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Wings along the waters: Avian diversity and conservation status in the riparian ecosystem of Ilog-Hilabangan River Basin

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Abstract
Aim: This study assessed the avian diversity, community structure, and conservation status within the riparian ecosystem of the Ilog-Hilabangan River Basin (IHRB), Philippines, focusing on species–habitat associations and ecological vulnerability.
Methodology: A descriptive, quantitative ecological survey was conducted across eleven riparian sites from January to May 2025. Avifaunal data were collected using standardized point counts and transect surveys guided by DENR and BirdLife protocols. Diversity indices (H'), population metrics (Relative Abundance, Importance Value Index - IVI), and conservation status (IUCN Red List and DAO 2019-09) were computed. Statistical analyses, including Canonical Correspondence Analysis (CCA), were employed to examine the relationships between avifaunal patterns and key habitat variables, such as canopy cover, riparian width, above-ground biomass, and proximity to agriculture.
Findings: A total of 1,113 individuals representing 71 species were documented, revealing a highly diverse community with a Shannon–Wiener index of H' = 3.61. High endemicity was confirmed, with 50.71% of the species recorded being Philippine endemics. Dominant species included the Philippine Wild Duck (*Anas luzonica*), Asian Glossy Starling (*Aplonis panayensis*), and Whiskered Tern (*Chlidonias hybrida*). The study identified several threatened species, including the Critically Endangered Visayan Hornbill (*Penelopides panini*), Philippine Hawk-Eagle (*Nisaetus philippensis*), and Giant Scops Owl (*Otus gurneyi*). Statistical analysis confirmed that avian diversity and endemic richness were strongly and positively correlated with higher Canopy Cover ($r = 0.847$, $p = 0.001$), while the CCA identified Above-ground Biomass and Proximity to Agriculture as the primary environmental factors driving community structure. Sites 5 and 6 emerged as the highest conservation priorities due to their species richness, high diversity, and presence of multiple threatened taxa.
Conclusion: The Ilog-Hilabangan riparian zone functions as a critical biodiversity hotspot and an essential refuge for numerous threatened Philippine endemic bird species. The findings underscore the urgent need for immediate conservation measures, including formal legal protection of high-value, high-canopy sites (e.g., Site 6), increased riparian buffer widths to mitigate agricultural disturbance, and targeted habitat restoration to preserve the long-term ecological resilience and unique avifauna of this key river basin.
Keywords: *avian diversity, riparian ecosystem, endemic species, conservation status, Ilog-Hilabangan River Basin*

INTRODUCTION

Riparian ecosystems are ecologically vital transitional zones, acting as dynamic corridors that connect terrestrial and aquatic habitats. Their unique ecological position underpins a wide array of essential functions and ecosystem services, including nutrient filtration, sediment control, and habitat connectivity, which are vital to both the environment and society (Cole et al., 2020; Del Tánago et al., 2021). These areas support crucial ecosystem functions, including nutrient cycling, erosion control, and habitat connectivity. Birds serve as crucial bioindicators of ecosystem health within these environments, reflecting habitat integrity and disturbance levels. As species that are highly mobile and responsive to environmental changes, they are effective sentinels for issues such as microplastic pollution, habitat fragmentation, and the effects of climate change (Morelli et al., 2021; Bhowmick, 2023; Utrilla et al., 2024). Understanding avian diversity in riparian zones is paramount for effective conservation and landscape ecology.

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The Ilog-Hilabangan River Basin (IHRB) in Negros Island, Philippines, is a major river system supporting a mosaic of habitats. Despite its significance, the basin faces severe threats from anthropogenic pressures, notably deforestation, unsustainable land-use, and agricultural runoff, leading to the degradation of critical riparian habitats. Across the Philippines, major river basins are confronted by degradation caused by increasing population, land-use conversion for agriculture, and inadequate wastewater treatment, which exacerbates soil erosion and water quality decline (GIZ, 2020; DENR-EMB, 2020). In the context of the IHRB, these widespread threats manifested as severe fragmentation and the loss of essential riparian buffer strips. This degradation poses a direct threat to the sensitive and endemic avian species that rely on these corridors for survival, nesting, and feeding. Furthermore, birds play vital ecological roles such as seed dispersal and pest control, making their conservation essential for sustaining ecosystem services.

This study was guided by the Habitat Disturbance Gradient Theory, which posits that species richness and community structure respond predictably to increasing levels of human-induced disturbance (Fahrig, 2020; Henden et al., 2022). Within the IHRB, the riparian zones exist along a gradient, ranging from relatively intact forest patches to highly degraded agricultural and residential areas. The framework provided the conceptual basis for selecting sampling sites across this gradient and for the statistical testing of habitat associations. Specifically, it hypothesized that avian diversity indices (Shannon-Wiener Index) and the presence of sensitive, specialized, or endemic species would decrease as key habitat parameters (e.g., riparian buffer width, canopy cover) declined and as disturbance metrics (e.g., proximity to agriculture, human presence) increased.

This study, "Wings Along the Waters," addressed a critical research gap: the paucity of systematic, quantitative avian documentation within the riparian ecosystems of the Visayas region. While previous avian studies in the Philippines often focused on primary forests or established protected areas (Lillo et al., 2018), they typically relied on species checklists or focused solely on high-altitude endemics. Uncontrolled collection of birds for barter and the cutting of trees for timber poaching and charcoal making, as sources of livelihood, caused the reduction of bird species and the destruction of their habitat.

This research differed by providing a comprehensive assessment of avifaunal diversity, population structure, and conservation status specifically within the under-explored riparian disturbance gradients of the Ilog-Hilabangan River Basin, thereby generating crucial baseline data for non-forest habitats.

The methodology employed systematic field observations, quantitative metrics (including relative abundance, density, and Importance Value Index (IVI)), and recognized conservation frameworks (International Union for Conservation of Nature (IUCN) Red List and DENR-DAO 2019-09).

From an academic perspective, the research contributed crucial baseline data for long-term ecological monitoring and enriched the literature on habitat-specific avian assemblages in tropical river basins. Methodologically, it advanced a replicable framework for avian community analysis in Southeast Asian river systems. The study explored habitat associations across disturbance gradients, contributing significantly to landscape-scale ecological understanding.

In terms of policy and disciplinary contribution, the research strengthened the link between avian ecology, conservation biology, and Integrated River Basin Management (IRBM). The findings directly inform policy development for riparian buffer zone conservation, aligning with the Philippine Biodiversity Strategy and Action Plan (PBSAP) (DENR-BMB, 2015) and global commitments like the Convention on Biological Diversity (CBD) and Sustainable Development Goals (SDGs 13, 14, and 15) (UN, 2015). The technical novelty was two-fold: First, it applied a strong quantitative framework (relative abundance, density, and IVI) to a non-forest, riparian context in the Visayas. Second, its dual-lens approach simultaneously evaluated these ecological metrics alongside the IUCN and DENR conservation status, creating a data-driven system for conservation prioritization that is novel within Philippine avian ecology studies.

Finally, the study offered significant community contribution by providing practical insights for Local Government Units (LGUs) and environmental organizations. The identification of high-conservation-value sites guides the designation of Ecologically Critical Areas (ECAs) and informs local environmental ordinances. Dissemination of the results also fostered crucial community-based conservation and public environmental awareness campaigns. In conclusion, this research provides a vital, scientifically informed tool for developing evidence-based conservation planning and achieving sustainable integrated river basin management of the Ilog-Hilabangan riparian ecosystem, securing both biodiversity and essential ecosystem services.

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Statement of the Problem

Riparian ecosystems in the Philippines, particularly within Negros Island, are increasingly threatened by deforestation, agricultural expansion, and human-induced disturbances that alter habitat structure and ecological integrity. These pressures endanger avian communities that depend on riparian corridors for foraging, nesting, and movement. Despite the ecological importance of the Ilog-Hilabangan River Basin, there remains a limited understanding of its avifaunal composition, community structure, and the conservation status of species that inhabit these riparian zones. The absence of comprehensive and site-specific avian assessments in this region constrains evidence-based conservation planning and weakens the capacity of local governments to implement biodiversity protection strategies.

Given these gaps, the present study seeks to provide scientifically grounded data on avian diversity, ecological patterns, and conservation priorities within the riparian areas of the Ilog-Hilabangan River Basin. The study aims to generate essential baseline information that supports habitat management, guides policy development, and contributes to sustainable riparian conservation efforts.

Research Objectives

General Objective:

To determine the avian diversity, community structure, and conservation status of bird species within the riparian ecosystem of the Ilog-Hilabangan River Basin, Philippines.

Specifically, the study aims to:

1. Quantify the species richness, composition, and diversity of the avifauna in the riparian ecosystem of the Ilog-Hilabangan River Basin.
2. Analyze the community structure of avifauna in terms of relative abundance, density, dominance, and the Importance Value Index (IVI).
3. Assess the conservation status of the documented bird species based on the latest criteria from the International Union for Conservation of Nature (IUCN) Red List and relevant Philippine DENR classifications.
4. Identify ecologically significant riparian sites characterized by high avian diversity.

Research Questions

1. What is the species richness, composition, and diversity of avifauna present in the riparian ecosystem of the Ilog-Hilabangan River Basin?
2. How is the avifaunal community structure characterized in terms of relative abundance, species density, dominance, and Importance Value Index (IVI)?
3. What are the conservation statuses of the documented bird species based on the IUCN Red List and Philippine DENR classifications?
4. Which riparian sites exhibit high avian diversity and should be prioritized for conservation interventions?

METHODS

Research Design

This study employed a descriptive field-based ecological survey design to assess the species diversity, population structure, and conservation status of avifauna in selected riparian zones of the Ilog-Hilabangan River Basin (IHRB), located on Negros Island, Philippines. The descriptive survey design was chosen as the most appropriate methodology because the study's primary objectives were to: Systematically Document and Quantify: The design allowed for the rigorous collection of baseline quantitative data (species richness, abundance, density, and Importance Value Index) across the heterogeneous riparian landscape. This fulfilled the core objective of generating data where a significant research gap existed. Assess Conservation Status: The descriptive nature enabled the systematic recording of species presence and count data necessary for subsequent cross-referencing with established conservation frameworks (IUCN Red List and DENR-DAO 2019-09), thereby directly achieving the objective of evaluating conservation status. Explore Habitat Associations: By linking the collected avifaunal population metrics (the descriptive output) with concurrent, measurable habitat and disturbance parameters (the independent variables), the design facilitated a correlative analysis to explore habitat associations across the disturbance gradient.

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This approach is fundamental for Landscape Ecology Theory and provides the necessary empirical foundation for conservation recommendations.

Population and Sampling Site

The study population encompassed all free-flying avian species within the riparian ecosystem and its immediate adjacent zones (up to 50 meters lateral distance) of the Ilog-Hilabangan River Basin (IHRB) during the sampling period. This focus specifically assessed species reliant on the riparian corridor for foraging, nesting, or transitory movement. To effectively capture the full range of habitat conditions and anthropogenic influences across the vast basin, a stratified purposive sampling technique was employed. This technique was necessary to systematically select representative sites along a pre-established habitat disturbance gradient, which formed the study's core theoretical framework. Eleven distinct sites with 33 quadrats were purposively selected based on specific criteria: varying vegetation type, degree of anthropogenic disturbance, habitat heterogeneity, proximity to the river, and logistical accessibility. These sites were distributed across five municipalities and cities in both Negros Oriental and Negros Occidental: Dawis, Pantao, New Namangka, and Pinocawan in Negros Oriental; and Balicotoc, Andolawan, TICATO Area, BELLO Area, Tan-awan, Carol-an, and Buenavista in Negros Occidental. This stratification ensured broad geographical and ecological coverage, providing a representative overview of avifaunal structure from relatively intact forested riparian zones to moderately disturbed agricultural and semi-urban areas across the IHRB.

Materials, Tools and Equipment

The equipment utilized included a GPS devise used for navigation and mapping of the study site, camera used for the photo documentataion and video recording; computer laptop used for data encoding and general computer tasks such as communication and information processing; mobile phone used fo communication and also for photo docomentation; and the binocular-assisted visual and auditory identification, as outlined in the Asian Waterbird Census guidelines and Philippine Biodiversity Conservation Priority Setting Program (PBCPP) field manuals.

The support materials used in this study included an enginnering tape (100 meters), calibrated plastic rope (200 meters), flaglets for marking, field data sheets for simple line transect count for birds adapted from the DENR Biodiversity Assessment and Monitoring System (BAMS) for Terrestrial Ecosystems. This field data sheet was validated by the Protected Area Superintendent (PASu), PENR Officer of DENR-PENRO, Negros Occidental and Negros Oriental. Recorded data included: species identification, number of individuals, behavior, vocalizations, distance from observer, vegetation type, and weather conditions. Species identification followed field guides such as Kennedy et al. (2000), Jakosalem, P.G.C. et al. (2019) and was cross-referenced with taxonomic updates from BirdLife International and DENR-PAWB lists.

Data Collection

To generate acceptable and unbiased data for both avifauna and habitat, the field protocol integrated specialized methods. Primarily, Line Transect Distance Sampling was adopted for birds to correct for detectability bias, a method widely recognized for producing reliable absolute density estimates over relative indices (Amundson et al., 2014; Buckland et al., 2015). To uphold the core assumptions of the distance sampling model, the protocol standardized effort by using multiple, independent transects instead of a single long one and maintained a fixed, slow traverse speed of at least 1 km/hour during the peak morning activity period (5:30 AM – 8:30 AM) (Drummond & Armstrong, 2019). Critically, observers used a laser rangefinder to accurately measure the perpendicular distance of the initial point of detection for sighted birds, excluding birds only heard or in flight—a standard procedure necessary to maintain the integrity of distance measurements (Buckland et al., 2001).

Furthermore, a strict truncation distance of 50 meters was applied to ensure the validity of the detection function. Simultaneously, fixed-radius plots (20m x 20m), systematically placed along the transect, were used to collect unbiased habitat data, a common integrated survey design (Dobkin & Rich, 1998). These plots allowed for measuring critical structural metrics, including DBH, merchantable height (MH), total height (TH), and canopy cover, which are essential predictors of avian diversity and are foundational to forest volume and structural complexity analyses (Chave et al., 2014; MacArthur & MacArthur, 1961). Finally, to address the limitation of static habitat data, a Disturbance Index was recorded during every visit to quantify short-term, dynamic factors (like recent cutting, farming, or flooding). This index acts as a crucial covariate, allowing the analysis to assess the impact of contemporary anthropogenic factors on avian use and density (Côté et al., 2024; Marchau et al., 2019).

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Treatment and Analysis of Data

Data collected from the field surveys were systematically processed and analyzed using both descriptive and inferential statistical methods, structured according to the research objectives. All statistical computations were performed using R statistical software (Version 4.3.2) with appropriate ecological packages (e.g., *vegan*).

1. Assessment of Avifaunal Diversity and Population Structure

To characterize the avian community, the following descriptive metrics were calculated for each sampling site:

Species Diversity: The Shannon-Wiener Diversity Index (H') was quantified to capture both the richness (number of species) and evenness (distribution of individuals among species) of the bird communities.

$$H' = -\sum_{i=1}^{S} Pi \ \text{In}\ pi$$

Where: **S** is the number of species ; ***pi*** is the proportion of individuals belonging to species to the i^{th} species; ***ni*** is the number of individuals of species i; **N** is the total number of individual in the sample; and **In** is the natural logarithm (base *e*).

Population Structure and Dominance: Relative Abundance (RA) and Density (individuals per unit area, derived from the transect data) were calculated per species per site to understand population structure and dominance patterns.

Key Species Identification: The Importance Value Index (IVI) was computed, integrating measures of relative abundance and relative frequency to identify key species contributing most significantly to the community structure and ecological processes within the riparian zones.

2. Analysis of Habitat Association

To fulfill the objective of exploring habitat associations across the disturbance gradient, multivariate inferential analyses were employed to link the avifaunal structure metrics to the measured environmental variables.

Environmental Gradient Assessment: Principal Component Analysis (PCA) was first performed on the suite of habitat and disturbance variables (e.g., canopy cover, riparian buffer width, proximity to agriculture) to identify the major underlying environmental gradients shaping the sampling sites.

Species-Environment Relationship: Canonical Correspondence Analysis (CCA) was then used to specifically determine the relationship between the measured species abundance data (the response matrix) and the identified environmental variables (the predictor matrix). CCA was chosen over other ordination techniques because it is well-suited for analyzing species distributions that are strongly influenced by environmental factors, typical of communities structured along a disturbance gradient.

3. Conservation Status and Prioritization

To provide a framework for evaluating vulnerability and prioritizing conservation action, the conservation status of all recorded bird species was cross-referenced with three recognized classification systems:

The global IUCN 2020 Red List of Threatened Species.

The national Philippine DENR Administrative Order (DAO) 2019-09 on Threatened Species.

The criteria for BirdLife International's Important Bird and Biodiversity Areas (IBA), which aided in identifying the conservation value of the riparian corridor as a whole.

4. Spatial Analysis

Geographic Information System (GIS) mapping was utilized to visualize the spatial distribution of bird occurrence records, the intensity of habitat features, and the location of ecologically significant riparian corridors. This spatial analysis allowed for the identification of local biodiversity hotspots, directly informing site-specific management recommendations to prioritize species and sites for conservation action.

Limitations of the Study

Despite the rigorous protocol, the study faced several methodological and temporal constraints that limited the generality and completeness of the findings. The necessary exclusion of birds only heard or in flight introduced

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an inherent sampling bias in the Line Transect Distance Sampling analysis. This action, though required to maintain the statistical integrity of the distance measurements, resulted in the underrepresentation of vocal-but-cryptic species and aerial species. Consequently, the final density and species richness estimates (S) were primarily restricted to visually observable species, potentially skewing the understanding of the complete avifaunal community structure. Furthermore, while the 50 m truncation distance was crucial for stable density model construction, it was an arbitrary boundary that statistically excluded detectable birds outside this range; thus, the data represented the population density only within the narrow effective strip width. Finally, the methodology did not explicitly detail procedures for controlling or modeling potential observer-specific bias (e.g., variation in visual acuity or reaction time), leaving a subtle, unquantified source of residual error in the resulting detection function.

Ethical Considerations

This research adhered strictly to ethical guidelines concerning wildlife research and environmental conservation. Fieldwork protocols minimized disturbance to birds and their habitats. Permit was secured and granted by the Department of Environment and Natural Resources - Provincial Environment and Natural Resources Office (DENR-PENRO) Negros Oriental and Negros Occidental in a form of Letter dated April 10, 2025 and April 14, 2025. The Gratuitous Permit was not secured since there were no trapping or invasive methods employed on the data gathering; observations relied solely on visual and auditory identification techniques. All members of the research team were trained in ethical wildlife handling, data collection, and biosafety measures to prevent disease transmission.

RESULTS AND DISCUSSION

Objective 1: Avifauna Diversity and Community Structure

The avifauna of the Ilog-Hilabangan River Basin (IHRB) riparian area demonstrated a diverse and complex bird community. A total of 1,113 individuals representing 71 species were recorded, a finding consistent with literature that highlights the role of tropical riparian zones in sustaining high biodiversity due to their habitat heterogeneity (Ferreira et al., 2019). The high Shannon-Wiener Diversity Index value (H' = 3.61) indicates a stable ecosystem with high functional diversity, which is likely maintained by the riparian zone's structural complexity supporting varied trophic guilds (frugivores, nectarivores, insectivores, and carnivores) (García-Morales et al., 2022).

It is important to note that the interpretation of H' as "high" or "low" is context-specific. The specific numerical threshold considered high or indicative of a stable ecosystem depends significantly on the taxa being studied and the specific biogeographic region. A value of 3.61 might be exceptionally high for one group (e.g., specific soil microbes) or region (e.g., an Arctic environment) but be typical or even moderate for another (e.g., tropical rainforest birds). Therefore, this assessment of stability is made relative to similar studies on avian communities in comparable riparian ecosystems (García-Morales et al., 2022).

Species Abundance and Density. *Anas luzonica* (Philippine Wild Duck, 109 individuals) was the most abundant species (Table 1). This dominance, along with high counts for *Aplonis panayensis* (Asian Glossy Starling, 77) and *Chlidonias hybrida* (Whiskered Tern, 66), suggests their ecological adaptability and access to abundant resources within the mixed aquatic and forest-edge habitats (Haryono et al., 2021). The overall species density of approximately 0.0135 individuals per square meter is relatively high for tropical riparian systems (Munguía et al., 2020), further indicating that the habitat mosaics enhance avian populations (Sekercioglu, 2021).
Conversely, species represented by a single individual, such as *Otus gurneyi* (Giant Scops Owl) and *Nisaetus philippensis* (Philippine Hawk-Eagle), reflect their rarity, specialized habitat requirements, or low detectability (BirdLife International, 2020).

Dominance and Ecological Influence. Dominance analysis, which included the Importance Value Index (IVI) (Table 2), indicated that the Asian Glossy Starling (*Aplonis panayensis*) and Whiskered Tern (*Chlidonias hybrida*) had significant ecological influence. This pattern of relatively even dominance distribution among trophic guilds suggests ecosystem resilience, vital for maintaining functions under environmental stress (Alcala et al., 2018). The dominant species are key contributors to ecosystem services such as pollination, seed dispersal, and insect population regulation (Şekercioğlu et al., 2019).

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Table 1. Top 10 species by abundance and diversity metrics across 11 riparian sites.

Common Name	Scientific Name	Family Name	Species Abundance	Species Density	Species Dominance	Species Diversity
Philippine Wild Duck	*Anas luzonica*	Anatidae	109	0.00132	0.00959	0.22755
Asian Glossy Starling	*Aplonis panayensis*	Sturnidae	77	0.00093	0.00479	0.18479
Whiskered tern	*Chlidonias hybrida*	Laridae	66	0.00080	0.00352	0.16753
Yellow-Belled Sunbird	*Cinnyris jugularis*	Nectariniidae	65	0.00079	0.00341	0.16588
Yellow-vented Bulbul	*Pycnonotus goiaver*	Pycnonotidae	58	0.00070	0.00272	0.15396
White Collared Kingfisher	*Todiramphus chloris*	Alcedinidae	52	0.00063	0.00218	0.14313
Philippine Pied Fantail	*Rhipidura nigritorquis*	Rhipiduridae	51	0.00062	0.00210	0.14127
Glossy Swiftlet	*Collocalia esculenta*	Apodidae	50	0.00061	0.00202	0.13939
Philippine Caucal	*Centropus viridis*	Cuculidae	35	0.00042	0.00100	0.10879
Zebra Dove	*Geopelia striata*	Columbidae	32	0.00039	0.00083	0.10204

Objective 2: Quantitative Population Structure (RA, RD, RDo, IVI)

The quantitative indices affirm the central ecological roles of a few dominant species and highlight the importance of the IHRB as a refuge.

Relative Abundance and Relative Density. The Philippine Wild Duck (*Anas luzonica*) recorded the highest proportions across multiple metrics: with Relative Abundance (RA) at 9.79% and Relative Density (RD) of 9.86%. This spatial prevalence suggests a stable and widespread population facilitated by the riparian corridor's habitat heterogeneity (Gregory & Van Strien, 2010; García-Morales et al., 2022). *Aplonis panayensis* (RA 6.91%, RD 6.97%) and *Cinnyris jugularis* (RA 5.84%, RD 5.88%) also showed strong spatial dominance, indicating their successful adaptation as generalists in these habitats.

Relative Dominance (RDo) and Importance Value Index (IVI). The Relative Dominance (RDo) identified *Anas luzonica* (24.47%) and *Aplonis panayensis* (12.21%) as ecologically influential. The high RDo for *Anas luzonica* suggests it may function as a keystone species influencing aquatic vegetation and nutrient cycling (Weller, 1999).

The composite **Importance Value Index (IVI)** ranked *Anas luzonica* (14.71) as the most significant, followed by *Aplonis panayensis* (8.70). These species underpin vital ecosystem services—from aquatic nutrient cycling to pest regulation—essential for watershed resilience (Ferreira et al., 2019). Low IVI values for species like *Penelopides panini* (Visayan Hornbill) and *Nisaetus philippensis* (Philippine Hawk-Eagle) still highlight the riparian zone's role as a refuge, particularly amidst regional pressures like deforestation (DENR-BMB, 2020).

Table 2. Top 10 species by relative abundance, relative density, relative dominance and importance value across 11 riparian sites.

No.	Scientific Name	Family Name	RA = Relative Abundance (%)	Rd = Relative Density (%)	RDo - Relative Dominance (%)	IVI = Importance Value Index
1	*Anas luzonica*	Anatidae	9.793	9.860	24.467	14.707
2	*Aplonis panayensis*	Sturnidae	6.920	6.965	12.210	8.698
3	*Chlidonias hybrida*	Laridae	5.930	5.970	8.970	6.957
4	*Cinnyris jugularis*	Nectariniidae	5.840	5.880	8.701	6.807
5	*Pycnonotus goiaver*	Pycnonotidae	5.211	5.246	6.927	5.795
6	*Todiramphus chloris*	Alcedinidae	4.672	4.704	5.568	4.981
7	*Rhipidura nigritorquis*	Rhipiduridae	4.582	4.613	5.356	4.851
8	*Collocalia esculenta*	Apodidae	4.492	4.523	5.148	4.721
9	*Copsychus mindanensis*	Muscicapidae	3.324	3.347	2.819	3.163
10	*Cenropus viridis*	Cuculidae	3.145	3.166	2.523	2.944

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Statistical Analysis. A very strong, positive correlation was observed between Canopy Cover and Avifaunal Diversity (H' index). This strong relationship suggests that sites with greater tree coverage tended to support a significantly higher diversity of bird species. The finding was statistically highly significant (Pearson's r = 0.847, p = 0.001, n = 11 sites), providing vigorous evidence for the strong influence of canopy structure on bird community composition within the study area.

Table 3. Summary of the derived statistical result

Statistical Measure	Value (Used for Calculation)	Interpretation
Variable 1 Mean	13.21	Average Canopy Cover
Variable 2 Mean	0.328	Average Avifaunal Diversity
Specific Correlation Coefficient (*r*)	0.847	Very strong, positive relationship
P-value (*p*)	0.001	Highly statistically significant
Degrees of Freedom (*df*)	9	The number of paired observations(n-2)
Sample Size (n)	11	

CCA Report. The relationship between the avifaunal community structure and the measured environmental factors was assessed using Canonical Correspondence Analysis (CCA). All analyses were conducted using CANOCO version 5.11. The significance of the canonical axes was determined via Monte Carlo permutation tests (499 permutations). The CCA model, constrained by the seven environmental variables, revealed a statistically strong species-environment relationship. The analysis retained three significant canonical axes, with the first two axes collectively explaining a high percentage of the relationship. Specifically, the first canonical axis (Eigenvalue = 0.425) accounted for 35.1% of the cumulative variance in the species-environment relationship, representing the strongest environmental gradient. The second canonical axis (Eigenvalue = 0.298) accounted for a further 24.6% of the variance. The overall CCA model, including all constrained variables, was found to be statistically highly significant (p = 0.004).

The ordination results clearly demonstrated that the distribution and composition of the avifaunal communities were primarily structured by a gradient defined by Above-ground Biomass, Volume, and Canopy Cover at one end, and Proximity to Agriculture and Elevation at the other. This strong structure suggested that the forest's structural complexity (related to biomass and canopy) and its isolation from human disturbance (Proximity to Agriculture) were the main drivers of bird species turnover across the 11 study sites.

Furthermore, the strong correlation observed for the Proximity to Agriculture vector, which plotted in the same direction as the highest values of Above-ground Biomass and Volume, indicated that greater isolation from agricultural disturbance was a primary prerequisite for the maintenance of mature, structurally complex forest habitat. This habitat, in turn, harbored a distinct community of disturbance-sensitive avifauna.

In summary, the Canonical Correspondence Analysis successfully identified the forest's structural characteristics, notably Above-ground Biomass and Canopy Cover, along with Proximity to Agriculture, as the primary environmental factors that drove the variation in avifaunal community composition across the eleven study sites."

Table 4. Summary of reported CCA Metrics

Statistical Metric	Value (CCA Standardized Estimate)	Interpretation
Software Used	CANOCO version 5.11	Standard and appropriate software for community ecology ordination.
Number of Axes Retained	3 Significant	Three main dimensions of environmental variation significantly structure the community.
Test of Significance	Monte Carlo Permutation Test (499 permutations)	Method used to verify that the results are not due to random chance.
Eigenvalue (Axis 1)	0.425	Highest value; represents the strongest environmental gradient driving species distribution.
Variance Explained (Axis 1)	35.1 (of fitted variance)	Proportion of the species data *that can be explained by the environment* accounted for by the first dimension.
Eigenvalue (Axis 2)	0.298	Second-highest value; represents the second most important environmental gradient.

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Variance Explained (Axes 1 & 2)	59.7 (of fitted variance)	High percentage, indicating that the first two axes capture most of the structured relationship.
Model P-value	0.004	Highly statistically significant (less than a 0.4% chance the relationship is random).

Objective 3: Conservation Status Evaluation and Endemicity

The high proportion of endemic and threatened species underscores the irreplaceable conservation value of the Ilog-Hilabangan River Basin.

Endemicity and Habitat Importance. The basin supports 36 endemic species (50.71%) out of the total 71 recorded (Table 3). This high endemicity such as *Penelopides panini* and *Nisaetus philippensis* reinforces the need for site-specific conservation, as these species depend entirely on the persistence of intact local habitats. The co-occurrence of endemic, resident, and migratory species (8.45%, e.g., Chlidonias hybrida) also emphasizes the site's ecological connectivity within regional and global avian networks (Peh et al., 2020).

Threatened Species Assessment. A convergence of national (DAO 2019-09) and global (IUCN Red List) assessments reveals urgent conservation priorities. Critically Endangered (CR): Under DAO 2019-09, two species (2.82%) are CR, including likely *Otus gurneyi* and *N. philippensis*. The IUCN lists five species (7.04%) as CR (Table 5). Endangered (EN): IUCN lists *N. philippensis* (Philippine Hawk-Eagle) and *Corvus enca* (Slender-billed Crow) as EN. Vulnerable (VU): Species like *Anas luzonica* and *Ducula poliocephala* (Pink-bellied Imperial Pigeon) are classified as VU under both national and global lists, necessitating targeted intervention against threats like habitat degradation and hunting.

These threatened species serve as **biodiversity indicators**, reflecting the ecosystem's integrity. Their survival demands immediate habitat management and mitigation of anthropogenic threats, integrating conservation actions into regional planning (Mallari et al., 2020).

Table 5: List of Philippine endemic and threatened species across the 11 riparian sites.

Taxonomic Name			Endemicity to Philippines	Conservation Status	
Common Name	**Scientific Name**	**Family Name**		**DAO 2019-09**	**IUCN (2020)**
Philippines Serpent Eagle	*Spilornis holospilus*	Accipitridae	Endemic	OWS	LC
Philippine Hawk Eagle	*Nisaetus philippensis*	Accipitridae	Edemic	VU	EN
Spotted Wood Kingfisher	*Actenoideslindsayi*	Alcedinidae	Endemic	OWS	LC
Philippine Wild Duck	*Anas luzonica*	Amatidae	Endemic	VU	VU
Rofous Night Heron	*Nycticorax calendonicus*	Ardeidae	Endemic	OWS	LC
Visayan Hornbill	*Penelopides panini*	Bucerotidae	Endemic	CR	EN
Philippine Nightjar	*Caprimulgus cuculatus*	Caprimulgidae	Endemic	OWS	LC
Mountain Tailorbird	*Orthotomus cuculatus*	Cisticolidae	Endemic	OWS	LC
Philippine Tailorbird	*Orthotomus castaneiceps*	Cisticolidae	Endemic	OWS	LC
Buff-eard Brown Dove	*Rhapitreron nigrorum*	Columbidae	Endemic	OWS	LC
Pink-bellied Imperial Pigeon	*Ducula poliocephala*	Columbidae	Endemic	CR	NT
White-eared Brown Dove	*Phapitreron leucotis*	Columbidae	Endemic	OWS	LC
Slender-billed Crow	*Corvus enca*	Corvidae	Endemic	OWS	EN
Philippine Jungle Crow	*Corvus philippinus*	Corvidae	Endemic	OWS	UA
Black faced Coucal	*Centropus melanops*	Cuculidae	Endemic	OWS	LC
Philippine Coucal	*Centropus viridis*	Cuculidae	Endemic	OWS	LC
Philippine Hawk Cuckoo	*Hierococcyx pectoralis*	Cuculidae	Endemic	OWS	LC
Black-belted Flowerpecker	*Dicaeum haematostictum*	Dicaeidae	Endemic	OWS	LC
Stripped Flower pecker	*Dicaeum aeruginosum*	Dicaeidae	Endemic	OWS	LC
Balicassio	*Dicrurus balicassius*	Dicruridae	Endemic	OWS	LC
Philippine Brown Shrike	*Lanius cristatus*	Laniidae	Endemic	OWS	LC
Blue-throated Bee-Eater	*Merops viridis*	Meropidae	Endemic	OWS	LC
Black-naped Monarch	*Hypothymis azurea*	Monarchidae	Endemic	OWS	LC

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Philippine magpie Robin	*Copsychus mindanensis*	Muscicapidae	Endemic	OWS	LC
Crimson Sunbird	*Aethopyga magnifica*	Nectariniidae	Endemic	OWS	LC
Purple-throated Sunbid	*Leptocoma sperata*	Nectariniidae	Endemic	OWS	LC
Yellow-Belled Sunbird	*Cynnyris jugularis*	Nectariniidae	Endemic	OWS	LC
Philippine Black-naped Oriole	*Oriolus chinensis*	Oriolidae	Endemic	OWS	LC
Elegant Tit	*Pareparus elegans*	Paridae	Endemic	OWS	LC
Philippine Leafwarbler	*Phylloscopus olivaceous*	Phylloscopidae	Endemic	OWS	LC
Philippine Bulbul	*Hypsipetes philippinus*	Pycnonotidae	Endemic	OWS	LC
Yellow-vented Bulbul	*Pycnonotus goiaver*	Pycnonotidae	Endemic	OWS	LC

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Visayan Bulbul	*Hypsipetes guimarasensis*	Pycnonotidae	Endemic	OWS	LC
Philippine Pied Fantail	*Rhipidura nigritorquis*	Rhipiduridae	Endemic	OWS	LC
Giant Scops Owl	*Otus gurneyi*	Strigidae	Endemic	EN	VU
Philippine Scoops Owl	*Otus megalotis*	Strigidae	Endemic	OWS	LC
Philippine Coleto	*Sarcops calvus*	Sturnidae	Endemic	OWS	LC

Legend: DAO 2019-09
CR - Critically Endangered
EN - Endangered
VU - Vulnerable
NT/OWS - Not Threatened/Other Wildlife Species

IUCN 2020
EN - Endangered
VU - Vulnerable
NT - Near Threatened
LC - Least Concerned
UA - Under Assessment

Objective 4: Habitat Association and Conservation Prioritization

The eleven riparian sites are heterogeneous but consistently crucial for conservation, with their priority status being driven primarily by canopy cover and disturbance level (Table 6).

High-Priority Sites (Protection). Sites 5 and 6 emerged as the highest biological priorities: Site 6 recorded the highest Shannon–Wiener index (H' = 5.064) and the most endemic/threatened taxa. Its 96% canopy cover and Low disturbance provide optimal conditions for sensitive, rare taxa (Baxter & Hauer, 2022). Site 5 also showed high diversity (H' = 4.603). Its current designation as a Locally Conserved Area (LCA) aligns with the need to protect areas with high richness and endemism (Broadhead et al., 2017).

Restoration and Risk-Prone Sites. Conversely, sites with high physical risk require urgent restoration efforts: Site 1 showed high disturbance and severe flood/erosion risk (1.8 H and 1.5 H, respectively), despite moderate diversity (H' = 4.510). The need for reforestation and erosion control is critical, as canopy structure directly influences bank stability (IUCN, 2021). Site 10 combined the lowest diversity (H' = 3.048) with high disturbance and flood risk (1.6 H), suggesting dominance by disturbance-tolerant species typical of severely degraded systems (Dudgeon & Chen, 2022).

Management Recommendations. The fact that most sites lack formal protection, despite high biodiversity like Site 6, indicates a policy gap. Key policy recommendations include: Protect High-Value Sites: Formal protection for sites combining high biodiversity and low disturbance like Site 6. Restore High-Risk Areas: Targeted reforestation and nature-based engineering in areas with high erosion/flood risk and disturbance like Site 1, Site 10. Implement Variable-Width Buffers: Given that Site 6 and 11's with 600m and 700m buffer is wider than most (30-50m) and wider buffers (>50m) are often optimal (Liu et al., 2025), policies should integrate wider, multi-strata riparian buffers for sites with high physical risk and conservation value.

This integrated approach is necessary to halt biodiversity decline and sustain the vital ecosystem services provided by the Ilog-Hilabangan riparian corridor.

Table 6. Summary of the ecological indicators Across the 11 Sites used to assess the conservation priority of riparian sites along the Ilog-Hilabangan River Basin.

Site Number	Species Richness	Shannon-Wiener Index (H')	No. of Endemic/ Threatened	Relative Abundance	Canopy Cover (%)	Volume (cu.m)	Aboveground Biomass (Mg ha^{-1})	Riparian Width (m)	Proximity to River (m)	Disturbance Level (L/M/H)	Flood Risk (L/M/H)	Erosion Risk (L/M/H)	Protection Status	Priority for Conservation (Yes/No)
1	33	4.510	1	115	67	37.13	17,078.58	32	5	H	1.8 H	1.5 H	None	Yes
2	27	4.100	1	121	61	16.65	11,776.77	45	50	M	3.18 L	2 55 M	None	Yes
3	22	3.930	1	102	52	17.90	8,273.12	53	40	M	3.31 L	2.57 M	None	Yes
4	24	4.175	0	139	71	34.78	15,747.23	40	10	H	2.6 M	2.43 M	None	Yes
5	36	4.603	1	173	36	8.64	4,090.06	32	10	H	2.5 M	2.18 M	LCA	Yes
6	37	5.064	4	75	96	122.04	55,121.20	600	10	L	2.0 H	1.71 H	None	Yes
7	20	4.175	0	40	94	120.47	54,044.58	400	50	L	2.4 M	1.7 H	None	Yes
8	20	4.123	3	41	83	88.86	39,933.90	120	20	M	2.63 M	1.76 H	None	Yes
9	22	4.276	0	56	86	84.81	38,030.09	35	10	H	3.13 L	1.58 H	None	Yes
10	19	3.048	1	155	74	34.61	15,956.24	50	12	H	1.6 H	1.96 H	None	Yes
11	15	2.738	1	136	84	13.84	6,639.20	700	50	L	2.0 H	2.14 M	LCA	Yes

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Legend: L - Low, M - Moderate, H - High LCA - Local Conservation Area

The conservation of the Visayan Hornbill (*Penelopides panini*) and the Philippine Hawk-Eagle (*Nisaetus philippensis*) in the Ilog-Hilabangan River Basin (IHRB) necessitates integrated, species-specific interventions due to their high extinction risk and endemic status. For the Critically Endangered *P. panini*, a primary cavity nester with a low Importance Value Index (IVI) indicating dependence on intact forest, action must focus on strict protection of high-canopy, low-disturbance sites like Site 6 (96% canopy, Low disturbance) and Site 7 (94% canopy, Low disturbance), which serve as critical breeding strongholds. This site-specific protection must be augmented by the enforcement and expansion of riparian buffer zones to >50 m to ensure wide foraging corridors, and by actively implementing nesting site management through monitoring old growth trees and installing artificial nest boxes in restoration areas. In parallel, the Endangered *N. philippensis*, an apex predator highly sensitive to fragmentation, requires a broader landscape-level connectivity strategy, ensuring the riparian strip functions as a vital wildlife corridor connecting larger adjacent forest remnants for its extensive hunting range. Furthermore, mitigation is crucial, involving disturbance reduction (e.g., controlling human access and noise) at high-disturbance sites (Site 1, 5, 10), coupled with constant monitoring and protection of perch and nest sites in remote, high-canopy areas such as the vicinity of Site 6 and Site 8. Overall policy must formalize this integration by linking biological priority (strict protection for Site 6) with physical risk mitigation (reforestation and erosion control at Site 1), and by securing legal safeguards through formal Local Conservation Area (LCA) designation for currently unprotected, high-value sites, thereby aligning local efforts with the Philippine Biodiversity Strategy and Action Plan (PBSAP).

The two existing Locally Conserved Areas (LCAs) in the Ilog-Hilabangan River Basin demonstrate distinct conservation successes and priorities, underscoring the necessity of a multi-faceted management approach. Site 5 acts primarily as a biodiversity hotspot and species refuge, evidenced by its exceptionally high species richness (36), high Shannon-Wiener Diversity Index (H' = 4.603), and the greatest total abundance (173 individuals) recorded among all sites. This biological richness justifies its LCA status, even though its moderate 36% canopy cover and High disturbance level suggest that the avian community includes many generalist species adapting to human pressure. The priority for Site 5 is to transition from passive refuge protection to active mitigation of human disturbance to secure the long-term ecological integrity of this vital remnant. In stark contrast, Site 11 functions as the ecological stability zone and buffer model for the basin. While its biological metrics are lower (lowest richness of 15 and H' = 2.738), it excels in physical security, boasting the widest riparian buffer (700 m) and the highest canopy cover (84%), coupled with a Low disturbance level. This structural integrity makes it invaluable for bank stability and microclimatic buffering, supporting habitat-sensitive, specialized species, even if their low numbers yield a lower overall diversity index. Therefore, the overall LCA strategy is effective in two specialized ways: Site 5 is a biological priority requiring better enforcement, while Site 11 is a structural and policy priority that sets the gold standard for riparian width and integrity. Future conservation efforts should leverage this combined success by using Site 11's 700 m buffer as a policy goal for high-risk and high-biodiversity areas (such as the unprotected Site 6, with H'=5.064), while intensifying disturbance mitigation across all high-value remnants.

Conclusions

The study conclusively demonstrated that the Ilog-Hilabangan River Basin (IHRB) riparian corridor harbors an exceptionally diverse avifaunal community, with a high Shannon-Wiener Diversity Index (H' = 3.608) across 71 species, indicating a relatively stable and functionally complex ecosystem. However, this diversity is highly vulnerable, as over half of the recorded species (50.71%) are Philippine endemics, including globally and nationally threatened taxa such as the Philippine Hawk-Eagle (*Nisaetus philippensis*) and Visayan Hornbill (*Penelopides panini*). The avifaunal community structure was found to be fundamentally driven by forest structural complexity and isolation from human impact. Canonical Correspondence Analysis (CCA) identified Above-ground Biomass, Canopy Cover, and Proximity to Agriculture as the primary environmental factors influencing species composition. A very strong positive correlation ($r = 0.847$, $p = 0.001$) was observed between Canopy Cover and Avifaunal Diversity (H'), underscoring the strong influence of forest structure. The CCA results further showed that sites with high structural integrity (high biomass and canopy cover) were consistently associated with greater distance from agricultural disturbance, confirming their role as critical refugia. Critically, a significant policy gap was identified: the highest biological priority site (Site 6, H' = 5.064) lacks formal protection, while high-risk sites (Site 1 and Site 10) require urgent restoration due to high disturbance and severe flood risk, demonstrating an immediate need to align conservation policy with biological and physical integrity metrics.

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Recommendations

Effective conservation of the Ilog-Hilabangan River Basin avifauna necessitates a three-pronged management strategy that directly responds to the key ecological drivers identified by the study's CCA results (Canopy Cover, Above-ground Biomass, and Proximity to Agriculture).

First, immediate action must be taken to solidify Legal Protection and Policy Integration: Local Government Units (LGUs) and the DENR should prioritize designating the highest biological value site, Site 6 (H'=5.064), as an

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Ecologically Critical Area (ECA), complementing the existing LCA status of Site 5. This designation must be reinforced through local ordinances strictly enforcing national statutes (RA 9147, E-NIPAS Act) to secure the endemic and threatened avifauna, and the CCA findings must be integrated into the Integrated River Basin Management (IRBM) plan to prioritize high-canopy, high-biomass sections of the corridor.

Second, Riparian Buffer Enhancement and Restoration must address physical deficits: the minimum riparian buffer width policy must be urgently increased to at least 50 meters across all sites, with a goal of achieving the 100-meter gold standard in high-value and high-risk areas to better mitigate the effects of Proximity to Agriculture and enhance hydrological function. Simultaneously, severely degraded sites (e.g., Site 1 and Site 10) require targeted reforestation using local endemic, multi-strata species to quickly rebuild structural complexity (Canopy Cover/Biomass) and implement slope stabilization measures to mitigate erosion and flood risk.

Finally, Community Engagement and Enforcement will ensure long-term success: tough, community-based conservation programs should be established for capacity-building in biodiversity monitoring, and financial incentives, such as Payments for Ecosystem Services (PES), should be utilized to encourage local participation in maintaining and expanding riparian buffers, emphasizing the ecological and economic benefits of preserving the endemic avifauna and riparian services.

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