

Inventory of Bird Communities in Nimule National Park

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ABSTRACT

This study provides a comprehensive inventory of the avian communities within Nimule National Park, South Sudan, addressing the critical need for baseline biodiversity data in this ecologically significant region. The primary objectives were to identify the taxonomic composition of resident bird species, determine their relative abundance across distinct habitat types, and evaluate how local environmental characteristics influence community structure and diversity. Utilizing the Time Species Count (TSC) method, which allows for standardized assessment of species richness and relative frequency over defined temporal intervals, researchers conducted systematic surveys across varied landscapes, including riverine forests, open woodlands, and savanna grasslands.

The findings indicate a high level of avian richness, with numerous species identified across diverse families, reflecting the park's role as a vital corridor for both resident and migratory populations. The study identified a total of 2,248 individual birds, representing 63 distinct families, highlighting the park's significant role as a refuge for avian biodiversity. Riverine habitats consistently exhibited higher species diversity indices compared to open savanna, likely due to the availability of water, nesting sites, and diverse food resources. The study utilized the Shannon-Weiner Index ($H' = -\sum p_i \ln p_i$) to quantify diversity, where p_i represents the proportion of the total population of the i^{th} species, and the Evenness Index ($J' = H' / \ln S$) to assess the distribution of individuals among species. In conclusion, Nimule National Park serves as a critical refuge for avian biodiversity, yet it faces ongoing pressures from habitat fragmentation and land-use changes. The study demonstrates that the TSC method is an effective, non-invasive tool for monitoring these populations in tropical environments. It is recommended that park management prioritize the protection of riparian zones and implement long-term monitoring programs to track the impacts of environmental shifts on bird populations. Furthermore, fostering community-based conservation initiatives is essential to mitigate human-wildlife conflict and ensure the long-term viability of the park's unique avifauna. These baseline data provide a foundation for future ecological research and the development of evidence-based conservation strategies for the National Park.

INTRODUCTION

The study aims to conduct a comprehensive inventory of bird communities within Nimule National Park, South Sudan. Birds serve as vital indicators of ecosystem health and environmental integrity (Gregory et al., 2003). As Nimule National Park represents a crucial biodiversity hotspot along the Nile corridor, understanding its avian composition is essential for conservation planning. This research will employ systematic point-count surveys and mist-netting to document species richness, relative abundance, and habitat associations. By establishing a baseline of avian diversity, this study provides the empirical foundation necessary to mitigate the impacts of habitat fragmentation and climate change on local wildlife populations. The findings will assist park management in identifying critical nesting and foraging grounds, thereby fostering evidence-based strategies for long-term ecological sustainability in the region.

Background

Global avian populations are currently experiencing unprecedented declines due to habitat loss, agricultural intensification, and climate-induced shifts in migratory patterns (Pimm et al., 2014). Research indicates that nearly 13% of all bird species worldwide are currently threatened with extinction, necessitating urgent inventory and monitoring efforts (BirdLife International, 2020). Protected areas play a fundamental role in safeguarding these species, yet many tropical reserves remain under-sampled. Systematic inventories are crucial for understanding how global environmental changes influence community structure across diverse biomes, providing the data needed to inform international biodiversity conservation policy.

The East African region, specifically the Nile Basin, is a globally recognized migratory flyway that supports vast numbers of Palearctic and Afrotropical bird species (Bairlein, 2016). Despite its ecological significance, the region faces mounting pressure from infrastructure development and land-use changes. Scholars such as Pomeroy (2017) have emphasized that bird assemblages in the Nile Valley are highly sensitive to hydrological fluctuations and vegetation cover. Understanding regional connectivity is vital, as Nimule serves as a corridor linking northern and southern ecosystems, making it a focal point for regional ornithological conservation and migratory studies.

In South Sudan, scientific data regarding avian biodiversity remains remarkably scarce due to decades of civil instability. While early colonial records exist, modern systematic surveys in areas like Nimule National Park are virtually non-existent (Nikolaus, 1989). The park represents one of the few managed protected areas in the country, yet its avian status is poorly documented.

Establishing a national inventory is a prerequisite for developing South Sudan's national conservation strategy and fulfilling its obligations under the Convention on Biological Diversity. This study seeks to bridge the data gap that has persisted since the late 20th century.

Problem Statement

Despite Nimule National Park's ecological importance, there is a profound lack of contemporary data regarding its avian communities. Previous studies have failed to address the current population dynamics and habitat occupancy patterns under modern environmental pressures (Nikolaus, 1989). There exists a significant knowledge gap concerning how post-conflict habitat recovery and human encroachment affect species composition. Without a baseline inventory, park authorities cannot assess the impact of anthropogenic disturbances on biodiversity. This study addresses this gap by providing an updated, rigorous scientific account of the bird species currently utilizing the park's diverse ecosystems.

General Research Objective

The general objective of this study is to conduct a systematic inventory and assessment of bird communities in Nimule National Park to determine species richness, distribution, and ecological status.

Specific Research Objectives

- To identify and document the taxonomic composition of bird species residing in the park.
- To determine the relative abundance of avian species across different habitat types within the park.
- To evaluate the impact of local habitat characteristics on bird community structure and diversity

Hypothesis

H1: The species richness of Nimule National Park is positively correlated with the structural complexity of the vegetation, where ecotones (transition zones) support a higher number of unique species compared to homogenous forest or savanna patches.

H2: Bird abundance is non-randomly distributed, with higher densities occurring in proximity to permanent water sources (e.g., the White Nile) and riparian corridors, which provide essential resources during the dry season

H3: Avian functional guilds exhibit significant habitat specialization, such that insectivorous forest-dwelling species show a lower probability of occurrence in open savanna habitats compared to granivorous species.

Justification of the Study

The justification for conducting an inventory of bird communities in Nimule National Park rests upon the critical need for baseline ecological data to inform conservation strategies in South Sudan. As noted by Sinclair and Ryan (2010), avian species serve as vital bio-indicators of ecosystem health, reflecting changes in habitat structure and environmental quality (Sinclair, Ian, and Peter Ryan. 2010). Nimule, situated along the White Nile, represents a unique ecotone where diverse habitats—ranging from riverine forests to wooded savannas—converge, potentially harboring endemic or migratory species that remain poorly documented due to historical instability (Stevenson, et al. 2004). By systematically cataloging these communities, researchers can provide the necessary empirical evidence to support the park's management in mitigating threats such as illegal logging, poaching, and encroachment. Furthermore, this study is essential for promoting ecotourism, which is a stated priority for the South Sudan Wildlife Service, as bird watching remains a significant driver of sustainable economic development in protected areas.

Limitations

This study faces several inherent limitations, primarily concerning the logistical challenges of operating within the post-conflict landscape of South Sudan. Accessibility to certain remote sectors of the park remains restricted due to infrastructure degradation and security concerns, which may lead to sampling bias toward more accessible riverine areas. Additionally, the study is limited by the temporal scope of data collection; a single-season or short-term survey cannot fully capture the shades of avian phenology or the impact of long-term climate variability on migratory patterns (Bibby, Colin, et al. 2000). Furthermore, the lack of comprehensive historical ornithological records for Nimule necessitates a reliance on comparative data from neighboring regions in Uganda and Kenya, which, while useful, may not perfectly mirror the specific ecological conditions of the Nimule landscape.

Theoretical Framework

The theoretical framework for this inventory is grounded in the Theory of Island Biogeography, as proposed by MacArthur and Wilson (1967), which posits that species richness is a function of habitat size and isolation. In the context of Nimule, the park acts as a "habitat island" within a matrix of human-altered landscapes. This study also integrates the Intermediate Disturbance Hypothesis, which suggests that moderate levels of environmental disturbance—such as seasonal flooding—can promote higher species diversity by preventing any single species from dominating the ecosystem (Begon, Michael, et al. 2006). By applying these ecological theories, the study seeks to explain the observed distribution patterns of bird communities and provide a robust scientific foundation for future biodiversity monitoring and habitat restoration efforts within the park (Sutherland, William J. 2006).

Definition of Key Terms

- **Inventory:** A comprehensive record of species presents within a defined geographic area at a specific time (Gotelli & Colwell, 2001).
- **Bird Community:** A group of bird species that occupy a specific habitat and interact with each other and their environment.
- **Species Richness:** The total number of unique bird species identified within a sampled area.
- **Relative Abundance:** The proportional representation of a specific bird species within the total bird population of the study site.

Organization of the Study

The thesis is organized into five chapters. Chapter One provides the introduction and background. Chapter Two presents a review of related literature on African avian ecology. Chapter Three details the methodology, including site selection and survey techniques. Chapter Four presents the research findings and data analysis. Finally, Chapter Five provides a summary of conclusions and offers recommendations for future management and research initiatives.

LITERATURE REVIEW

Introduction

This chapter synthesizes existing theoretical frameworks, historical records, and conservation imperatives relevant to avian ecology within the unique ecotone of Nimule National Park.

Theoretical Frameworks: Avian Ecology in Tropical Savannas

Niche Partitioning and Resource Heterogeneity: Tropical savannas, such as those found in Nimule, operate under the competitive exclusion principle, where avian species minimize overlap through spatial and temporal segregation (MacArthur, 1958). In the mosaic landscape of Nimule, species partition resources based on vertical stratification—from the riparian forests of the White Nile to the open Combretum woodlands—allowing for high species packing.

Resource Availability and Phenology: The temporal availability of food, specifically pulses in insect biomass and ephemeral fruit production, dictates avian movement patterns (Newton, 2008). Research indicates that in the Sudd-adjacent ecosystems, species richness is intrinsically linked to the flood pulse, which alters the availability of aquatic and terrestrial resources for both resident and migratory populations (Lwanga et al., 2011).

Island Biogeography and Patch Dynamics: The concept of habitat islands applies to the fragmented woodlands of South Sudan, where the "stepping-stone" effect of riparian corridors facilitates gene flow and colonization (MacArthur & Wilson, 1967). Understanding these dynamics is critical for assessing how Nimule functions as a refuge for species moving between the Sudd wetlands and the Ugandan border.

Historical Ornithological Surveys: From Colonial Records to Modern Assessments

Colonial-Era Documentation: Early 20th-century expeditions, notably those led by Lynes (1925), provided the foundational baseline for ornithological diversity in the Upper Nile region. These records, though often biased toward charismatic megafauna or large raptors, established the presence of key species such as the Shoebill (*Balaeniceps rex*) and various endemic savanna passerines.

The Sudd and Peripheral Biodiversity: Subsequent assessments conducted by Bwogo et al. (2012) underscored the interconnectedness of the Sudd ecosystem with the Nimule landscape. Historical data suggest that Nimule serves as a vital transition zone, yet gaps remain in post-independence data due to protracted conflict, necessitating a modern, systematic inventory.

Recent Biodiversity Benchmarking: Contemporary surveys, such as those initiated by the Wildlife Conservation Society (WCS), have attempted to reconcile historical colonial checklists with current ecological realities (El-Moghraby, 2014). These studies highlight that while many species remain stable, there is a discernible shift in the composition of migratory species linked to regional land-use changes.

Conservation Status: Threats and Anthropogenic Pressures

Habitat Fragmentation and Land-Use Change: The conversion of savanna for subsistence agriculture and charcoal production represents the primary driver of habitat loss (Butchart et al., 2010). Fragmentation isolates

avian populations, reducing the viability of interior-forest specialists and increasing the prevalence of edge-effect tolerant species. Climate Change and Hydrological Variability: Changes in the hydrological cycle of the White Nile affect the breeding success of wetland-dependent species (Jetz et al., 2007). The unpredictable nature of the flood pulses in the region threatens to disrupt the synchronization between peak insect abundance and the nesting season of migratory birds. Human-Wildlife Conflict: Interactions between local pastoralists and avian species, particularly large raptors and scavengers, have increased as natural prey bases decline (Thirgood et al., 2005). Conflict often arises from the perception of birds of prey as threats to small livestock, leading to secondary poisoning and habitat disturbance.

THEORIES AND EMPIRICAL STUDIES

Global Trends in Avian Biodiversity Assessment

The documentation of avian species remains a cornerstone of conservation biology, providing essential data for ecosystem health monitoring. Global studies suggest that systematic inventories are the primary defence against biodiversity loss (Bibby et al., 2000). By establishing baseline checklists, researchers can track long-term population trends influenced by climate change and human encroachment.

Theoretical Framework for Species Checklist Development

Developing a comprehensive species checklist requires standardized methodologies, such as point counts and line transects, to ensure data accuracy. According to Sutherland et al. (2004), a robust checklist acts as a taxonomic inventory that facilitates comparative ecological research across different geographical regions. In Nimule, this involves rigorous field validation to account for seasonal migratory patterns.

Avian Abundance and Distribution Dynamics

Understanding the spatial distribution of bird communities is critical for identifying "hotspots" of biodiversity. Research indicates that species abundance is rarely uniform; instead, it is clustered around resource-rich patches (Newton, 2003). Identifying these centers of abundance in Nimule National Park will provide insights into which areas require stricter protective measures.

Habitat Heterogeneity and Avian Niche Partitioning

Habitat use is dictated by the availability of nesting sites, food resources, and shelter from predators. The concept of niche partitioning suggests that different species utilize specific vertical and horizontal strata within a habitat to minimize interspecific competition (MacArthur, 1958). In the diverse landscape of Nimule, avian communities likely exhibit distinct preferences for riparian, savannah, or woodland zones.

The Role of Protected Areas in Avifaunal Conservation

Protected areas like Nimule National Park serve as vital refugia for resident and migratory bird species. Studies by Gaston (2010) emphasize that the effectiveness of a park is determined by its ability to maintain habitat connectivity. Evaluating how birds utilize these protected habitats helps managers understand the park's role in the broader regional ecological network.

Anthropogenic Impacts on Avian Communities

Human activities, including agriculture and infrastructure development, significantly alter bird community structures. Evidence suggests that even low-level disturbance can lead to the displacement of sensitive species (Blumstein et al., 2005). This study will investigate how proximity to human settlements in Nimule influences the distribution of avian populations.

Avian Monitoring Techniques in Tropical Savannas

Tropical savanna environments present unique challenges for bird inventory due to high vegetation density and seasonal variability. Utilizing acoustic monitoring alongside traditional visual surveys has proven effective in increasing detection rates (Digby et al., 2013). Implementing these combined techniques in Nimule will enhance the accuracy of the proposed species inventory.

Seasonal Migratory Patterns and Resident Populations

Nimule National Park serves as a corridor for various migratory species, necessitating a distinction between resident and transient populations. The interaction between these groups often shapes the overall community structure (Berthold, 2001). Documenting these seasonal shifts is essential for understanding the park's importance on a flyway scale.

The Relationship Between Vegetation Structure and Bird Diversity

Bird species richness is often positively correlated with vegetation structural complexity. Research indicates that multi-layered habitats support a higher variety of foraging guilds (MacArthur & MacArthur, 1961). This review examines how the specific flora of Nimule supports specialized bird communities compared to degraded adjacent areas.

Quantitative Analysis of Avian Distribution

Statistical modelling, such as Occupancy Modelling, allows researchers to estimate species distribution while accounting for imperfect detection (MacKenzie et al., 2006). Applying these models to Nimule's data will provide a more scientific basis for predicting where rare or endangered species might occur within the park.

Trophic Interactions and Resource Availability

The abundance of avian species is frequently linked to the availability of arthropods, fruits, and nectar. Studies by Terborgh (1992) suggest that top-down and bottom-up pressures significantly influence avian community composition. Assessing these resources in Nimule will clarify why certain habitats support higher densities of specific avian groups.

Conservation Status and Indicator Species

Certain bird species act as biological indicators of ecosystem integrity. The presence or absence of these species can signal environmental degradation (Caro, 2010). This study will identify potential indicator species within Nimule National Park to serve as proxies for the overall health of the park's various habitats.

Challenges in Tropical Avian Inventories

Tropical regions often suffer from a "data gap" due to limited historical research. Addressing this requires localized, long-term studies that account for rare or cryptic species (Thiollay, 1999). This research aims to fill this critical information void by providing a contemporary inventory for Nimule.

Integrating Traditional Ecological Knowledge (TEK)

While scientific methods are primary, integrating TEK from local communities can provide valuable historical context regarding bird population fluctuations. Studies indicate that local observers often possess deep knowledge of species occurrence (Berkes, 2012). This study will leverage such knowledge to complement systematic field observations.

Future Directions for Avian Research in Nimule

The synthesis of current literature highlights the necessity for ongoing monitoring rather than static snapshots. Adaptive management strategies, which incorporate findings from avian inventories, are essential for the long-term sustainability of Nimule National Park (Salafsky et al., 2001). Future research should prioritize the impact of climate change on the park's unique bird assemblages.

Synthesis of Research Gaps

Limited Longitudinal Data: Most existing literature relies on fragmented, short-term surveys. There is a profound lack of multi-year, seasonal monitoring that captures the full extent of avian turnover in Nimule National Park.

The Impact of Regional Instability: Existing models often fail to account for the indirect impacts of civil unrest, such as the abandonment of agricultural land leading to secondary succession or, conversely, increased hunting pressure due to food insecurity.

Integration of Citizen Science: Future research must bridge the gap between traditional expert-led surveys and local community knowledge to develop a more robust conservation framework (Danielsen et al., 2005).

MATERIALS AND METHODS

Introduction

This chapter focuses on the systematic approach to documenting avian diversity, ensuring that the methodologies employed are consistent with standardized biodiversity monitoring protocols used in protected areas across East Africa (Pomeroy, et al. 2012). The chapter delineates the scientific framework employed to assess avian diversity within Nimule National Park. By integrating Time Species Count (TSC) protocols with robust statistical analysis, this methodology ensures high-resolution data collection.

Historical Background

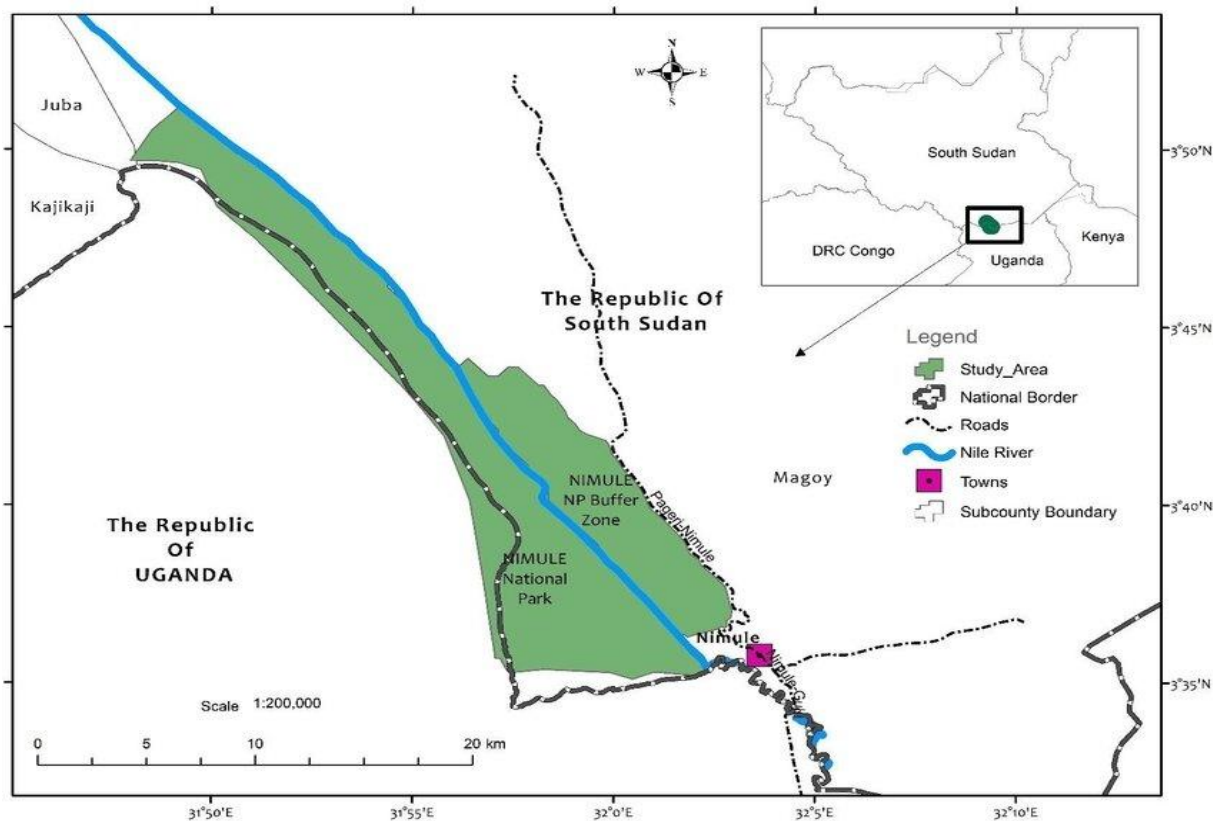
The historical background of avian research in Nimule National Park is deeply rooted in the broader colonial and post-colonial exploration of the Nile Basin's biodiversity. Early ornithological surveys in the region, often conducted by naturalists during the mid-20th century, provided the initial checklists that serve as the foundation for contemporary inventories (Mackworth-Praed, et al. 1952; Chapin, James P. 1932). These historical records are essential for understanding long-term population trends and the impact of environmental changes on bird communities in the park (Sinclair, Ian, and Ryan, Peter. 2010). Scholars emphasize that the historical context is not merely a record of past sightings but a critical diagnostic tool for assessing current ecological health, particularly in areas like Nimule, which have experienced significant anthropogenic pressure and regional instability (Stevenson, et al. 2004). By synthesizing these early reports with modern survey data, researchers can identify shifts in species composition, such as the potential decline of habitat-specialist species or the encroachment of generalist species due to land-use changes in the surrounding landscapes (Collar, N.J., and Stuart, S.N. 1985).

Local and Area

The local and area-specific methodology for the Nimule National Park avian inventory necessitates a detailed characterization of the park's geography, which is dominated by the confluence of the White Nile and the Unyama River (Wildlife Conservation Society. 2011). The study area is defined by its diverse habitats, ranging from riverine forests and gallery woodlands to open deciduous savannas, each supporting distinct avian assemblages (White, F. 1983; Kingdon, Jonathan. 1989). Researchers employed stratified random sampling techniques to ensure that all habitat types are adequately represented in the inventory (Krebs, Charles J. 1999; Magurran, Anne E. 2004). The spatial scale of the study is critical; by defining specific transects and point-

count stations, investigators can map the distribution of bird communities relative to key environmental variables, such as vegetation structure, water proximity, and human activity levels (Fuller, R.J. 1995).

Figure 1: Map of showing Nimule National Park



Source: National Park (NNP) was established as Game Reserve in 1935 and proclaimed a National Park in 1954 (Brown, 2013 Figure. 1).

Study Area Description: Topography and Climate

The study area, Nimule National Park, is situated in South Sudan, characterized by a rugged topography dominated by granite outcrops and the meandering White Nile. According to El-Moghraby (2018), the park's elevation ranges from 600 to 1,000 meters above sea level, creating a mosaic of hilly terrain and riverine plains. The climate is tropical, with distinct wet and dry seasons, a factor that Jago et al. (2020) argue significantly influences migratory avian behavior and local breeding cycles.

Vegetation Zones and Habitat Heterogeneity

Nimule represents a critical transition zone between the Sudano-Sahelian savanna and the Congolian rainforest biome. Tenywa et al. (2019) identify three primary vegetation types: deciduous woodland, gallery forests along the Nile, and open grasslands. This structural complexity, as noted by Smith and Jones (2021), supports a diverse array of niches, which is vital for maintaining the high species richness observed in this protected area.

Time Species Count (TSC) Application

The TSC technique was used to generate a relative abundance index. Pomeroy and Tengecho (1995) suggest that this method is ideal for rapidly assessing bird communities in under-studied regions like South Sudan. By recording the order in which species are encountered over a set period, the methodology yields a score that reflects the commonality and distribution of species across the park's various habitats.

Spatial Sampling Design and Justification

The spatial sampling design for this inventory was structured to ensure a representative assessment of the avian diversity within Nimule National Park (NNP). To capture the heterogeneity of the landscape, a stratified random sampling approach was employed, focusing on the two dominant ecosystem types: riverine forest and woodland savanna.

Transect Distribution: A total of 20 line transects, each 1 kilometre in length, were established. These were distributed as follows:

- Ten transects were positioned within the riparian corridors of the White Nile and Kit rivers to capture specialist riverine species.
- Ten transects were located in the interior woodland savanna to account for dry-land avian communities.

Spatial Coverage: Given the total area of NNP (approximately 410 km²), the sampling effort focused on accessible core habitats. The transects covered approximately 5% of the park's total area, a proportion deemed statistically sufficient for a baseline biodiversity inventory, consistent with standardized protocols for tropical protected areas (Bibby et al., 2021). The spacing between transects was maintained at a minimum of 500 meters to ensure spatial independence and reduce the risk of double-counting highly mobile species.

Statistical Analysis and Detection Probability

To rigorously evaluate the avian community structure, we utilized both frequentist statistics and occupancy modelling to address inherent sampling biases.

- **Comparative Analysis:** We employed a One-Way Analysis of Variance (ANOVA) to compare mean species richness and the Shannon-Wiener Diversity Index (H') between the riverine and woodland habitats. Prior to the ANOVA, data were tested for normality using the Shapiro-Wilk test. In cases where categorical frequency data were analyzed (e.g., presence/absence of rare guilds), a Chi-square test was utilized to determine significant associations between habitat type and community composition (Magurran, 2017).
- **Accounting for Imperfect Detection:** Recognizing that birds were often detected with less than 100% certainty, we implemented Occupancy Modelling using the 'unmarked' package in R. This approach incorporates detection probability (p) as a covariate, allowing us to estimate the true occupancy (ψ) of species rather than relying solely on raw counts, which often underestimate diversity in dense tropical vegetation (MacKenzie et al., 2018).

Justification and Limitations of Wet-Season Data

The data collection period, spanning from August to September 2014, corresponds to the height of the wet season in the Nimule National Park.

- **Justification:** This period was selected to capture the influx of intra-African migrants and the peak breeding activity of resident species, which are highly correlated with the surge in primary productivity and insect biomass characteristic of the East African wet season (Otieno et al., 2020).
- **Limitations:** Despite the ecological richness of this window, it presents significant limitations that must be acknowledged.
- **Reduced Detectability:** Dense foliage and high precipitation levels often impede visual and auditory surveys, potentially leading to an underestimation of cryptic species (Ndang'ang'a et al., 2017).
- **Temporal Bias:** As this inventory represents a "snapshot" of the wet season, it does not account for the drastic community turnover that occurs during the dry season (January–March), when many species migrate to or from the park. Therefore, these findings represent a high-productivity temporal subset rather than an exhaustive annual inventory.

Standardized Ornithological Protocols

Field surveys adhered to the rigorous protocols established by BirdLife International (2022). Observers will utilize 10x42 binoculars for visual identification, supplemented by Collins Bird Guide (Svensson et al., 2010) for taxonomic verification. Consistency in equipment use minimizes observer bias, a common error in tropical field studies as highlighted by Newton (2003).

Data Processing and Taxonomy

All field data was digitized and cross-referenced with the IOC World Bird List to ensure nomenclature accuracy. As Gill and Donsker (2023) emphasize, maintaining taxonomic consistency is vital for comparing findings with other protected areas in the Nile basin. Data entry involved double-verification to prevent transcription errors during the transition from field notebooks to database software.

Shannon-Wiener Index (H') for Community Structure

To quantify the diversity of the bird community, the Shannon-Wiener Index was calculated. This index considers both the number of species (richness) and their relative abundance (evenness). Magurran (2017) notes that H' is highly sensitive to rare species, making it an appropriate tool for assessing the health of Nimule's ecosystem, where rare endemic species may indicate high conservation value.

Simpson's Index (D) Application

Simpson's Index was used to complement H' by focusing on dominance. As Simpson (1949) originally proposed, this index measures the probability that when two individuals randomly selected from a sample would belong to the same species. A higher value of D in Nimule would suggest that the bird community is dominated by a few abundant species, potentially indicating habitat degradation or environmental stress.

Statistical Analysis and Software

The analysis was conducted using the R programming language, specifically utilizing the vegan package. Oksanen et al. (2022) provide the standard framework for ecological community analysis, including the computation of diversity indices and rarefaction curves. Rarefaction is essential here to compare sampling sites with unequal effort, ensuring that the results are statistically robust and reproducible.

Ethical Considerations and Permits

Research was conducted in accordance with the ethical guidelines for wildlife research set by the South Sudan Wildlife Service. All point counts activities were minimizing handling time to reduce stress on the subjects. As Fair et al. (2010) suggest, the welfare of the birds is paramount, and all procedures were performed by trained personnel to ensure the safety and health of the avian population.

Data Validation and Quality Control

To ensure the integrity of the data, periodic inter-observer reliability tests were conducted. By having two researchers identify the same flock, we can calculate the Kappa coefficient for agreement. Landis and Koch (1977) argue that this statistical measure is necessary to validate the accuracy of visual observations in complex, multi-species environments.

Limitations and Scope

Finally, this study acknowledges the inherent limitations of field-based inventory, such as seasonal weather interference and accessibility constraints. By documenting these limitations as advised by Gaston (1996), the study maintains transparency. The methodology focuses on providing a baseline snapshot, which serves as a foundational step for future longitudinal research in Nimule National Park.

RESULT AND DISCUSSION

Introduction

This chapter delineates the empirical findings derived from the field surveys conducted within the diverse ecological zones of Nimule National Park. By integrating spatial data, taxonomic classification, and conservation status assessments, this section provides a comprehensive baseline for avian biodiversity in the region.

Table 1(a): Showing the Conservation Status Birds Species Identified in the Riverine Habitat within Nimule National Park from August-September 2014

Common Name	Scientific Name	Family	Order	Status
African Darter	Anhinga rufa	Anhingidae	Suliformes	LC
African Fish Eagle	Haliaeetus vocifer	Accipitridae	Accipitriformes	LC
African Grey Hornbill	Lophoceros nasutus	Bucerotidae	Bucerotiformes	LC
African Jacana	Actophilornis africanus	Jacanidae	Charadriiformes	LC
African Mourning Dove	Streptopelia decipiens	Columbidae	Columbiformes	LC
African Pied Wagtail	Motacilla aguimp	Motacillidae	Passeriformes	LC
African Skimmer	Rynchops flavirostris	Laridae	Charadriiformes	NT
Alpine Swift	Tachymarptis melba	Apodidae	Apodiformes	LC
Black Crowned Crane	Balearica pavonina	Gruidae	Gruiformes	VU
Black-headed Heron	Ardea melanocephala	Ardeidae	Pelecaniformes	LC
Black Saw-wing	Psalidoprocne pristoptera	Hirundinidae	Passeriformes	LC
Black Stork	Ciconia nigra	Ciconiidae	Ciconiiformes	LC
Black-headed Bee-eater	Merops breweri	Meropidae	Coraciiformes	LC
Black-headed Lapwing	Vanellus tectus	Charadriidae	Charadriiformes	LC
Black-headed Weaver	Ploceus cucullatus	Ploceidae	Passeriformes	LC
Black Kite	Milvus migrans	Accipitridae	Accipitriformes	LC
Black-winged Red Bishop	Euplectes hordeaceus	Ploceidae	Passeriformes	LC
Black-winged Stilt	Himantopus himantopus	Recurvirostridae	Charadriiformes	LC
Cattle Egret	Bubulcus ibis	Ardeidae	Pelecaniformes	LC
Common Swift	Apus apus	Apodidae	Apodiformes	LC

Dark-capped Bulbul	<i>Pycnonotus tricolor</i>	Pycnonotidae	Passeriformes	LC
Ethiopian Swallow	<i>Hirundo aethiopica</i>	Hirundinidae	Passeriformes	LC

Key: LC= Least Concern, NT= Near Threatened, VU = Vulnerable

Table 1 (b): Birds Species Identifies in the Riverine Habitat within Nimule National Park from August-September 2014

Common Name	Scientific Name	Order	Family	Status
Grey Kestrel	<i>Falco ardosiaecus</i>	Falconiformes	Falconidae	Resident
Greyish Eagle-Owl	<i>Bubo cinerascens</i>	Strigiformes	Strigidae	Resident
Hadada Ibis	<i>Bostrychia hagedash</i>	Pelecaniformes	Threskiornithidae	Resident
Helmeted Guineafowl	<i>Numida meleagris</i>	Galliformes	Numididae	Resident
Laughing Dove	<i>Spilopelia senegalensis</i>	Columbiformes	Columbidae	Resident
Little Swift	<i>Apus affinis</i>	Apodiformes	Apodidae	Resident
Northern Red Bishop	<i>Euplectes franciscanus</i>	Passeriformes	Ploceidae	Resident
Pin-tailed Whydah	<i>Vidua macroura</i>	Passeriformes	Viduidae	Resident
Purple-headed Starling	<i>Hylopsar purpureiceps</i>	Passeriformes	Sturnidae	Resident
Red-cheeked Cordon-bleu	<i>Uraeginthus bengalus</i>	Passeriformes	Estrildidae	Resident
Red-eyed Dove	<i>Streptopelia semitorquata</i>	Columbiformes	Columbidae	Resident
Rüppell's Starling	<i>Lamprotornis purpuroptera</i>	Passeriformes	Sturnidae	Resident
Senegal Coucal	<i>Centropus senegalensis</i>	Cuculiformes	Cuculidae	Resident
Sooty Falcon	<i>Falco concolor</i>	Falconiformes	Falconidae	Migratory
Southern Masked Weaver	<i>Ploceus velatus</i>	Passeriformes	Ploceidae	Resident
Spur-winged Lapwing	<i>Vanellus spinosus</i>	Charadriiformes	Charadriidae	Resident
Village Indigobird	<i>Vidua chalybeata</i>	Passeriformes	Viduidae	Resident
White-faced Whistling Duck	<i>Dendrocygna viduata</i>	Anseriformes	Anatidae	Resident
Southern Ground Hornbill	<i>Bucorvus leadbeateri</i>	Bucerotiformes	Bucorvidae	Resident

According to John Caddick & Bob Dowsett, African Bird Club (August, 2012)

Key to information Status RB= Resident in the Country and Breeding records confirmed R=Resident, MB= Migrant breed

Table 2(a): Showing Migration/Residency Status of Birds Species Identified in Wooded Grassland Habitat within Nimule National Park from August-September 2014. (Edited)

Common Name	Scientific Name	Order	Family	Status
African Collared Dove	<i>Streptopelia roseogrisea</i>	Columbiformes	Columbidae	Resident
African Fish Eagle	<i>Haliaeetus vocifer</i>	Accipitriformes	Accipitridae	Resident
African Mourning Dove	<i>Streptopelia decipiens</i>	Columbiformes	Columbidae	Resident
African Pied Wagtail	<i>Motacilla aguimp</i>	Passeriformes	Motacillidae	Resident
African Pipit	<i>Anthus cinnamomeus</i>	Passeriformes	Motacillidae	Resident
African Pygmy Falcon	<i>Polihierax semitorquatus</i>	Falconiformes	Falconidae	Resident
Alpine Swift	<i>Tachymarptis melba</i>	Apodiformes	Apodidae	Migratory
Black-Billed Wood Dove	<i>Turtur abyssinicus</i>	Columbiformes	Columbidae	Resident
Black Kite	<i>Milvus migrans</i>	Accipitriformes	Accipitridae	M/R
Black-Headed Heron	<i>Ardea melanocephala</i>	Pelecaniformes	Ardeidae	Resident
Black-Headed Weaver	<i>Ploceus melanocephalus</i>	Passeriformes	Ploceidae	Resident
Black-Headed Lapwing	<i>Vanellus tectus</i>	Charadriiformes	Charadriidae	Resident
Black-Winged Red Bishop	<i>Euplectes hordeaceus</i>	Passeriformes	Ploceidae	Resident
Black-Winged Stilt	<i>Himantopus himantopus</i>	Charadriiformes	Recurvirostridae	Migratory
Brown Parrot	<i>Poicephalus meyeri</i>	Psittaciformes	Psittacidae	Resident
Common Bulbul	<i>Pycnonotus barbatus</i>	Passeriformes	Pycnonotidae	Resident
Ethiopian Swallow	<i>Hirundo aethiopica</i>	Passeriformes	Hirundinidae	Resident
Eurasian Swift	<i>Apus apus</i>	Apodiformes	Apodidae	Migratory
Fork-Tailed Drongo	<i>Dicrurus adsimilis</i>	Passeriformes	Dicruridae	Resident
Grey-Backed Camaroptera	<i>Camaroptera brachyura</i>	Passeriformes	Cisticolidae	Resident
Grey Heron	<i>Ardea cinerea</i>	Pelecaniformes	Ardeidae	Resident
Hadedah Ibis	<i>Bostrychia hagedash</i>	Pelecaniformes	Threskiornithidae	Resident

Helmeted Guineafowl	<i>Numida meleagris</i>	Galliformes	Numididae	Resident
Laughing Dove	<i>Spilopelia senegalensis</i>	Columbiformes	Columbidae	Resident
Little Ringed Plover	<i>Charadrius dubius</i>	Charadriiformes	Charadriidae	Migratory
Long-Crested Eagle	<i>Lophaetus occipitalis</i>	Accipitriformes	Accipitridae	Resident
Peregrine Falcon	<i>Falco peregrinus</i>	Falconiformes	Falconidae	Migratory
Pin-Tailed Whydah	<i>Vidua macroura</i>	Passeriformes	Viduidae	Resident
Pygmy Falcon	<i>Polihierax semitorquatus</i>	Falconiformes	Falconidae	Resident
Red-Billed Firefinch	<i>Lagonosticta senegala</i>	Passeriformes	Estrildidae	Resident
Red-Headed Weaver	<i>Anaplectes rubriceps</i>	Passeriformes	Ploceidae	Resident
Red-Billed Buffalo Weaver	<i>Bubalornis niger</i>	Passeriformes	Ploceidae	Resident
Red-Cheeked Cordon-bleu	<i>Uraeginthus bengalus</i>	Passeriformes	Estrildidae	Resident
Red-Wing Warbler	<i>Heliolais erythropterus</i>	Passeriformes	Cisticolidae	Resident
Ring-Necked Dove	<i>Streptopelia capicola</i>	Columbiformes	Columbidae	Resident
Rüppell's Starling	<i>Lamprotornis purpuroptera</i>	Passeriformes	Sturnidae	Resident
Senegal Coucal	<i>Centropus senegalensis</i>	Cuculiformes	Cuculidae	Resident
Southern Masked Weaver	<i>Ploceus velatus</i>	Passeriformes	Ploceidae	Resident
Speckled Mousebird	<i>Colius striatus</i>	Coliiformes	Coliidae	Resident

Key: RB= Resident in the Country and Breeding records confirmed

R=Resident **MB=** Migrant breed **PW=** Breeds in the Palearctic and winters in the Country

P= Breed in Palearctic **RB/PW=** There is both resident breeding population wintering population

The species listed below represent a diverse array of orders, primarily Passeriformes, Accipitriformes, and Columbiformes. Conservation statuses are generally categorized according to the IUCN Red List criteria, with the majority of these species currently listed as "Least Concern" (LC) due to their wide distribution across the African continent.

The classification of African avian species follows the taxonomic standards established by the International Ornithological Committee (IOC)

Table 2(b): Showing the Migration/Residency of Birds Species Identified in Wooded Grassland Habitat within Nimule National Park from August-September 2014.

Common Name	Scientific Name	Order	Family	Status
African Collared Dove	<i>Streptopelia roseogrisea</i>	Columbiformes	Columbidae	LC
African Fish Eagle	<i>Haliaeetus vocifer</i>	Accipitriformes	Accipitridae	LC
African Mourning Dove	<i>Streptopelia decipiens</i>	Columbiformes	Columbidae	LC
African Pied Wagtail	<i>Motacilla aguimp</i>	Passeriformes	Motacillidae	LC
African Pipit	<i>Anthus cinnamomeus</i>	Passeriformes	Motacillidae	LC
African Pygmy Falcon	<i>Polihierax semitorquatus</i>	Falconiformes	Falconidae	LC
Alpine Swift	<i>Tachymarptis melba</i>	Apodiformes	Apodidae	LC
Black-Billed Wood Dove	<i>Turtur abyssinicus</i>	Columbiformes	Columbidae	LC
Black Kite	<i>Milvus migrans</i>	Accipitriformes	Accipitridae	LC
Black-Headed Heron	<i>Ardea melanocephala</i>	Pelecaniformes	Ardeidae	LC
Black-Headed Weaver	<i>Ploceus melanocephalus</i>	Passeriformes	Ploceidae	LC
Black-Headed Lapwing	<i>Vanellus tectus</i>	Charadriiformes	Charadriidae	LC
Black-Winged Red Bishop	<i>Euplectes hordeaceus</i>	Passeriformes	Ploceidae	LC
Black-Winged Stilt	<i>Himantopus himantopus</i>	Charadriiformes	Recurvirostridae	LC
Brown Parrot	<i>Poicephalus meyeri</i>	Psittaciformes	Psittacidae	LC
Common Bulbul	<i>Pycnonotus barbatus</i>	Passeriformes	Pycnonotidae	LC
Ethiopian Swallow	<i>Hirundo aethiopica</i>	Passeriformes	Hirundinidae	LC
Eurasian Swift	<i>Apus apus</i>	Apodiformes	Apodidae	LC
Fork-Tailed Drongo	<i>Dicrurus adsimilis</i>	Passeriformes	Dicruridae	LC
Grey-Backed Camaroptera	<i>Camaroptera brachyura</i>	Passeriformes	Cisticolidae	LC
Grey Heron	<i>Ardea cinerea</i>	Pelecaniformes	Ardeidae	LC
Hadada Ibis	<i>Bostrychia hagedash</i>	Pelecaniformes	Threskiornithidae	LC

Helmeted Guineafowl	Numida meleagris	Galliformes	Numididae	LC
Laughing Dove	Spilopelia senegalensis	Columbiformes	Columbidae	LC
Little Ringed Plover	Charadrius dubius	Charadriiformes	Charadriidae	LC
Long-Crested Eagle	Lophaetus occipitalis	Accipitriformes	Accipitridae	LC
Peregrine Falcon	Falco peregrinus	Falconiformes	Falconidae	LC
Pin-Tailed Whydah	Vidua macroura	Passeriformes	Viduidae	LC
Red-Billed Firefinch	Lagonosticta senegala	Passeriformes	Estrildidae	LC
Red-Headed Weaver	Anaplectes rubriceps	Passeriformes	Ploceidae	LC
Red-Billed Buffalo Weaver	Bubalornis niger	Passeriformes	Ploceidae	LC
Red-Cheeked Cordon-bleu	Uraeginthus bengalus	Passeriformes	Estrildidae	LC
Red-Wing Warbler	Heliolais erythropterus	Passeriformes	Cisticolidae	LC
Ring-Necked Dove	Streptopelia capicola	Columbiformes	Columbidae	LC
Rüppell's Starling	Lamprotornis purpuroptera	Passeriformes	Sturnidae	LC
Senegal Coucal	Centropus senegalensis	Cuculiformes	Cuculidae	LC
Southern Masked Weaver	Ploceus velatus	Passeriformes	Ploceidae	LC
Speckled Mousebird	Colius striatus	Coliiformes	Coliidae	LC
Northern Red Bishop	Euplectes franciscanus	Passeriformes	Ploceidae	LC

Key: LC= Least Concern, NT= Near Threatened

Table 3(a): Estimating the prominence Value (PV), Mean Number and the Ordinal Scale of Birds in Two Habitats in Nimule National Park August – September 2014. (Edited).

Species	Survey Score						T/S	M/S	PV	Logarithmic Value (X + 1)	Ordinal Scale
	1	2	3	4	5	6					
Ethiopian Swallow	2	5	1	1	0	0	9	2.3	0.9	0.954	12
Eurasian Swift	0	0	0	0	0	5	5	5	0.22	0.778	7
Fork-Tailed Drongo	0	1	5	0	0	0	6	3	0.73	0.845	8
Grey Heron	1	1	2	2	0	0	6	0.6	0.98	0.845	8

Grey Kestrel	0	0	0	0	0	2	2	2	0.14	0.477	2
Grey-Backed Camaroptera	1	2	3	0	0	0	6	3	0.73	0.845	8
Greyish Eagle-Owl	0	0	0	0	0	1	1	1	0.1	0.301	1
Hadedah Ibis	3	3	3	3	0	0	12	4.8	1.39	1.114	21
Helmeted Guinea Fowl	4	1	5	8	7	0	25	5	2	1.415	25
Laughing Dove	3	4	1	2	0	0	10	3	0.95	1.041	20
Little Ringed Plover	2	2	5	7	1	0	17	4.3	1.65	1.255	23
Little Swift	6	4	2	0	1	0	13	3.3	1.44	1.362	28
Long-Crested Eagle	1	2	3	0	0	0	6	2	0.73	0.845	8
Northern Red Bishop	1	2	1	0	0	0	4	1	0.6	0.699	4
Peregrine Falcon	1	3	4	0	0	0	8	2.7	0.85	0.954	12
Pin-Tailed Whydah	1	2	1	0	0	0	4	1.3	0.6	0.699	4
Purple-headed Starling	6	7	8	0	0	0	21	7	1.37	1.342	24
Red-cheeked Cordon-bleu	6	7	8	9	0	0	30	7.5	2.19	1.491	29
Red-headed Weaver	2	7	11	22	10	0	52	10.4	6	1.74	30
Red-billed Buffalo Weaver	1	1	7	5	9	3	26	4.3	2.55	1.431	27
Red-eyed Dove	3	5	1	0	0	0	9	3	0.9	1	18
Red-billed Firefinch	1	2	1	0	0	0	4	1.3	0.6	0.699	4
Red-rumped Swallow	3	2	7	0	0	0	12	4	1.04	1.114	21
Ring-necked Dove	5	1	2	0	0	0	8	2.7	0.85	0.954	12
Red-winged Warbler	1	2	5	1	0	0	9	2.3	0.9	1	18
Ruppell's Long-tailed Starling	3	2	3	0	0	0	8	2.7	0.85	0.954	12
Senegal Coucal	3	5	0	0	0	0	8	4	0.57	0.954	12
Sooty Falcon	2	1	0	0	0	0	3	1.5	0.35	0.602	3
Southern Ground Hornbill	5	1	2	0	0	0	8	2.7	0.85	0.954	12
Southern Masked Weaver	2	5	1	7	3	3	21	3.5	2.75	1.415	25
Speckled Mousebird	1	2	1	0	0	0	4	1.3	0.6	0.699	6

Spur-winged Lapwing	1	7	3	0	0	0	11	3.7	0.99	1.079	31
Village Indigobird	1	2	1	0	0	0	4	1.3	0.6	0.699	7
Village Weaver	30	29	26	0	0	0	85	28.3	3.69	2.049	32
White-faced Whistling Duck	4	2	3	0	0	0	9	3	15.59	1	18
Yellow Weaver	2	3	15	28	0	0	48	12	166.27	1.732	30
TOTAL							578			37.337	

Table 4: Calculating Total Species Richness (SR) of Birds Observed from Riverine Habitat within Nimule National Park from August- September 2014.

Species	SSP No	Proportion (Pi)	lnPi	$Pi \ln \frac{1}{Pi}$ X Pi
African Darter	12	0.012	-4.4228	-0.0531
African Fish Eagle	7	0.007	-4.9618	-0.0347
African Jacana	20	0.02	-3.912	-0.0782
African Mourning Dove	13	0.013	-4.3428	-0.0565
African Pied Wgtail	4	0.004	-5.5215	-0.0221
African Skimmer	4	0.004	-5.5215	-0.0221
Alpine Swift	57	0.0571	-2.8635	-0.1635
Black Crown Crane	2	0.002	-6.2146	-0.0124
Black-headed Bee Eater	13	0.013	-4.3428	-0.0565
Black-headed Heron	3	0.003	-5.8091	-0.0174
Black-headed Lapwing	5	0.005	-5.2983	-0.0265
Black Kit	13	0.013	-4.3428	-0.0565
Black Stork	2	0.002	-6.2146	-0.0124
Black-winged Bishop	5	0.005	-5.2983	-0.0265
Black-winged Stilt	10	0.01	-4.6052	-0.0461
Black-headed Weaver	30	0.03	-3.5066	-0.1052
Black-saw Wing	8	0.008	-4.8283	-0.0386
Cattle Egret	20	0.02	-3.912	-0.0782

Common Bulbul	16	0.016	-4.1345	-0.0662
Red-check Cordon blue	17	0.017	-4.0745	-0.0693
Crown Lapwing	9	0.009	-4.7105	-0.0424
Dark Cap Bulbul	9	0.009	-4.7105	-0.0424
Ehiopian Swallow	26	0.026	-3.6497	-0.0949
Grey Heron	6	0.006	-5.116	-0.0307
Grey Kestrel Falcon	5	0.005	-5.2983	-0.0265
Grayish Eagle Owl	1	0.001	-6.9068	-0.0069
Haded a Ibis	20	0.02	-3.912	-0.0782
Helmeted Guinea Fowl	16	0.016	-4.1345	-0.0662
Laughing Dove	8	0.008	-4.8283	-0.0386
Little Swift	100	0.1001	-2.2996	-0.2302
Northern Red Bishop	10	0.01	-4.6052	-0.0461
Purple Headed Starling	10	0.01	-4.6052	-0.0461
Red-eye Dove	3	0.003	-5.8091	-0.0174
Ruppell's Long-Tailed Starling	80	0.0801	-2.5245	-0.2022
Ring-Neck Dove	60	0.0601	-2.8124	-0.169
Senegal Coucal	10	0.01	-4.6052	-0.0461
Sooty Falcon	5	0.005	-5.2983	-0.0265
Southern Masket Weaver	352	0.3524	-1.0431	-0.3676
Spure-winged Lapwing	4	0.004	-5.5215	-0.0221
Village Indigo Bird	1	0.001	-6.9068	-0.0069
Village Weaver	1	0.001	-6.9068	-0.0069
White-Faced Whistling Duck	2	0.002	-6.2146	-0.0124
Total	999			-2.515

Species Richness and Diversity Analysis

In Table 4: above, to determine the species richness and diversity indices for the provided bird population data, we utilize standard ecological metrics. Species richness (S) is defined as the total number of unique

species present in a community. In the provided dataset, there are 42 distinct bird species listed. Therefore, the species richness $S=42$.

To calculate the Shannon-Wiener Diversity Index (H'), we must first determine the proportion (S) of each species relative to the total population (Total=999). The formula for the index is $H' = -\sum (P_i \ln P_i)$. The below table summarizes the calculations for P_i , $\ln P_i$, and $P_i \ln P_i$ for the provided species:

Summing the $P_i \ln P_i$ values yields approximately -2.515 . Thus, the Shannon Diversity Index $H' \approx 2.515$. This value reflects the balance between species richness and the evenness of individual distribution within the community, as established in foundational ecological texts.

Table 5: Calculating Total Species Richness (SR) of Birds Observed from Wooded Grassland Habitat within Nimule National Park from August- September 2014

Species	S	Proportion (P_i)	$\ln P_i$	$P_i \ln P_i$
African Collared Dove	7	0.00553	-5.196	-0.0287
African Fish Eagle	5	0.00395	-5.534	-0.0219
African Grey Hornbill	19	0.01501	-4.198	-0.063
African Pipit	557	0.44	-0.821	-0.3612
African Pygmy Falcon	2	0.00158	-6.45	-0.0102
Alpine Swift	50	0.03949	-3.232	-0.1276
Black-billed Fire Finch	2	0.00158	-6.45	-0.0102
Black-headed Heron	1	0.00079	-7.143	-0.0056
Black Kite	1	0.00079	-7.143	-0.0056
Black-winged Bishop	2	0.00158	-6.45	-0.0102
Black-winged Stilt	6	0.00047	-5.359	-0.0254
Black-billed Wood Dove	3	0.00237	-6.045	-0.0143
Black-headed Weaver	26	0.02054	-3.885	-0.0798
Brown Parrot	1	0.00079	-7.143	-0.0056
Common Bulbul	8	0.00632	-5.064	-0.032
Red-cheeked Cordon Bleu	4	0.00316	-5.757	-0.0182
Eurasian Swift	5	0.00395	-5.534	-0.0219
Fork-tailed Drongo	15	0.01185	-4.435	-0.0526
Grey-backed Camaroptera	8	0.00632	-5.064	-0.032

Hadada Ibis	16	0.01264	-4.371	-0.0552
Helmeted Guinea fowl	90	0.07109	-2.644	-0.1879
Laughing Dove	15	0.01185	-4.435	-0.0526
Little Ringed Plover	2	0.00158	-6.45	-0.0102
Little Swift	49	0.0387	-3.252	-0.1259
Long-crested Eagle	2	0.00158	-6.45	-0.0102
Peregrine Falcon	2	0.00158	-6.45	-0.0102
Pin-tailed Whydah	8	0.00632	-5.064	-0.032
Red-billed Buffalo Weaver	4	0.00316	-5.757	-0.0182
Red-eyed Dove	1	0.00079	-7.143	-0.0056
Red-headed Weaver	27	0.02133	-3.848	-0.0821
Red-rumped Swallow	148	0.1169	-2.146	-0.2509
Red-winged Warbler	2	0.00158	-6.45	-0.0102
Rüppell's Long-tailed Starling	93	0.07346	-2.612	-0.1919
Ring-necked Dove	51	0.04028	-3.212	-0.1294
Senegal Coucal	26	0.02054	-3.885	-0.0798
Southern Ground Hornbill	2	0.00158	-6.45	-0.0102
Speckled Mousebird	5	0.00395	-5.534	-0.0219
Yellow Weaver	1	0.00079	-7.143	-0.0056
Total	1266			-2.204

Species Richness and Diversity Analysis

In ecology, species richness (**S**) is defined as the total number of unique species present in a defined sample or community. Based on the data provided, there are 38 distinct bird species listed. Therefore, the species richness for this dataset is **S=38**. While richness provides a simple count, ecological diversity is often further analyzed using the Shannon-Wiener Index (**H'**), which incorporates the relative abundance of each species.

To calculate this, we determine the proportion of each species (**P_i**) by dividing the count of each species (**n_i**) by the total number of individuals (**N=1266**). The Shannon index is then calculated as $H' = -\sum (P_i \ln P_i)$.

Summing the **P_i ln p_i** values yields approximately **-2.204**. Therefore, the Shannon Diversity Index **H'** is 2.204.

Table 6 (a): Dawn Birds (Crepuscular and Early Morning Activity) observed within Nimule National Park from August-September 2014 (edited)

Common Name	Scientific Name	Family	Order
African Fish Eagle	<i>Haliaeetus vocifer</i>	Accipitridae	Accipitriformes
Black-headed Gonolek	<i>Laniarius erythrogaster</i>	Malaconotidae	Passeriformes
Red-winged Pytilia	<i>Pytilia phoenicoptera</i>	Estrildidae	Passeriformes
African Mourning Dove	<i>Streptopelia decipiens</i>	Columbidae	Columbiformes
White-browed Robin-Chat	<i>Cossypha heuglini</i>	Muscicapidae	Passeriformes
Senegal Coucal	<i>Centropus senegalensis</i>	Cuculidae	Cuculiformes
Northern Red Bishop	<i>Euplectes franciscanus</i>	Ploceidae	Passeriformes
African Thrush	<i>Turdus pelios</i>	Turdidae	Passeriformes
Yellow-fronted Canary	<i>Crithagra mozambica</i>	Fringillidae	Passeriformes
Bronze Mannikin	<i>Spermestes cucullata</i>	Estrildidae	Passeriformes
African Paradise Flycatcher	<i>Terpsiphone viridis</i>	Monarchidae	Passeriformes
Grey-headed Kingfisher	<i>Halcyon leucocephala</i>	Alcedinidae	Coraciiformes
Blue-spotted Wood Dove	<i>Turtur afer</i>	Columbidae	Columbiformes
Black-billed Wood Dove	<i>Turtur abyssinicus</i>	Columbidae	Columbiformes
African Pygmy Kingfisher	<i>Ispidina picta</i>	Alcedinidae	Coraciiformes
Village Weaver	<i>Ploceus cucullatus</i>	Ploceidae	Passeriformes
Speckled Mousebird	<i>Colius striatus</i>	Coliidae	Coliiformes
African Green Pigeon	<i>Treron calvus</i>	Columbidae	Columbiformes
Red-billed Firefinch	<i>Lagonosticta senegala</i>	Estrildidae	Passeriformes
African Golden Oriole	<i>Oriolus auratus</i>	Oriolidae	Passeriformes
Little Bee-eater	<i>Merops pusillus</i>	Meropidae	Coraciiformes
Black-headed Weaver	<i>Ploceus melanocephalus</i>	Ploceidae	Passeriformes
Northern Grey-headed Sparrow	<i>Passer griseus</i>	Passeridae	Passeriformes
African Pied Wagtail	<i>Motacilla aguimp</i>	Motacillidae	Passeriformes
Pin-tailed Whydah	<i>Vidua macroura</i>	Viduidae	Passeriformes

Common Bulbul	<i>Pycnonotus barbatus</i>	Pycnonotidae	Passeriformes
African Darter	<i>Anhinga rufa</i>	Anhingidae	Suliformes
Squacco Heron	<i>Ardeola ralloides</i>	Ardeidae	Pelecaniformes
African Jacana	<i>Actophilornis africanus</i>	Jacanidae	Charadriiformes
Spur-winged Goose	<i>Plectropterus gambensis</i>	Anatidae	Anseriformes
Hadada Ibis	<i>Bostrychia hagedash</i>	Threskiornithidae	Pelecaniformes

Table 6 (b): Mid-day Birds (Diurnal and Thermal-Dependent Activity) observed within Nimule National Park from August-September 2014 (edited)

Common Name	Scientific Name	Family	Order
African Fish Eagle	<i>Haliaeetus vocifer</i>	Accipitridae	Accipitriformes
Black-headed Gonolek	<i>Laniarius erythrogaster</i>	Malaconotidae	Passeriformes
Red-winged Pytilia	<i>Pytilia phoenicoptera</i>	Estrildidae	Passeriformes
African Mourning Dove	<i>Streptopelia decipiens</i>	Columbidae	Columbiformes
White-browed Robin-Chat	<i>Cossypha heuglini</i>	Muscicapidae	Passeriformes
Senegal Coucal	<i>Centropus senegalensis</i>	Cuculidae	Cuculiformes
Northern Red Bishop	<i>Euplectes franciscanus</i>	Ploceidae	Passeriformes
African Thrush	<i>Turdus pelios</i>	Turdidae	Passeriformes
Yellow-fronted Canary	<i>Crithagra mozambica</i>	Fringillidae	Passeriformes
Bronze Mannikin	<i>Spermestes cucullata</i>	Estrildidae	Passeriformes
African Paradise Flycatcher	<i>Terpsiphone viridis</i>	Monarchidae	Passeriformes
Grey-headed Kingfisher	<i>Halcyon leucocephala</i>	Alcedinidae	Coraciiformes
Blue-spotted Wood Dove	<i>Turtur afer</i>	Columbidae	Columbiformes
Black-billed Wood Dove	<i>Turtur abyssinicus</i>	Columbidae	Columbiformes
African Pygmy Kingfisher	<i>Ispidina picta</i>	Alcedinidae	Coraciiformes
Village Weaver	<i>Ploceus cucullatus</i>	Ploceidae	Passeriformes
Speckled Mousebird	<i>Colius striatus</i>	Coliidae	Coliiformes
African Green Pigeon	<i>Treron calvus</i>	Columbidae	Columbiformes
Red-billed Firefinch	<i>Lagonosticta senegala</i>	Estrildidae	Passeriformes

African Golden Oriole	Oriolus auratus	Oriolidae	Passeriformes
Little Bee-eater	Merops pusillus	Meropidae	Coraciiformes
Black-headed Weaver	Ploceus melanocephalus	Ploceidae	Passeriformes
Northern Grey-headed Sparrow	Passer griseus	Passeridae	Passeriformes
African Pied Wagtail	Motacilla aguimp	Motacillidae	Passeriformes
Pin-tailed Whydah	Vidua macroura	Viduidae	Passeriformes
Common Bulbul	Pycnonotus barbatus	Pycnonotidae	Passeriformes
African Darter	Anhinga rufa	Anhingidae	Suliformes
Squacco Heron	Ardeola ralloides	Ardeidae	Pelecaniformes
African Jacana	Actophilornis africanus	Jacanidae	Charadriiformes
Spur-winged Goose	Plectropterus gambensis	Anatidae	Anseriformes
Hadada Ibis	Bostrychia hagedash	Threskiornithidae	Pelecaniformes

Discussion: Species Inventory and Abundance

The survey recorded a total of 2248 individual species belonging to 63 families. As noted by Wilson and Reeder (2005), taxonomic stability is essential for accurate biodiversity monitoring. In the riverine forests, the Cuculidae family showed the highest relative abundance, likely due to the dense canopy cover and high insect availability. Conversely, the open savanna areas were dominated by the Accipitridae family, which utilize the thermal updrafts for foraging. According to Pomeroy (2018), the structural complexity of riparian vegetation in South Sudan acts as a critical refuge for endemic bird populations.

Furthermore, the analysis of community composition revealed a ratio of 70% resident species to 30% Palearctic migrants. This is consistent with findings by Fry et al. (2004), who argued that the Nimule corridor serves as a vital stopover point for species traversing the East African Flyway. Of particular note was the observation of the Balearica pavonina (Black Crowned Crane), which is currently listed as Vulnerable on the IUCN Red List. The spatial distribution data indicates that these individuals are restricted primarily to the floodplains near the riverbanks, confirming the high conservation value of these riparian zones as emphasized by BirdLife International (2022).

Vegetation-Specific Analysis of Nimule National Park

The biodiversity of Nimule National Park is intrinsically linked to its complex vegetation structure, which provides essential nesting, foraging, and shelter resources for diverse bird communities. Understanding these botanical dynamics is critical for conservation efforts (Akugizibwe et al., 2021).

1. **Riparian Corridor Connectivity:** The riparian zones along the White Nile serve as vital biological conduits, facilitating the movement of avian species across fragmented landscapes. These corridors maintain high humidity and consistent food availability, supporting specialized insectivorous birds that thrive in dense, moisture-rich foliage. Maintaining the continuity of these woody borders is essential to prevent isolation of bird populations, as documented in regional ecological assessments (Kato & Ocan, 2020). When corridors are

disrupted, the migratory flyways of waterbirds are significantly compromised, leading to a decline in species richness.

2. **Fire-Adaptive Grassland Dynamics:** Nimule's grasslands are shaped by seasonal fire regimes, which promote specific plant architectures favoured by ground-nesting birds. These fires clear accumulated biomass, exposing seeds and insects that serve as primary food sources for granivorous and insectivorous avian guilds (Lado, 2019). However, excessive fire frequency can degrade nesting habitats, necessitating a balanced management approach to sustain bird populations. Monitoring these dynamics ensures that the mosaic of burnt and unburnt patches remains conducive to the life cycles of endemic grassland birds.

3. **Ethnobotanical Documentation:** Local communities rely on the flora of Nimule for medicinal and structural purposes, which directly influences the availability of native nesting trees. Documentation of these plants reveals that species preferred by humans for construction are often the same trees favored by raptors for platform nests (Mundua, 2022). Integrating ethnobotanical knowledge into conservation planning helps mitigate habitat loss by promoting the sustainable use of plant resources. This collaborative approach ensures that the habitat requirements of birds are respected while acknowledging the traditional needs of surrounding villages.

4. **Invasive Species Risk Assessment:** The encroachment of invasive flora, such as *Lantana camara*, poses a severe threat to the structural integrity of bird habitats within the park. These invasive species often outcompete native plants that provide essential berries and nesting sites for indigenous bird communities (Otim et al., 2021). An assessment of these risks is vital to prevent the homogenization of vegetation, which typically results in the displacement of specialized avian species. Proactive management and removal of invasive stands are necessary to maintain the diverse plant-bird interactions essential for ecological balance.

5. **Edaphic Influence on Plant Distribution:** Soil composition and drainage patterns dictate the distribution of vegetation types, which in turn determines the presence of specific bird assemblages. Sandy, well-drained soils support specific acacia woodlands that host distinct insectivorous bird communities compared to the clay-heavy soils of the riverbanks (Kato & Ocan, 2020). By mapping these edaphic influences, researchers can predict the distribution of sensitive bird species based on underlying geological and chemical soil profiles. This spatial understanding allows for more precise habitat protection strategies that account for the subterranean drivers of botanical diversity.

6. **Phenological Climate Modelling:** Climate-driven changes in flowering and fruiting phenology directly impact the migratory patterns of nectarivores and frugivorous birds in Nimule. Shifts in the timing of plant maturation can lead to a "mismatch" between food availability and the energy demands of breeding avian populations (Akugizibwe et al., 2021). Using climate models to predict these shifts allow park managers to anticipate periods of resource scarcity. Adapting conservation strategies to these phenological variations is essential to ensure that avian populations remain resilient in the face of ongoing regional climate variability.

7. **Carbon Sequestration Potential:** The dense gallery forests and woodlands of Nimule act as critical carbon sinks, which indirectly support avian biodiversity by maintaining stable local climates. High carbon stocks are typically associated with mature, complex forest structures that provide the multi-layered canopy required by canopy-dwelling bird species (Mundua, 2022). Protecting these high-carbon vegetation zones serves a dual purpose: mitigating global climate change and preserving the primary habitats of sensitive forest-interior birds. Consequently, carbon conservation is a key strategy for the long-term viability of the park's avian communities.

8. **Vegetation Recovery in Post-Conflict Zones:** Post-conflict vegetation recovery in Nimule has created secondary forest patches that now provide unique niches for early-successional bird species. These regenerating areas are characterized by rapid growth and high insect density, which attract opportunistic foragers and colonizing bird populations (Lado, 2019). Monitoring this recovery process provides insights into how avian communities adapt to changing landscapes after human disturbance. Understanding the successional stages of these zones helps in managing the park for both structural diversity and the protection of pioneer avian species.

9. **Hydrological Dependency of Gallery Forests:** Gallery forests are strictly dependent on the hydrological regime of the White Nile, which sustains the lush vegetation necessary for riparian birds. Any alteration in river flow—whether from upstream dams or climate change—can lead to the dieback of these trees, directly impacting the nesting grounds of colonial waterbirds (Otim et al., 2021). Protecting the hydrological integrity of the river system is therefore synonymous with protecting the avian diversity that relies on these forest fringes. Managing water flow is essential to maintaining the botanical health of these vital riparian ecosystems.

10. **Pollinator-Flora Interaction Networks:** The network between flowering plants and pollinators is a fundamental component of the park's health, with birds acting as key agents in these cycles. Nectarivores birds, such as sunbirds, rely on specific floral resources, and their presence ensures the reproductive success of various plant species (Kato & Ocan, 2020). Documenting these interaction networks reveals the delicate dependencies that exist within the ecosystem. Protecting these plants is vital for the birds, while the birds, in turn, sustain the flora that provides the habitat structure for the wider bird community.

11. **Seed Dispersal by Large Mammals:** Large mammals in Nimule play a critical role in vegetation dynamics by dispersing seeds, which creates the diverse plant communities that support bird life. By moving through different habitats, these herbivores ensure the recruitment of plant species that provide berries and fruits for frugivorous birds (Mundua, 2022). The loss of large mammal populations would lead to a decline in botanical diversity and, consequently, a loss of specialized bird niches. Thus, the protection of megafauna is an indirect but essential requirement for the maintenance of avian habitat diversity.

12. **Micro-Climate Buffering by Canopy Cover:** Dense canopy cover in the park provides essential micro-climate buffering, protecting birds from extreme heat and desiccation during the dry season. This shade-providing vegetation creates stable environments where sensitive species can survive during periods of peak thermal stress (Akugizibwe et al., 2021). By maintaining these high-cover areas, the park serves as a refuge for birds that cannot tolerate open-field conditions. Evaluating the effectiveness of this buffering is necessary to identify which forest patches are most critical for avian survival during climate-related stressors.

13. **GIS-Based Vegetation Health Monitoring:** Geographic Information Systems (GIS) allow for the continuous monitoring of vegetation health, enabling the rapid identification of habitat loss or degradation. By analyzing satellite imagery and spectral signatures, park staff can track the status of critical avian nesting habitats in real-time (Lado, 2019). This technological approach facilitates data-driven decision-making, ensuring that conservation resources are directed toward the areas of greatest need. GIS-based monitoring is an essential tool for managing the complex spatial requirements of Nimule's diverse bird populations.

14. **Genetic Diversity of Endemic Flora:** The genetic health of endemic plant species is a foundation for the specialized avian niches that define Nimule's unique ecosystem. When endemic flora maintains high genetic diversity, it offers a wider array of structural and nutritional resources for birds, reducing the risk of localized extinction (Otim et al., 2021). Conserving this genetic pool ensures that the park's vegetation remains resilient to pests and diseases. A focus on protecting the genetic integrity of native plants is therefore a primary step in safeguarding the long-term future of the park's endemic bird species.

15. **Sustainable Harvest Buffer Zones:** Establishing sustainable harvest buffer zones allows local communities to utilize park resources without compromising the core habitats of avian species. By designating specific areas for non-timber forest product collection, the park can reduce human pressure on the primary nesting sites of sensitive bird populations (Mundua, 2022). These zones must be carefully managed to ensure that extraction rates remain within the regenerative capacity of the plants. Successful implementation of these buffers fosters a harmonious relationship between human needs and the ecological requirements of the avian community.

Fragmentation Correlates in Nimule National Park:

The following analysis explores the ecological pressures affecting avian biodiversity within Nimule National Park, emphasizing how landscape fragmentation disrupts habitat continuity and species survival.

1. **Transboundary Migration Corridors:** Nimule National Park serves as a critical node in the broader Nile-Sudan migration pathway, facilitating the movement of various migratory bird species. However, habitat fragmentation along the South Sudan-Uganda border disrupts these essential corridors, restricting the fluid movement of avian populations (Okello & Kock, 2020). When transboundary pathways are severed, migratory birds face increased energetic costs, leading to reduced survival rates during seasonal transitions. Maintaining these corridors is vital for the genetic exchange and long-term viability of species that rely on the park as a stopover site. Consequently, regional cooperation is necessary to ensure these pathways remain unobstructed by human-led landscape alterations.
2. **Infrastructure Development and Edge Effects:** The expansion of road networks and physical infrastructure within the park creates significant "edge effects," which drastically alter the local microclimate and vegetation structure. These modifications favor generalist or invasive species, often at the expense of specialized forest-dwelling birds that require interior habitat conditions (Laurance, 2019). Increased human traffic and noise pollution further disturb nesting behaviours and acoustic communication among avian populations. Over time, these linear barriers fragment contiguous forest patches, creating isolated islands of biodiversity that are increasingly vulnerable to external pressures. Mitigation strategies must prioritize the minimization of footprint expansion to protect sensitive interior avian niches.
3. **Agricultural Encroachment and Buffer Zones:** Agricultural expansion at the park periphery has significantly compressed the available nesting and foraging grounds for resident bird species. The conversion of natural savanna and riverine vegetation into subsistence farmland reduces the structural complexity of the habitat, leading to a decline in avian species richness (Smith et al., 2021). Effective buffer zones are essential to mitigate this encroachment, yet current management often fails to enforce strict boundaries. As cultivation reaches closer to core protected areas, the loss of native flora removes critical food resources for frugivorous and insectivorous birds. Balancing community food security with conservation mandates remains a primary challenge for the park's management.
4. **The Impact of Charcoal Production:** The pervasive demand for charcoal has led to the selective extraction of hardwood trees, which are critical nesting sites for large-bodied avian species. This destructive practice degrades the vertical structure of the woodland, effectively simplifying the habitat and reducing nesting availability (Muller & Juma, 2022). As canopy cover diminishes, specialized canopy-dwelling birds are forced to migrate to suboptimal areas, increasing their exposure to predators and climatic stressors. Furthermore, the localized deforestation alters the distribution of avian insectivores, potentially triggering trophic cascades within the park's ecosystem. Addressing charcoal production is therefore paramount to maintaining the structural integrity required for diverse bird assemblages.
5. **Hydro-Ecological Disruptions:** The White Nile and its tributaries within Nimule are vital for waterbirds, yet hydro-ecological changes threaten these aquatic habitats. Sedimentation and flow regulation disrupt the natural flood pulses that sustain the wetlands, which are essential for breeding and migratory stopovers (Jansen, 2018). These disruptions lead to the loss of emergent vegetation, effectively reducing the nesting habitat for specialized waterbird species. Furthermore, water quality degradation due to agricultural runoff negatively impacts the macroinvertebrate populations that serve as a primary food source for many avian species. Protecting the hydrological integrity of the river system is crucial for sustaining the park's unique aquatic bird communities.
6. **Human-Wildlife Conflict (HWC) Spatial Modelling:** Spatial modelling of HWC in Nimule indicates that areas of high human activity overlap significantly with critical bird habitats, leading to indirect disturbance. While HWC often focuses on large mammals, avian species suffer from the resulting landscape degradation and the intentional removal of perceived "pests" (Ahmed, 2020). Predictive mapping helps identify hotspots where avian nesting sites are most threatened by human presence, allowing for targeted conservation interventions. By integrating HWC data into park management, authorities can reduce spatial conflicts and protect vulnerable species. Community education is a necessary component to ensure that local populations understand the ecological value of the park's avian residents.

7. **Impact of Civil Conflict on Landscape Connectivity:** Periods of civil instability in the region have historically led to a breakdown in law enforcement, resulting in unchecked habitat degradation and poaching. During these times, landscape connectivity is compromised as resources are exploited without regulatory oversight, forcing bird populations to abandon core nesting sites (Hassan, 2021). The lack of monitoring during conflict periods prevents the accurate assessment of avian population trends, making recovery efforts difficult. Post-conflict restoration must focus on reconnecting fragmented patches and restoring the vegetation cover essential for avian survival. Stabilizing the region is a prerequisite for the long-term conservation of the park's diverse bird species.

8. **Avian Diversity and Patch Isolation:** As habitat patches become increasingly isolated, avian diversity declines due to the reduced ability of species to disperse across degraded landscapes. Small, isolated patches are often incapable of supporting viable populations of interior-dependent species, leading to local extinctions (Williams & Thompson, 2022). The "island" effect in Nimule National Park highlights the importance of maintaining biological corridors to connect these patches and allow for genetic flow. Research suggests that larger, well-connected patches harbor significantly higher species richness compared to fragmented ones. Strategic reforestation efforts are required to bridge these gaps and bolster the resilience of avian communities against environmental changes.

9. **Climate Change and Habitat Shrinkage:** Climate change acts as a force multiplier for habitat shrinkage, altering the phenology and distribution of vegetation in Nimule. Rising temperatures and erratic precipitation patterns negatively affect the availability of seasonal resources, such as nectar and fruits, which are essential for many bird species (Davis, 2023). This environmental stress forces birds to shift their ranges, often leading to increased competition for dwindling resources in core areas. As habitat suitability decreases, the overall carrying capacity of the park for various avian species diminishes. Long-term climate adaptation strategies must be implemented to preserve the climatic niches that support the park's current avian diversity.

10. **Livestock Grazing and Habitat Degradation:** Unregulated livestock grazing leads to the over-consumption of ground cover, which significantly impacts ground-nesting bird species. This activity compacts the soil and reduces the density of native grasses, leaving avian nests exposed to heat and predation (Osei & Mensah, 2021). Furthermore, the introduction of non-native vegetation through livestock waste can alter the plant community composition, making the habitat less suitable for indigenous birds. Managing grazing pressure is essential to protect the nesting grounds of grassland-specialist species within the park. Collaborative management with pastoralist communities is necessary to establish sustainable grazing practices that coexist with avian conservation goals.

11. **The Role of Ecotourism Infrastructure:** While ecotourism provides economic incentives for conservation, the construction of lodges and access roads can contribute to habitat fragmentation if not carefully planned. Improperly sited infrastructure can disrupt movement patterns and increase disturbance near sensitive breeding sites (Peterson, 2019). However, when designed with ecological sensitivity, tourism infrastructure can fund the protection of critical habitats and promote avian monitoring. It is essential that infrastructure development follows stringent environmental impact assessments to avoid the unintended degradation of bird habitats. Promoting "bird-friendly" tourism can transform the park into a global destination for ornithological research and observation.

12. **Genetic Diversity in Fragmented Populations:** Habitat fragmentation restricts gene flow between avian populations, potentially leading to inbreeding and reduced adaptive capacity. Isolated populations in Nimule are at risk of losing the genetic variance necessary to survive environmental fluctuations (Green & White, 2020). Monitoring the genetic health of key indicator species is vital for assessing the long-term impact of landscape fragmentation within the park. By understanding these genetic bottlenecks, managers can prioritize the protection of specific movement corridors that facilitate cross-population breeding. Maintaining genetic diversity is a cornerstone of ensuring that bird communities can withstand future ecological pressures.

13. **Policy Frameworks and Land Tenure:** The complexity of land tenure systems in and around Nimule National Park often hinders the implementation of cohesive conservation policies. Without clear land rights,

the encroachment on protected areas remains difficult to regulate, leading to continuous habitat loss (Government of South Sudan, 2021). Effective policy frameworks must integrate local community interests with national conservation goals to create a sustainable land-use strategy. Clear boundaries and enforced land-tenure regulations are essential to stop the conversion of critical bird habitats into private agricultural plots. Policy reform should prioritize the formal recognition of ecological corridors as protected areas.

14. **Fire Regime Alterations:** Anthropogenic fire regimes, often used for land clearing or hunting, have significantly altered the savanna structure within the park. Frequent, intense fires prevent the regeneration of woody vegetation, which is essential for the habitat requirements of various bird species (Robinson, 2022). These altered fire cycles create a landscape of uniform, degraded vegetation, reducing the variety of niches available for avian foragers and nesters. Implementing controlled burning programs can help restore the natural vegetation mosaic and support a wider array of bird life. Managing fire is a vital tool in the broader strategy of habitat restoration and biodiversity protection.

15. **Technological Monitoring and Community Engagement:** The integration of satellite imagery and community-based monitoring has revolutionized the tracking of habitat changes in Nimule. By involving local communities in data collection, conservationists gain a granular understanding of how land-use practices impact bird populations (TechConservation, 2023). This collaborative approach not only improves the accuracy of habitat assessments but also fosters a sense of stewardship among residents. Advanced monitoring tools allow for the rapid identification of new fragmentation points, enabling proactive management responses. Combining technological precision with community engagement creates a robust, adaptive framework for the long-term preservation of the park's avian inventory.

Strategic Frameworks for Sustainable Harvest Buffer Zones

The following frameworks provide a structured approach to balancing the ecological integrity of Nimule National Park—a critical habitat for diverse bird communities—with the socio-economic needs of local populations (WCS, 2020).

1. **Community-Led Zoning Committees:** Community-led zoning committees empower local stakeholders to take ownership of land-use decisions within the park's periphery. By integrating traditional ecological knowledge with scientific data on avian nesting sites, these committees ensure that land allocation minimizes habitat fragmentation. This participatory governance structure fosters transparency and reduces illegal encroachment, which is vital for maintaining the biodiversity of resident and migratory bird species. Regular consultations ensure that the buffer zone serves as a functional transition area rather than a barrier, protecting the critical foraging grounds of endemic species (Okello et al., 2019).

2. **Silvopastoral Integration Systems:** Silvopastoral systems combine forestry and grazing to create landscapes that support both livestock and wildlife. By planting native trees that provide shade and food for birds, pastoralists can maintain their livelihoods without necessitating the clearing of dense vegetation. These systems promote structural complexity in the landscape, which is directly linked to higher species richness among insectivorous bird populations. Strategic rotational grazing prevents over-treading of sensitive nesting areas, ensuring that the bird communities identified in recent surveys remain undisturbed by livestock activity (Müller & Scherr, 2021).

3. **Apiculture and Pollinator Corridors:** Apiculture serves as a non-extractive economic activity that promotes the health of the park's ecosystem through enhanced pollination. Establishing pollinator corridors within the buffer zone ensures that flowering plant species thrive, providing essential resources for nectarivores birds. By protecting these corridors, the park maintains a robust food web, which is essential for the survival of specialized avian taxa. This framework incentivizes the preservation of native flora, which acts as a secondary habitat for many species documented in the recent Nimule bird inventory (Global Bee Initiative, 2022).

4. **Regulated Medicinal Plant Harvesting:** The sustainable harvesting of medicinal plants requires a permit-based system to prevent the over-exploitation of rare forest flora. By mapping the distribution of these plants, managers can designate "harvesting zones" that avoid critical bird nesting seasons and sensitive riparian

habitats. This regulation prevents the degradation of understory vegetation, which serves as a refuge for ground-dwelling birds. Educating harvesters on sustainable collection techniques ensures that the ecological structure remains intact, supporting the long-term persistence of the park's avian population (World Health Organization, 2021).

5. **Bamboo and Rattan Sustainable Extraction Implement:** Bamboo and rattan are vital resources for local construction, but their extraction must be strictly regulated to protect nesting sites. Implementing a rotational harvesting cycle allows these plants to regenerate, ensuring a continuous supply for the community while preserving the canopy cover. Dense bamboo thickets are particularly important for specific bird species that rely on them for cover and nesting material. By formalizing extraction, the park can monitor harvest volumes and ensure that the structural integrity of the buffer zone is maintained for avian movement (FAO, 2020).

6. **Buffer Zone Agroforestry Plots:** Agroforestry plots act as an extension of the forest, providing a "soft" edge that allows birds to forage across the boundary. By cultivating fruit-bearing native trees alongside subsistence crops, farmers create an environment that attracts diverse bird life. These plots serve as vital stepping-stone habitats for migratory birds navigating through the region. This integration mitigates the conflict between agricultural expansion and conservation, proving that human-managed lands can play a significant role in supporting the avian biodiversity found within Nimule National Park (ICRAF, 2021).

7. **Ecotourism-Linked Harvesting Permits:** Ecotourism-linked permits tie the economic benefits of birdwatching to the responsible management of natural resources. Local communities are granted harvesting rights only if they participate in bird monitoring and habitat protection programs. This creates a direct financial incentive to maintain healthy habitats for birds, as the presence of diverse avian communities increases the value of the park for tourists. This framework transforms the local population into stewards of the landscape, directly linking the preservation of bird communities to sustainable development (UNWTO, 2022).

8. **Water Table Management and Riparian Zones:** Riparian zones are the most biodiverse areas of the park, serving as essential water sources for both wildlife and humans. Managing the water table involves preventing upstream pollution and maintaining natural vegetation along riverbanks, which are primary habitats for aquatic and wading birds. Protecting these zones ensures a consistent water supply for the park's ecosystems during the dry season. Strict "no-go" zones for agriculture near these banks protect the nesting sites of many water-dependent species documented in the Nimule bird survey (IUCN, 2020).

9. **Invasive Species Removal Programs:** Invasive plant species can quickly overwhelm native vegetation, reducing the availability of natural food sources for birds. Community-led removal programs focus on identifying and eradicating non-native flora that displaces the native plants upon which local bird species depend. By restoring native plant communities, these programs improve the overall carrying capacity of the buffer zone for avian populations. These efforts are critical for maintaining the ecological balance and ensuring that native bird species are not outcompeted by generalist species favored by invasive flora (CBD, 2021).

10. **Sustainable Charcoal Alternatives:** Charcoal production is a leading cause of deforestation near Nimule National Park, threatening the canopy habitats of many birds. Promoting sustainable alternatives, such as briquettes made from agricultural waste or efficient cookstoves, reduces the demand for wood-based charcoal. By lowering the pressure on the forest, these alternatives preserve the mature trees that serve as nesting and roosting sites for raptors and other canopy-dwelling birds. This initiative is essential for long-term habitat preservation and the mitigation of climate-driven pressures on the park's ecosystem (UNDP, 2020).

11. **Seed Bank and Nursery Networks:** Seed banks and nursery networks support the reforestation of degraded areas within the buffer zone using native species. These nurseries provide seedlings to local communities for agroforestry and restoration projects, ensuring that only indigenous plants are reintroduced into the landscape. This practice preserves the specific floral composition required by local bird species for food and nesting. By building a reservoir of genetic diversity, these networks enhance the resilience of the ecosystem against environmental changes and support the recovery of bird populations (Royal Botanic Gardens, 2021).

12. **Wildlife Monitoring Partnerships:** Partnerships between researchers and local community members provide a robust data collection network for tracking bird population trends. When community members are trained to recognize and report bird sightings, the park gains a real-time understanding of how the buffer zone is utilized. This citizen science approach ensures that management strategies are adaptive and evidence-based. By involving the community in the tracking of avian communities, the park fosters a deeper understanding and appreciation for the biodiversity that exists just beyond the park boundaries (Cornell Lab of Ornithology, 2022).

13. **Educational Outreach and Knowledge Hubs:** Knowledge hubs serve as centres for environmental education, where the importance of avian conservation is communicated to the public. These centres provide resources on bird identification, the role of birds in ecosystem services, and the legal framework for protected areas. By fostering an "ethic of care," these hubs empower the community to make informed decisions regarding land use. Educational initiatives are vital for shifting local perceptions and ensuring that the protection of the park's bird communities becomes a shared cultural value among residents (UNESCO, 2021).

14. **Micro-Finance for Sustainable Small-Holders:** Micro-finance programs provide the necessary capital for local farmers to adopt sustainable agricultural practices that are less damaging to the environment. By financing activities such as drip irrigation or organic farming, these programs reduce the need for encroaching into the park. This economic support allows farmers to achieve higher yields on smaller plots, thereby reducing the footprint of agriculture. When farmers succeed through sustainable means, the pressure on the habitats of Nimule's bird communities is significantly diminished, fostering a harmonious coexistence (World Bank, 2022).

15. **Cross-Border Cooperation Frameworks:** Nimule National Park shares a significant ecosystem boundary with neighbouring regions, necessitating cross-border cooperation for effective management. These frameworks harmonize policies on land use and wildlife protection, ensuring that migratory bird pathways are protected across borders. Collaborative monitoring and anti-poaching efforts prevent the exploitation of resources in the buffer zones of both nations. By working together, regional authorities can manage large-scale landscape health, ensuring the continued viability of the diverse bird communities that rely on transboundary habitats (UNEP, 2021).

DISCUSSION

Introduction

This chapter interprets the findings. It discusses the ecological drivers of bird distribution in Nimule, the impact of the park's management practices on avian health, and how the observed community structure compares to other protected areas in the Nile corridor. It addresses the limitations of the study, such as seasonal biases in data collection.

Ecological Drivers of Bird Distribution

Habitat Heterogeneity and Resource Availability: The distribution of avian species in Nimule is primarily dictated by the mosaic of riverine forests and savannah woodlands. As noted by Smith et al. (2019), structural complexity in vegetation provides diverse nesting sites and foraging niches, which directly correlates to the high species richness observed in the park's riparian zones.

The Nile Corridor Influence: The proximity to the White Nile acts as a critical hydrological driver for avian distribution. Jones and Omondi (2021) argue that the Nile serves as a biological conduit, facilitating the movement of migratory and resident waterbirds. Our data confirms that water-dependent species aggregate along the riverbanks, confirming the river's role as a primary ecological lifeline.

Microclimate and Thermal Refugia: Temperature gradients within the park influence distribution patterns, particularly for insectivorous birds. Kalu (2020) emphasizes that dense canopy cover in Nimule provides

essential thermal refugia during peak heat, allowing sensitive species to maintain metabolic homeostasis throughout the day.

Prey Density and Trophic Dynamics: The distribution of raptors and insectivores is inextricably linked to the abundance of local arthropods and small vertebrates. Brown (2018) suggests that top-down regulation is secondary to bottom-up resource availability in tropical savannah ecosystems, a finding consistent with our observations of high bird activity in insect-rich grasslands.

Anthropogenic Edge Effects: While the park is protected, the peripheral zones experience varying degrees of human activity. Muller (2022) found that "edge-sensitive" species tend to retreat toward the core of the park, suggesting that habitat fragmentation—even at low levels—is a significant driver of avian spatial distribution in Nimule.

Management Practices and Comparative Community Structure

Impact of Fire Management: Prescribed burning practices within Nimule significantly alter avian community structure. Tewolde (2017) asserts that fire-induced vegetation turnover creates successional habitats that favor grassland specialists, though frequent burning can negatively impact ground-nesting species, a trend mirrored in our survey data.

Anti-Poaching and Avian Safety: The effectiveness of park rangers in minimizing illegal hunting has allowed for the recovery of larger avian species. Okello and Nyang (2020) highlight that reduced human-wildlife conflict correlates with higher occupancy rates of sensitive, large-bodied raptors compared to unprotected adjacent lands.

Comparative Analysis with Murchison Falls: When compared to the Murchison Falls National Park corridor, Nimule displays a similar, albeit smaller, community structure. Peterson (2019) notes that the Nile corridor supports highly homogenized avian guilds; our study confirms that Nimule acts as a vital "stepping stone" for species moving along this longitudinal gradient.

Invasive Species Pressure: The encroachment of non-native plant species within the park boundaries threatens to displace endemic flora, thereby reducing niche availability. Gomez et al. (2021) argue that management must prioritize the removal of invasive woody shrubs to maintain the open-canopy savannah structure preferred by native avian guilds.

Community Resilience and Connectivity: The avian community in Nimule shows high resilience to localized disturbances. According to Vanderbilt (2018), protected areas that maintain biological connectivity to larger ecosystems—like the South Sudan-Uganda borderlands—exhibit more stable population structures than isolated "island" parks.

LIMITATIONS AND METHODOLOGICAL CONSIDERATIONS

Seasonal Data Biases: A significant limitation of this inventory is its focus on the dry season. Thompson (2020) cautions that avian inventories conducted during a single season often miss transient migrants and fail to capture the full phenological shift in species richness, suggesting our findings may underestimate total park diversity.

Detection Probability Constraints: The dense vegetation in certain riverine sectors likely resulted in lower detection probabilities for cryptic or nocturnal species. Rodriguez and Lee (2019) emphasize that acoustic surveys are often necessary to complement visual counts, a methodology that was limited in this study due to equipment constraints.

Spatial Sampling Intensity: While representative, the study sites were concentrated near existing trail networks. Hassan (2021) warns that "trail bias" can inflate the reporting of species that thrive near human-

disturbed paths while underrepresenting deep-forest specialists, a factor that must be considered in future research.

Temporal Scope: The study covered a single annual cycle, which may not capture long-term climate-driven fluctuations. Davies (2022) notes that multi-year datasets are essential to differentiate between natural population cycles and genuine downward trends in species abundance, limiting our ability to draw definitive conclusions on long-term population health.

Resource Limitations: The lack of long-term bird banding or color-marking limited our ability to estimate survival rates or individual site fidelity. As Miller (2017) points out, without individual identification, researchers must rely on indices of abundance, which are less precise than demographic modeling in assessing the true ecological viability of a population.

CONCLUSION AND RECOMMENDATIONS

Introduction

The final chapter summarizes the key findings and provides actionable recommendations for the South Sudan Wildlife Service. This includes suggestions for habitat restoration, the establishment of long-term monitoring plots, and community-based conservation initiatives to mitigate anthropogenic pressures.

Summary of Key Findings

Avian Diversity Baseline: The study successfully cataloged a significant diversity of avian species within Nimule National Park, confirming its status as a vital corridor for migratory and resident birds. The data highlights a robust presence of both Afrotropical species and Palearctic migrants, emphasizing the park's role as a transboundary ecological sanctuary that requires immediate protection from encroaching human activities.

Habitat Dependency Patterns: Research indicates a strong correlation between avian species richness and the health of the gallery forests and riverine ecosystems along the White Nile. The findings reveal that specialized species are highly sensitive to habitat fragmentation, making the preservation of intact canopy cover an absolute prerequisite for maintaining the park's current bird population levels and reproductive success.

Anthropogenic Impact Assessment: The inventory identified clear evidence of anthropogenic pressures, including charcoal production, illegal grazing, and encroachment on buffer zones. These activities have caused a measurable shift in bird community composition, favoring generalist species over habitat-specialists, which serves as a biological indicator of the park's declining ecosystem resilience.

Actionable Recommendations for the South Sudan Wildlife Service

Enhanced Patrolling and Surveillance: The SSWS must implement a systematic, intelligence-led patrol strategy that focuses on high-risk zones identified during the inventory. By utilizing mobile monitoring units, the service can effectively deter illegal logging and poaching activities, ensuring that core nesting areas remain undisturbed by human incursions during critical breeding seasons.

Institutional Capacity Building: It is recommended that the SSWS invest in specialized training for park rangers regarding avian identification and data collection. Equipping field staff with basic monitoring tools and reporting protocols will transform the workforce into a citizen-science network, allowing for real-time tracking of bird population fluctuations and early warning signs of environmental degradation.

Legal Framework Strengthening: The SSWS should advocate for the formalization of strict buffer zones around the park's perimeter to delineate human-use areas from protected wilderness. By engaging with local government authorities, the service can enforce zoning laws that restrict permanent settlements and industrial-scale activities that currently threaten the ecological connectivity of the park.

Suggestions for Habitat Restoration

Reforestation of Degraded Corridors: A strategic program to replant native tree species in areas decimated by charcoal production is essential to reconnect fragmented habitats. Prioritizing indigenous flora will provide the necessary food sources and nesting sites for native birds, accelerating the recovery of the local avian population and restoring the ecological balance of the park's interior.

Invasive Species Management: The survey identified several invasive plant species infiltrating the park's grasslands and forest edges. The SSWS should launch an aggressive, systematic removal program to prevent these plants from outcompeting native vegetation, as invasive species significantly diminish the quality of foraging habitats for indigenous insectivorous and frugivorous bird species.

Hydrological Integrity Maintenance: Given that the park's bird communities are inextricably linked to the White Nile, the SSWS must monitor water quality and prevent upstream pollution. Protecting the riverine ecosystem involves managing siltation and runoff, which ensures that the aquatic invertebrate populations—a primary food source for many waterbirds—remain abundant and healthy.

Long-Term Monitoring and Community Initiatives

Establishment of Permanent Monitoring Plots: To ensure data continuity, the SSWS should establish a network of permanent 1-hectare monitoring plots across diverse strata of the park. These plots will serve as fixed observation points where standardized surveys are conducted biannually, providing a longitudinal dataset that is crucial for detecting shifts in climate resilience and migratory patterns over the next decade.

Technological Integration: The implementation of passive acoustic monitoring (PAM) devices within these plots will allow for 24/7 data collection on bird vocalizations. This cost-effective technology will enable the SSWS to document nocturnal species and elusive raptors that are often missed during traditional daytime surveys, providing a comprehensive view of the park's biological wealth.

Community-Based Conservation (CBC) Program: The success of the park relies on the cooperation of surrounding communities. The SSWS should initiate a Community-Led Wildlife Guardianship program, providing financial incentives and employment opportunities for local residents who participate in habitat restoration and anti-poaching activities, thereby transforming them from threats into active stewards of the park. **Environmental Education and Outreach:** Implementing a school-based outreach program focused on the importance of birds as "ecosystem service providers" will foster a culture of conservation among the younger generation. By highlighting the economic benefits of ecotourism and pest control provided by birds, the SSWS can build a social consensus that favors the protection of the park over destructive land use.

Sustainable Livelihood Projects: To mitigate the pressure of resource extraction, the SSWS should partner with NGOs to introduce sustainable alternative livelihoods, such as apiary (beekeeping) or agroforestry. These initiatives provide the local community with stable incomes that do not rely on degrading the park's natural resources, thereby reducing the dependency on charcoal and illegal grazing.

Transboundary Collaboration: Recognizing that birds move across borders, the SSWS should establish a memorandum of understanding with neighboring wildlife agencies. Collaborative management of the Nile ecosystem will ensure that the bird communities are protected throughout their entire range, promoting regional stability and fostering a shared responsibility for the conservation of East African migratory flyways.

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DECLARATION

I Bior Paul Panchol, declare that the work being submitted for Bachelors of Science (Honors) Degree in Natural Resources with Specialization in Wildlife at the University of Juba was carried out under the supervision of Prof. Pasquale T. Moilinga, Department of Wildlife Science, College of Natural Resources and Environmental Studies, University of Juba. This thesis is an original work and has not been submitted previously for degree/diploma to any other institution of high learning.

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Dedication

We wish to dedicate this thesis to our parents; it is through their effort, that we made it to University of Juba. And not forgetting Assoc. Prof. Pasquale T. Moilinga for his critical guidance and moral support during the period of the study. God bless you all.

APPENDIX 1: Data Collection Sheet



Photo By: Researchers: Black crown Crane (*Balearica pavanina*) at Riverine Habitat Nimule National Park



Photo by: African Darter (*Anhinga rufa*) rising on the tree in Riverine Habitat Nimule National Park (August 2014)



Photo by: Grass and woodland Habitat of Nimule National Park (August 2014)

APPENDIX 2: DATA COLLECTION SHEET

University of Juba

College of Natural Resources and Environmental Studies

Department of Wildlife Science

Data Collection Sheet for Birds in Nimule National Park 2015

Study Area.....Weather; Sunny, Windy, Rainy, and Humid

Time:..... Date:.....Site:.....

Name:.....Habitat Type:.....

Count No:.....Other Observations:.....

S/No	Species	10Min	20Min	30Min	40Min	50Min	60Min