"Ecological and Conservation Governance Condition Analysis Using Ecological Diversity Indices: A Study of Bhawal National Park"

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Abstract:

Once a historical biodiversity hotspot, the Bhawal National Park (BNP) in Bangladesh faces severe threats to its ecological integrity, despite its protected status. Located approximately 40 km north of Dhaka, the park's original coppice Sal forest (Shorea robusta) ecosystem is now fragmented and degraded due to illegal deforestation and encroachment, leading to a drastic decline in native wildlife. This research aims to analyze the park's current ecological condition, document its biodiversity richness, and critically assess its governance strategy. Using a mix of existing paper review, field survey, interviews of park rangers and the community, and conservation strategy analysis, this paper assesses an adhered-to multipronged reframing strategy for conservation. Key future initiatives include implementing comprehensive zoning for core habitats, recovering illegally occupied land through legal and collaborative means, and enhancing the effectiveness of women's leadership in the governance of protected areas. The ultimate goal is to measure the current biodiversity status and the potential for enrichment through conventional approaches that adopt proactive, inclusive strategies for ecosystem restoration and sustainable management.

Keywords for interpreting this section:

Abstract, Bhawal National Park, Conservation, Biodiversity, Governance, Women's Leadership.

Introduction:

Protected areas are critical for conserving biodiversity and maintaining ecosystem services, particularly in rapidly urbanizing regions. By a royal contribution to the Earth and nature, first established by King Rajendra Narayan as a private forest area, the assets of the Bhawal Royal Estate were formerly part of the Modhupur forest. The Bahawal National Park was officially established in 1974 and declared a protected forest area and habitat on the 11th of May, 1982, by the Wildlife Preservation Act, section 23(3), Bangladesh, covering a total area of 5022 hectares. The geographical coordination between 24.033° N and 24.183° N latitude and from 90.350° E to 90.467° E longitude, with common central coordinates, is 24.09583° N, 90.4039° E (approximately). Bhawal National Park falls under the IUCN category IV, which is a protected conservation area or sanctuary and habitat of various diverse species that require active governance, monitoring for protection, and conservation. The Bhawal National Park governance authority is the Forest and Wildlife Conservation Department. The total forest is covered with a tree species very native to our country, "Shorea Robusta," locally known as "Shal," along with other flora species. Despite being a nationally protected forest area and wildlife sanctuary, the Bhawal National Park area is now illegally occupied by a few locals, various industries, and resorts. Many forest areas are cleared for agriculture and settlements. The number is large, approximately 1000 acres out of a total declared forest area of 5022 hectares. Historical evidence and the presence of various wildlife like elephants, leopards, tigers, peacocks, and other species are now only a faded trail of the past. Historically, BNP supported a diverse assemblage of animals, including iconic species such as the tiger (Panthera

tigris), leopard (Panthera pardus), and peacock (Pavo cristatus), all of which have been extirpated following decades of habitat loss and hunting (Kabir & Ahmed, 2005). Currentfaunal studies indicate the persistence of small and medium-sized mammals, including the fishing cat (Prionailurus viverrinus), Bengal fox (Vulpes bengalensis), golden jackal (Canis aureus), small Indian civet (Viverricula indica), wild boar (Sus scrofa), peafowl, and the vulnerable Northern Plains gray langur (Semnopithecus entellus) (Rahman et al., 2020).

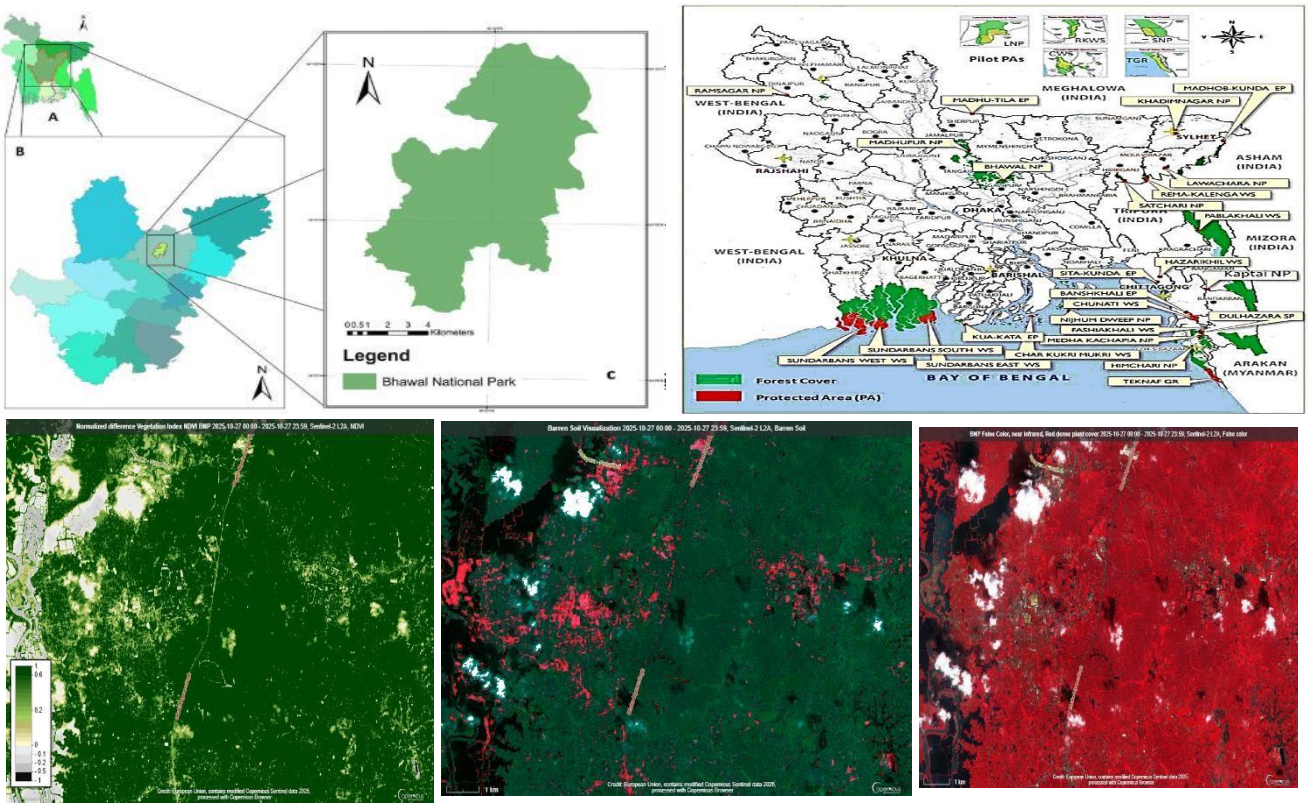
Avifaunal diversity remains one of the strongest components of BNP's biodiversity. Surveys have recorded at least 146 species, with both resident and migratory populations contributing to the park's importance as an Important Bird and Biodiversity Area (IBA) (Islam et al., 2021). Threatened raptors such as the Greater Spotted Eagle (Clanga clanga) and Grey-headed Fish Eagle (Ichthyophaga ichthyaetus), along with species like the Red-breasted Parakeet (Psittacula alexandri), reflect the ecological value of the park's mosaic of forest and wetland habitats (Jahan et al., 2018). The Jungle Babbler (Turdoides striatus) is often cited as one of the most abundant resident birds (Kabir & Ahmed, 2005; Shome et al., 2024).

Research on herpetofauna, though limited, documents species such as the Nepal Cricket Frog (Fejervarya nepalensis), Skipper Frog (Euphlyctis cyanophlyctis), and Common Tree Frog (Polypedates teraiensis), indicating the ecological significance of the park's aquatic and semi-aquatic niches (Jahan et al., 2017). Invertebrate studies record at least 44 butterfly species, dominated by Lycaenidae, whose populations are sensitive to host-plant variation and microclimatic changes (Akand et al., 2020). Fish diversity includes 56 species, with 13 threatened, reflecting the vulnerability of BNP's wetland systems to overfishing and habitat modification (Roshni et al., 2022).

Bhawal National Park (BNP) is one of the last remaining fragments of the Madhupur Sal forest, a historically extensive moist deciduous ecosystem in central Bangladesh (Hossain & Das, 2018). Located in the Gazipur district, BNP serves as a vital ecological refuge, safeguarding regional biodiversity while sustaining important ecosystem services (Karim et al., 2020). Despite its protected status, urbanization, encroachment, plantation expansion, and forest degradation have altered the park's ecological character for the last two decades (Chowdhury, 2019). Under current ecological threats, focused and timely ecological assessments play a key role in monitoring change and guiding adaptive management (Chowdhury, 2019). The park, its forest area, and its diversity have gone through a crucial threat of existence the past few decades, despite their protected area status. Bhawal National Park has suffered from intense anthropogenic pressure. Significant sections of the forest have been destroyed. This habitat degradation has led to the disappearance of most large wildlife species. Park authorities are planning and reframing various conservation efforts to conserve the biodiversity by recovering the illegally occupied forest area of 1000 acres and reconstructing the boundary area of the park, which is now compromised. In this study our focus is to analyze the present status of biodiversity in relation to historical and previous abundance and probable future diversity by reframing conservation strategies and their perfect execution. While a co-management program has been in effect since 2008, conservation challenges persist. Recently park governance authorities have shown their dedication towards conservation, reframing various strategies and planning for further enrichment.

Keywords for interpreting this section:

Introduction, Bhawal National Park, Bhawal State, Bangladesh Wildlife Preservation Act, and Protected Area.



Methodology

This study employed a mixed-methods ecological assessment to evaluate biodiversity status and governance effectiveness in Bhawal National Park (BNP), Bangladesh. Fieldwork was conducted over one month following official approval from the Bangladesh Forest Department. A combination of quantitative ecological sampling and qualitative socio-environmental inquiry was used to capture multi-taxa biodiversity patterns and ecosystem conditions. Vegetation data were collected using a nested quadrat design, where tree species were sampled in 25 × 20 m plots, shrubs in 5 × 5 m plots, and herbs in 1 × 1 m plots. Within these plots, species identity, abundance, and structural parameters, such as diameter at breast height (DBH), were recorded for biomass estimation. Faunal diversity was assessed through direct visual encounters, line transect walks, acoustic identification (particularly for birds), binocular-assisted observations, and opportunistic sightings along forest trails and edge habitats. Semi-structured interviews were conducted with forest officials, local residents, and field staff to supplement species records and to document long-term ecological changes and governance practices. Aquatic ecosystem quality was assessed by collecting water samples from multiple sites within the park and by collecting samples from two different parts of the lake. These samples were sent to a laboratory for analysis. Later, the sample water quality parameters were analyzed in the lab to correlate with the observation of microinvertebrate bioindicator potential. A D-frame kick net

(4-foot-long handle, 25 cm frame width, and 0.25 mm mesh size) facilitates sampling macroinvertebrates from the lake. Macroinvertebrates were sampled from the lake using a D-frame kick net (4-foot-long handle, 25 cm frame width, and 0.25 mm mesh size). Water quality parameters were analyzed in the laboratory for pH, dissolved oxygen (DO), electrical conductivity (EC), and total dissolved solids (TDS). . A population survey was carried out along with a line transect adjacent to the lake. Fauna was primarily identified through direct observations, supplemented by Nikon Monarch 5 10.42x binoculars, acoustic surveys, photographs, and opportunistic encounters. All individuals were recorded to estimate species richness and relative abundance, respectively. In addition, secondary data from published literature and remote sensing-based studies were reviewed to contextualize historical biodiversity trends and land-use changes. Biodiversity metrics, including the Shannon–Wiener diversity index (H'), Simpson's diversity index (1 − D), and Pielou's evenness index (J'), were calculated to assess species richness, abundance distribution, and ecological balance across taxonomic groups. Aboveground biomass, carbon stock, and carbon sequestration potential were estimated using DBH-based allometric approaches applied to sampled tree plots and extrapolated to the park scale.

Keywords for interpreting this section:

Methodology, remote sensing satellite images, paper review, quadrats, ABG, line transect, kick net, binoculars, and sound counter.

Results and Discussion

Floral Diversity:

The nested quadrat survey covered a total of 5000 m² of vegetation sampling area. Although previous studies documented approximately 89 plant species in BNP.

Tree Canopy Cover:
Shorea robusta remained dominant, consistent with earlier reports of Sal-dominated forest structure. Other observed species included Acacia, Eucalyptus, Xylia xylocarpa, Terminalia arjuna, Lagerstroemia speciosa, Ficus benghalensis, Phyllanthus emblica, Swietenia mahagoni, Gmelina arborea, Tectona grandis, Zanthoxylum rhetsii, Hevea brasiliensis, and Terminalia catappa. In total, 370 individual trees belonging to 15 species were identified in the plot area. The dominant species identified here is Shorea robusta (Shal), occupying 18.92% of the total population observed (n = 70) in the study area. The next prominent species after the above one is Acacia, and Terminalia arjuna (n = 40). Various biodiversity indices were calculated to assess the ecological structure of the forest community. The ecosystem exhibited a high level of biological diversity, as the Shannon-Weiner Diversity Index (H) value was 2.52. Also, the Simpson's Index of Diversity (1 – D) value was 0.91, indicating a 91.0% probability that two randomly selected individuals would belong to different species. Moreover, the value of Pielou's Species Evenness Index (J') was quite high—0.93.This implies that although Sohrobusta was numerically dominant, its individual trees were equally spread among other co-occurring species.

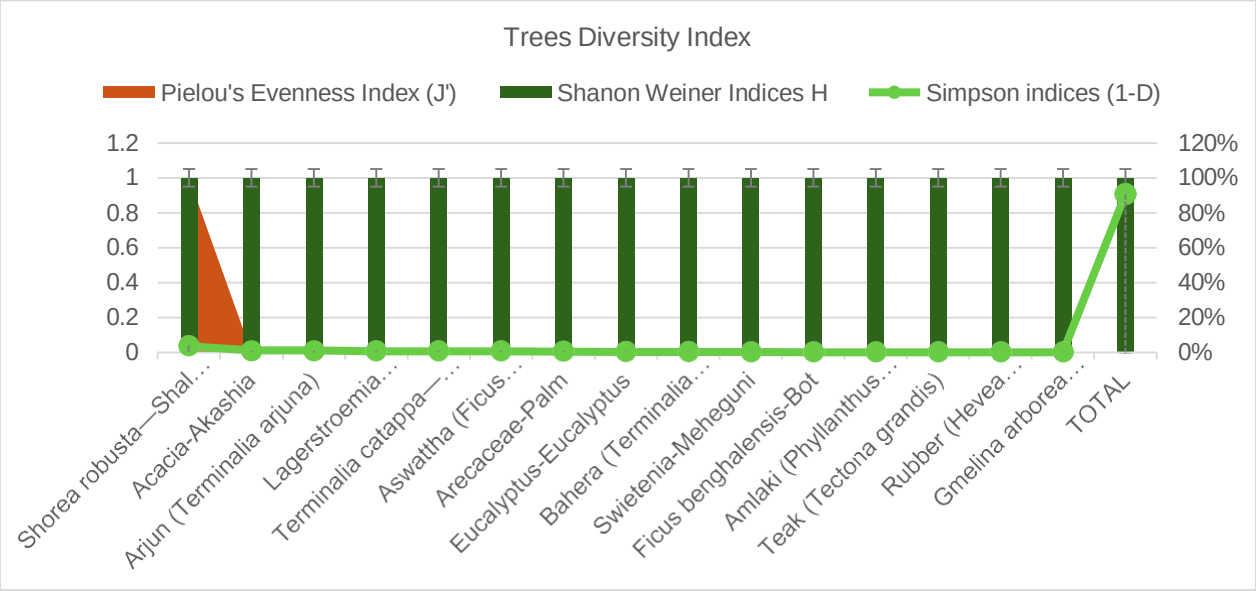
A substantial number of non-native or plantation-origin species (notably Acacia, Eucalyptus, Hevea, and Tectona) indicates a mixed landscape where native Sal stands are increasingly influenced by introduced species. The proportion of native to non-native trees was approximately 60:40 within the sampled area.

Table 1: Lists of Flora Groups

Group of Species	Number of species
Trees	3
Shrubs	47
Herbs	2
Climbers	2

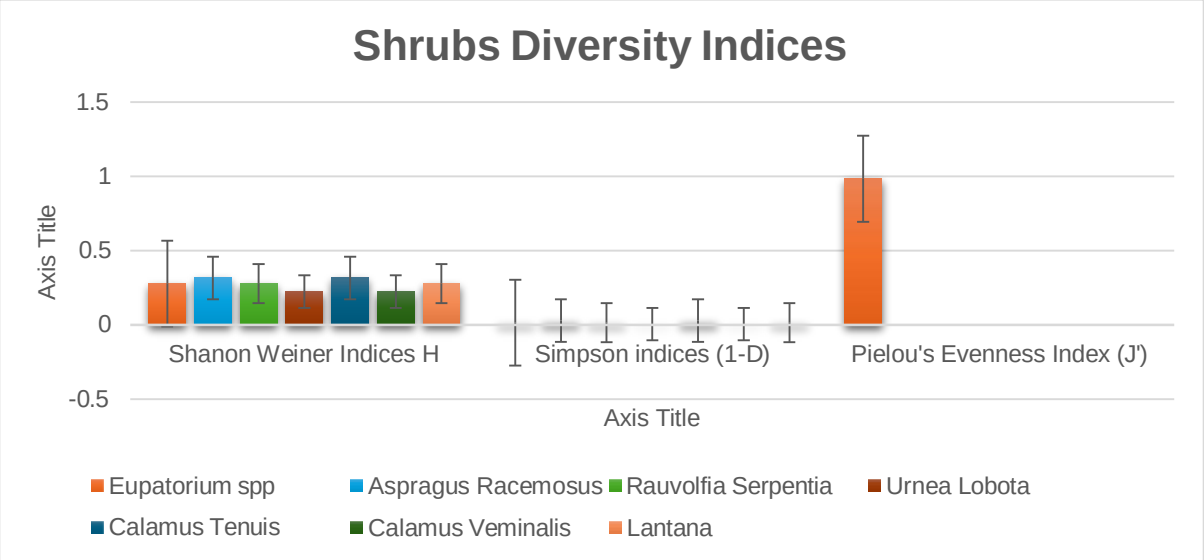
Table 2: Species Richness and Diversity Index (Flora)

Group	Shannon Winner Index (H) | index(H)	Simpson index(1-D)	Pielou's Evenness Index (J')
Trees	2.5225	0.9078	0.9314
Climbers	1.3664	0.7867	0.9856
Shrubs	1.9135	0.8904	0.9833
Herbs	1.0851	0.7047	0.9877



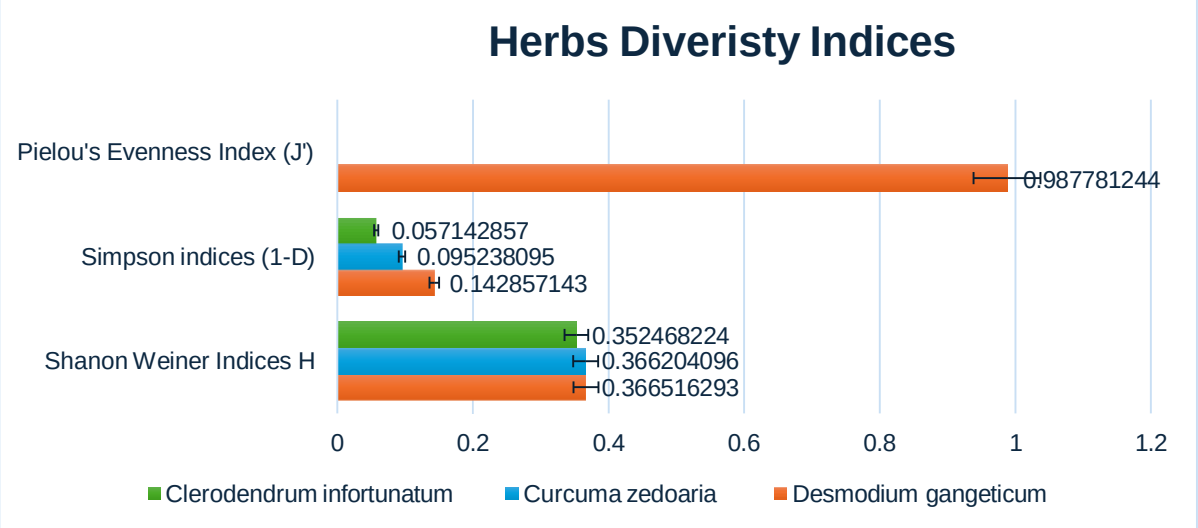
Shrubs:

Earlier studies reported around 16 shrub species in the park, while the present survey documented 7 species: Asparagus racemosus, Calamus tenuis, Eupatorium spp., Rauvolfia serpentina, Lantana camara, Urena lobata, and Calamus viminalis. The dominance of disturbance-tolerant species such as Lantana reflects ongoing habitat modification.



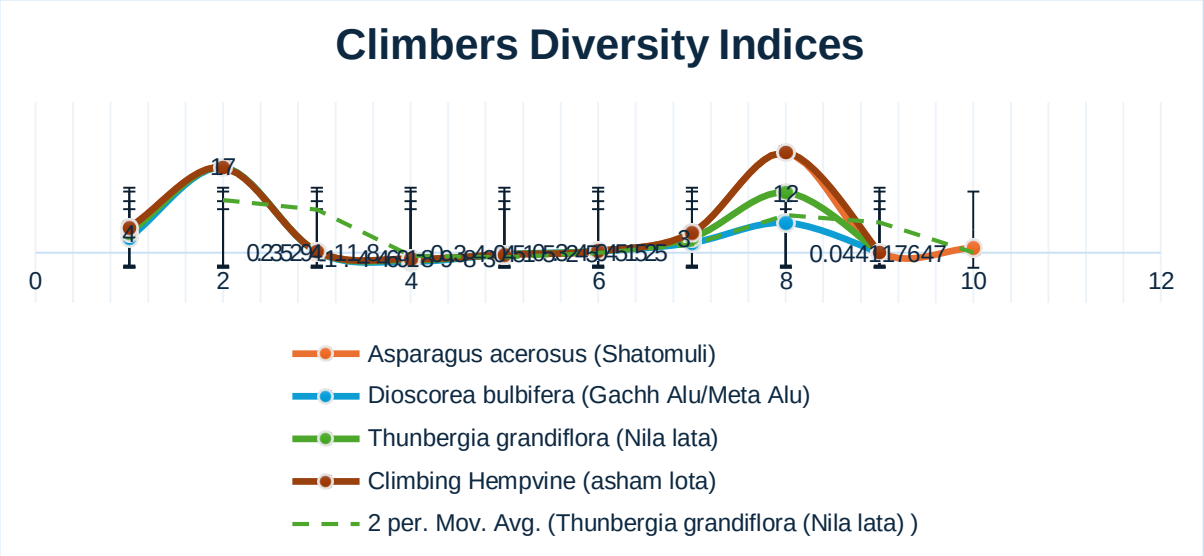
Herbs:

Previous literature lists roughly 31 herbaceous species, whereas the current sampling recorded 3 species: Desmodium gangeticum, Curcuma zedoaria, and Clerodendrum infortunatum. All three have known ethnobotanical uses, indicating that medicinal herbs persist in understory patches.



Climbers:

Historical records document approximately 16 climber species in BNP. The present survey noted like five climbers species during sampling.



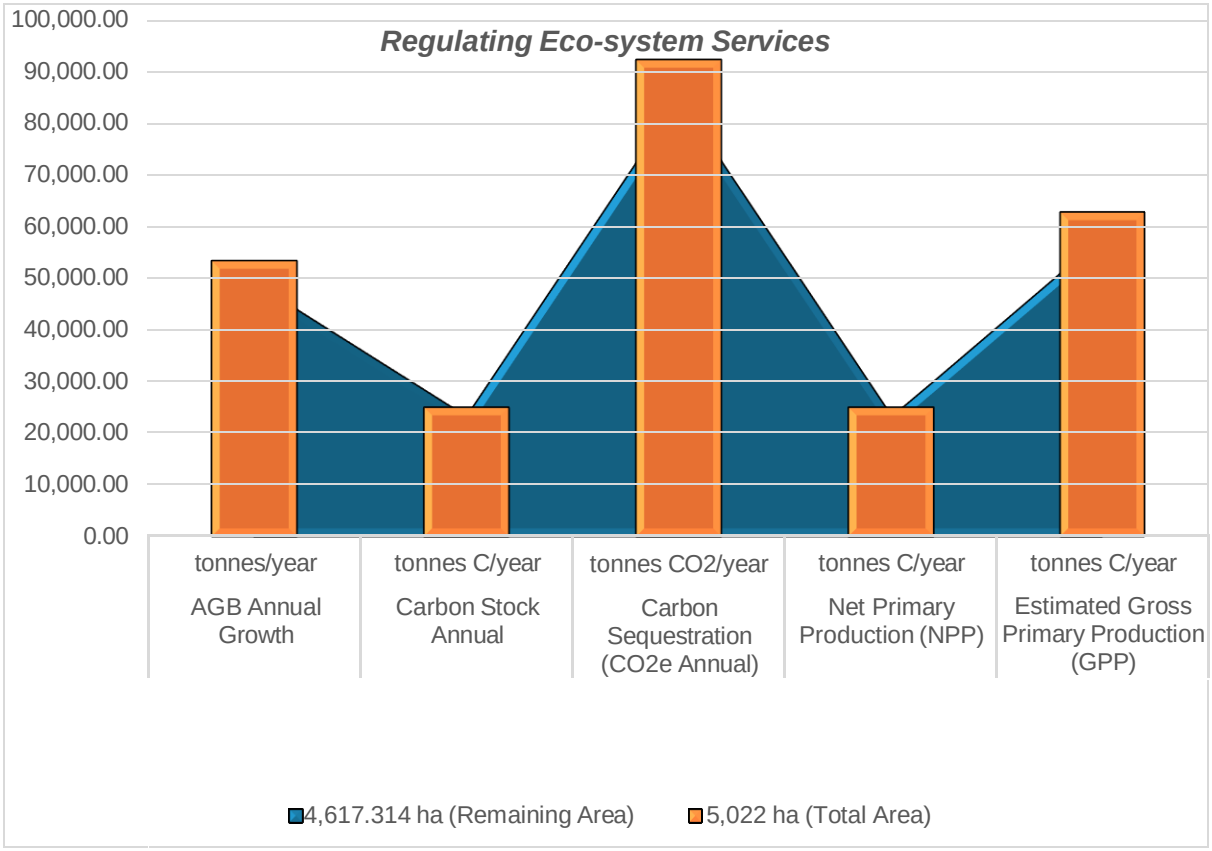
Diversity Indices:

Shannon-Wiener, Simpson, and Pielou's Evenness Index (J') indices were assessed for the sampled floral community. Trees showed the highest diversity, followed by shrubs and herbs, while climbers exhibited the lowest richness. These values reflect both sampling constraints and real ecological patterns shaped by long-term degradation, invasion by non-native species, and reduced undergrowth density documented in multiple studies. An analytical assessment of these multi-strata alpha-diversity parameters reveals an intricately partitioned community architecture governed by a definitive, mathematically formalized trade-off between vertical structural complexity and log-linear demographic equity. In the dominant overstory tier, high Shannon entropy (H = 2.5225) and exceptional intrinsic patch-diversity (1-D = 0.9079) co-occur with a highly robust Pielou's metric (J' = 0.9315). This profile indicates that despite the pronounced demographic footprint of Shorea robusta, 19% of the canopy layer avoids ecological monopolization, preserving an equitable distribution across the remaining fourteen co-occurring tree species via stable niche differentiation. Crucially, descending the vertical forest profile induces a stark decoupling between species richness and demographic evenness; while absolute taxonomic diversity contracts systematically through the understory layers of seven species observed for shrubs, 4 for climbers, and 3 for herbs. Pielou's evenness advances in an inverse linear progression, peaking at a near-unit asymptote in the ground stratum (J') = 0.9877. This structural configuration points to a severe overstory canopy filtering effect, where canopy-mediated photo-synthetically active radiation (PAR) attenuation and intensive root-zone nutrient drawdown impose severe microclimatic and resource-availability thresholds on the forest floor. Because the localized resource matrix is constrained by this dominant canopy

envelope, no individual understory or ground-layer species can mobilize sufficient competitive momentum to secure an asymmetrical advantage or trigger competitive exclusion. This environmental ceiling enforces a highly democratic, equitable division of micro-niches, which successfully restricts aggressive pioneering competitors and invasive taxa—such as Lantana camara and Eupatorium spp.—to identical low frequencies as native elements. Consequently, while this pervasive cross-strata evenness secures high short-term functional redundancy against stochastic localized patch disturbances, the acute truncation of understory species richness of 7 exposes a critically compromised long-term evolutionary and structural resilience.

When framed within the specific biogeographical context of Protected Areas (PAs) in Bangladesh—such as the highly fragmented Shorea robusta (Sal) forests of Bhawal National Park, Madhupur National Park, or the regional wildlife sanctuaries—this structural signature carries profound conservation implications. The severe truncation of understory species richness 7 observed alongside near-unit evenness directly mirrors the chronic, localized anthropogenic press-disturbances that characterize Bangladeshi PAs. Decades of illegal logging, fuelwood collection, and continuous cattle grazing create a structural "understory filtering vacuum" where late-sugccessional understory specialists are systematically eliminated, leaving behind an exceptionally sparse but perfectly democratized assembly of resilient generalists. This local ecological profile strongly aligns with global macro-ecological assessments of tropical deciduous and secondary protected forest fragments across Southeast Asia and Latin America, which demonstrate that structural isolation drives a steep collapse in baseline understory richness long before changes are detectable in the long-lived overstory canopy. Globally, ecosystems exhibiting maximum evenness coupled with low species richness are recognized as structurally fragile and hyper-susceptible to ecological tipping points. Because aggressive, high-impact alien invasive species (AIS) like Lantana camara and Eupatorium spp. are already structurally embedded within this sub-canopy matrix at low demographic frequencies, the entire forest floor exists in a volatile state of arrest. In line with the global "Invasion Window" hypothesis, any sudden anthropogenic edge-effects, illegal canopy thinning, or climate-induced windthrows within the PA boundaries will disrupt the overstory light-filtering envelope. The resulting surge in ground-level PAR and soil nutrient availability will immediately break the understory's delicate democratic equilibrium. These opportunistic invaders possess the physiological plasticity to rapidly exploit these resource flushes, precipitating a catastrophic collapse in Pielou's evenness and driving the protected understory toward a severely degraded, low-diversity monoculture.

An annually significant amount of aboveground biomass, 49120.40 tons and 53425.50 tons, is produced annually by the forest. Total carbon stock of 23086.60 tons and 25110 tons. The park and forest sequester 84,727.70 and 92,153.70 tons of carbon dioxide equivalent, which is a significant contribution to regulating the climate. The forest’s annual net primary production is 23,086 or 25,110 tons. Where gross primary production is 57,716.40 and 62,775.00 tons, respectively.



Faunal Diversity:

The moderate faunal richness observed during the survey suggests that BNP continues to support a mix of generalist and edge-tolerant species. However, when compared to historical accounts of higher faunal abundance, the current assemblage reflects a landscape undergoing long-term fragmentation, invasive species spread, and anthropogenic disturbance. A detailed list of the recorded terrestrial fauna groups and their relative diversity and richness is presented.

Table 3: Lists of Fauna Groups

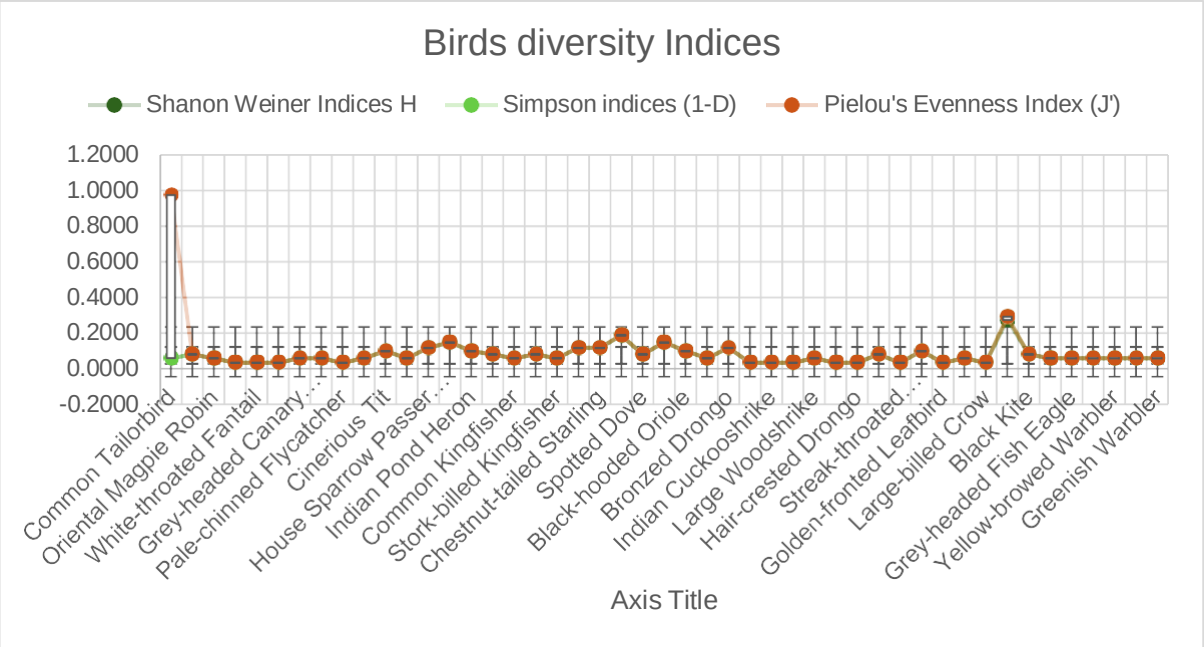
Group of Species	Number of species
Mammals	3
Birds	47
Fish	8
Reptiles	2
Amphibians	2
Butterflies	20
Dragonflies	4
Macroinvertebrates	3

Table 4: Species Richness and Diversity Index (Fauna)

Group of Species	Shannon Winner's Index (H)	Simpson Index (1-D)	Pielou's Evenness Index (J')
Birds	3.5261	0.9635	0.9158
Mammals	1.039	0.8333	0.9463
Reptiles	0.6931	1	1
Amphibians	0.3622	0.2205	0.5225
Fishes	1.8344	0.9111	0.9427
Butterflies	2.3568	0.8636	0.7867
Dragonflies	1.0139	0.5904	0.7313
Macro invertebrates	0.4433	0.2266	0.4035

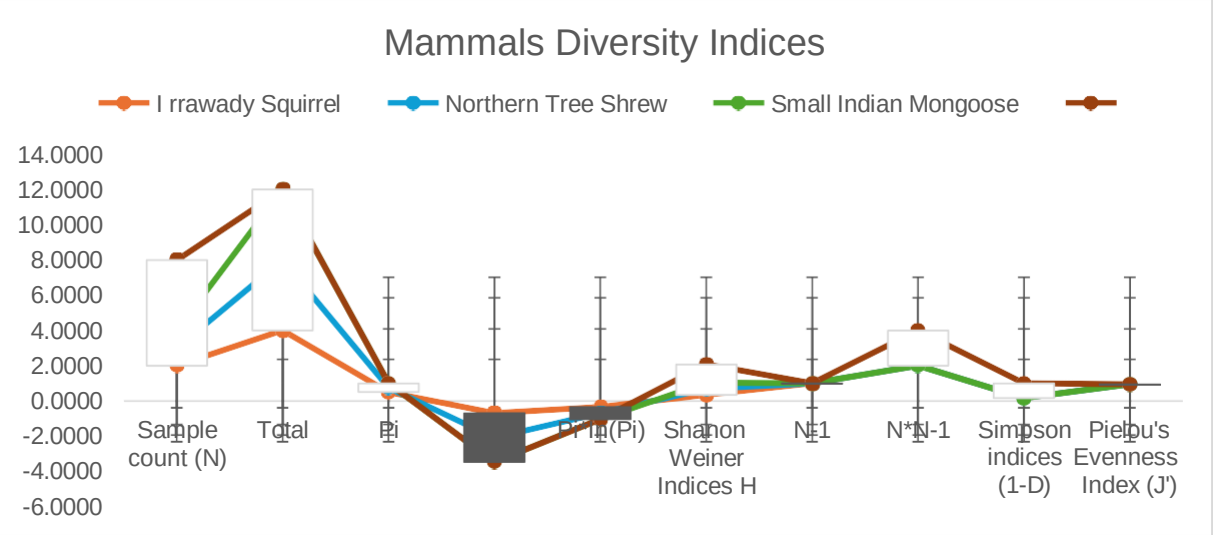
Birds:

The bird population exhibited the highest species richness, consistent with previous studies identifying Bhawal National Park as an important avian habitat. The butterfly and dragonfly diversity recorded during the short survey period illustrates the ecological value of wetland–forest edge habitats present along the trail. Birds are represented as the most diverse group in the park, with 47 species totaling 146 individuals being detected through visual and call-based identification. The avian community was dominated by passerine species. The House Crow (n=20), Indian Pied Starling (n=10), and Jungle Babbler (n=7) appeared to be the most abundant species. 8 winter migrants (e.g., Taiga Flycatcher, Greenish Warbler) confirm the area's role as habitat for seasonal visitors. The presence of raptors such as the grey-headed fish eagle (n=2), crested serpent eagle (n=2), and black kite (n=3) indicates a functioning trophic structure. One bird species made a remark, i.e., the square-tailed drongo-cuckoo, which was seen for the first time in the park. Overall, bird diversity appears relatively high despite anthropogenic pressures, suggesting that the remaining semi-natural patches continue to support a varied avifauna. The bird population exhibited the highest species richness, consistent with previous studies identifying Bhawal National Park as an important avian habitat. The butterfly and dragonfly diversity recorded during the short survey period illustrates the ecological value of wetland–forest edge habitats present along the trail.



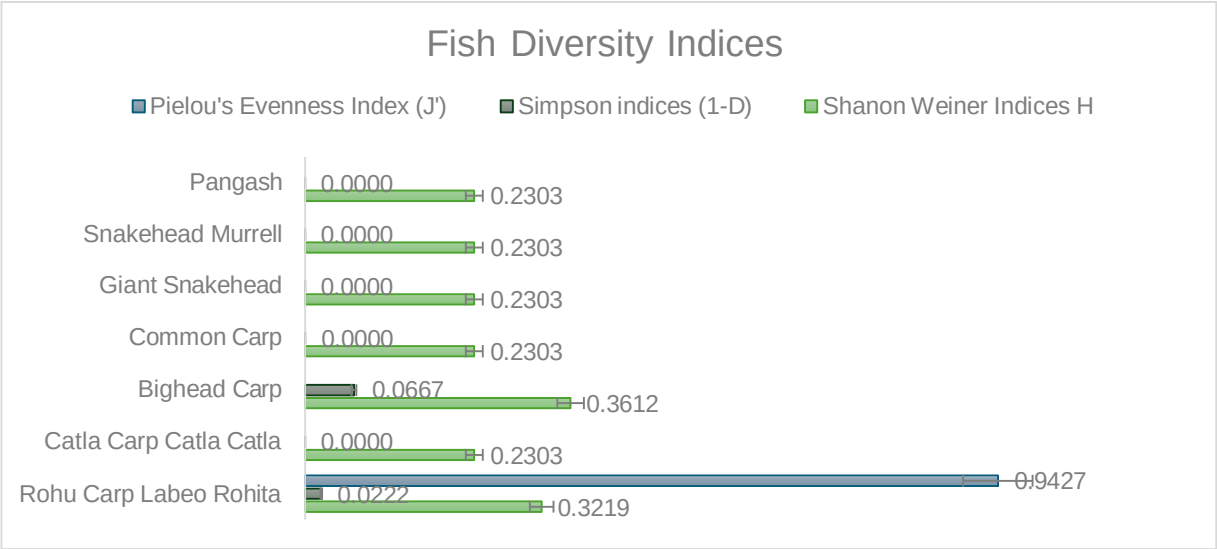
Mammals:

Three mammals under three families were encountered, represented by five individuals. The small Indian mongoose (n=2) and Irrawaddy squirrel were observed at the forest edge, while the northern tree shrew was detected a few meters into the bushes. The tree shrew record is noteworthy, as there was no prior record of its occurrence in BNP in the available literature. Therefore, the low count of mammals is likely due to the short survey period and difficulty of visually observing nocturnal or secretive species in the field. However, interview data suggested the presence of several other species, such as wild boars and rhesus macaques.



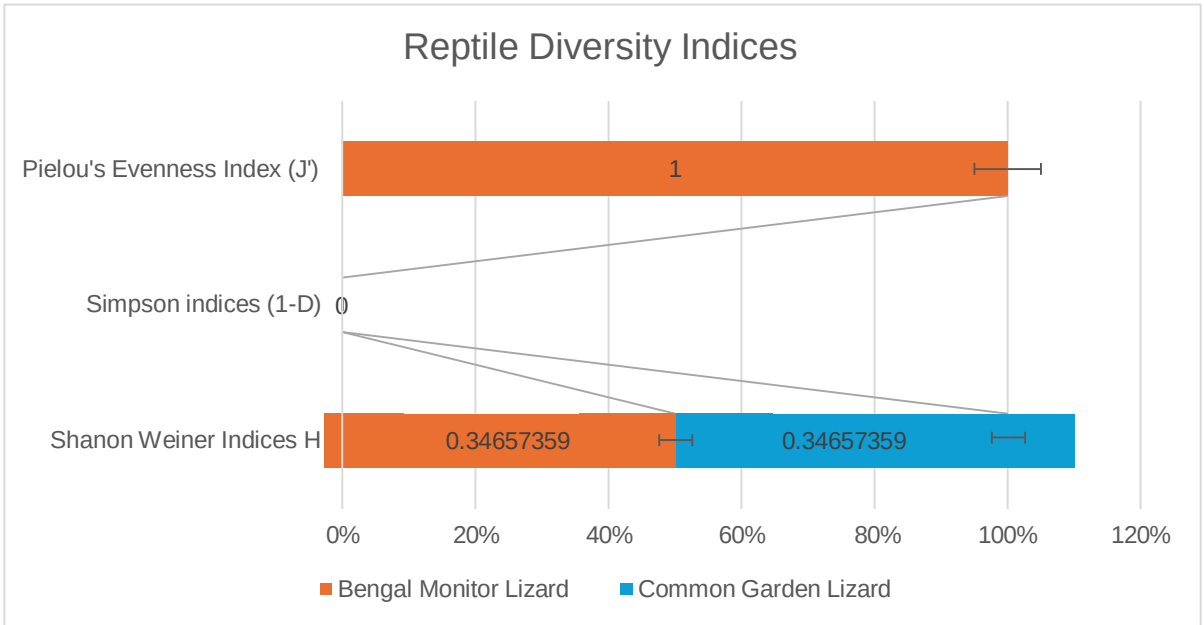
Fish Species:

Eight fish species are observed in the canals. They are Rohu Carp (Labeo Rohita), Catla Carp (Catla Catla), Bighead Carp, Common Carp, Giant Snakehead, Snakehead Murrell, and Pangash.



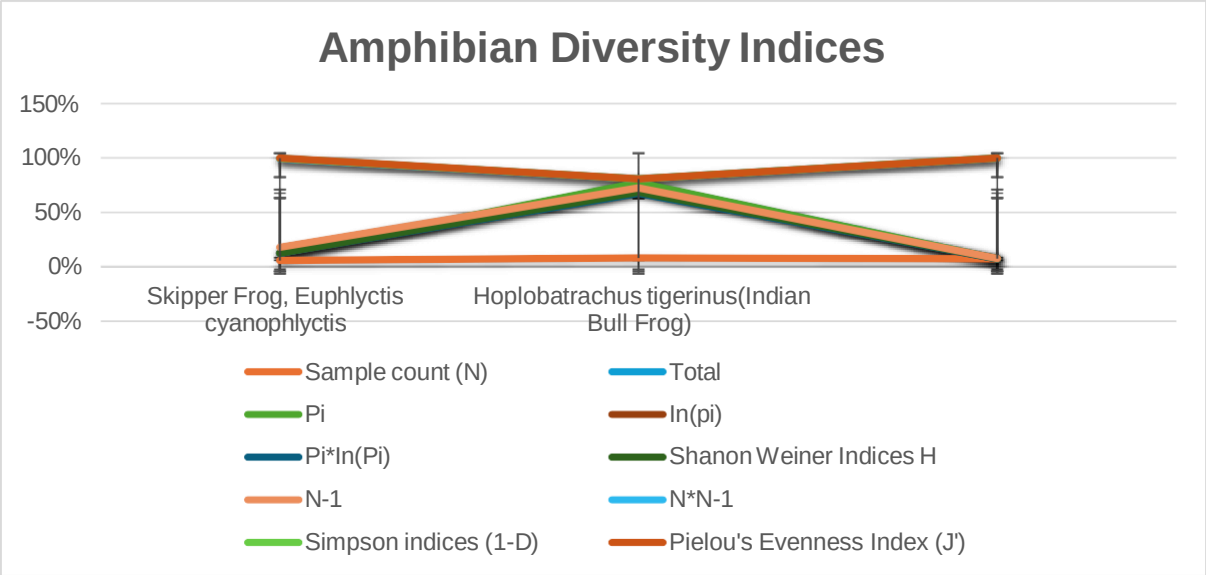
Reptiles:

Two reptiles under two families were found, represented by two individuals. In addition, direct observation has led to the identification of only two reptile species: an oriental garden lizard (Calotes versicolor) and a Bengal monitor (Varanus bengalensis). The IUCN does not classify either as a threatened species (Cota et al., 2018). Posters set up by park authorities confirm the presence of the Asian cobra (Naja naja) and the banded krait (Bungarus fasciatus), two snake species that are also not threatened (Anslem de Silva et al., 2019; Chelmala Srinivasulu et al., 2011). Five interviews from park staff indicate the reintroduction of a threatened snake species, the Burmese python (Python bivittatus) (Iskandar et al., 2011), with one staff member also observing cobras during her approximately 15-16 years of service. However, no snake was observed directly by us in the field. We did observe two crested serpent eagles, suggesting that there are enough snakes there as a food source.



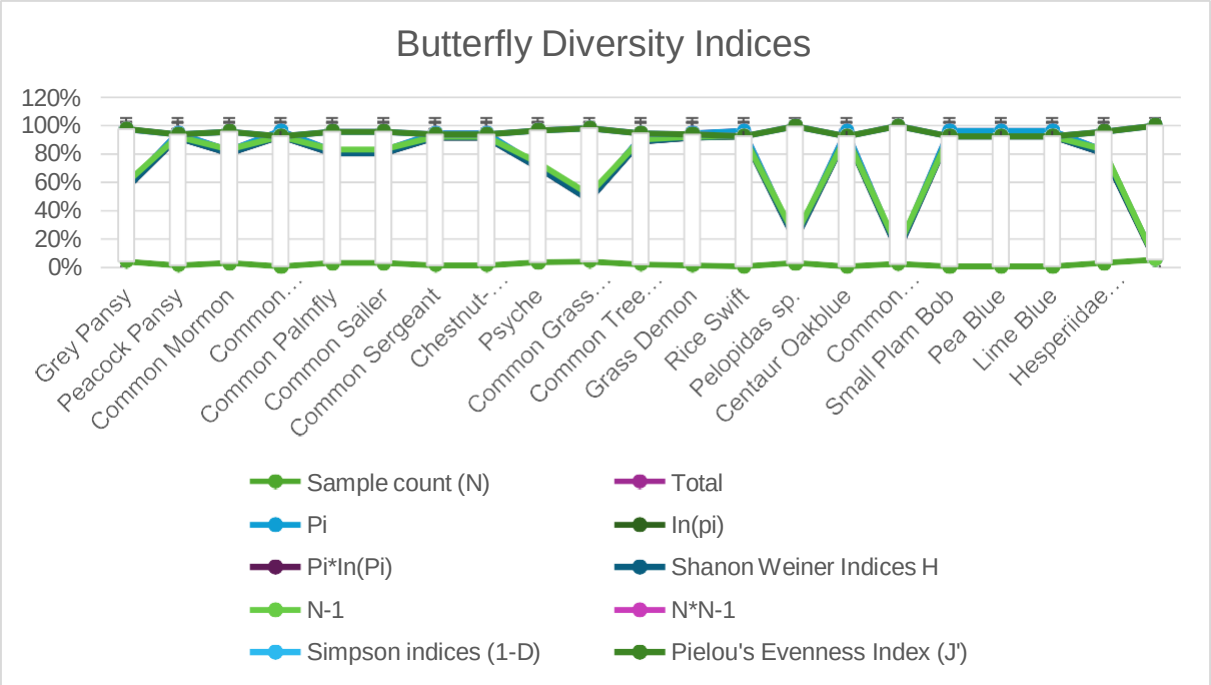
Amphibians:

Amphibians were mainly encountered around shallow lake margins. Two dead specimens found along the track could not be identified due to deterioration. Amphibian richness is likely understated because standard nocturnal surveys were not conducted.



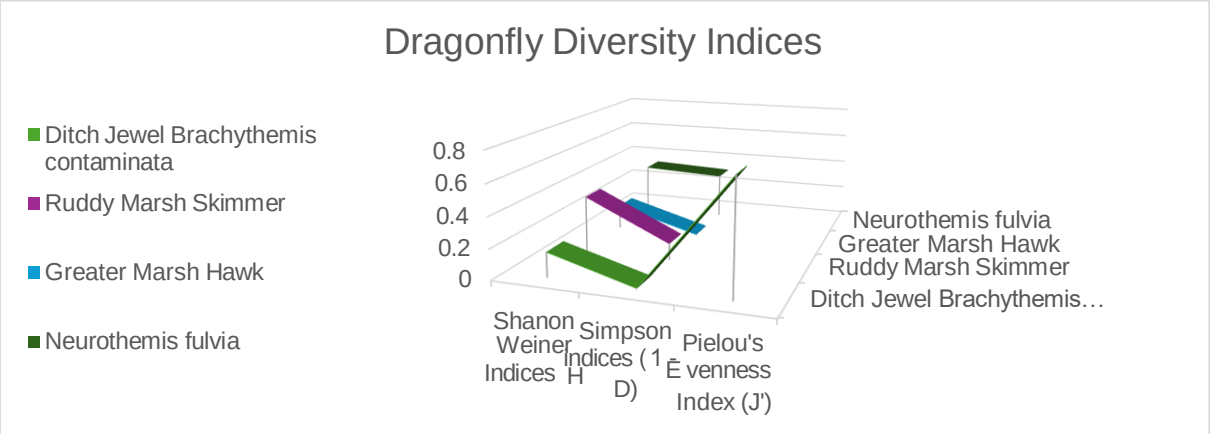
Butterflies:

Twenty butterfly taxa representing 103 individuals were recorded, mostly in shrub- and herb-dominated patches. Several individuals remained unidentified due to rapid flight or a lack of clear diagnostic features. The assemblage reflects moderate diversity within edge habitats and semi-open forest patches.



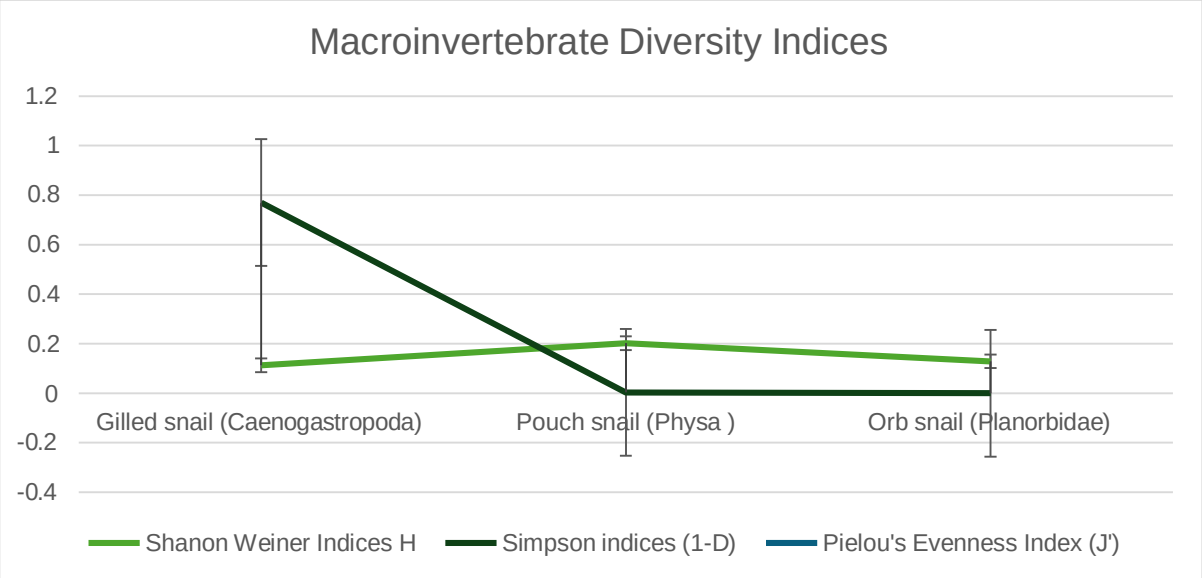
Dragonflies:

Sixteen individuals from three dragonfly families were identified, while an additional 20 individuals could not be confirmed to the species level. Their presence indicates functioning aquatic-associated habitats, though more extensive sampling would yield a more complete assessment.



Macroinvertebrates:

In the canals and ponds, three taxa of mollusca were found during the sample. Both of them were single-shelled. Among these two, one is the orb snail (Planorbidae), a pouch snail belonging to the family Physidae and a gilled snail belonging to the class Gastropoda. The first one is not sensitive to pollution, but the other one is. We found stable abundance and dominance of the gilled snails. We come to a decision after finding a large number of gilled snails in the water body that the water quality is great, with a high level of DO. It is clean and free from pollutants and toxins, which is the necessary water quality for gilled snails to survive and breathe. Later, we collected 3 water samples from the park and analyzed the water quality parameters in the lab, which also matched our decision exactly.



Water Quality:

Water samples collected from the lake were analyzed for pH, dissolved oxygen (DO), and total dissolved solids (TDS). These values were compared with standard freshwater.

Table 5: Water Quality Parameters

Water body	PH	EC(ms/cm)	TDS(ppm)	Nacl(%)	DO(ppm)
Canal 1	6.64	48.1	24.1	0.1	8.56
Canal 2	5.64	43	21.6	0.1	8.99
Pond	5.91	47.1	23.1	0.1	9.37

Water parameters lab analysis showed a high level of DO concentration and an absence of pollutants and toxins, which is proven based on the examination of micro-invertebrate sampling and breathing mechanisms and characteristics of the gilled snail, as well as an analysis of water quality parameters based on the collected sample from the site. It shows a constant correlation regarding the health of the water bodies.

Six faunal groups were recorded: mammals, birds, reptiles, amphibians, butterflies, and dragonflies. Among them are 3 mammal species, 47 bird species, 8 fish species, 2 reptile species, 2 amphibian species, 20 butterfly taxa, and 4 dragonfly species observed. The faunal assemblage recorded during the present study demonstrates considerable variation in species diversity, richness, dominance, and evenness among different taxonomic groups. Diversity was evaluated using the Shannon–Wiener diversity index (H′), Simpson's diversity index (1–D), and Pielou's evenness index (J′), which together provide a comprehensive understanding of community structure and ecological stability.

Birds exhibited the highest overall species richness and abundance among all faunal groups surveyed. A total of 144 individuals representing numerous species were recorded, with a Shannon–Wiener diversity index of H′ = 3.5261, Simpson's diversity index of 1–D = 0.9635, and Pielou's evenness index of J′ = 0.9158.

The high Shannon index indicates a highly diverse avian community with substantial heterogeneity in species composition. Similarly, the Simpson's index approaching 1 suggests low dominance and a high probability that two randomly selected individuals belong to different species. The elevated evenness value further implies that individuals are relatively well distributed among species, indicating ecological stability and habitat suitability for avifaunal assemblages.

Species such as Indian Pied Starling, Black Drongo, Common Myna, House Sparrow, and Small Minivet contributed significantly to total abundance, whereas several species occurred as singletons, reflecting habitat specialization and microhabitat heterogeneity. The coexistence of both common and rare species indicates a structurally complex ecosystem capable of supporting diverse trophic guilds.

Fish fauna showed moderate diversity with a Shannon index of H′ = 1.8344, Simpson's index of 1–D = 0.9111, and evenness value of J′ = 0.9427.

Although species richness was comparatively low, the high evenness suggests that fish individuals were distributed relatively uniformly across species. Dominance by Bighead Carp was observed to some extent; however, no single species overwhelmingly monopolized the habitat. The moderately high Simpson's index indicates a stable aquatic assemblage with balanced species composition.

The lower Shannon value relative to birds may be attributed to limited aquatic habitat heterogeneity, seasonal hydrological fluctuations, and anthropogenic disturbances affecting fish recruitment and habitat availability.

Mammalian diversity was comparatively low, with H′ = 1.0397, 1–D = 0.8333, and J′ = 0.9464.

Despite low species richness, the high evenness value demonstrates equitable distribution of individuals among recorded species. Irrawaddy Squirrel was relatively more abundant than Northern Tree Shrew and Small Indian Mongoose, suggesting adaptation to available vegetation cover and food resources. The reduced diversity likely reflects habitat fragmentation, human interference, and limited sampling encounters typical of mammalian surveys.

Reptiles exhibited the lowest taxonomic richness, represented by only two species with H′ = 0.6931, 1–D = 1.0, and J′ = 1.0.

The perfect evenness value indicates equal abundance of the two reptilian species (Bengal Monitor Lizard and Common Garden Lizard). However, the low Shannon index reflects poor species richness rather than ecological imbalance. Such reduced reptilian diversity may result from habitat simplification, insufficient basking and nesting microhabitats, or anthropogenic pressures.

Amphibians showed low-to-moderate diversity with H′ = 0.3622, 1–D = 0.2206, and J′ = 0.5226.

The markedly low Simpson's and evenness values indicate strong dominance within the amphibian community. Skipper Frog (Euphlyctis cyanophlyctis) constituted the majority of individuals recorded, while unidentified amphibians were comparatively scarce. Such dominance suggests restricted habitat conditions favoring a limited number of tolerant amphibian species, possibly associated with water quality, hydroperiod variation, and breeding-site availability. Dragonflies demonstrated moderate diversity, with H′ = 1.0139, 1–D = 0.5905, and J′ = 0.7314.

The assemblage was strongly dominated by Neurothemis fulvia, which contributed the largest proportion of individuals. Moderate evenness indicates uneven distribution among species, while the intermediate Simpson's index suggests moderate habitat quality. Since odonates are sensitive bioindicators of freshwater ecosystems, the observed diversity reflects partially suitable aquatic and riparian conditions.

Butterflies displayed relatively high diversity with H′ = 2.3580, 1–D = 0.8617, and J′ = 0.7867.

The high Shannon and Simpson indices indicate a diverse and moderately stable butterfly assemblage. Species such as Common Evening Brown, Pelopidas sp., and Common Grass Yellow were abundant, whereas several species were represented by few individuals. Moderate-to-high evenness suggests balanced resource utilization and availability of nectar plants, larval host plants, and suitable microclimatic conditions.

Butterflies are recognized as sensitive ecological indicators; therefore, their relatively high diversity reflects favorable vegetation structure and habitat heterogeneity within the study area.

Comparative analysis of faunal diversity indices revealed that birds and butterflies exhibited the highest diversity and ecological stability, indicating the presence of heterogeneous habitats and relatively favorable environmental conditions. Fish and dragonflies showed moderate diversity, reflecting moderately stable aquatic ecosystems. In contrast, reptiles, amphibians, and mammals exhibited comparatively lower diversity, likely due to habitat disturbance, limited niche availability, and anthropogenic pressures.

The high evenness values observed in most faunal groups suggest that species distribution was generally balanced, although amphibians and dragonflies showed signs of dominance by a few tolerant species. Overall, the diversity indices collectively indicate that the study area supports a moderately healthy ecosystem with varying habitat suitability across faunal groups.

The observed diversity patterns are consistent with ecological theory stating that structurally heterogeneous habitats support higher species richness and evenness. Avian and lepidopteran communities demonstrated higher diversity because these taxa respond positively to vegetation complexity, food availability, and habitat stratification. Similar findings have been reported in tropical and subtropical ecosystems where birds and butterflies serve as indicators of habitat integrity and ecological resilience.

Conversely, lower diversity among amphibians and reptiles may indicate environmental stressors such as habitat alteration, pollution, or microclimatic instability. Amphibians are particularly sensitive to hydrological and physicochemical changes; therefore, their reduced diversity may signal early ecological degradation.

The dominance of tolerant species in aquatic and semi-aquatic taxa further suggests that certain habitats within the study area may experience anthropogenic influence. Nevertheless, the relatively high Simpson's diversity values for most faunal groups indicate that complete ecological homogenization has not occurred.

Overall, the faunal diversity indices suggest that the study area retains significant ecological value and biodiversity potential, emphasizing the need for habitat conservation, restoration of aquatic microhabitats, and long-term biodiversity monitoring to maintain ecosystem stability and faunal integrity.

Although macroinvertebrates exhibited comparatively low diversity with a Shannon–Wiener diversity index of H′ = 0.4433, Simpson's diversity index of 1–D = 0.2267, and Pielou's evenness index of J′ = 0.4035. The assemblage was strongly dominated by the gilled snail

(Caenogastropoda), which accounted for the majority of individuals recorded (88% of the total abundance). In contrast, Pouch snails (Physa sp.) and orb snails (Planorbidae) were represented by very few individuals. Dominance of gilled snails (Caenogastropoda) is a sign of an overall healthy aquatic ecosystem of the park.

Parks' governance structure:

Led by the forest departments, the wildlife conservation and protection wing. The park's whole forest area is governed by one range officer, leading a team of 26 rangers under the direction of the district forest officer. Directly supervised by Range Officer Shakhera Akter Shimu and his team of rangers, who are monitored by the district forest officer Sharmin Akter under the Ministry of Environment, Forest, and Climate Change, and guided by Syeda Rizwana Hasan. (Advisor). Total conservation was guided, directed, and led by women and showed a positive result and acceleration in biodiversity, and planned strategies also showed a potential for more enrichment. Under this leadership framework, many initiatives have been taken that are already proven fruitful for the conservation approach, like the legislative approach for recovering park area from the illegal occupiers and ensuring administrative physical boundaries; demolishing unnecessary infrastructure and reforestation; digging and increasing canal depth; restricting amusement activity in the forest area and banning noise and other disturbances; implementing zoning systems; planning for drone monitoring; and increasing the ranger force in the park for robust patrolling. These adhered-to and planned initiatives are either already proven successful or have huge potential for success in the near future.

Conservation strategies and planning insight (by interviewing park officials):

We got an overall overview of the park's present status of conservation strategies, which are presently adhered to, and future frameworks. Present initiatives are the minimization of tourism in the park's core forest area and wildlife habitats and the nourishing of existing floral and faunal communities. Future planned initiatives are zoning for wildlife habitats; creating a wildlife corridor for connecting both sides of the park, which are right now divided by a highway; reforestation in the area of 404.686 hectares after recovering from illegal occupation as well as demolishing unnecessary infrastructure like cottages, rest houses, and watchtowers; increasing the depth of canals and ponds by digging them; using drones for better wildlife monitoring; and securing the total boundary of the parks.

Global Case Studies:

We studied cases of several national parks in the world. Nature conservation in the Serengeti National Park, Tanzania, is an example of the importance of collaboration and contribution from various organizations, as well as the community. IUCN collaborated with Serengeti National Park with policy advice, establishing an ecological monitoring system of the park in partnership with UNESCO, UNF, and the International Zoological Society (FZS). (Arie Kusuma Paksi, 2023) The case study of Banff National Park, Canada, represents the positive impacts of a wildlife corridor, which is established by public and private partnership and ultimate facilitation and support for wildlife. (Adam T. Ford, 2009) For the Torres del Paine National Park, Chilean Southern Patagonia is the case of impacts on the wildlife and ecology

of ecotourism's negativity of uncontrolled access and high mobility of tourists. Also, the importance of ecotourism and its management. (José Barrena Ruiz, 2019) Zoning in protected area management is a scenario of Plitvice Lakes National Park, Croatia, by which they conserve wildlife to ensure the conservation approaches supported by IUCN and achieve the status of World Heritage Site from UNESCO. (MAJA VURNEK1, 2019) Khadim Nagar National Park and swamp forest, Sylhet, Bangladesh, conservation by community management is both a challenge and a hope here; there is a need for more engagement to strengthen the capacity of both the forest department and the community towards conservation. (Md. Mahfuz-Ur-Rahman, 2021) During the assessment of mammal diversity of the Baraiyadhala National Park, Chottogram, it was witnessed that various threats are present in the path of conservation, like intentional forest fires and poaching. Regular patrolling and community engagement are the keys to conservation. (Md. Kamrul Hasan, 2024)Eco-tourism potential, along with the conservation of the protected area Lawachara National Park, Sylhet, is a double and cooperative effort towards ecotourism and conservation. (M. S. Islam, 2012) Along with all the references from the protected national parks from the globe as well as Bangladesh, our study site Bhawal National Park's various present and planned combined conservation initiatives, like zoning; afforestation; patrolling with checklists, community engagements; limiting tourism to only a little part of the park despite the core forest area, habitat restoration; wildlife corridors, and monitoring by drones, definitely have a present positive impact and probable near-future impact on the overall ecosystem and sustainable management of the protected area.

We found present increases in vegetation cover and moderate abundance of mammals, birds, reptiles, and fish species. The condition of water bodies is fine. Despite various existing threats from human activity, the park's forest and diversity still exist in abundance due to the planned initiatives and conservation approaches. We may witness the park again as one of the biodiversity hotspots and an ideal protected area and wildlife sanctuary of Bangladesh, as well as of the world. This assessment provides an updated snapshot of the floral and faunal diversity of Bhawal National Park and allows comparison with earlier records. Overall, Bhawal National Park continues to play an essential role as a semi-natural refuge within a rapidly urbanizing landscape. Yet the gradual shift in vegetation composition and the incomplete representation of faunal groups signal that management interventions will be necessary to maintain ecological integrity. Protection against Encroachment: Several ecologically important areas remain under human occupation or pressure. Recovering and restoring these lands could substantially increase available habitat, particularly for ground flora and small vertebrates. Local communities and park staff have valuable ecological knowledge, especially regarding elusive mammals and reptiles. Integrating their observations into a participatory monitoring system can improve species detection and encourage stewardship. Increasing isolation of forest patches threatens the long-term viability of mammalian populations. Restoring habitat corridors within and around the park would improve genetic flow and reduce local extinctions. The comparatively high diversity of avifauna and insects makes the park an ideal site for citizen science initiatives. Structured programs can increase data availability while fostering public awareness.

Periodic analysis of land-use and land-cover change through satellite imagery should become part of the park's management routine. This would help track illegal encroachment, vegetation loss, and regeneration over time.

Recommendation for gradually phasing out acacia and eucalyptus from the park:

Need a plan for phasing out acacia and eucalyptus from the park, as they are observed to be plentiful in number in the park. Gradually, there is a need to reforest with native trees in exchange for these invasive and ecologically harmful species.

Recommendation for shelter & introduction of captive elephants in the park:

Elephants are keystone species and ecosystem engineers of the Shorea robusta forest. Once abundant species of the park are now extinct from the park and severely abused by their inhumane lives of captivity. Our recommendation is to introduce those captivated and abused elephants to the parks, which will be a great initiative for elephant conservation as well as the conservation of the park itself.

Recommendation for policy and laws regarding protecting forest land law reformation for swift recovery and protection of forest areas:

Through overall research, assessment, interviewing, and observation, we addressed some key necessary law updates and strengthening for leveraging the conservation approaches and sustaining the initiatives. We recommend the laws' reformation regarding the forest and protected areas land protection law, which is still under the civil judiciary procedure, which makes recovering illegally occupied land from the grasps of occupiers difficult. Recommending "specialized law for land management and restoration of forest and protected areas within a short time."

Limitations of the study:

One month restricts the ability to capture seasonal variations in species composition, abundance patterns, and ecosystem dynamics, particularly in a tropical forest system where phenology and faunal activity fluctuate across wet and dry periods. Second, mammalian diversity is likely underestimated due to the inherently low detectability of many species, especially nocturnal, cryptic, and wide-ranging taxa, which cannot be reliably documented within limited field observation windows and without extended camera-trap deployment. Third, the limited number of replicate sampling units for both vegetation plots and water quality assessments reduces statistical robustness and may constrain the precision of diversity and environmental estimates. Collectively, these limitations suggest that while the study provides a valuable baseline snapshot of biodiversity and ecological conditions in Bhawal National Park, longer-term and more intensive sampling designs would be necessary to generate more comprehensive and seasonally representative ecological inferences.

Conclusion:

Bhawal National Park represents a vital ecological resource with significant flora and faunal diversity. Historical analyses reveal the challenges faced by this ecosystem but also highlight the potential for recovery through concerted conservation efforts. Moving forward, a collaborative approach involving local communities, government agencies, and conservation organizations will be essential for ensuring the long-term sustainability of biodiversity in Bhawal National Park.

List of Abbreviations:

BNP: Bhawal National Park.

IUCN: International Union for Conservation of Nature.

DBH: Diameter at Breast Height.

DO: Dissolve Oxygen.

Ph: Potential of Hydrogen.

TDS: Total Dissolved Solid

EC: Electric Conductivity

NPP: Net Primary Production

GPP: Gross Primary Production.

AGB: Above Ground Biomass.

BGB: Below-Ground Biomass.

IBA:

H: Shannon Weiner Index

J': Pielou's Evenness Index

UNESCO: United Nations Educational, Scientific, and Cultural Organization.

UNF: United Nation Foundation.

FZS: Frankfurt Zoological Society.

IBA: Important Bird and biodiversity Area.

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