, 40 MM Binocular and CANON 200 IID DSLR Camera with 75-300 mm Zoom Lens. Surveys were undertaken during periods of maximum hornbill activity, primarily during the early morning (approximately 0600–1000 h) and late afternoon (approximately 1600–1800 h), under favorable weather conditions to maximize species detectability.

Each protected area was surveyed systematically by traversing existing forest roads, patrol tracks, trails, and accessible habitat patches. Observation points were selected to provide representative coverage of different habitat types while minimizing observer disturbance. At each point count station, observations were made after allowing a brief settling period to reduce disturbance caused by the observer's arrival. All hornbill individuals detected visually or acoustically were recorded, along with the corresponding location, date, time, habitat type, and number of individuals observed.

To minimize double counting, individuals moving between adjacent observation sites were carefully monitored, and observations were recorded only once whenever possible. All surveys were conducted by the same observer following a standardized field protocol

to maintain consistency throughout the study.

## Diversity analysis

Species diversity was evaluated using commonly accepted ecological diversity indices. Simpson's Index (D), Simpson's Diversity Index ( $1 - D$ ), Simpson's Reciprocal Index ( $1/D$ ), Shannon–Wiener Diversity Index ( $H'$ ), and Shannon Equitability Index (EH) were calculated to assess species dominance, diversity, richness, and evenness among the study areas. These indices are widely used in ecological studies for comparing biodiversity patterns among habitats and protected landscapes

The calculated diversity indices were used to compare hornbill community composition among the four protected areas and to identify spatial variation in species diversity within the Terai region of Uttar Pradesh.

## Statistical analysis

Descriptive statistics, including species abundance, mean, standard deviation, minimum and maximum values, were computed to summarize hornbill observations from each protected area. Diversity indices were calculated using standard ecological methods, and comparative analyses were performed among the four study sites to evaluate variation in hornbill diversity and community composition. The results were presented using tables and graphical representations to facilitate comparison of abundance and diversity patterns across the study areas.

Biodiversity index of Indian Grey Hornbill and Oriental Pied Hornbill Terai region of Uttar Pradesh by using - Simpson's index (D), Simpson's Diversity index ( $1-D$ ), Simpson's Reciprocal index ( $1/D$ ), Shannon - Weiner Diversity index (H), Shannon Equitability Index (EH).

**Simpson's index (D):** Simpson's index (D) is a mathematical formula that measures how diverse a community is. It measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species). The value of  $D$  ranges between 0 and 1. With this index, 1 represents infinite diversity and

0, no diversity.

Formula:  $D = 1 - (\sum n_i(n_i - 1)) / (N(N - 1))$

D: The diversity index

$n_i$ : The number of individuals in species  $i$

N: The total number of individuals of all species

**Simpson's diversity index (1-D):** also known as the Gini-Simpson index. The value of this index also ranges between 0 and 1, but now, the greater the value, the greater the sample diversity.

Another way of overcoming the problem of the counter-intuitive nature of Simpson's Index is to take the reciprocal of the Index:

**Simpson's reciprocal index (1/D):** The value of this index starts with 1 as the lowest possible figure. This figure would represent a community containing only one species. The higher the value, the greater the diversity. The maximum value is the number of species (or other category being used) in the sample.

**Shannon-wiener diversity index (H')**: The Shannon-Wiener diversity index (H') is used to measure species diversity within a community by considering both species richness and species evenness. The value of the index generally ranges from 0 to 5, where values below 1 indicate low diversity, values between 1 and 3 indicate moderate diversity, and values above 3 indicate high diversity.

Formula - s.  $H' = - \sum p_i \ln p_i \quad i=1$

H' is the species diversity index,

s is the number of species, and

$p_i$  is the proportion of individuals of each species belonging to the  $i$ th species of the total number of individuals.

$p_i = n_i / N$

$n_i$  = Number of individuals of the  $i$ th species

N = Total number of individuals of all species

**Shannon equitability index (EH):** The Shannon equitability index is useful for understanding how similar the abundances of different species are in a community. For example, it can be used to compare the diversity of species in different communities, even if they have the same species richness.

Formula -  $EH = H / \ln(S)$

H: The Shannon Diversity Index, which measures the overall diversity of species in a community.

S: The total number of unique species in the community.

## RESULT AND DISCUSSION

### Species occurrence and abundance across protected areas

A total of two hornbill species, namely the Indian Grey Hornbill (*O. birostris*) and Oriental Pied Hornbill (*A. albirostris*), were recorded during the surveys conducted across the four protected areas of the Terai region of Uttar Pradesh. The occurrence and abundance of both species varied among the study sites (Table 2, Graph 1).

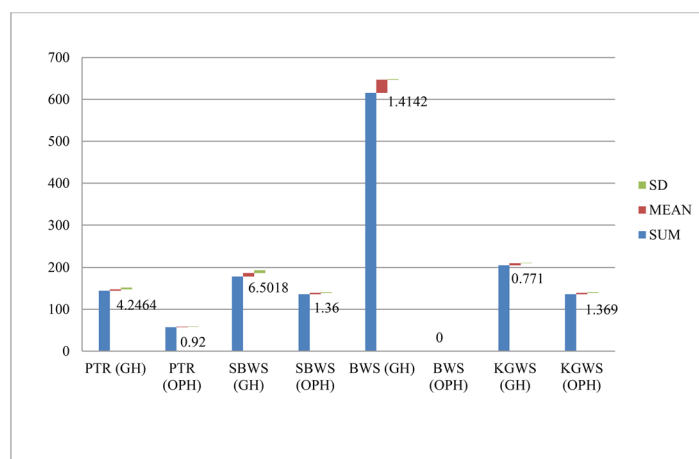
Indian Grey Hornbill was recorded from all four protected areas and exhibited the highest total abundance in Bakhira Bird Sanctuary, followed by Katarniaghat Wildlife Sanctuary, Sohagi Barwa Wildlife Sanctuary, and Pilibhit Tiger Reserve. Oriental Pied Hornbill was recorded from Pilibhit Tiger Reserve, Sohagi Barwa Wildlife Sanctuary, and Katarniaghat Wildlife Sanctuary but was not observed in Bakhira Bird Sanctuary during the study period. The highest abundance of Oriental Pied Hornbill was recorded in Sohagi Barwa Wildlife Sanctuary and Katarniaghat Wildlife Sanctuary, whereas Pilibhit Tiger Reserve recorded comparatively fewer individuals.

The descriptive statistics further indicated differences in the mean abundance and variability of hornbill observations among the protected areas. Indian Grey Hornbill recorded higher mean abundance

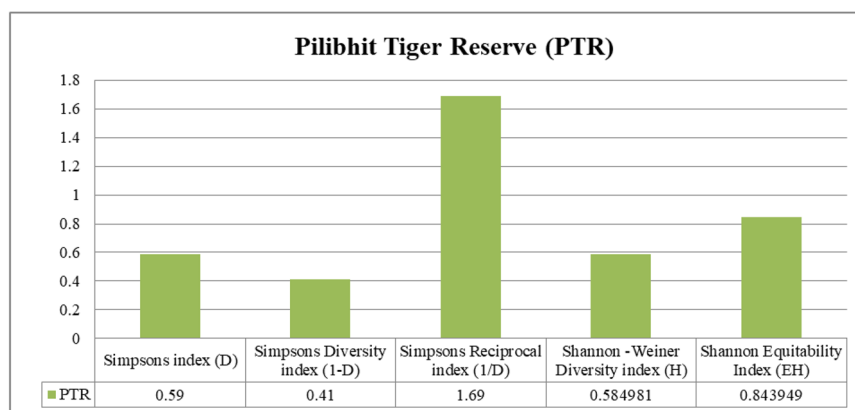
**Table 2.** Sum, Mean, Standard Deviation (SD) of Indian Grey Hornbill (IGH) and Oriental Pied Hornbill (OPH) in 4 Protected areas of Terai Region of Uttar Pradesh

|      | PTR (GH)    | PTR (OPH) | SBWS (GH)   | SBWS (OPH) | BBS (GH)    | BBS (OPH) | KGWS (GH) | KGWS (OPH) |
|------|-------------|-----------|-------------|------------|-------------|-----------|-----------|------------|
| SUM  | 144         | 57        | 178         | 136        | 615.461819  | 0         | 205       | 136        |
| MEAN | 3.512195122 | 1.39024   | 8.476190476 | 3.31       | 31.56214457 | 0         | 5         | 3.317      |
| SD   | 4.2464      | 0.92      | 6.5018      | 1.36       | 1.4142      | 0         | 0.771     | 1.369      |

PTR – Pilibhit Tiger Reserve, SBWS – Sohagi Barwa Wildlife Sanctuary, KGWS – Katarniaghat Wildlife Sanctuary, BBS – Bakhira Bird Sanctuary.



**Graph 1.** SUM, MEAN, SD of Indian Grey Hornbill (IGH) and Oriental Pied Hornbill (OPH) in 4 Protected areas of Terai Region of Uttar Pradesh



**Graph 2.** Diversity Index of Hornbill species at Pilibhit Tiger Reserve.

than Oriental Pied Hornbill across the study sites, while standard deviation values indicated variation in the frequency of observations among protected areas (Table 1).

### Hornbill diversity across the protected areas

Species diversity differed among the four protected areas as reflected by Simpson's Index, Simpson's

**Table 3.** Diversity index of Hornbill species at 4 Protected areas of Terai Region of Uttar Pradesh.

| Diversity Index                     | PTR  | SBWS | KGWS | BBS |
|-------------------------------------|------|------|------|-----|
| Simpsons index (D)                  | 0.59 | 0.59 | 0.52 | 1   |
| Simpsons Diversity index (1-D)      | 0.41 | 0.49 | 0.48 | 0   |
| Simpsons Reciprocal index (1/D)     | 1.69 | 1.97 | 1.93 | 1   |
| Shannon -Weiner Diversity index (H) | 0.58 | 0.59 | 0.67 | 0   |
| Shannon Equitability Index (EH)     | 0.8  | 0.85 | 0.96 | 0   |

**Note:** The calculated diversity indices demonstrated that the relative distribution of hornbill species differed among the four protected areas, with variation in both species diversity and species evenness.

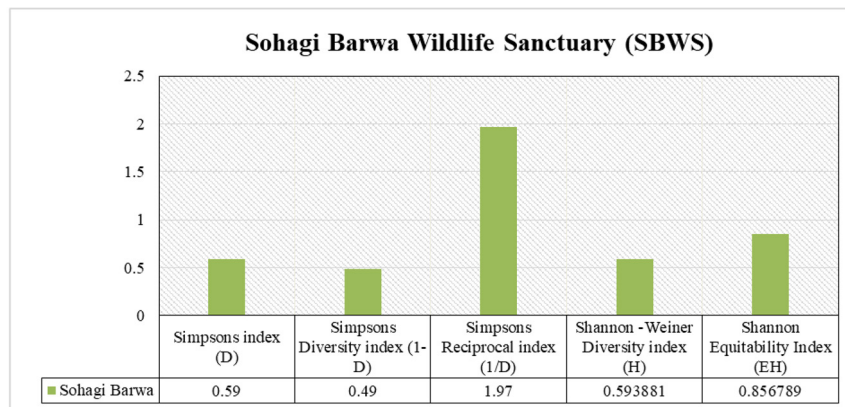
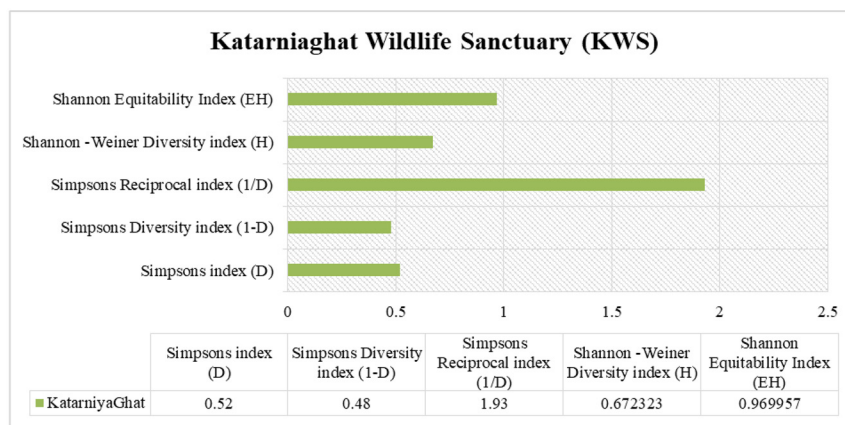
Diversity Index, Simpson's Reciprocal Index, Shannon-Weiner Diversity Index, and Shannon Equitability Index (Table 3).

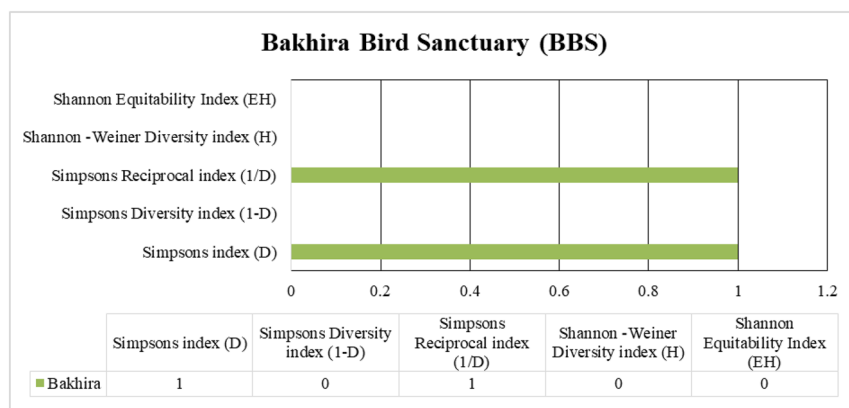
Among the surveyed protected areas, Katerniaghat Wildlife Sanctuary recorded the highest Shannon-Weiner Diversity Index ( $H = 0.67$ ) and Shannon Equitability Index ( $EH = 0.96$ ), followed by Sohagi Barwa Wildlife Sanctuary and Pilibhit Tiger Reserve. Bakhira Bird Sanctuary recorded the lowest diversity values, with Simpson's Diversity Index and Shannon Diversity Index equal to zero because only one hornbill species was recorded during the survey.

### Protected area-wise diversity pattern

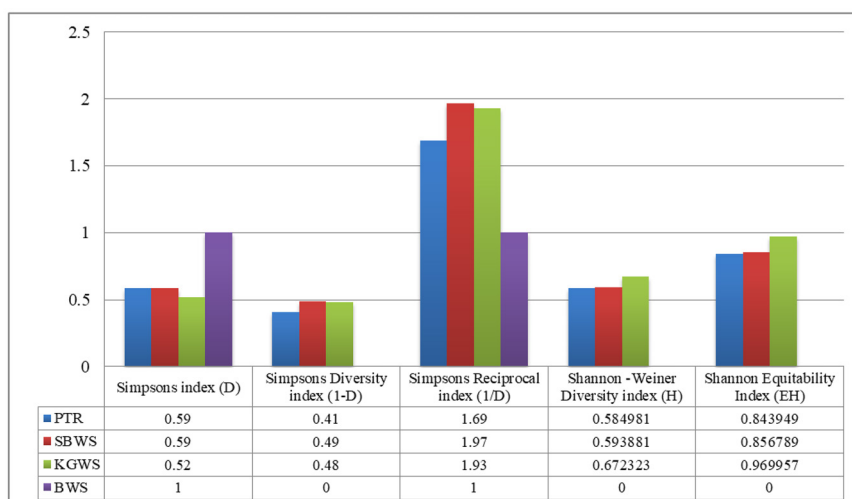
#### Pilibhit tiger reserve

The diversity indices calculated for Pilibhit Tiger

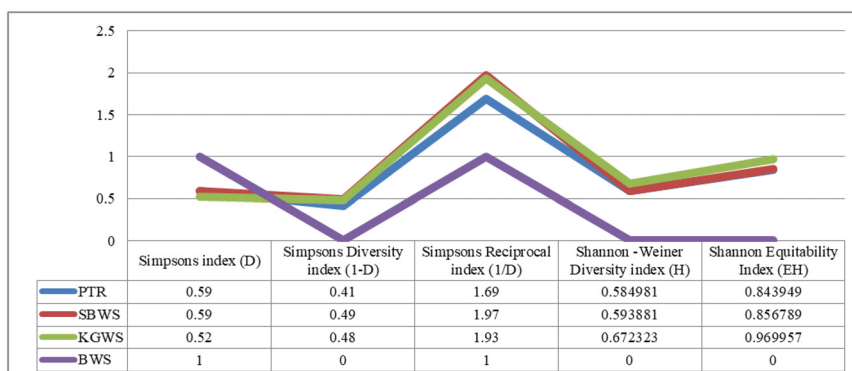
**Graph 3.** Diversity Index of Hornbill species at Sohagi Barwa Wildlife Sanctuary.**Graph 4.** Diversity Index of Hornbill species at Katerniaghat Wildlife Sanctuary.



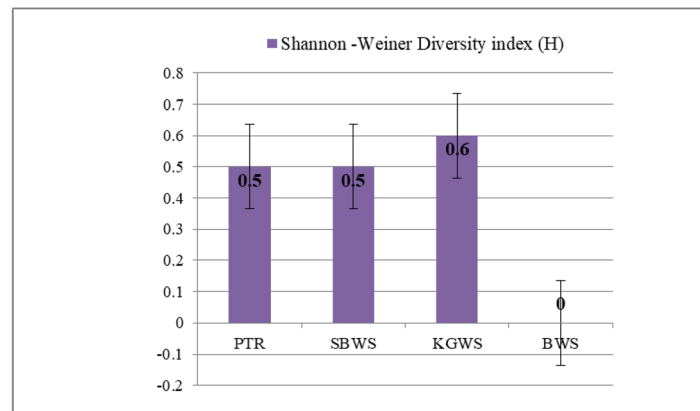
**Graph 5.** Diversity Index of Hornbill species at Bakhira Bird Sanctuary.



**Graph 6.** Comparative Analysis of Hornbill Diversity Index at 4 Protected areas of Terai Region of Uttar Pradesh.



**Graph 7.** Species Abundance & Species Richness of Hornbills at 4 Protected areas of Terai Region of Uttar Pradesh.



**Graph 8.** Species Richness of Hornbills at 4 Protected areas of Terai Region of Uttar Pradesh.



**Graph 9.** Species Abundance of Hornbills at 4 Protected areas of Terai Region of Uttar Pradesh.

Reserve indicated the occurrence of both hornbill species during the survey period. Simpson's Index (0.59), Shannon–Weiner Diversity Index ( $H = 0.58$ ), and Shannon Equitability Index ( $EH = 0.80$ ) reflected moderate diversity and relatively balanced representation of the two recorded species (Graph 2).

#### **Sohagi barwa wildlife sanctuary**

Sohagi Barwa Wildlife Sanctuary recorded both Indian Grey Hornbill and Oriental Pied Hornbill during the survey. The calculated diversity indices included Simpson's Index of 0.59, Shannon–Weiner Diversity Index of 0.59, and Shannon Equitability Index of 0.85, indicating moderate species diversity with relatively high evenness (Graph 3).

#### **Katarniaghat wildlife sanctuary**

Among all study sites, Katarniaghat Wildlife Sanctuary recorded the highest Shannon–Weiner Diversity Index ( $H = 0.67$ ) and Shannon Equitability Index ( $EH = 0.96$ ). Simpson's Diversity Index and Simpson's Reciprocal Index also indicated comparatively higher diversity relative to the other protected areas (Graph 4).

#### **Bakhira bird sanctuary**

Only Indian Grey Hornbill was recorded from Bakhira Bird Sanctuary during the present study. Consequently, Simpson's Diversity Index, Shannon–Weiner Diversity Index, and Shannon Equitability

Index recorded values of zero, while Simpson's Index indicated complete dominance by a single recorded species (Graph 5).

### **Comparative diversity among protected areas**

The comparative analysis of diversity indices demonstrated variation in hornbill community composition among the four protected areas (Graph 6). Katarniaghat Wildlife Sanctuary recorded the highest Shannon Diversity and Shannon Equitability values, followed by Sohagi Barwa Wildlife Sanctuary and Pilibhit Tiger Reserve. In contrast, Bakhira Bird Sanctuary exhibited the lowest diversity values because only one hornbill species was recorded during the survey period.

### **Species richness and relative abundance**

The comparison of species richness and abundance (Graphs 7–9) indicated differences in hornbill occurrence among the protected areas. Pilibhit Tiger Reserve, Sohagi Barwa Wildlife Sanctuary, and Katarniaghat Wildlife Sanctuary recorded the presence of both hornbill species, whereas only Indian Grey Hornbill was recorded from Bakhira Bird Sanctuary. Indian Grey Hornbill exhibited higher overall abundance than Oriental Pied Hornbill across the study sites, although the magnitude of abundance varied among protected areas.

The graphical analyses further illustrated that Shannon Diversity and Shannon Equitability values differed among the protected areas, with Katarniaghat Wildlife Sanctuary recording the highest values and Bakhira Bird Sanctuary the lowest. These findings are consistent with the diversity indices presented in Table 3.

## **DISCUSSION**

### **Spatial variation in hornbill distribution across the terai protected areas**

The present investigation revealed marked spatial variation in the occurrence and abundance of Indian Grey Hornbill (*Ocyrceros birostris*) and Oriental Pied Hornbill (*Anthraceroceros albirostris*) across the four

protected areas of the Terai region of Uttar Pradesh. Such variation is likely to reflect differences in habitat composition, vegetation structure, and the availability of essential ecological resources rather than random distribution patterns. Although both species were recorded from forested protected areas, their abundance differed considerably among sites, indicating species-specific habitat preferences.

Indian Grey Hornbill was recorded from all four protected areas and exhibited the highest abundance in Bakhira Bird Sanctuary, suggesting its broader ecological tolerance and ability to utilize heterogeneous landscapes. In contrast, Oriental Pied Hornbill was restricted to the forest-dominated protected areas and was absent from Bakhira Bird Sanctuary during the study period. This distribution pattern indicates that Oriental Pied Hornbill may be more dependent on structurally complex forest habitats that provide suitable nesting cavities, fruit-bearing trees, and continuous canopy cover. Similar habitat associations have been reported for hornbill species in other tropical forest ecosystems, where habitat quality strongly influences their occurrence and local abundance.

### **Influence of habitat characteristics on hornbill diversity**

The diversity indices calculated in the present study demonstrated clear differences in hornbill community composition among the protected areas. Katarniaghat Wildlife Sanctuary exhibited the highest Shannon–Weiner Diversity Index and Shannon Equitability Index, indicating comparatively balanced representation of both hornbill species. In contrast, Bakhira Bird Sanctuary recorded the lowest diversity because only Indian Grey Hornbill was observed throughout the survey.

These differences are likely associated with variation in habitat structure among the study sites. Katarniaghat Wildlife Sanctuary is characterized by extensive tropical moist deciduous forests, mature tree stands, and relatively intact habitat conditions that provide suitable foraging and nesting opportunities for both hornbill species. Similarly, Sohagi Barwa Wildlife Sanctuary supported moderate diversity, reflecting the availability of heterogeneous forest hab-

itats capable of sustaining multiple hornbill species.

Conversely, the wetland-dominated ecosystem of Bakhira Bird Sanctuary differs substantially from the forest ecosystems represented by the other protected areas. The absence of Oriental Pied Hornbill from this landscape may indicate limited availability of large cavity-bearing trees and continuous forest cover that are generally associated with breeding and foraging requirements of forest-dependent hornbills. However, additional long-term ecological investigations incorporating habitat variables would be necessary to determine the specific environmental factors responsible for this observed distribution pattern.

### **Species-specific habitat associations**

The contrasting distribution patterns observed between the two hornbill species suggest differences in ecological adaptability. Indian Grey Hornbill demonstrated a wider spatial distribution and occurred across all surveyed protected areas, including landscapes influenced by human activities. This observation supports previous studies describing the species as relatively adaptable to fragmented habitats, agricultural interfaces, and semi-urban environments, provided that suitable nesting and feeding resources remain available.

In contrast, Oriental Pied Hornbill showed greater association with protected forest habitats, where relatively undisturbed vegetation and mature tree communities persist. Although the present study did not directly evaluate habitat characteristics or breeding ecology, the observed distribution pattern suggests that forest integrity may play an important role in maintaining viable populations of this species within the Terai landscape. Future investigations integrating vegetation structure, fruit availability, and nesting-site characteristics would provide a more comprehensive understanding of these habitat relationships.

### **Ecological significance of hornbill diversity**

Hornbills perform essential ecological functions within tropical forest ecosystems through long-distance seed dispersal, thereby contributing to forest regeneration and maintenance of plant diversity.

Consequently, variation in hornbill distribution may also reflect differences in ecological condition among protected landscapes.

The comparatively balanced occurrence of both hornbill species in Katarniaghat Wildlife Sanctuary and Sohagi Barwa Wildlife Sanctuary suggests that these protected forests continue to support ecological conditions favorable for sustaining hornbill communities. Conversely, the dominance of a single species in Bakhira Bird Sanctuary indicates reduced hornbill community diversity within the surveyed landscape. Although this finding should not be interpreted as ecological degradation in isolation, it emphasizes that different habitat types support different hornbill assemblages depending on their structural and ecological characteristics.

The present findings therefore provide baseline ecological information that may contribute to long-term monitoring of hornbill populations within the Terai Arc Landscape and assist in evaluating future changes in species composition associated with habitat modification.

### **Comparison with previous studies**

The observed spatial variation in hornbill diversity is broadly consistent with earlier investigations conducted in other regions of India, where hornbill occurrence has been closely linked to forest composition, habitat connectivity, and the availability of mature nesting trees. Studies from the Western Ghats and Northeast India have similarly reported greater hornbill diversity in relatively undisturbed forests than in fragmented or modified landscapes.

Although the diversity values recorded in the present study are comparatively lower than those reported from several hornbill-rich tropical forests, this difference should be interpreted cautiously because diversity estimates are influenced by regional species pools, sampling design, habitat characteristics, and landscape composition. Nevertheless, the present investigation represents one of the few systematic assessments of hornbill diversity within the protected areas of the Terai region of Uttar Pradesh and therefore provides important baseline information

for future ecological comparisons.

### **Conservation implications**

The present study demonstrates that protected forest landscapes within the Terai region continue to provide important habitats for both Indian Grey Hornbill and Oriental Pied Hornbill. Since hornbills depend upon mature trees for nesting and fruit-bearing trees for feeding, conservation efforts should prioritize the maintenance of forest structure and ecological integrity within protected areas.

Particular attention should be directed towards conserving large cavity-bearing trees, promoting natural forest regeneration, and minimizing habitat fragmentation within forest corridors connecting protected landscapes. Continuous ecological monitoring of hornbill populations would further assist in evaluating population trends and identifying changes associated with habitat alteration and anthropogenic disturbances.

Importantly, the present study establishes baseline distributional information that can support future conservation planning and long-term biodiversity monitoring within the Terai region.

### **Study limitations and future research**

The present investigation was based primarily on field observations obtained through random sampling and point count surveys. Although these methods are widely employed for avifaunal assessments, they may underestimate species detectability under varying environmental conditions. Furthermore, the study focused on spatial distribution and diversity and did not quantify habitat variables, seasonal resource availability, breeding activity, or detection probability.

Future research should incorporate long-term seasonal monitoring, habitat quality assessment, occupancy modelling, breeding ecology, and spatial analyses using geospatial techniques to better understand the ecological factors influencing hornbill distribution in the Terai landscape. Such multidisciplinary approaches would provide stronger scientific evidence for developing habitat-specific conservation

strategies and evaluating population dynamics under changing environmental conditions.

### **CONCLUSION**

The present study provides baseline information on the spatial distribution and diversity of Indian Grey Hornbill and Oriental Pied Hornbill across four protected areas of the Terai region of Uttar Pradesh. Considerable spatial variation was observed among study sites. Katarniaghat Wildlife Sanctuary exhibited the highest species diversity and evenness, whereas Bakhira Bird Sanctuary was represented solely by Indian Grey Hornbill, resulting in the lowest diversity values. Indian Grey Hornbill occurred in all four protected areas and displayed greater abundance than Oriental Pied Hornbill, indicating broader habitat occupancy within the study landscape. The observed differences in diversity indices among protected areas suggest that habitat characteristics influence hornbill community composition. These findings provide baseline ecological information that can support future monitoring and conservation assessments of hornbill populations in the Terai region.

### **Conflict of interest**

The authors declare that there is no conflict of interest.

### **Ethical statement**

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