TRENDS IN AVIAN SPECIES DIVERSITY AND COMPOSITION IN GREEN SPACES OF NAIROBI COUNTY IN KENYA

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A thesis submitted in partial fulfilment of the requirements for the award of the degree of Master of science in environment and natural resources management in the department of environment and natural resource management at the school of science and technology of Africa Nazarene University

April 2026

Declaration

I hereby declare that this thesis is my original work and has not been presented for the award of a degree or diploma in this or any other University.

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We have examined this thesis, and the research has met or exceeded the requirement for the degree sought, in addition, the candidate has sufficiently defended the material presented to merit the awarding of the degree of **Degree of Master of Science in Environment and Natural Resources Management**

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Notes: (Pass, Pass with Distinction)

Dedication

This study is fondly dedicated to my parents: Patrick Ngugi and Hannah Wanjiru for their encouragement and prayers during my studies.

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Abstract

This study evaluated avian species diversity, community composition, and seasonal trends at the National Museums of Kenya (NMK) and Karen Karara (KK) between 2014 and 2020. Utilizing a retrospective quantitative research design, the study analysed secondary bird ringing records for 3,843 individuals representing 147 species. Data was standardized using rarefaction to reduce the unequal sampling biasness. The methodology employed Shannon-Wiener diversity (H'), Pielou's evenness (J'), and Jaccard's similarity indices, with composition differences statistically validated through Permutational Multivariate Analysis of Variance (PERMANOVA). Results revealed that Karen Karara maintained a more evenly distributed community structure (median $J' \approx 0.87$) compared to the NMK site ($J' \approx 0.78$), where a few species tended to dominate, indicating a greater degree of niche partitioning in the former. However, Karen Karara exhibited a statistically significant decline in Shannon diversity over the seven-year period ($p < 0.005$, $R^2 = 0.68$), whereas the decline at NMK was statistically non-significant ($p = 0.081$). Species similarity between the two sites remained consistently low (Jaccard index < 0.4), indicating that these proximate green spaces support distinct avian assemblages requiring site-specific management interventions. Furthermore, while seasonal variation significantly influenced the species present (PERMANOVA: $p = 0.001$), overall diversity levels did not vary significantly across seasons, suggesting a pattern of functional species replacement rather than net diversity loss during different periods of the year. The study concludes that Nairobi's avian communities within green spaces are undergoing measurable erosion, with peri-urban forests like Karen Karara exhibiting higher vulnerability to species turnover than central urban refuges. The observed decoupling between alpha diversity stability and high beta diversity turnover highlights a system undergoing significant compositional reorganization. To mitigate these trends, the study recommends the enhancement of habitat heterogeneity at NMK and the implementation of urgent restoration efforts and buffer zone creation at Karen Karara. Although sampling efforts differed between the sites, there is an imperative need for increased long-term monitoring to protect declining species and enhance urban biodiversity while reducing pressure on the remaining green corridors in the county. Ultimately, effective urban conservation strategies must move beyond aggregate diversity counts to prioritize seasonal composition shifts and the specific, fine-scale habitat requirements necessary to sustain avian biodiversity in an increasingly fragmented landscape.

Definition of terms

Ecosystem Services: These are the advantages gained from the natural environment through the regulation of ecosystem functions, including the supply of food, water, and wood (provisioning services); the control of air quality, climate, and flood hazards (regulating services); opportunities for leisure, tourism, and learning (cultural services); and critical foundational processes such as soil creation and nutrient recycling (supporting services).

Endemic Bird Area (EBA): a geographic region where the breeding ranges of two or more limited-distribution terrestrial bird species overlap, with the entire habitat range of at least two species contained wholly within the zone.

Moulting: Bird plumage renewal.

Nature-based Solutions (NbS): strategies that involve the conservation, sustainable management, and restoration of natural or altered ecosystems to tackle societal challenges in a flexible and effective manner, while also enhancing human well-being and supporting biodiversity.

Climate Change or Climate variation: refers to a shift in the condition of the Earth's climate system that can be recognized through statistical analysis, by alterations in the average state and/or variability of characteristics such as rainfall and temperature, sustained over an extended duration, usually decades or longer. Such changes may result from natural internal dynamics such as fluctuations in solar activity, volcanic eruptions, or long-term human-induced changes in atmospheric composition or land use patterns.

Abbreviation and acronyms

ES: Ecosystem Services

KFS: Kenya Forestry Service

KK: Karen Karara

NMK: Nairobi National Museums of Kenya

RSEA: Ringing Scheme of East Africa

WWF: World Wildlife Fund

PSR: Pressure-State-Response

OECD: Organization for Economic Cooperation and Development

Chapter One: Introduction and Background

This chapter presents the study's background, problem statement, study objectives, significance of the study, study constraints, scope boundaries, theoretical and conceptual frameworks of the study.

1.1. Background of the Study

Urban green spaces refer to all urban land (either private or public grounds) that is covered by vegetation of any kind (WHO, 2017). Urban vegetated areas differ in scale and purpose, and may also incorporate blue areas, which consist of small aquatic features like ponds, lakes, or streams. Vegetated areas are a part of ecological infrastructure and play a vital role in maintaining environmental functions such as supporting biodiversity, controlling pollution, conserving soil, and sequestering carbon (Muluneh & Worku 2022, Smith et al., 2013). Urban natural areas have been demonstrated to significantly contribute to individuals' emotional well-being, physical fitness, and psychological health (Okech & Nyadera, 2022).

Urban green spaces play a critical role in the conservation of bird species, particularly in rapidly urbanizing environments where natural habitats are increasingly fragmented (Barth et al., 2014). Urban parks, riparian forests, and vegetated corridors provide essential nesting sites, food resources, and shelter for both resident and migratory birds (Huang et al., 2015). Studies found that areas with greater vegetation complexity, larger habitat patches, and retained mature trees supported significantly higher bird richness and abundance compared to heavily paved or simplified urban landscapes. For example, McClure et al. (2015) reported that riparian forests within urban corridors positively influenced bird occupancy and species diversity, while Shanahan et al. (2015) showed that retaining remnant trees in new urban developments enhanced bird diversity to levels comparable with urban parks. Similarly, research in Beijing urban parks highlighted that habitat area, plant diversity, and insect availability were key predictors of breeding bird populations (Huang et al., 2015). These findings collectively emphasize that conserving and expanding urban green spaces is essential for maintaining avian biodiversity and ecological resilience in cities.

Avian species' characteristics (such as composition, diversity, and trends) are good indicators of changes occurring to an ecosystem (Cox et al., 2014). This is because birds respond to changing habitat factors and weather conditions by moving from the area to either higher or lower latitudes or higher elevations in tropical ecosystems (Forero-Medina, et al., 2011). Avian characteristics therefore can be used to monitor changes in habitat quality in urban green spaces and their ability to provide ecological services to the human population.

In Nairobi, green spaces are diminishing rapidly due to infrastructural development such as roads, settlement, and commercial infrastructures triggered by urban population increase (Makwaro & Mireri, 2011; Nairobi City County Government, 2018). Although the trend is being experienced across the city, its effects are experienced strongly in ecologically significant areas, such as the urban green space of the National Museums of Kenya (NMK) and other significant green spaces within the city. Being a central park, it is getting encroached on by the thick urbanization that is constantly creeping in. This will impact the ecological soundness as well as the potential of the place to host key biodiversity, especially birds. Spatial analyses demonstrate that the continuous loss of green spaces in Nairobi has steadily followed an increasing trend between 1988 and 2016 (Derdouri et al., 2025). Nairobi's green spaces cover only 68.208 km², representing 9.86% of the city's total area—a proportion considerably lower than in many cities of comparable size (Odhengo et al.,2024). While this figure reflects broader urbanization trends, the NMK grounds face increasing pressure as urban expansion continues to fragment and reduce their green cover.

The assessment of avian community dynamics in urbanized landscapes is increasingly predicated on the Urban Filter Hypothesis, which posits that the transformation of natural habitats into urbanized matrices creates a selective environment that favours synanthropic species while excluding specialists. Recent longitudinal studies, such as those by Aronson et al. (2014) and McKinney (2006), emphasize that urban green spaces—ranging from formal botanical gardens to suburban patches—act as critical refugia, yet their efficacy is governed by structural complexity and spatial isolation. By adopting a comparative framework, researchers can disentangle the effects of anthropogenic pressures from the intrinsic ecological value of these sites, moving toward a mechanistic understanding of how urban infrastructure filters species pools across heterogeneous landscapes (Poff, 1997).

Temporal variability remains a significant, yet often overlooked, dimension in urban avian ecology, as static, snapshot-based studies often fail to account for inter-annual population fluctuations driven by regional climatic oscillations. According to Magurran (2004), long-term monitoring is essential for distinguishing between stochastic population trends and deterministic successional responses to landscape change. In the context of Nairobi, where rapid urbanization has fragmented once-contiguous habitats, a seven-year longitudinal study (2014–2020) provides the temporal depth required to evaluate the stability of dominance hierarchies and species turnover. This approach aligns with modern ecological modelling, which advocates for the use of dynamic indices that account for both richness and evenness to detect subtle shifts in community composition before they manifest as outright extirpation (Gotelli & Colwell, 2001).

Finally, the integration of seasonal data within a long-term comparative design allows for a more nuanced interpretation of community assembly. By comparing sites like the National Museums of Kenya (NMK) and Karen Karara, this study framework addresses a gap in East African urban ecology by providing a high-resolution analysis of how seasonal rainfall and annual variability interact with site-specific habitat quality. Such an approach is vital for developing science-based conservation strategies, ensuring that urban green spaces are managed not just as aesthetic amenities, but as functional ecological corridors capable of sustaining biodiversity amid ongoing urban expansion.

1.2. Statement of the Problem

Birds are widely recognized as important bio-indicators because they respond rapidly to environmental changes, making them useful in assessing ecosystem health and ecological stability. Changes in bird distribution, abundance, migration, and breeding patterns often reflect broader environmental disturbances such as habitat degradation, pollution, and climate variability. However, increasing anthropogenic activities, particularly habitat destruction, urban expansion, and climate change, continue to threaten avian populations globally by disrupting migratory routes, breeding habitats, and feeding grounds (Newton, 1998; Alerstam et al., 2001). Urbanization has emerged as one of the leading drivers of biodiversity loss, especially in developing cities where natural habitats are continually converted into residential, industrial, and infrastructural developments.

The rapid and unplanned urbanization of Nairobi has led to the progressive fragmentation of natural habitats, creating a mosaic of isolated green spaces that now function as the primary refugia for local avian communities. While these areas are essential for maintaining biodiversity, they are subject to selective pressures—often termed the "urban filter"—which restrict the regional species pool to those capable of navigating human-dominated environments, patterns consistent with possible habitat or seasonal influences. A critical problem facing conservation efforts in the city is the lack of empirical, long-term data regarding how these sites, such as the National Museums of Kenya (NMK) and Karen Karara, compare in their ability to support avian populations. Without a rigorous, comparative analysis of species composition and dominance between such distinct institutional and suburban-fringe landscapes, urban planners remain unable to determine which management regimes effectively mitigate biotic homogenization.

Furthermore, there is a persistent lack of longitudinal evidence concerning the stability of these sites in the face of urban densification. Many existing studies rely on short-term inventories that fail to distinguish between transient population oscillations and deterministic trends of successional decline. This creates a significant knowledge gap: it remains unclear whether the avian diversity at NMK and Karen Karara is experiencing long-term successional stability or a steady erosion of specialist species due to the encroaching "urban squeeze." Consequently, there is an urgent need to evaluate these sites through the lens of temporal diversity indices to identify potential regime shifts and assess whether these urban islands are losing their ecological resilience as the surrounding matrix becomes increasingly inhospitable.

The problem is further exacerbated by the failure to account for seasonal bottlenecks in Nairobi's urban conservation strategies. Seasonal rainfall in East Africa acts as a powerful temporal filter, dictating the pulses of food and water availability that avian guilds—particularly insectivores and migrants—depend upon for survival. Empirical evidence suggests that if urban green spaces fail to provide these essential resources during the dry season, they may transform from "functional refugia" into "ecological traps." Despite this, there is limited documentation on how the NMK and Karen Karara facilitate avian persistence through these challenging seasonal cycles. This lack of seasonal data prevents the implementation of targeted habitat restoration efforts, such as the strategic planting of drought-resistant vegetation or the maintenance of year-round water sources, which are critical for preserving avian life throughout the year.

Ultimately, the lack of an integrated research framework linking site-specific composition, longitudinal diversity trends, and seasonal resource dynamics leaves Nairobi's urban biodiversity management in a state of reactive uncertainty. Current policies often manage green spaces as static aesthetic amenities rather than dynamic, connected ecological corridors. By failing to understand the interplay between site-specific habitat quality and temporal climatic filters, conservationists risk losing the very avian communities that provide essential ecosystem services, such as pollination and pest control, within the metropolitan area. This study, therefore, addresses this multifaceted problem by providing a robust longitudinal assessment of NMK and Karen Karara, aimed at shifting urban management from descriptive, site-based snapshots toward a predictive, evidence-based model capable of sustaining avian diversity in an era of unprecedented urban growth.

The NMK grounds and Karen Karara represent critical urban habitats that may support resident and migratory bird populations within Nairobi. However, inadequate documentation of species composition, diversity patterns, and seasonal variation within these sites' limits understanding of their ecological importance and conservation value. The absence of localized and long-term avifaunal data creates a major knowledge gap that constrains evidence-based conservation planning and urban biodiversity management. Without sufficient understanding of how avian communities respond to urban pressures and climatic variability in these areas, conservation interventions are likely to remain reactive rather than preventive.

Therefore, there is a need to document changes in avian species composition, diversity, and seasonal variation within selected urban green spaces in Nairobi. This study would provide critical baseline information on the ecological status of bird communities within the NMK grounds and Karen Karara and contribute to understanding the influence of urbanization and climate variability on avian biodiversity. The findings would also support the development of informed conservation strategies aimed at protecting urban bird populations, particularly migratory species that are highly vulnerable to habitat loss and environmental change.

1.3. Purpose of the Study

The purpose of this study is to examine the avian species composition, diversity, and seasonal trends within urban green spaces in Nairobi County, specifically focusing on the National Museums of Kenya (NMK) grounds and Karen Karara. As rapid urbanization continues to threaten biodiversity through habitat fragmentation and destruction, this research seeks to address the significant knowledge gap regarding bird populations vary between the two sites. By leveraging longitudinal data collected between 2014 and 2020, the study aims to establish a baseline understanding of the ecological status and resilience of avian communities in fragmented urban habitats, which is essential for identifying long-term trends and site-specific metric changes across the seasons. By investigating the ecological significance of these urban refuges, the research intends to inform policy and planning decisions that balance urban development with biodiversity conservation, aligning with frameworks such as the Kenya Climate Change Policy. Ultimately, the study contributes to a broader understanding of how urban green spaces function as essential biodiversity reservoirs, reinforcing the need for targeted conservation strategies that address the cumulative impacts of human activity and climate variability in rapidly urbanizing landscapes.

1.4. Objectives

The National Museums of Kenya has ringed birds consistently in the NMK ground in Nairobi and Karen Kara since 2014. The study aims to leverage on this data to achieve the following goals.

1.4.1. General Objective

To examine avian species composition, diversity and seasonal trends in two urban green spaces in Nairobi County in Kenya.

1.4.2. Specific Objectives

1) To compare avian species composition and species dominance between Karen Karara and National Museums of Kenya during the period 2014 - 2020
2) To assess temporal changes in species diversity between Karen Karara and the NMK during the period 2014 - 2020
3) To evaluate annual seasonal variations of avian species in NMK and Karen Karara urban green spaces in Nairobi County, Kenya during the period 2014- 2020.

1.5. Research Questions

The following are the research questions of this study:

i) What are the changes in avian species composition during 2014 - 2020 in the urban green spaces in Nairobi County?

ii) What are the changes in avian species diversity during 2014 - 2020 in the urban green space of Nairobi County?

iii) How does species composition differ with seasonality and between the sites in the urban green spaces of Nairobi County during 2014-2020?

1.6. Significance of the Study

This study contributes to the growing body of knowledge on the ecological significance of urban green spaces and their role in sustaining avian biodiversity within rapidly urbanizing cities. By assessing bird species composition, diversity, and seasonal variation in relation in changing weather patterns and anthropogenic pressures, the study generates critical ecological data on the functioning and resilience of urban ecosystems under changing environmental conditions. Birds are highly sensitive to habitat alteration and climatic fluctuations, making them reliable bio-indicators of ecosystem integrity and environmental change (Newton, 1998; Alerstam et al., 2001). Consequently, documenting avian community dynamics within the National Museums of Kenya (NMK) grounds and Karen Karara will provide important insight into the ecological status and conservation value of Nairobi's urban green spaces.

This study advances research in urban ecology, conservation biology by addressing existing knowledge gaps on the long-term dynamics of avian communities in urban landscapes. While previous studies have examined the effects of urbanization and climate change independently, limited attention has been given to the seasonal avian variability in urban green spaces and even the changes in composition, dominance and distribution within Nairobi's urban ecosystems. The study therefore establishes species diversity, trends and composition over time bringing more understanding of the ecological role and resilience of fragmented urban habitats under increasing environmental stress. In addition, the findings will provide baseline data for future ecological monitoring, biodiversity assessments, and comparative studies on urban avifauna in Kenya's urban centres and other rapidly urbanizing regions.

From a policy and management perspective, the findings will support evidence-based decision-making in urban biodiversity conservation and environmental planning at both national and county levels. The study will generate localized ecological data on seasonal avian variance, composition and diversity at the face of increasing human activities within urban habitats, thereby informing strategies aimed at enhancing ecological resilience and biodiversity conservation. The findings will further contribute to the implementation of national environmental and climate frameworks, including the Kenya Climate Change Policy (2016), Climate Change Act (2016), and the National Climate Change Action Plan III (2023–2027), by providing scientific evidence necessary for climate adaptation planning and sustainable urban ecosystem management.

The study will additionally benefit conservation institutions such as the Kenya Wildlife Service (KWS) by providing detailed information on bird species diversity, composition, spatial distribution, and seasonal dynamics within urban green spaces. Such information will strengthen avian monitoring programs and support the development of targeted conservation interventions for both resident and migratory bird species. The recommendations arising from this study may also assist environmental stakeholders in formulating long-term urban biodiversity conservation strategies that address the cumulative impacts of habitat degradation and climate variability.

Finally, the study provides practical significance for county governments, urban planners, and environmental managers by generating scientific evidence to guide the development, restoration, and management of urban green spaces. The findings will support policies that integrate biodiversity conservation into urban planning frameworks while promoting ecological sustainability and human well-being. By emphasizing the ecological and climatic functions of urban green infrastructure, the study reinforces the need to balance urban development with environmental conservation. Ultimately, the research contributes to strengthening national conservation priorities and climate adaptation strategies while improving understanding of the role urban ecosystems play in sustaining biodiversity within rapidly expanding cities such as Nairobi.

1.7. Scope of the Study

This research investigates bird communities inhabiting the urban green space within Nairobi County, addressing three core research aims: (1) establishing the current avian species composition, (2) examining species diversity and similarity within the green space, and (3) analysing annual seasonal variations between two green sites in Nairobi County. The investigation centres specifically on the National Museum's green space and Karen Karara at the periphery of the central business district within the city as a characteristic urban conservation zone, while recognizing possible ecological interactions with the adjacent urban landscape. The study uses annual weather patterns within Nairobi to discern climate-driven variations on bird populations between the two sites. In addition, it aligns with the bird ringing exercise conducted within Nairobi and its environs every 3-4months annually. While the study recognizes human development within the city and its environs, the research maintains its principal focus on the three defined objectives concerning species composition, diversity patterns, and temporal variations across the years.

1.8. Limitations of the Study

This study focused on analysing avian species diversity of two urban green spaces in Nairobi County over a period of seven years. The study also examined species similarity and seasonal variations across the years between the two sites. Although the sites are small compared to the relative size of Nairobi city which it represents, the inconsistence in data collection in other sites make it hard compare more sites within the city. The data is collected through mist nets; this has a limitation on spatial distribution of the species. However, the green spaces are small and therefore this does not have a huge influence on distribution.

1.9. Delimitations of the Study

The study covered the urban green space within Nairobi County. The areas were purposely selected for this research due to their bird ringing work and long-term data on bird characteristics. The study will not look at changes in the spatial distribution of the birds, due to limited variation in the ecological conditions in the study site as well as lack of spatial distribution. Other green spaces in Nairobi city could not be covered due to budget constraints and lack of consistent data collection.

1.10. Assumptions of the Study

The thesis explicitly identifies two primary assumptions upon which the research rests:

- **Representativeness of the Sample:** The study assumes that the bird populations captured during the ringing exercises are representative of the broader avian community within the Nairobi urban landscape.
- **Constancy of Moderating Variables:** The research assumes that intervening or moderating variables (such as inconsistent environmental monitoring or changes in sampling effort) remained constant or equal throughout the study period, allowing for meaningful analysis of the seven-year dataset.

Implicit Methodological Assumptions

Given that the research utilizes bird ringing (banding) data from 2014 to 2020, the study relies on several methodological foundations:

- **Standardization of Effort:** By using a longitudinal dataset from the National Museums of Kenya, the study assumes that the ornithological field procedures—specifically mist-netting effort, handling time, and equipment usage—were sufficiently standardized across the seven-year period to enable valid comparisons of species composition and diversity between the two sites.

- **Stability of Study Sites:** The comparison between the Nairobi National Museums (NMK) grounds and Karen Karara assumes that these sites functioned as stable green refuges throughout the study period. It assumes that observed changes in bird populations are attributable to external factors (such as climate variability and urban pressure) rather than unrecorded, drastic shifts in the internal micro-habitat structure of the sites themselves.
- **Accuracy of Taxonomic Identification:** Because the study relies on unique identifiers (metal leg bands) and standardized ringing data, it assumes the accuracy of species identification and data recording by the certified ornithological personnel involved in the original ringing exercises.

1.11. Theoretical Framework

This study is based on the Environmental Sustainability Theory (Vos, 2007) and the Pressure- State-Response (PSR) Framework of Sustainability.

1.11.1. Environmental Sustainability Theory

The Environmental Sustainability Theory (Vos, 2007) offers a thorough structure for analysing and interpreting the impacts of both anthropogenic and climatic factors on bird species within the urban green space of the Nairobi National Museum. Using this approach, the study investigated the balance between urban growth and biodiversity protection, highlighting the need for sustainable urban green space management for long-term ecological, social, and economic sustainability. This linkage with theory guarantees that the study not only adds to the scientific understanding of urban biodiversity but also informs policy and conservation measures aimed at protecting both bird species and residents' quality of life.

Environmental sustainability is a broad concept that encompasses resilience, equilibrium, and interdependence, enabling human society to fulfil its needs without exceeding the ability of the supporting ecosystem to regenerate essential services while preserving biological diversity (Vos, 2007). The concept can be described as the capacity to sustain ecological equilibrium in the Earth's natural systems and preserve natural resources to ensure the welfare of both present and future generations. Sustainability has three interdependent and mutually reinforcing pillars or domains (Figure 1.1), which include: economic, social, and environmental protection (WHO, 2005). Voinov and Smith (1994) and Adams (2006) propose that "sustainability is achieved when the physical and societal conditions that support human health and the environment are preserved or enhanced over time, without surpassing the ecological limits that sustain them." Additionally, various scholars and international bodies have identified culture as the fourth pillar or dimension of sustainable development. (UNESCO, 2002).

Figure:1.1. The key pillars or dimensions of sustainability adopted from Elkington, (1997).

The relationship between the three pillars or dimensions of sustainability have been described to occur in a physical causal relationship between society and nature. The concept termed as the Pressure-State-Response (PSR) model is grounded in a causal framework where human actions place "pressures" on the environment, altering the condition and availability of natural resources (the "state"); in turn, society addresses these shifts through environmental, economic, and sector-specific policies (the "response"), creating a feedback loop that influences future human activities and pressures (OECD, 2004). This theory explains how species are pressured by anthropogenic activities resulting in changes in species diversity, distribution and seasonal assemblage.

1.12.2 The Pressure- State-Response (PSR) Framework of Sustainability

The Pressure-State-Response (PSR) framework was established by the Organisation for Economic Co-operation and Development (OECD). It was originally introduced as a tool for examining the relationships among environmental stresses, the condition of the environment, and society's responses to these changes (Rapport & Friend, 1979). The PSR model is based on the concept of causality, if human activities exert pressures on the environment which alter the state (quality and quantity) of natural resources and call for certain responses by the society. The PSR model is based on the following ideas (OECD, 2004).

Environmental stresses frequently arise from human actions. These pressures may be indirect such as species loss caused by pollutant discharge or direct, like excessive resource exploitation or pollution emissions. Indicators of environmental pressure are strongly linked to consumption and production trends and are commonly represented by pollutant outputs. Environmental conditions encompass the health of ecosystems, natural surroundings, and factors influencing human wellbeing and quality of life. Environmental state indicators reflect pollutant levels or biodiversity status, providing a snapshot of environmental health and how it changes over time.

Response refers to how societies through individual or collective efforts address environmental challenges, often in the form of environmental, economic, or sector-specific policies. Response indicators are generally associated with mitigation and regulatory actions. A more extensive PSR concept was developed by Kristensen (2004), where the indicators in the framework are classified using the Driver (D)-Pressure (P)-State (S)-Impact (I)- Response (R) framework (Kristensen, 2004). This DPSIR framework illustrates where along the cause-effect chain indicators are located. Drivers include the human activities that drive pressures (e.g., natural resource use, emissions) that lead to a change in the socioeconomic and ecological state and impacts on these systems that eventually lead to societal responses (e.g., policy responses).

1.12. Conceptual Framework

This study adopts a comparative longitudinal framework to assess the avian community dynamics across two urban green spaces. The framework posits that the interplay between site-specific characteristics (e.g., habitat quality of NMK vs. Karen Karara) and temporal factors (annual and seasonal changes) acts as an 'ecological filter.' This filter dictates the observed avian species composition, dominance, and diversity. By analysing data from 2014 to 2020, the study accounts for temporal fluctuations, allowing for a robust comparison of how these urban habitats support avian communities over time

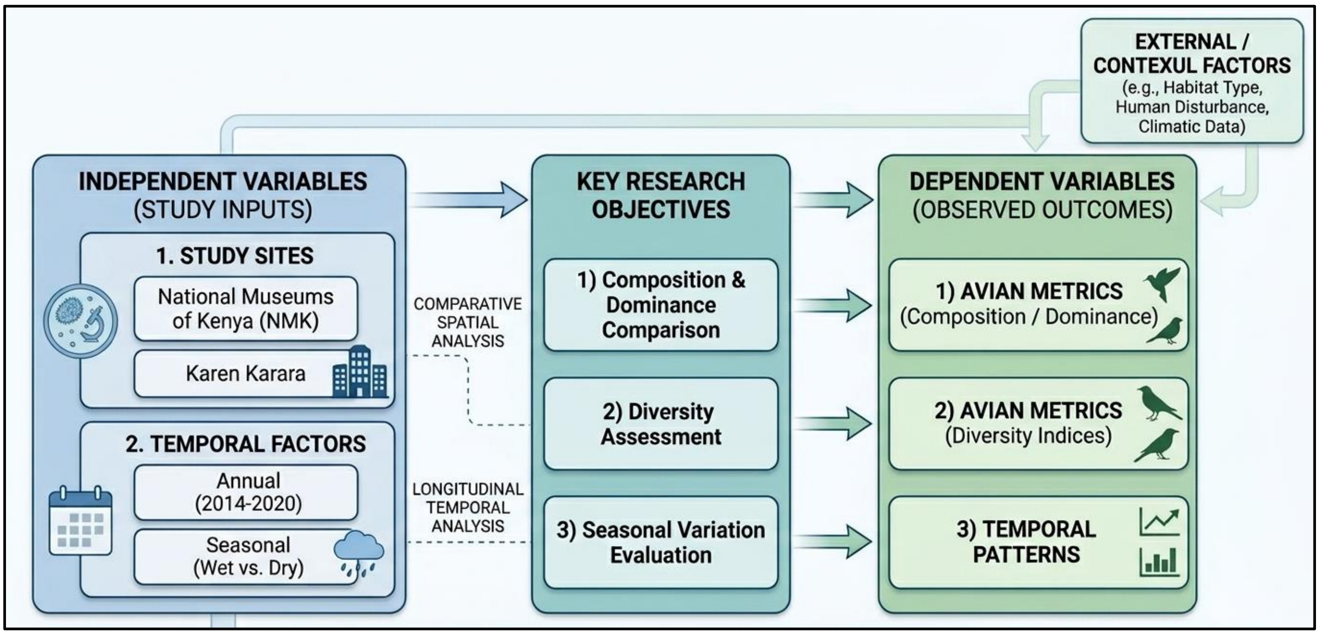

Figure 2: Conceptual framework depicting the relationship between factors affecting urban green space and avian characteristics and their habitat within the urban centres.

The central postulate of this framework is the ecological Filter Hypothesis, which conceptualizes the urban environment as a series of selective abiotic and biotic pressures that constrain species pools (Poff, 1997). In this model, the two study sites act as independent filters that exert varying levels of selection based on site-specific traits, such as vegetation structural complexity, anthropogenic noise levels, and resource availability.

These site-specific characteristics function in tandem with temporal forcing mechanisms—specifically annual climatic variability and intra-annual seasonal oscillations (wet vs. dry seasons). The "filter" is therefore dynamic rather than static; the permeability of the urban landscape to specific avian guilds (e.g., insectivores, nectarivores, or synanthropes) fluctuates in response to these combined spatial and temporal dimensions.

Chapter Two: Literature Review

2.1. Introduction

This chapter provides a review of the literature on the study's key variables, with a focus on species diversity, similarity composition and seasonal variations in urban green spaces. Because the study is conducted in an urban green space, namely the Nairobi National Museum and Karen Karara, the review also investigates the moderating influence of conservation techniques and policies in preserving bird biodiversity in urban settings. The chapter is divided into urban green space, bird species composition and diversity, factors influencing avian species occurrence and distribution and a summary evaluation of the literature and identification of research gaps.

2.1.1. Urban Green Spaces

Urban natural spaces encompass all urban areas, whether privately or publicly owned, that are covered with vegetation of any type (World Health Organization, 2017). Urban green spaces vary in scale and function and may also encompass blue spaces, which include small water bodies like ponds, lakes, and streams or rivers. They form part of green infrastructure and play a crucial role in environmental regulation, offering benefits such as biodiversity conservation, pollution mitigation, soil preservation, and carbon sequestration. A related concept in land-use planning is urban open space, which refers to land or water areas kept free from buildings, purposefully designated or publicly managed to fulfil both conservation and urban development roles, while also offering recreational opportunities (Firehock& Walker 2015). Bryne & Sipe, (2010), defines green spaces as undeveloped areas set aside for parks, green zones, and other open landscapes. The character of urban open spaces differs, spanning from sports fields and meticulously designed areas to more natural settings.

Generally open to the public, some urban open spaces may be privately owned, including university campuses, community parks and gardens, as well as corporate or institutional grounds. However, regions outside city boundaries, such as state and national parks or rural open areas, are not considered urban open spaces. Likewise, streets, piazzas, plazas, and city squares are not always categorized as urban open spaces in land-use planning (Harnik, 2010). Across the world, major cities have demonstrated how urban green spaces can be strategically designed and managed to provide ecological, social, and climatic benefits. A prominent illustration is New York City, where the planning and maintenance of Central Park have created a worldwide benchmark for urban green spaces. Central Park is not merely a leisure destination but also serves as a crucial refuge for migratory birds, thereby enhancing the city’s ecological diversity. The park plays a crucial role in managing the urban climate by mitigating the heat island effect, enhancing air quality, and capturing carbon, (Peterson et al.,1998). Likewise, London's Royal Parks and Green Belts are essential components of the city's environmental framework, enhancing both ecological sustainability and community resilience. (Davies et al 2015). Singapore adopted the concept of a “city within a garden”, that integrated greenery into its metropolitan landscape through green rooftops initiatives, vertical vegetation, and expansive parks like Gardens by the Bay. These initiatives exemplify how urban green areas can be deliberately embedded into the built environment to create versatile green spaces that enhance biodiversity, lower energy usage, and elevate overall well-being, (Chong et al 2015).

2.1.2. Urban Green Space in Sub Saharan Africa

Rapid expansion of urban areas and rising population in Sub-Saharan Africa are exerting pressure on city green spaces. As urban centres expand, the accessibility and condition of these spaces are often compromised, making it more challenging to preserve their environmental and societal functions. Nonetheless, many cities in the region are acknowledging the value of these areas, prompting increased efforts to preserve and improve urban green spaces (Asibey et al 2024). Urban green spaces are becoming increasingly vital to the environmental and social framework of Lagos, Nigeria (Dipeolu et al., 2025). The Lagos State Government has introduced the Lagos Green Development Initiative, which seeks to increase urban greenery, enhance biodiversity, and improve public well-being. Likewise, Addis Ababa, Ethiopia, has made notable strides in urban reforestation, with its Green Development Strategy aiming to expand tree coverage and foster green spaces within the city. These community initiatives highlight the importance of urban green spaces in alleviating the effects of rapid urban growth, such as heat stress, air pollution, and loss of biodiversity (Getachaw et al 2017). However, challenges remain in the enforcement of green space policies across Sub-Saharan Africa. Land ownership disputes, financial constraints, and urbanization pressures frequently hinder the development and maintenance of green areas. Nevertheless, many communities in the region are increasingly acknowledging the crucial role of green spaces in enhancing climate resilience and elevating residents' quality of life (Ichamura 2003).

Nairobi city features six prominent public open spaces: Uhuru/Central Park, Jamhuri Park, City Park, Arboretum, Kamukunji, and Jevanjee Gardens, along with two forested areas like Karura Forest and Ngong Road Gardens and private gardens such as Karen Karara. The National Museum, located on Museum Hill, approximately five minutes by car from the city centre, serves as a green space that encompasses the Snake Park and the Botanic Garden. It is also linked to the John Michuki Memorial Conservation Park, through which the Nairobi River flows (Makworo&Mireri, 2011).

According to UN-Habitat, 2020, Kenya, particularly Nairobi, is experiencing rapid urban growth, with the city's population expanding from approximately 2.1 million from the year 2000 to over 5 million by 2020. This swift surge has led to a decline in both the extent and quality of urban green spaces, as urban expansion threatens critical natural areas. Despite these challenges, Nairobi still boasts significant urban green spaces, including Nairobi National Park, Karura Forest, and Ngong Forest, which play a vital role in preserving biodiversity while also offering essential recreational opportunities for city dwellers. Nairobi National Park, situated seven kilometres from Nairobi's central business district, is a unique urban sanctuary that hosts a wide variety of wildlife, lions, giraffes, zebras and especially birds.

2.1.3. Avian Species Composition in Urban Green spaces

Avian species composition is the variety and relative abundance of bird species in each geographic region or habitat. It sheds light on the structure, ecological balance, and functional dynamics of bird communities, as well as how they respond to environmental and anthropogenic causes. Bird's live in a wide variety of environments on all continents (Schweizer and Liu, 2018). However, no bird species is genuinely global; each species is limited to certain locations or ecological niches determined by climatic conditions, plant type, and resource availability. As a result, ecological and evolutionary processes such as speciation, extinction, and colonization alter the makeup of bird species in a particular area, determining patterns of coexistence and community organization.

The comparative analysis of avian community composition and species dominance within urban green spaces is a fundamental pillar of modern urban ecology, particularly as anthropogenic habitat transformation accelerates in rapidly developing cities like Nairobi. The Urban Filter Hypothesis, originally formulated by Poff (1997) and adapted for avian populations by McKinney (2006), serves as the theoretical foundation for this study. This hypothesis posits that urban matrix function as selective filters, where the physical and biological characteristics of a site—such as the vegetation structure at the National Museums of Kenya (NMK) versus the suburban-fringe nature of Karen Karara—determine which species can persist. These sites, while spatially disparate, act as critical ecological refugia that modulate the regional avian pool. By comparing these two distinct locations, this study seeks to identify how site-specific habitat management influences the transition from natural biodiversity to urban-adapted assemblages.

Central to the objective of comparing species composition is the assessment of biotic homogenization, a process where distinct urban sites become increasingly dominated by a small, shared set of synanthropic or generalist species (Aronson et al., 2014). In the context of Nairobi, this phenomenon is often exacerbated by the loss of connectivity between green corridors and the intensification of surrounding land use. The NMK, with its managed botanical legacy, may offer a specialized niche environment, whereas Karen Karara's proximity to residential development likely attracts different avian guilds.

Dominance hierarchies represent a more nuanced measure of community structure than simple species lists, as they reveal the "evenness" or "stability" of an ecological assemblage. When a site is dominated by a few highly successful species—such as common weaver birds or colies—the resulting low evenness index often signals a simplified, and potentially fragile, ecological state (Magurran, 2004). The application of the Berger-Parker Index provides a quantitative mechanism to assess these dominance patterns, allowing for a direct comparison between the NMK and Karen Karara. Significant research suggests that dominance is not solely an intrinsic trait of the species themselves, but an emergent property of the interaction between species traits and the degree of human-mediated disturbance within the site (Blair, 1996). Grounding this study in these two specific sites allows for an assessment of whether higher levels of botanical structure in one site successfully buffer against the dominance of invasive or overly aggressive generalists.

Furthermore, the integration of long-term longitudinal data (2014–2020) is crucial to verifying whether observed dominance patterns are persistent or merely transient artifacts. Short-term studies often fail to account for the "stochastic noise" of annual climatic fluctuations or local ecological disturbances that can temporarily displace dominant species. According to Gotelli and Colwell (2001), consistent sampling over an extended period is a prerequisite for identifying stable community hierarchies. In the Nairobi metropolitan context, this is particularly relevant given the rapid densification of suburban corridors near Karen Karara compared to the relative stability of institutional land at the NMK. This seven-year window provides the temporal depth necessary to determine if these urban green spaces are maintaining distinct "ecological identities" or if they are trending toward a common, simplified community state characterized by high dominance and low richness.

The theoretical framework for this objective is further strengthened by the concept of Landscape Complementation, which suggests that avian movement between sites is often dictated by the availability of specialized resources (e.g., fruit for frugivores or nesting cavities for specialists). While the NMK and Karen Karara may have different species compositions, they may fulfil complementary roles within the broader Nairobi ecological network. Research by Clergeau et al. (2006) highlights that avian community structure in cities is often a function of both the patch-level characteristics and the surrounding landscape matrix. By focusing on these two sites, this study bridges the gap between purely site-specific inventory work and the broader landscape-level requirements of urban bird conservation, providing a clear basis for future urban planning and green space management policies in Kenya.

Ultimately, this study addresses a critical knowledge gap in East African urban ornithology by providing a high-resolution, comparative account of how site-specific filters dictate avian community dynamics. Despite the global trend toward urbanization, there is a paucity of long-term longitudinal research comparing formal botanical institutions with semi-natural suburban patches in sub-Saharan megacities. By anchoring this research in the NMK and Karen Karara, we move beyond generic urban ecological models toward site-specific conservation strategies. This objective sets the stage for a comprehensive evaluation of how anthropogenic land-use regimes in Nairobi can be refined to maintain, or potentially restore, the avian diversity that is essential for the ecological health and resilience of urban environments.

2.1.4. Avian Species diversity in Urban Green spaces

The variety and abundance of various bird species within a specific geographic area or habitat is known as avian species diversity. It clarifies how bird populations react to anthropogenic disturbances and environmental variety, as well as their richness, evenness, and structural complexity. On every continent, birds occupy a variety of ecological niches (Schweizer and Liu, 2018). But no single habitat sustains every species; instead, each site maintains a distinct degree of diversity based on disturbance regimes, resource availability, and habitat layout. The variety of bird species in each area is thus changed by ecological processes including competition, predation, and habitat modification, which determine patterns of community stability and ecosystem performance.

The assessment of temporal changes in avian species diversity within urban green spaces is essential for understanding the long-term impacts of habitat fragmentation and urban densification. As urban centres like Nairobi undergo rapid land-use changes, the longitudinal stability of biodiversity becomes a primary indicator of ecosystem health. Urbanization is one of the leading drivers of global biodiversity change and has substantially altered the structure and composition of avian communities worldwide, Silva et al. (2015). As natural habitats are transformed into built environments, many bird species experience habitat loss, fragmentation, and changes in resource availability, resulting in shifts in species richness, abundance, and community composition. Nevertheless, urban green spaces such as parks, wetlands, cemeteries, riparian corridors, and botanical gardens continue to function as important ecological refugia for birds within cities. Studies conducted across Europe, Asia, and the Americas have shown that urban green spaces with greater vegetation cover, habitat heterogeneity, and larger patch sizes support higher avian richness and diversity (Lepczyk et al., 2017; Leveau et al., 2019). Similarly, Silva et al. (2015) demonstrated that vegetation diversity, green space availability, and reduced impervious surfaces positively influenced bird richness and abundance in urban landscapes. These findings indicate that the ecological quality and structural complexity of urban habitats are critical determinants of avian diversity in cities.

Globally, research on urban avifauna has increasingly emphasized the role of urban green infrastructure in mitigating the negative impacts of urban expansion on biodiversity. Urban green spaces not only provide nesting, feeding, and breeding habitats for resident bird species, but also serve as stopover sites for migratory species. Studies in Central Europe and East Asia have reported that differences in habitat structure, vegetation composition, and landscape connectivity strongly influence avian assemblages within urban ecosystems (Stagoll et al., 2017; Lin et al., 2017). Furthermore, urban ecological studies suggest that fragmented green patches can still support considerable bird diversity when habitat quality and ecological connectivity are maintained. However, urbanization often promotes biotic homogenization, where generalist and synanthropic species dominate while habitat specialists decline (Lepczyk et al., 2017). Consequently, the conservation and management of urban green spaces have become increasingly important components of sustainable urban planning and biodiversity conservation globally.

In Africa, urban ecological research on avian diversity remains comparatively limited despite rapid urban expansion across the continent. Existing studies indicate that African urban areas generally exhibit lower bird species richness than surrounding rural habitats, although some urban ecosystems continue to maintain significant functional and ecological diversity (Lee et al., 2021). Research from Afrotropical cities has shown that urban green spaces can act as critical refugia for bird communities, particularly where native vegetation is retained and human disturbance is minimized. Recent studies in Nigerian cities demonstrated that wildlife parks and structurally complex green spaces supported higher bird diversity than heavily modified urban landscapes, while vehicular and pedestrian disturbances negatively affected avian communities (Kumdet et al.,2025). These findings underscore the importance of habitat quality, vegetation structure, and landscape management in sustaining bird diversity within rapidly urbanizing African cities.

In Kenya, studies on urban biodiversity have primarily focused on vegetation structure, wetland ecology, and broader environmental change, with relatively limited emphasis on long-term avian diversity within urban green spaces (Hasell et al., 2020, Toroitich et al., 2024). Existing research in Nairobi has shown that urban wetlands and remnant forest patches are important habitats for aquatic and terrestrial bird species, although increasing urbanization continues to threaten their ecological integrity. Toroitich et al. (2021) reported that wetland fragmentation and alteration negatively affected aquatic bird biodiversity within Nairobi's urban landscape. Similarly, studies on Nairobi's green spaces have highlighted increasing anthropogenic pressure, habitat degradation, and vegetation changes associated with urban growth (Nyambane et al., 2016). Despite these findings, there remains inadequate localized information on species composition, diversity patterns, and seasonal variation of avifauna within many urban green spaces in Nairobi. This knowledge gap limits effective conservation planning and biodiversity management within the city's rapidly changing urban environment.

2.1.5. Avian Species and Seasonal Weather Changes

Seasonal weather patterns play a fundamental role in shaping avian species occurrence, distribution, migration, breeding behaviour, and community composition across the globe. Variations in temperature, precipitation, humidity, and wind regimes influence food availability, habitat suitability, reproductive success, and migratory timing in bird populations. In temperate regions, seasonal climatic changes strongly regulate migration cycles, with many species moving between breeding and wintering grounds in response to fluctuations in temperature and resource availability (Newton, 2008). Similarly, changes in rainfall and seasonal productivity have been shown to affect bird abundance and species richness in tropical and subtropical ecosystems. Global studies indicate that climate variability and extreme weather events increasingly alter phenological patterns, leading to shifts in migration timing, breeding periods, and species distributions (Both et al., 2006; Şekercioğlu et al., 2012). These climatic influences are particularly significant in urban ecosystems where habitat fragmentation and anthropogenic disturbance may intensify environmental stress on avian communities.

Research conducted in Europe, North America, and Asia has demonstrated that seasonal weather conditions significantly affect avian assemblages within both natural and urban landscapes. Temperature and rainfall patterns influence vegetation productivity and insect emergence, which in turn determine food availability for birds during breeding and migratory seasons. For example, studies have shown that warmer spring temperatures may advance breeding periods and migratory arrivals, while prolonged droughts reduce habitat quality and reproductive success (Crick, 2004; Both et al., 2006). In urban environments, seasonal weather variability interacts with habitat structure and urban heat island effects to shape bird occurrence and community dynamics. Species richness and abundance often fluctuate seasonally in response to rainfall intensity, vegetation phenology, and resource distribution within urban green spaces. Consequently, understanding the relationship between weather variability and avian ecology has become increasingly important in predicting biodiversity responses to climate change and urbanization globally.

In Africa, seasonal rainfall patterns are among the most important determinants of avian species occurrence and movement due to the strong dependence of ecosystems on wet and dry seasonal cycles. Many Afrotropical bird species synchronize breeding activities with rainy seasons when food resources such as insects, fruits, and seeds are more abundant. Seasonal rainfall also influences migratory behaviour, habitat occupancy, and species distribution across savannah, wetland, and forest ecosystems (Borrow & Demey, 2014). Studies conducted in southern and eastern Africa have shown that bird diversity and abundance often increase during wet seasons because of improved habitat productivity and availability of breeding resources. Conversely, prolonged dry periods and climate variability may lead to reduced breeding success, altered migration timing, and localized declines in species occurrence (Cunningham et al., 2015). Urban areas in Africa are particularly vulnerable because climatic fluctuations interact with habitat fragmentation and land-use change, thereby increasing ecological pressure on urban bird populations.

In Kenya, seasonal weather variability plays a major role in influencing avian diversity, distribution, and migratory patterns due to the country's ecological heterogeneity and position along major migratory flyways. Rainfall seasonality strongly affects habitat productivity within forests, wetlands, grasslands, and urban ecosystems, thereby influencing bird occurrence and abundance. Studies in Kenyan wetlands and urban habitats have shown that bird species richness and abundance tend to increase during rainy seasons when water levels, vegetation cover, and food resources are more favourable (Toroitich et al., 2021). Migratory species visiting Kenya from the Palearctic region are also influenced by seasonal climatic conditions that determine stopover suitability and resource availability. In Nairobi, increasing climate variability combined with rapid urbanization has altered habitat conditions within urban green spaces, potentially affecting seasonal bird movements and community composition. However, despite the ecological significance of weather variability in shaping avian occurrence, there remains limited long-term research examining how seasonal climatic changes influence bird diversity and species dynamics within Nairobi's urban ecosystems.

The evaluation of annual seasonal variations in urban avian communities is critical for understanding how species track dynamic resource pulses within fragmented green spaces. In tropical and sub-tropical urban ecosystems like Nairobi, seasonality is primarily driven by bimodal precipitation patterns, which regulate the phenology of flowering, fruiting, and insect abundance. Empirical research demonstrates that avian populations exhibit significant intra-annual shifts in both abundance and composition as they respond to these fluctuating resource bases (Zúñiga-Vega et al., 2025). During the wet season, the surge in primary productivity often supports a wider array of insectivorous and frugivorous species, whereas the dry season acts as an "environmental bottleneck," forcing birds to concentrate in refugia that provide perennial water and reliable food sources. Grounding this study in the National Museums of Kenya (NMK) and Karen Karara allows for a clear examination of whether these sites serve as stable "hubs" that maintain avian populations through these resource-limited periods.

Species-specific traits dictate the degree of seasonal turnover within urban patches. Migratory species, both intra-African and Palearctic, demonstrate high sensitivity to seasonal resource availability, often using urban green spaces as stopover points during transit. Studies have shown that while resident synanthropes maintain a relatively constant presence throughout the year, the "migratory component" of an avian community contributes to significant seasonal pulses in species richness (Lack, 1986). Research conducted in suburban and institutional landscapes across Africa demonstrates that avian communities are rarely sedentary; rather, they exhibit seasonal shifts in habitat use, moving between urban patches based on the availability of perennial water sources and native woody vegetation (Bennun & Njoroge, 1999). For instance, studies in West African urban green belts have shown that while resident generalists maintain stability, insectivorous guilds often undergo significant seasonal turnover, tracking the availability of invertebrate prey linked to wet-season vegetation flushes (La Sorte & Graham., 2021)

2.2. Summary and Research Gaps

Although several studies have examined vegetation within urban green spaces, there remains inadequate localized information on species composition, diversity patterns, and seasonal variation of avifauna within many urban green spaces in Nairobi. This knowledge gap limits effective conservation planning and biodiversity management within the city’s rapidly changing urban environment. Evidence suggests that species may respond to a warming climate by shifting their ranges to higher altitudes or latitudes. Such distributional changes are well documented in temperate regions but are less common in tropical areas (Jetz et al., 2007). In the tropics, where temperature gradients across latitudes are relatively small, species are more likely to seek refuge at higher elevations. However, there is limited evidence that many tropical species can do so successfully, placing them at greater risk of decline under climate-related disturbances (Forero-Medina et al., 2011).

This study provides a comprehensive evaluation of avian community dynamics across the National Museums of Kenya (NMK) and Karen Karara, utilizing a comparative longitudinal framework spanning 2014–2020. By synthesizing data across three objectives—species composition/dominance, temporal diversity trends, and seasonal variations—the research elucidates how urban green spaces act as filtered refugia. The framework identifies the NMK and Karen Karara as distinct ecological islands, where site-specific habitat quality and management regimes interact with temporal climatic pulses to constrain the avian species pool. This integrative approach moves beyond static inventories, establishing a predictive model for how Nairobi's urban green spaces maintain, or fail to maintain, biological integrity amidst rapid metropolitan expansion.

Despite the growing body of literature on urban ornithology, significant research gaps remain that this study is uniquely positioned to address. Firstly, while global studies confirm the phenomenon of biotic homogenization in cities, there is a paucity of long-term longitudinal data in East Africa that compares institutional green spaces with suburban-fringe patches. Most regional research relies on short-term "snapshot" assessments, which are often confounded by stochastic climatic noise rather than deterministic ecological trends. This study fills this gap by employing a seven-year dataset to disentangle successional community shifts from transient population fluctuations. Furthermore, the reliance on diversity metrics that account for both richness and evenness, such as the Shannon-Wiener, provides a more granular understanding of dominance hierarchies than previous descriptive studies.

The third research gap addresses the lack of site-specific seasonal data that accounts for the phenological requirements of avian guilds in tropical urban settings. While it is well-established that seasonal rainfall regulates resource pulses—such as insect emergence and fruit ripening—in African ecosystems, there is limited empirical understanding of how these patterns manifest within the specific confines of Nairobi's urban infrastructure. By grounding this analysis in the NMK and Karen Karara, the study determines if these sites provide "temporal insurance" through the dry season or if they serve as resource bottlenecks. Bridging these gaps is essential for moving from descriptive urban ecology to actionable conservation policy, ensuring that urban green spaces are managed as functional ecological corridors capable of sustaining avian biodiversity through both seasonal variability and long-term urban densification.

Chapter Three: Research Methodology

3.1. Introduction

The study utilized a retrospective ex post facto quantitative design. This approach is appropriate because it allows for the systematic analysis of pre-existing longitudinal data collected over eight years without the need for experimental manipulation. In ecological research, this design is vital for distinguishing long-term variance of biodiversity decline from annual "noise" or fluctuations.

3.2. Research Design

The investigation adopted a retrospective quantitative research design to examine the avian biodiversity patterns observed between 2014 and 2020 in urban spaces. This design is particularly appropriate as it allows for the examination of pre-existing conditions without experimental manipulation of variables. To enhance the robustness of findings, the study incorporated an ex post facto quantitative approach that systematically evaluates how avian species composition, avian diversity are affected by weather seasonality in urban green spaces while identifying statistical patterns and correlations.

3.3. Study Area

The study focused on the ecologically significant green spaces of the Nairobi National Museum (NNM) and Karen Karara Forest within A Rocha Kenya office. The Nairobi National Museum constitutes a riparian habitat along the Nairobi River corridor (illustrated in Figure 3.1). This site is located at 1°16′S latitude and 36°49′E longitude, with an elevation of 1,798 meters above sea level (Nairobi City County Government, 2018). The Karen Karara is located along Ngong road behind the Karen hub and is part of the A Rocha Kenya covering an area of approximately 15 acres of forested ecosystem at an altitude of 1872m above sea level. The area was established as an education centre and currently serves as an environment education centre and a tree nursery. The area is mainly dominated by residential houses with recent land use changing to agriculture in adjacent farms.

The study sites experience a moderate tropical climate characterized by an average temperature of 29°C (Oyugi et al., 2017). Precipitation follows a distinct bimodal pattern, with the long rainy season occurring from March to May averaging 230 mm rainfall, and shorter rains between October and December averaging 160 mm (Ndolo, 2017). These climatic conditions create favourable environments for both resident and migratory avian species while influencing vegetation growth patterns in the urban green space.

The vegetation within the grounds of the National Museums of Kenya (NMK) is primarily defined by the Nairobi Botanical Garden, which functions as a curated display of Kenya’s diverse ecological heritage. Spanning approximately 12 acres, the site includes thematic botanical exhibits such as a succulent garden that represents arid and semi-arid ecosystems, an orchid house, and a wooded garden featuring various indigenous tree species characteristic of Kenyan woodlands and exotic species such as Eucalyptus. Additionally, the grounds incorporate a riparian habitat along the Nairobi River corridor, which supports a mixture of water-adapted vegetation, including papyrus and various water lilies. These gardens serve as an important site for biodiversity conservation, hosting a significant collection of indigenous and exotic plant species, including medicinal and rare flora, while providing an essential green refuge within the urban landscape.

The vegetation at the A Rocha Kenya site in Nairobi, located on a plot of land known as Karara in the rural suburbs of Karen, is characterized by several key features dedicated to conservation and education: Indigenous Forest: The site features a nature trail that winds through an area of indigenous forest. Indigenous Tree Nursery: There is an extensive indigenous tree nursery on the property, which is used to support reforestation efforts and regular management activities. These efforts include the active removal of invasive or exotic vegetation to restore the native habitat. Demonstration Farm: The site includes demonstration farm plots that utilize the "Farming God's Way" methodology, which emphasizes organic, no-till agriculture techniques. This location serves as the Nairobi base for A Rocha Kenya, functioning as a hub for both conservation education and practical environmental management.

The area's soil profile shows distinct variations, with water-absorbent black cotton soils interspersed among porous red earth formations. This diverse physical environment creates multiple habitat types that affect biological distribution patterns. The research location at Nairobi National Museum particularly benefits from its position adjacent to the Nairobi River, which establishes a biologically rich riparian zone through the property. The vegetation community is characterized by dominant species including *Acacia xanthophloea*, *Cordia africana*, and *Ficus sycomorus*, which collectively form a biodiverse habitat supporting numerous avian species.

The selection of the sites was informed by several strategic considerations:

a) Ringing datasets exist for both sites and do not for anywhere else in Nairobi
b) The consistent and standardized management practices implemented at NMK ensure environmental stability, facilitating reliable longitudinal monitoring in both sites.
c) The riparian ecosystem created by the Nairobi River presents a unique microhabitat with elevated moisture levels and distinct ecological characteristics.
d) The site's proximity to urban development provides an ideal context for examining anthropogenic impacts on avian populations.

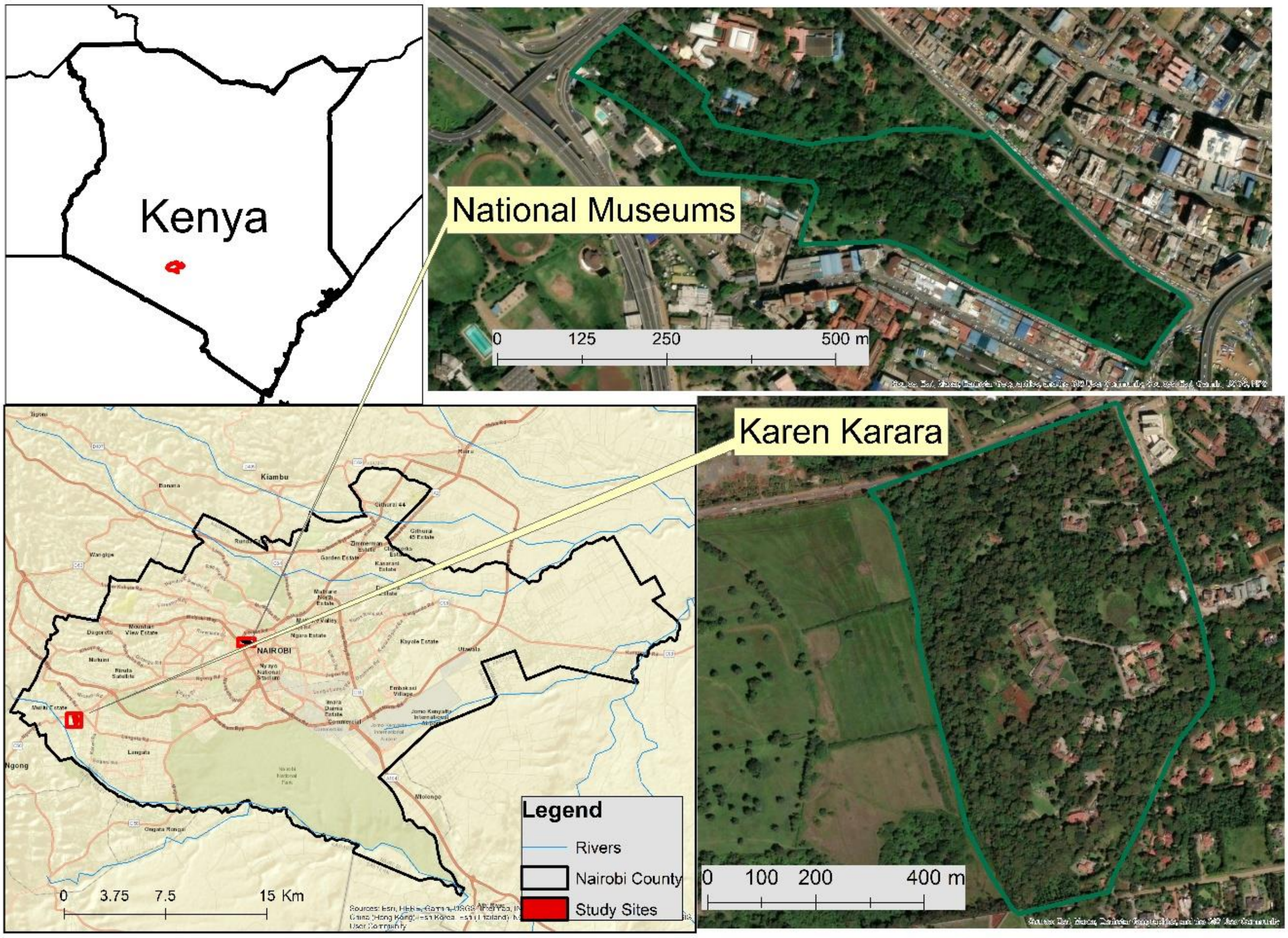

Figure 3: Map of Nairobi County showing the location of the study sites

3.4. Data collection

The National Museum of Kenya has been collecting data and ringing birds countrywide following established protocols globally. The birds were captured through mist-netting. The method involves erecting fine nylon mesh nets, usually between 2–4 m high and 6–18 m long, along bird flight paths, forest edges, wetlands, savannahs, or understory vegetation where bird activity is concentrated. Nets are typically opened during peak bird activity periods, particularly from early morning to mid-morning and sometimes late afternoon, and are checked at regular intervals, usually every 15–30 minutes, to minimize stress, injury, or predation risks to captured birds (Ralph et al., 1993). Once removed from the nets, birds are commonly identified to species level, ringed or banded, aged, sexed where possible, weighed, and measured before being released back into their habitat.

Although mist nets are effective in capturing birds, most mist nets are deployed at ground level, which biases the captured data toward understory species. Canopy-dwelling birds are frequently missed or under sampled unless expensive, complex elevated net rigs are used. Studies have shown that mist-net capture rates can be skewed, with larger or more robust birds being harder to catch or more adept at bouncing out of the mesh than smaller, lighter species (Tattoni & LaBarbera. 2022). This study recognizes these inherent challenges in sampling especially in the forested areas of Karen Karara leading to unequal sampling efforts between the sites.

3.4.1. Target Population

The research focused on the complete avian community inhabiting the National Museums of Kenya and the Karen Karara green spaces between 2014- 2020, encompassing both resident species that maintain year-round populations and migratory species that utilize the area seasonally. This study targeted a longitudinal dataset of avian population counts from the Nairobi National Museum's and Karen Karara among other urban green spaces that was gathered between 2014 and 2020. The database contained a total of 4,014 individual birds recorded from both resident and migratory species (127 in total) in the entire county. However, data was filtered to maintain birds ringed within the selected study sites yielding 3843 individuals of 123 species. It also has locational information (location, date and time), life history information (age, sex, numbers) as well as morphological characteristics relevant for this study (species) pertaining to ringed birds in Kenya. The large size of the database was critical to analysis because it allowed for the tracking of compositional shifts in urban-adapted species, accurate calculation of biodiversity indices, and credible comparisons of diversity trends across seasons and years, ultimately measuring the impact of urbanization, climate variance and human pressure on the avian community.

3.4.2. Data collection protocols and Instrumentation used

Although this research is not associated with new field research, clarification of the quality of data is impossible without knowing about original instrumentation and protocols that were used. The data collection tools employed by the researchers at NNM were standardized in ornithology. They comprised mist nets (3 x 12 m) positioned in high bird activity areas; breathable bird bags for temporary individual storage during processing and unique number identification aluminium leg rings that can be used to identify them long after their release. Mist-netting operations between 2014 - 2020 were carefully designed to maximize capture efficiency while minimizing stress to birds. During active netting sessions, field personnel conducted checks at 30-minute intervals to promptly extract any birds captured, ensuring their safety and reducing potential stress or injury. Each bird was carefully removed from the net and placed in a breathable cloth bird bag for temporary holding before processing. Morphological measures were taken with a digital calliper, wing ruler and precision weighing scales (0.1g). For environmental monitoring, field teams were equipped with portable GPS, manual weather recording, and thermometers, whereas bird field guides were used to properly identify species age and sex.

The duration of these mist-netting sessions is largely determined by the timing of peak bird activity and local weather conditions. Sessions typically commence at sunrise and continue for approximately four to five hours, concluding once bird activity notably decreases, which is standard practice in such longitudinal studies to ensure consistent sampling effort. While the specific number of nets deployed can vary depending on the site characteristics and research objectives, these standardized protocols ensure that the capture data remains comparable across different sampling days and locations, forming a reliable basis for long-term ecological monitoring and biodiversity assessment (Nussbaumer et al., 2022).

3.5. Study Sample

3.5.1 Sampling Procedure

The database contained 4,014 individual birds of 127 species ringed in various sites within Nairobi County. The data was filtered to maintain the individuals ringed within Karen Karara and Nairobi National Museums grounds only. All captured birds had been banded with an aluminium leg band with a unique number which enabled them to be identified later in any subsequent capture. Observations of the bird species observed/heard during fieldwork were also recorded.

3.5.2. Study Sample Size

The sample encompasses all avian species captured during mist-netting sessions carried out in two urban places: Nairobi National Museum grounds and Karen Karara. The data was filtered to maintain data from individual birds ringed within Karen Karara and Nairobi National Museums grounds between 2014 - 2020 obtaining a sample of 3,843 individuals from 123 species, with 696 individuals sampled from Karen Karara and 3147 individuals sampled from NMK.

3.6. Description of the Datasets

3.6.1 Data structure, variables and coverage

This study was based on secondary data that was collected in documented materials that are found in the Nairobi National Museum. The data is organized in the form of bird-ringing records. They are annual recordings between 2014-2020. The sampling design follows the Jolly Seber model (Hightower et al., 2016) mark-recapture method to estimate the size of various bird populations and gauge their trends over time. Adjustments were made to accommodate death, birth, immigration, and emigration records. With this model, birds are periodically captured, tagged, released and recaptured so the researcher could estimate the population parameters at multiple points in time. Besides the data regarding the capture of birds (which details age and sex determination based on plumage characteristics, morphometric measurements such as wing chord, tarsus length, and body mass, breeding condition and moult status), the archives also consist of meteorological records recording changes of precipitation and temperature, field notes connected with the description of the species peculiarities and the situation in which they breed, and ecological observations.

3.6.2. Data Management

Data integrity was maintained by intensive management procedures. Ringing records were recorded in uniform ringing ledgers and supplemented by photographic records and field notes. Digital records could exist over time and be accessed using backup systems. The initial fieldwork staff were bound to the standard protocols of measurements as well as ethical treatment practices improving the reliability and consistency of data over the seven-year data collection period.

3.7. Data Quality Assurance (DQA) and Cleaning Protocols

In lieu of pilot testing (which is intended for primary instrument design), the following DQA protocols were applied to ensure the integrity of the secondary data:

a) **Data Filtering:** The raw database was filtered to include only individuals ringed within the two target study sites (NMK and Karen Karara) between 2014 and 2020. This resulted in a validated core sample of 3,843 individuals.

b) **Taxonomic Standardization:** All species were cross-referenced against the eBird/Clement's checklist to resolve nomenclature discrepancies and ensure accurate richness counts. This standardization is essential in longitudinal studies where taxonomic reclassifications may occur over the study period (Sullivan et al., 2009).

c) **Recapture Management:** To prevent the artificial inflation of abundance and diversity metrics, unique aluminium leg ring numbers were used to identify and manage recaptures. Multiple captures of the same individual within a single sampling session were excluded from the analysis. However, only one recapture was recorded.

d) **Temporal Alignment:** Capture dates were categorized into four three-month quarters based on local climate patterns: Rainy (March-May), Dry (December-February), Cold (July-August), and Mid-Warm (September-November).

3.7.1. Data standardization

To account for inherent disparities in sampling intensity between the National Museums of Kenya (NMK) and Karen Karara, individual-based rarefaction was employed to standardize avian species richness. This method uses a resampling approach to estimate the number of species expected in a sub-sample of a specific size, effectively allowing for an equitable comparison between sites with unequal total observation counts. Using the vegan package in R (Oksanen et al., 2022), rarefaction curves were generated to visualize the rate of species accumulation relative to sampling effort, with the analysis constrained to the minimum sample size (N = 696 individuals) recorded across the two study sites. To determine if observed differences in species richness were statistically significant, 95% confidence intervals were calculated for the rarefied richness estimates; an overlap in these intervals at the standardized sample size served as the criterion for identifying statistically indistinguishable avian communities between the institutional and suburban-fringe study areas.

3.7.2. Data Processing and Statistical Analysis

All statistical computations were performed in R (R core team 2025) with a significance threshold established at $p < 0.05$. Avian diversity within each of the sites was quantified using the Shannon-Wiener diversity index (H'), and similarity between sites across the study period was evaluated using Jaccard's similarity index. To examine seasonal variation in bird community composition, the year was partitioned into four 3-month seasonal quarters (rainy, dry, and cold periods). This was also aligned to the bird ringing seasons conducted after every 3-4 months annually and consistently conducted at the NMK and Karen Karara between 2014 and 2020. In addition, since the sites are close to one another and the movement of the species specifically for birds within the urban centres is also high, the study maintained a three-month seasonality. This helped to detect slight changes and catered for fledging of the birds if all or any of the bird species breed in any of the site. Differences across seasons and sites were evaluated using non-parametric Kruskal–Wallis tests. The seasons include:

- Rainy season: March April, May
- Dry season: December, January, February
- Cold season: June, July, August
- Mid-Warm: September, October, November

3.6.1 Analysis of Community Composition (PERMANOVA and Pielou's J)

To evaluate the influence of site and season on avian species composition, a Permutational Multivariate Analysis of Variance (PERMANOVA) based on Bray-Curti's dissimilarity was employed. PERMANOVA is the recognized standard for multivariate ecological data as it is non-parametric and accounts for species identity and relative abundance simultaneously (Anderson, 2001).

To complement this, Pielou's Evenness Index (J) was calculated to measure species dominance. This index represents the ratio of observed diversity to the maximum possible diversity (H'/H' $_{max}$) using the formula:

$$J' = \frac{H\prime}{H'max} = \frac{H\prime}{In(S)}$$

Where: **J'**: Pielou's Evenness Index, H': Shannon index, H'max: Maximum diversity, S: Total number of species in the sample

3.6.2 Diversity Trend Analysis (Shannon-Wiener & Linear Regression)

The Shannon-Wiener Index (H') was calculated to quantify alpha diversity, accounting for both species richness and evenness. To model the trajectory of diversity over the eight-year study period, Linear Regression was applied to the *H'* values. This frequentist modelling approach is appropriate for detecting longitudinal trends in biodiversity.

The Shannon index was calculated using the following equation all:

$$H' = -\sum_{i-1}^{s} piInpi$$

where H' is the species diversity index, s is the number of species, and pi is the proportion of individuals of each species belonging to the ith species of the total number of individuals.

3.6.3 Seasonal and Similarity Analysis (Kruskal-Wallis & Jaccard)

Since biodiversity indices frequently violate the assumptions of normality, the Kruskal-Wallis Rank Sum Test was used to compare Shannon diversity across the four seasonal quarters. This non-parametric approach is robust for determining whether observed differences in diversity across climatic seasons are statistically significant (Bennun & Fanshawe, 1997).

Finally, Jaccard's Similarity Index was utilized to quantify the beta-diversity (species overlap) between the two study sites. This index is particularly appropriate for presence-absence data in fragmented landscapes.

The Jaccard's index was calculated using the formula:

J (A, B) = |A∩B| / |A∪B|

Where, A∩B Number of common species in both sets.

A∪B: Total unique species across both sets

3.7 Legal and Ethical Considerations

While this study did not capture bird directly, data was collected by National Museums of Kenya and adhered to the Best Practices in Bird Handling, ensuring that primary data collection (by NMK personnel) involved 30-minute net checks to minimize stress. Formal research permits were obtained from the NACOSTI and WRTI. All sensitive ecological data, such as specific nesting locations, have been kept confidential to protect the species from disturbance.

Table 1: Summary of data analysis table

Study Objective	Independent Variable	Dependent Variable	Statistical Analysis
1. Determine changes in avian species composition	● Year	● Trends in species composition ● Species Composition	● PERMANOVA ● Shannon-Wiener Index
2. Assess changes in avian species diversity	● Year	● Species richness ● Species diversity	● Shannon-Wiener Index ● Jaccard's Index
3.Evaluate associations between temporal trends and variations in avian species diversity and different climatic regimes	● Year ● Seasonal variations	● Species diversity ● Trends in species composition	● PERMANOVA ● Kruskal Wallis

3.7.3. Data Security and Confidentiality

Responsible data management practices were applied throughout the study. Sensitive information, such as nesting or roosting site locations, will remain confidential to prevent disturbance. Data was securely stored on encrypted digital platforms with access restricted to authorized personnel. Where possible, anonymized datasets will be shared under open science principles, fostering transparency without compromising ecological integrity.

Chapter Four: Results

4.1. Introduction

This study investigated avian species composition, diversity and seasonal variations within two green spaces in Nairobi (National Museums of Kenya and Karen Karara). Data was obtained from the National Museums of Kenya bird monitoring database. The data contained information of the ringed birds in Kenya with location, date and time, age and sex of the birds as well as morphological characteristics listed.

4.2. Sampling effort

Since both sites were sampled unequally, to control for unequal sampling intensity, individual-based rarefaction was performed using the vegan package in R. As illustrated in the rarefaction curves (Fig.4), both the NMK and Karen Karara sites exhibit similar species accumulation rates at lower sampling intensities (up to N=696). This overlap demonstrates that the higher observed species richness at the NMK is a direct function of increased sampling effort (N =3147) rather than an inherent disparity in local biodiversity. The lack of an asymptote for either curve indicates that the avian communities at both sites remain under-sampled, and future monitoring efforts are warranted to fully characterize the regional species pool.

Table 2: Sampling effort per site showing number of days, nets set and total hours sampled

Site	Number of days	Number of Nets	Total hours	Birds ringed
NMK	230	3	3450	3147
Karen Karara	23	2	230	696
Totals	**253**	**5**	**3680**	**3843**

Species richness was standardized using individual-based rarefaction to a common sample size of 696 individuals. After correcting for unequal sampling effort, the National Museums of Kenya (56.02 ± 3.32 species) and Karen Karara (54 species) demonstrated comparable avian diversity. The overlap in the 95% confidence intervals indicates that site-specific richness is statistically indistinguishable when sampling effort is controlled. This result highlights that the higher raw richness recorded at the NMK in this study is primarily a reflection of higher observation frequency rather than a genuine biological disparity in community richness between the institutional grounds and the suburban-fringe patch

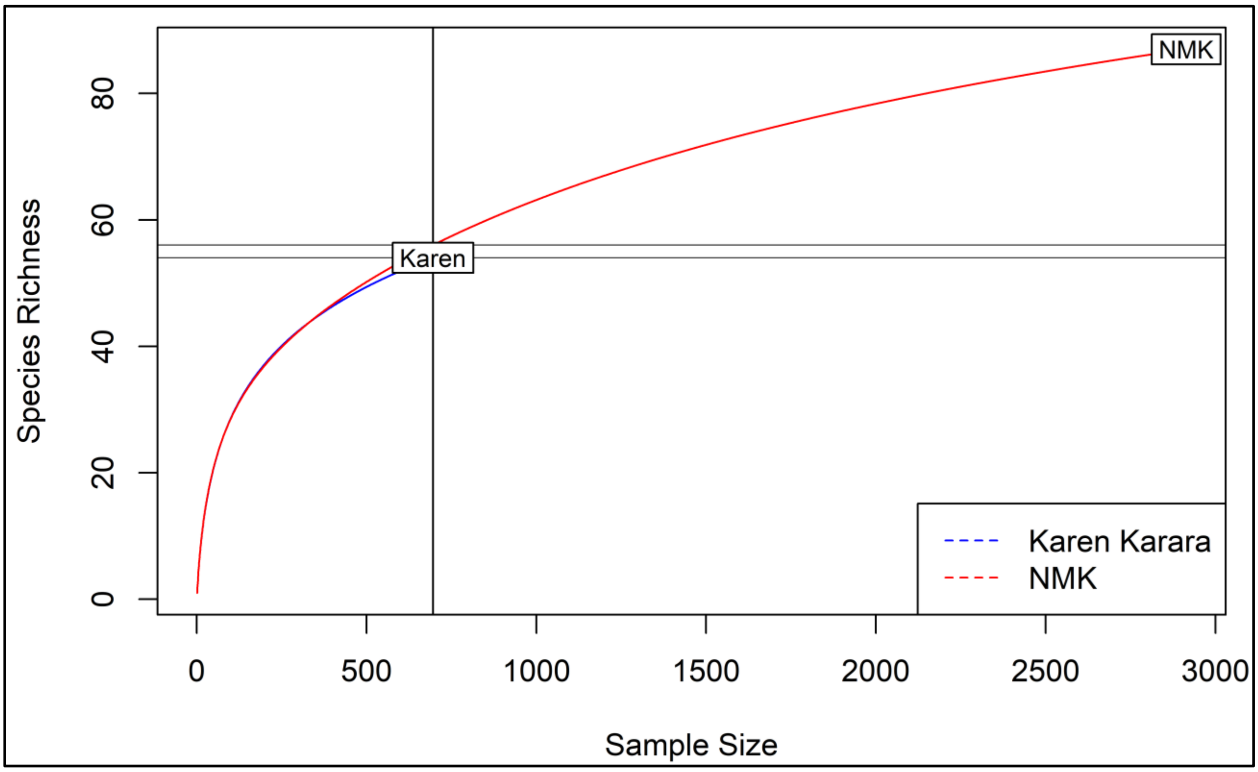

Figure 4: A rarefaction curve comparing Karen Karara and NMK

4.3. Species Characteristics

A total of 3843 bird records were obtained from Karen Karara and NMK. Most birds (82%) were sampled from NMK while the rest were sampled in Karen Karara. (See table 2)

Table 3: Summary of bird population characteristics sampled in the study sites.

Site	**No. of birds**	**No. of species**
Karen Karara	696	54
NMK	3147	88

4.4. Avian species composition and dominance

Pielou's evenness (*J'*) values revealed a distinct disparity in community structure between the two study sites, indicating that the avian assemblage at Karen Karara is more equitably distributed than at the NMK locality (Fig. 4). Pielou's evenness values were generally higher in Karen than in NMK. The median evenness in Karen was approximately 0.87, whereas NMK exhibited a lower median of 0.78. The interquartile range for Karen was relatively narrow, indicating moderate variability among species with most values ranging between roughly 0.85 and 0.87. The box plot for Karen shows a relatively compressed interquartile range (IQR), with values predominantly clustered between 0.85 and 0.87. This tight clustering, coupled with the observation that most data points fall within or slightly above the upper quartile, suggests a high level of consistency in relative species abundance across the sampling units. In contrast, NMK showed slightly greater dispersion, with values spanning approximately 0.76 to 0.84 (Fig.4). The highest observed evenness occurred in Karen (approximately 0.91), whereas the lowest value was recorded in NMK (approximately 0.76). This suggests that while certain sampling points in NMK may approach higher evenness, the overall community is subject to greater dominance by a subset of species compared to the more balanced community composition observed in Karen. Overall, species assemblages in Karen Karara were more evenly distributed among species compared with those in NMK, suggesting greater community evenness at the Karen locality.

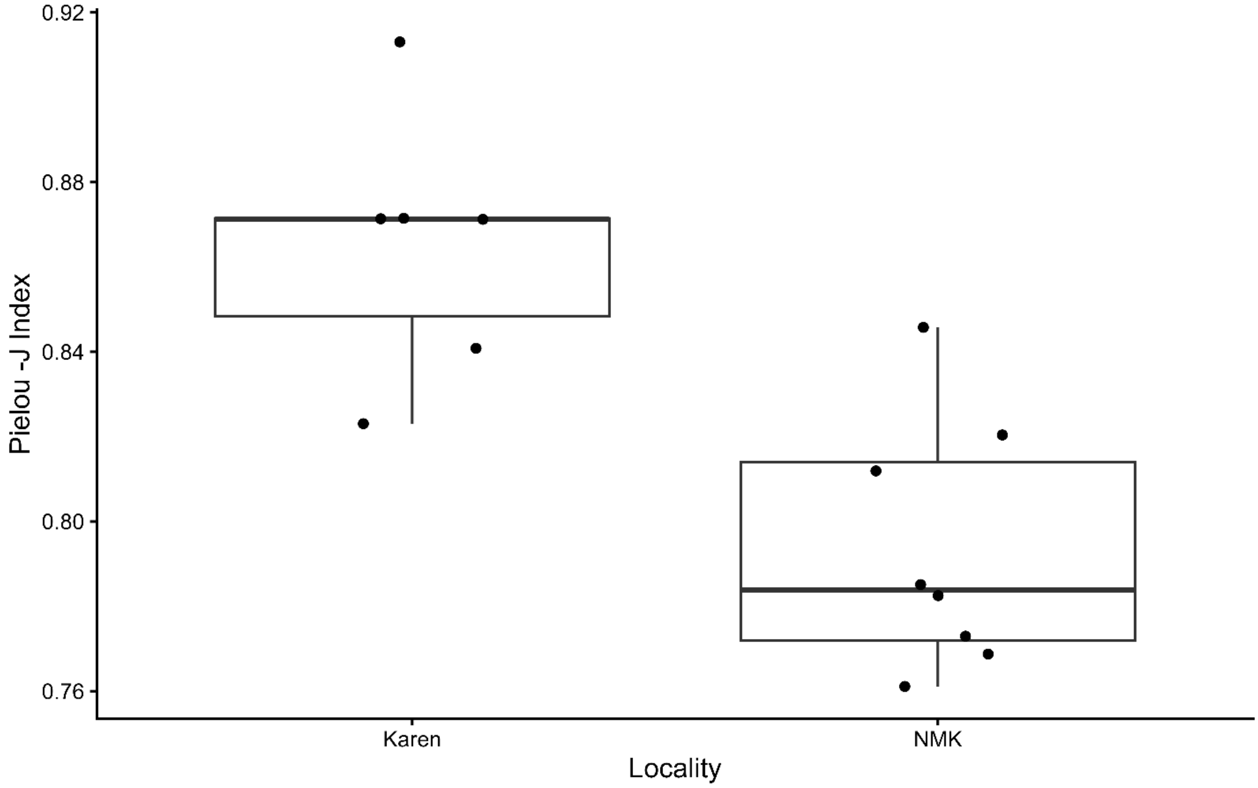

Figure 5: Box plot showing Pielou index of avian species between Karen Karara and NMK Nairobi.

The observed difference in Pielou's evenness between Karen Karara (median 0.87) and NMK (0.78) suggests that these two localities maintain distinct avian community structures. In ecological theory, community evenness is a critical component of biodiversity that reflects how equitably individuals are distributed among species.

4.4.1. Common Species

In this dataset, the NMK exhibits higher raw counts for its top-ranked species, such as the Red-billed Firefinch (N=464) and Baglafecht Weaver (N=389), whereas Karen Karara shows lower absolute totals, with the Cabanis's Greenbul leading at (N=121).When interpreting species dominance metrics between the National Museums of Kenya (NMK) and Karen Karara, it is critical to first account for the disparity in sampling effort, as raw abundance counts are highly sensitive to the number of survey days and total observations.

Table 4: Dominant species by site between NMK and Karen Karara

Species	Karen Karara	Species	NMK
Cabanis's Greenbul	121	Red-billed Firefinch	464
Grey-backed Camaroptera	62	Baglafecht Weaver	389
White-starred Robin	61	Village Indigobird	234
Rüppell's Robin Chat	56	Olive Thrush	213
Yellow-whiskered Greenbul	55	Common Bulbul	206

4.5. Changes in avian species diversity

4.5.1. Species diversity Trends

Species diversity was quantified using the Shannon–Wiener index (H′), which reflects species richness and evenness at each site. Shannon diversity ranged from two (2) to four (4) at both sites but showed an overall decline over the study period. At the NMK grounds, H′ decreased from 3.09 (2014) to 2.90 (2015), increased to 3.20 (2016), but then declined continuously thereafter to 1.90 (2020). At the KK site, H′ increased slightly from 2.90 to 3.20 early in the review period declined through 2017, rose briefly in 2018 (H′ = 2.90**)**, and continued to decrease thereafter (Fig.5). Temporal trends were evaluated using linear regression, which showed a significant decline in diversity over time at Karen Karara ($p < 0.05$) and insignificant trend at the NMK ($p = 0.081$) and a significant difference in diversity between sites (Fig. 5).

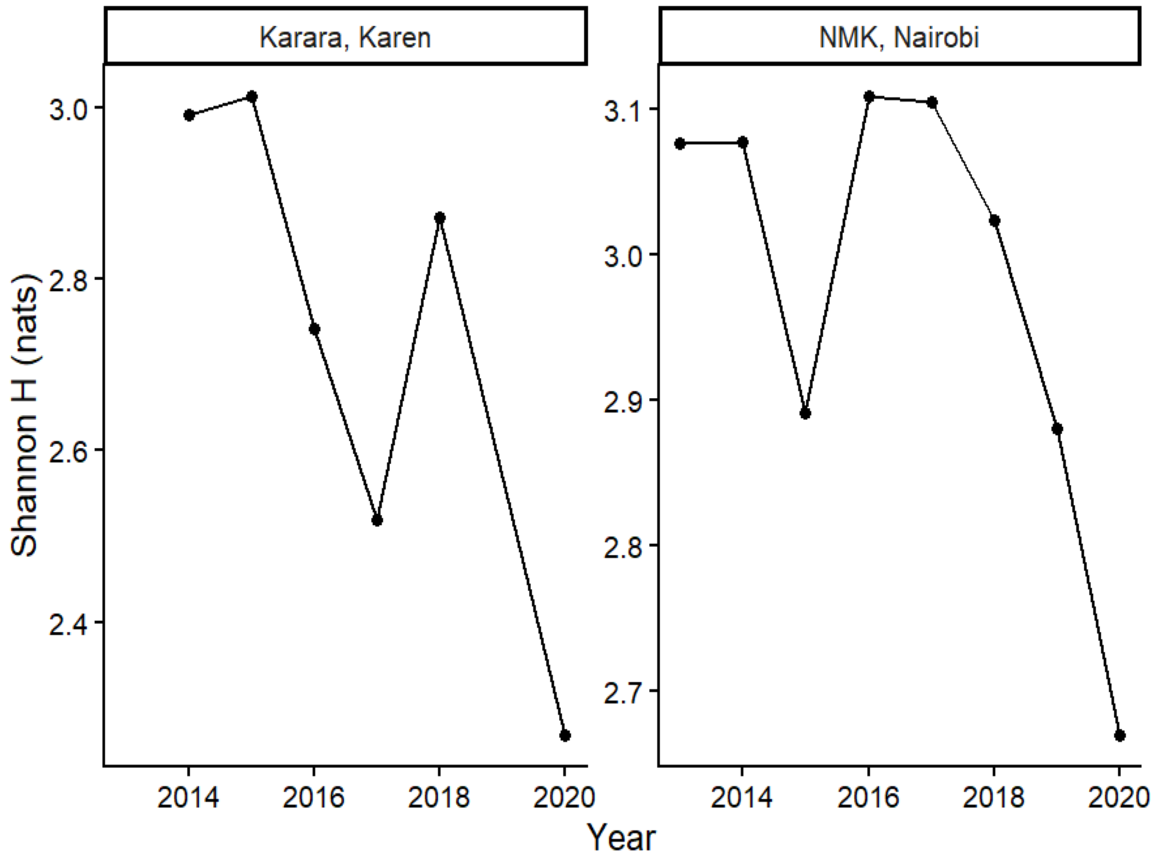

Figure 6: Shannon index avian species diversity between Karen Karara and NMK between 2014 and 2020.

Temporal changes in Shannon diversity index further revealed differing patterns of annual variation between the two localities (Figure B). At Karen, avian diversity exhibited pronounced fluctuations over time. Shannon diversity declined substantially between 2015 and 2017, followed by a marked increase between 2017 and 2018. However, the largest decline occurred between 2018 and 2020, where the diversity index decreased by approximately 0.60 units. These fluctuations suggest considerable instability in avian community composition within Karen during the study period, potentially reflecting changing habitat conditions, anthropogenic disturbance, or climatic influences affecting species occurrence and abundance.

In comparison, NMK demonstrated relatively moderate year-to-year variation in Shannon diversity. Although diversity declined between 2014–2015, 2017–2018, 2018–2019, and 2019–2020, the magnitude of change was generally smaller than that observed at Karen Karara. A moderate increase in diversity was recorded between 2015 and 2016, after which diversity gradually declined toward 2020. Overall, the relatively narrower variation and consistently higher Shannon H′ values at NMK suggest a more stable and resilient avian assemblage compared to Karen. This pattern may indicate that NMK provides more favourable habitat conditions, greater vegetation heterogeneity, or lower ecological disturbance, thereby supporting sustained avian diversity over time.

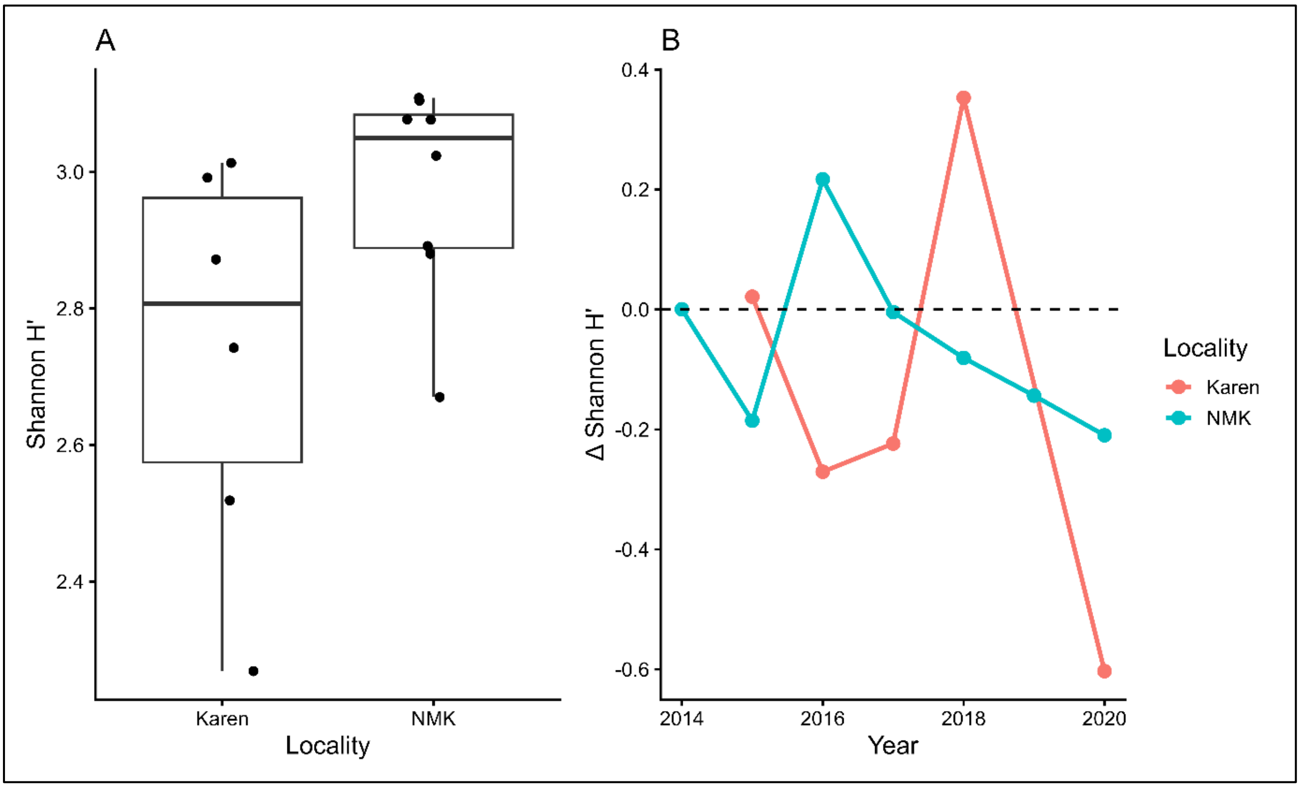

Figure 7: Median Shannon index (A) and variance in Shannon Index (B)across the years for the Karen Karara and National Museums of Kenya between 2014-2020

Figure 5 (A) indicates that NMK consistently exhibited higher Shannon diversity values compared to Karen throughout the study period. Figure B illustrates temporal variation in avian diversity, measured using the Shannon diversity index (H′), between the Karen and National Museums of Kenya (NMK) study sites. NMK recorded a higher median diversity index, with values largely concentrated above 2.8, suggesting relatively high and stable species diversity. In contrast, Karen displayed lower median diversity values and a wider range of variation, with Shannon H′ values ranging from approximately 2.27 to 3.01. The greater spread observed in Karen indicates higher temporal variability in avian community structure relative to NMK.

Shannon diversity at Karen Karara shows a significant declining trend over time (slope = −0.111, $p < 0.05$, $R^2 = 0.68$). This indicates a substantial reduction in avian diversity across the study period, with time explaining approximately 68% of the observed variation in diversity. The steep negative slope suggests a consistent loss of species richness and/or evenness, potentially reflecting increasing habitat disturbance or environmental change at the site. In contrast, Fig. 4.1 shows that NMK exhibits a weaker, non-significant declining trend (slope = −0.041, $p = 0.081$, $R^2 = 0.42$).

Although diversity appears to also decrease over time, the relationship is not statistically significant at the 0.05 level, and time explains a smaller proportion of the variance compared to Karen Karara. This suggests relative stability in overall diversity at National Museums of Kenya, despite minor interannual fluctuations, and indicates that there are site-specific temporal dynamics in bird diversity. The significant decline observed at Karen Karara contrasts with the more stable pattern at National Museums of Kenya, highlighting spatial heterogeneity in biodiversity trends within the same regional context.

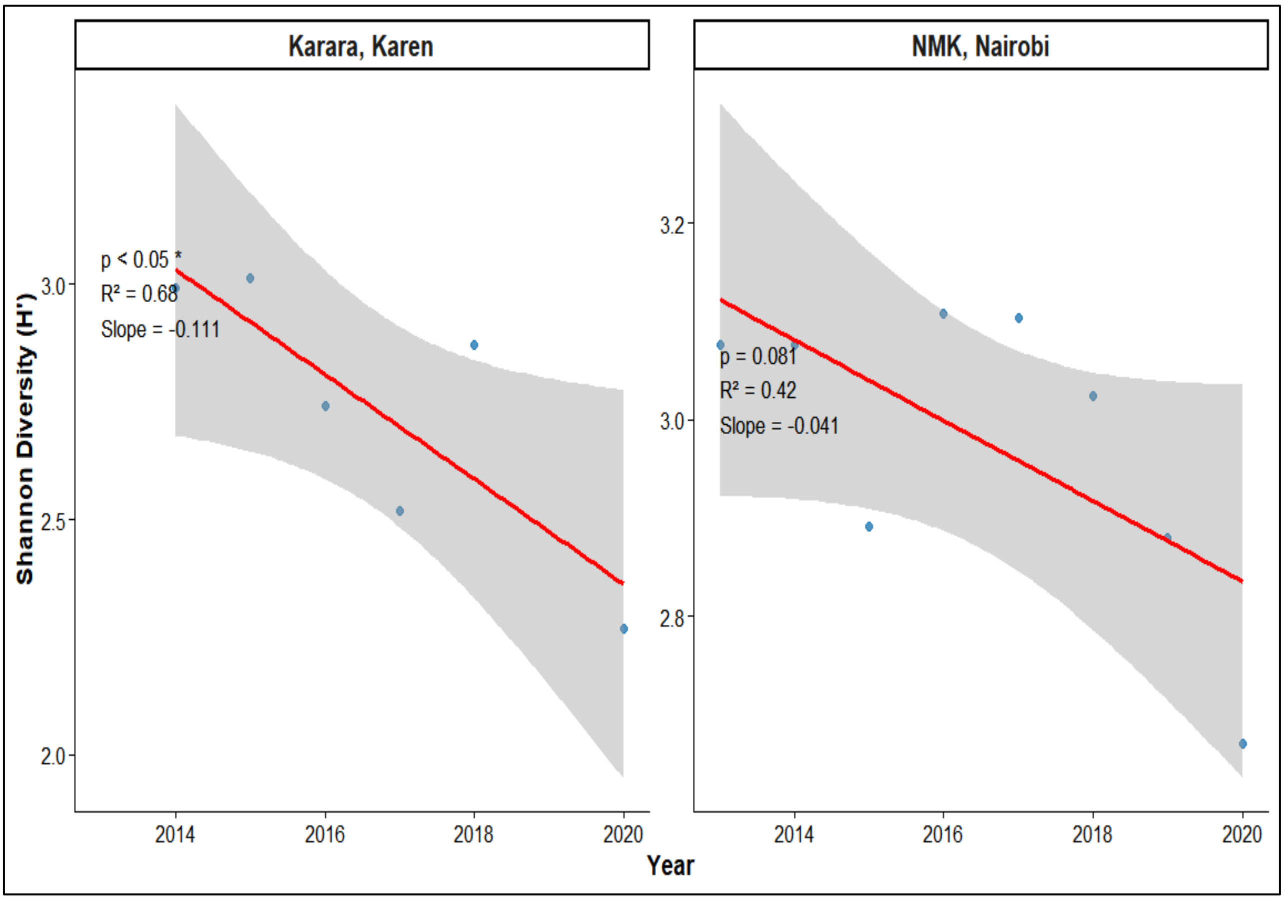

Figure 8: Avian species trends in Shannon Diversity index (2014-2020) in Karen Karara and NMK.

4.5.2. Species Similarity

To evaluate the degree of shared avian composition between Karen Karara and NMK, Jaccard's similarity index was calculated for each year from 2014 to 2020. The analysis revealed consistently low similarity indices across the study period, with all recorded values falling below 0.4 (Fig.8). This suggests that the two localities maintain distinct avian assemblages, with relatively little species overlap despite their geographical proximity.
The trajectory of the Jaccard index displays significant year-to-year fluctuation, characterized by periods of moderate similarity followed by sharp declines. For instance, the data shows peaks in similarity around 2015 and 2018, which are interspersed with pronounced troughs, most notably in 2017 and 2020. These oscillations indicate that the community composition at these sites is dynamic, potentially influenced by annual variations in migratory patterns, local environmental conditions, or transient species presence that periodically alters the degree of shared biodiversity as well as sampling effort.

Using the rarefaction data, similar results were obtained, community indices reveal a pattern of persistent diversity and stable compositional turnover at both the National Museums of Kenya (NMK) and Karen Karara study sites over the 2014–2020 period (Fig.9). The median Shannon values remained consistently robust, typically oscillating between 1.5 and 2.5. Parallel to the Shannon diversity trends, the Jaccard similarity index provided evidence of high compositional stability within the avian communities. Throughout the study period, Jaccard values demonstrated consistent horizontal trends with relatively low inter-annual variance, suggesting that the core species assemblage at both sites remains highly resistant to turnover. Unlike the Shannon index, which is susceptible to fluctuations in raw abundance, the Jaccard index remained stable, reinforcing the conclusion that while the number of individuals observed might vary, the identity of the bird species utilizing these habitats is characterized by significant site fidelity and long-term presence.

Despite these annual fluctuations, generalized linear model (GLM) analysis was employed to determine if there was a directional shift in site similarity over time. The results indicated that there is no statistically significant temporal trend in the Jaccard similarity ($p = 0.145$). This lack of significance suggests that the avian communities at Karen Karara and NMK are not trending toward convergence (biotic homogenization) or further divergence; rather, they appear to maintain a stable, albeit low, level of community distinctness over the studied seven-year interval.

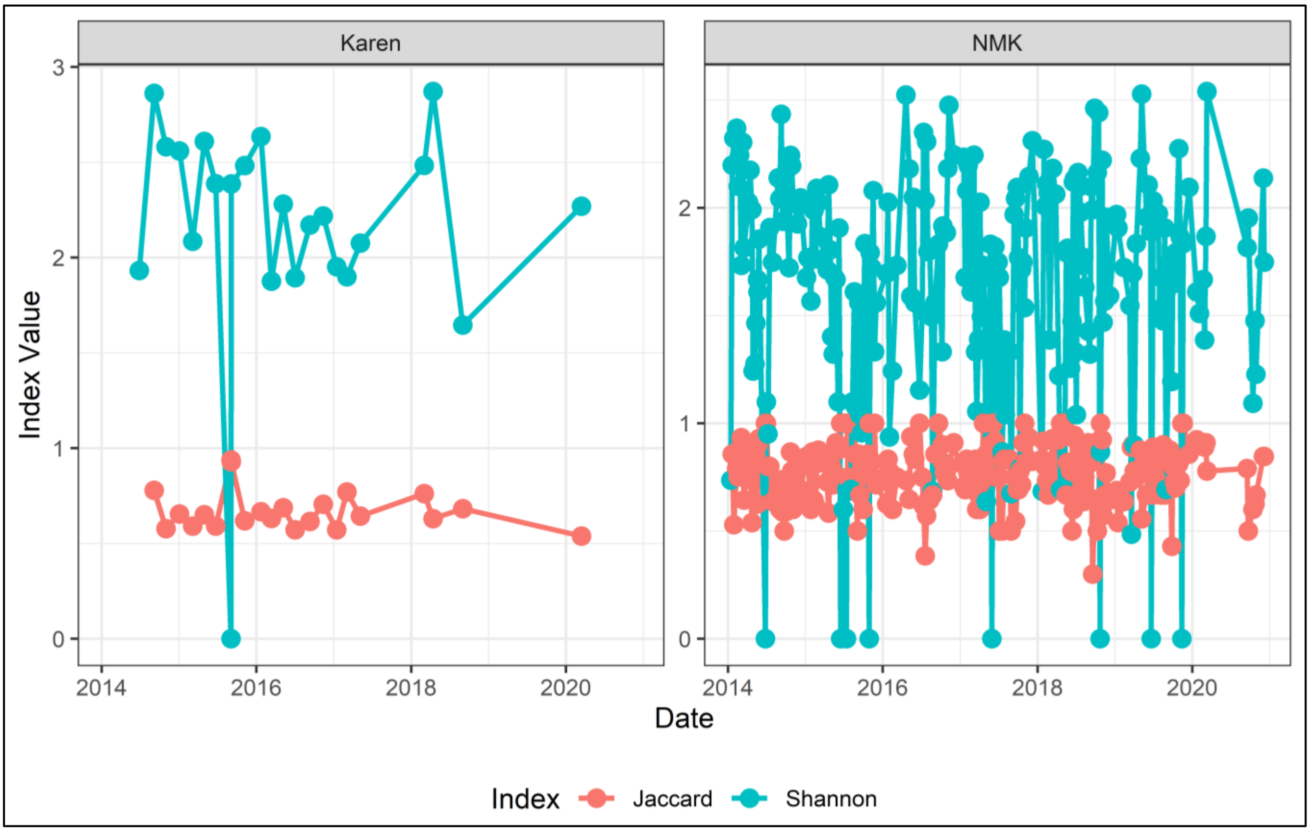

Figure 9: Shannon and Jaccard similarity indices of avian species between Karen Karara and NMK between 2014 and 2020.

4.6. Seasonal diversity of avian species and population trends

High diversities were recorded in the months of September through November at the NMK while high diversities were recorded in March, April and May at Karen Karara. Between 2014 and 2016, higher diversities (H = 0.18) and (H = 0.41) were recorded in NMK in the annual dry periods (June - August) and later dropped to H = 0.21 in 2017. Similarly, in Karen Karara, there was a drop from H = 0.13 to H = 0.07 in 2016 (Fig. 4.3). Despite these localized peaks and troughs in Shannon diversity, statistical testing indicated that the overall diversity did not differ significantly between seasons. Kruskal Wallis test showed that overall, species index did not differ between the seasons using Kruskal Wallis Test (p=0.174 for NMK and p=0.3085 for Karen Karara). Dunn's post-hoc tests revealed no significant pairwise differences in Shannon diversity among seasons after Bonferroni correction (all adjusted p-values > 0.05), indicating that seasonal variation in overall diversity was limited despite significant differences in species composition supporting the findings of objective one (Fig 4.5)

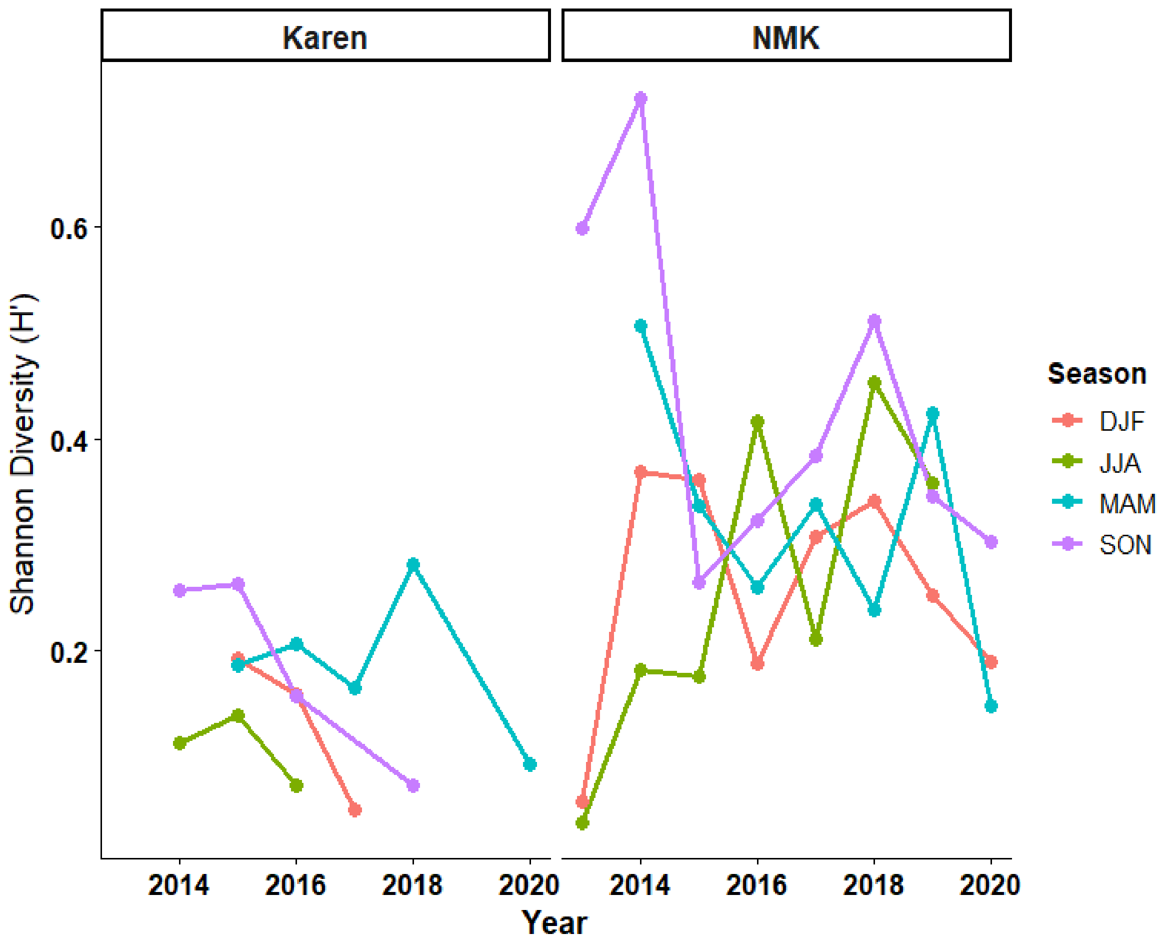

Figure 10: Seasonal variation in bird diversity (2014-2020) in Karen Karara and NMK Nairobi (Seasons ranged between December, January, February (DJF), March, April, May (MAM), June, July, August (JJA) and September, October and November (SON).

Bird species composition was tested whether they differed by season, site and the interaction between the sites using Permutational Multivariate Analysis of Variance (PERMANOVA) using Bray-Curtis dissimilarity tests which tests community composition and not just diversity. The analysis revealed significant differences in bird community composition across seasons and between localities (F = 3.84, R^2 = 0.42, p = 0.001), indicating strong seasonal structuring of species assemblages with site-specific responses. Season and locality together explain 42% of the variation in species composition. This suggests that temporal and spatial environmental variation contributed substantially to differences in avian community structure among the sampled sites and seasons.

Table 5: PERMANOVA of bird species composition.

Source of Variation	Df	Sum of Squares	R2	F-statistic	P-value
Season	7	0.0083	0.439	3.80	0.001***
Residual	34	0.0107	0.561	-	-
Total	**41**	**0.0190**	**1.000**	**-**	**-**

To further investigate the nature of these compositional shifts, an assessment of multivariate homogeneity of dispersion was conducted. Assessment of multivariate homogeneity of dispersion using betadisper analysis showed significant variation in community dispersion among seasons (F = 3.6901, p = 0.0193).

The assumption of homogeneity of multivariate dispersions was tested using the betadisper procedure based on Bray-Curtis dissimilarity. The average distances to the group medians were found to be comparable across all four seasons (December-February: 0.016, June-August: 0.016, March-May: 0.019, September-November: 0.024), indicating that the observed seasonal differences in community composition are not confounded by unequal variance between the groups (Fig.11) These results suggest that avian assemblages were more heterogeneous during September-November season compared to the other seasons, indicating increased variability in species composition during this period.

These findings suggest a decoupling of "diversity" and "composition." Although the total number of species and their relative abundances—represented by the Shannon index—do not shift significantly on a seasonal basis, the identity of the species present changes substantially throughout the year. The higher dispersion during the September–November window indicates that avian assemblages are more heterogeneous and variable during this period, likely reflecting a distinct seasonal turnover or the transient presence of species that distinguishes this window from the rest of the annual cycle.

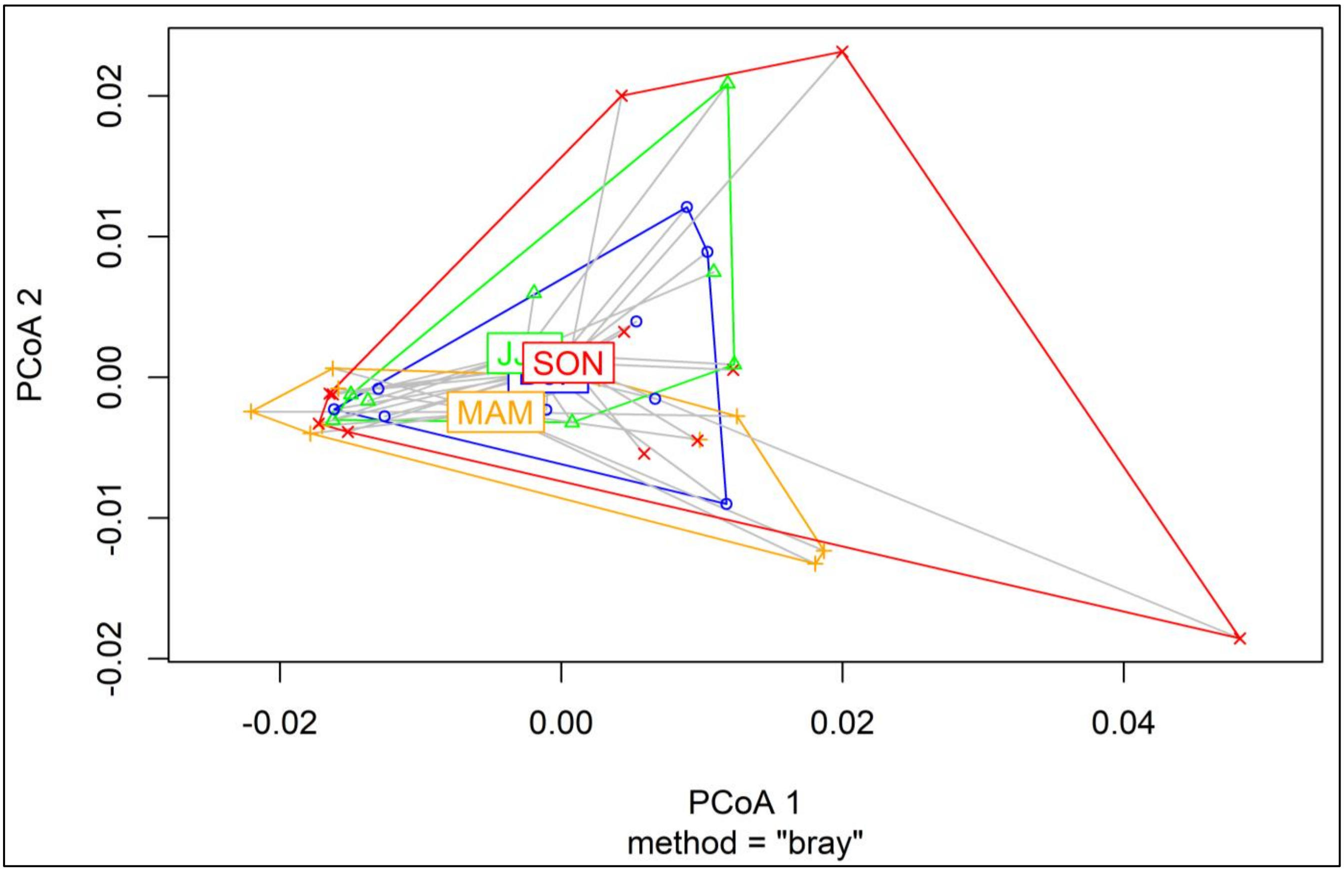

Figure 11: PCoA of Seasonal avian species dispersion in Karen Karara and NMK

Chapter Five: Discussion, Conclusion and Recommendations

5.1. Introduction

This study investigated avian species diversity, composition and variance by seasonality within two urban green places in Nairobi Kenya utilizing bird ringing data from National Museums of Kenya database. This chapter presents discussions, summary, conclusions, and recommendations from the study's findings.

5.2. Discussion

5.2.1. Avian species composition

The analysis of the Pielou's Evenness Index indicates clear differences in community structure between the two localities. Karen exhibited consistently higher evenness values than NMK, suggesting that species in Karen are distributed more uniformly in terms of relative abundance. The comparison of species evenness between Karen and NMK demonstrates that Karen supports a more evenly distributed community structure, whereas NMK is characterized by lower evenness and a higher likelihood of species dominance (Morelli et al., 2016). These findings suggest underlying differences in ecological conditions between the two localities and highlight the importance of maintaining habitat conditions that promote balanced species assemblages. Future research incorporating additional ecological variables such as habitat characteristics, disturbance regimes, and species composition could further clarify the drivers of the observed patterns in community evenness (Toroitich et al., 2021).

In ecological communities, higher evenness generally reflects a more balanced assemblage where no single species strongly dominates the community. This pattern may indicate more stable ecological conditions or reduced competitive exclusion among species within the Karen locality. In contrast, NMK showed lower evenness values and slightly greater variability among species. Lower evenness typically indicates that a few species dominate the assemblage while others occur at relatively low abundances. Such patterns can arise from environmental stress, habitat heterogeneity, anthropogenic disturbance, or differences in resource availability. The wider spread of observations in NMK may also suggest spatial or temporal fluctuations in species dominance within this locality.

5.2.2. Avian species diversity

The observed temporal patterns in Shannon–Wiener diversity indicate a sustained decline in avian diversity at both study sites, with clear differences in the magnitude and statistical strength of this trend. Similar long-term declines in urban and peri-urban bird diversity have been widely documented and are commonly attributed to progressive habitat modification and intensifying anthropogenic pressures (Aronson et al., 2014; Sol et al., 2014). Although diversity values at both sites remained within the moderate range (H = 2–4), the significant negative trajectories suggest gradual losses in species richness and/or evenness, a pattern frequently associated with urban land-use change and ecological homogenization (McKinney, 2008; Morelli et al., 2016). The sharper and statistically significant decline at Karen Karara, where time explained a substantial proportion of the variation in diversity ($R^2 = 0.68$), points to persistent and cumulative pressures, likely linked to increasing habitat disturbance or reduced habitat quality, as observed in other rapidly transforming peri-urban landscapes (Beninde et al., 2015; Ibáñez-Álamo et al., 2017). In contrast, the weaker and non-significant decline at the National Museums site may reflect higher habitat heterogeneity or site-level management practices that partially buffer avian communities against long-term degradation, consistent with studies showing that structurally complex urban green spaces can mitigate biodiversity loss (Shwartz et al., 2014; Lepczyk et al., 2017).

The brief periods of recovery recorded at both sites, particularly the transient increases in diversity at NMK in 2016 and Karen Karara in 2018, likely represent short-term responses to favourable environmental conditions or episodic resource availability, such as increased food or breeding opportunities; however, such temporary gains are often insufficient to counteract sustained long-term declines (Shochat et al., 2010; Alberti et al., 2017). Collectively, these results reinforce evidence that avian communities in urban and peri-urban ecosystems are undergoing gradual but measurable erosion of diversity over time, underscoring the need for targeted conservation and habitat management interventions to slow or reverse these trends (Aronson et al., 2017; Ikin et al., 2019).

Temporal analysis of the Shannon diversity index further demonstrated contrasting interannual dynamics between the two study sites. Karen exhibited pronounced fluctuations in avian diversity, including substantial declines between 2015–2017 and especially between 2018–2020. These sharp reductions may indicate ecological stress associated with increasing anthropogenic pressure, habitat alteration, or climatic variability affecting species occurrence and community turnover in the adjacent areas. Temporal instability in urban bird communities has been linked to reductions in habitat quality, changes in vegetation phenology, and altered food resource availability resulting from climatic fluctuations and urban expansion (Chace & Walsh, 2006). The marked increase observed between 2017 and 2018 may represent short-term ecological recovery following favourable environmental conditions or temporary improvement in habitat suitability. However, the subsequent decline toward 2020 suggests that such recovery was not sustained. In comparison, NMK exhibited relatively moderate year-to-year changes in Shannon diversity, implying greater ecological buffering capacity against environmental perturbations. The gradual decline observed after 2017 may nevertheless indicate emerging pressures associated with urban intensification and climatic stressors that could progressively alter avian community composition if unmanaged.

The contrasting diversity trajectories between NMK and Karen have important implications for urban biodiversity conservation and ecosystem resilience in rapidly urbanizing tropical cities. Stable avian diversity at NMK suggests that well-maintained urban green spaces can function as important ecological refugia capable of sustaining relatively diverse bird assemblages despite surrounding urbanization. This finding aligns with studies demonstrating that urban habitats with higher vegetation complexity and lower disturbance intensity support greater avian stability and functional diversity over time (Aronson et al., 2014; Lepczyk et al., 2017). Conversely, the substantial temporal variability observed at Karen highlights the vulnerability of fragmented or ecologically stressed green spaces to biodiversity decline although this could be treated with caution due to variance in vegetation structure and inclusion of riparian vegetation at the National Museums of Kenya. From a conservation perspective, the observed patterns emphasize the importance of maintaining habitat connectivity, vegetation diversity, and long-term ecological management within urban landscapes. Furthermore, the declining diversity trends observed toward 2020 at both sites may reflect broader environmental pressures, including climate variability and intensified urban disturbance, underscoring the need for integrated urban ecological planning and continuous biodiversity monitoring within Nairobi's green infrastructure.

5.2.3. Species similarity

The consistently low Jaccard similarity indices (< 0.4) observed throughout the study period indicate that the avian assemblages at the two sites remained largely distinct, sharing relatively few species despite being monitored over the same temporal window. Persistent low similarity among nearby urban and peri-urban sites has been widely reported and is typically attributed to strong environmental filtering driven by differences in habitat structure, vegetation complexity, resource distribution, and disturbance regimes (Aronson et al., 2014; Beninde et al., 2015). Such low species overlap is consistent with ecological differentiation between urban and peri-urban environments, where localized land-use patterns and management practices can generate highly distinct community assemblages even across short spatial scales (Lepczyk et al., 2017; Morelli et al., 2016). These findings suggest that landscape context and site-specific habitat characteristics play a dominant role in shaping avian community composition, overriding potential homogenizing effects of proximity or species mobility.

The absence of a significant temporal trend in similarity, as indicated by the generalized linear model results ($p = 0.145$), further implies that the degree of compositional differentiation between the two sites has remained stable over time. Despite concurrent declines in overall diversity at both locations, species loss and turnover appear to have occurred in a site-specific manner rather than through convergence toward a more homogeneous community, a pattern observed in several long-term urban biodiversity studies (Sol et al., 2014; Ibáñez-Álamo et al., 2017). This stability in low similarity suggests that the key ecological drivers maintaining distinct assemblages—such as habitat configuration, disturbance intensity, and resource availability—have not undergone substantial directional change during the study period. Consequently, these results reinforce the importance of local habitat characteristics in structuring avian communities and highlight that diversity loss does not necessarily imply compositional homogenization across urban landscapes (Ikin et al., 2019).

5.2.4. Seasonal diversity in avian species and population trends

The significant season and locality effect suggests that seasonal dynamics in bird communities are context dependent, likely reflecting differences in habitat structure, resource availability, and local environmental conditions. Together, these results indicate site-specific temporal dynamics in bird diversity. The significant decline observed at Karara contrasts with the more stable pattern at NMK, highlighting spatial heterogeneity in biodiversity trends within the same regional context. Importantly, these findings align with PERMANOVA results, which showed significant changes in species composition over time and season, even where overall diversity metrics remained relatively stable.

In this study, the observed decoupling between alpha and beta diversity provides critical insights into the ecological dynamics of the Karen Karara and NMK sites. The relative stability of Shannon diversity (H') across seasons indicates that, despite fluctuations in individual index values, the overall richness and evenness—the fundamental building blocks of alpha diversity—remain largely consistent within each locality. This suggests that the local environment at both sites possesses a stable "carrying capacity" that supports a steady number of species, with relative abundances that do not undergo dramatic, systematic shifts when assessed as a singular aggregate metric.

However, the significant results from the PERMANOVA analysis reveal a much more complex underlying reality characterized by high beta diversity. While the magnitude of diversity (alpha) remains stable, the taxonomic identity of the species present (beta) shifts significantly across seasons. This indicates that the community is not static; rather, it undergoes seasonal turnover where species are regularly replaced by others of similar functional roles or resource requirements. By distinguishing between these two metrics, it becomes clear that the sites do not just experience "diversity" in a vacuum, but rather maintain complex, dynamic assemblages that respond to temporal environmental cues through constant compositional reorganization rather than simple increases or decreases in total species numbers.

Seasonal stratification of the sampling period provided a refined framework for examining temporal variability in avian communities within an urban context. The use of three-month intervals, aligned broadly with local climatic patterns and avian life-history processes such as breeding and fledging, is appropriate for detecting short-term ecological responses in highly mobile taxa like birds (Bibby et al., 2000). The contrasting peaks in diversity observed between sites—September to November at the National Museums of Kenya (NMK) and March to May at Karen Karara—suggest that seasonal drivers operate differently across localities, likely reflecting site-specific differences in vegetation phenology, food availability, and microclimatic conditions as well as seasonal anthropogenic disturbances. Similar asynchronous seasonal responses have been reported in urban bird communities, where habitat structure and resource supplementation can decouple diversity patterns from regional climatic seasonality (Chace & Walsh, 2006; Shochat et al., 2010).

Despite these localized seasonal peaks, overall, Shannon diversity did not differ significantly among seasons, as indicated by the Kruskal–Wallis and post-hoc Dunn's tests. This suggests that while individual species may fluctuate in abundance or presence across seasons, total diversity remains relatively stable, potentially due to compensatory dynamics where declines in some species are offset by increases in others (Magurran, 2004). The decline in seasonal diversity indices observed after 2016 at both sites, however, may point to broader environmental pressures overriding seasonal effects, such as progressive habitat alteration or increased anthropogenic disturbance. This aligns with the construction of the Karen hub which is located next to Karen Karara and the Museum interchange which could have had an impact on species occurrence and diversity. The lack of statistically significant seasonal differences in diversity aligns with findings from other urban avifaunal studies, where temporal variability in species composition is often more pronounced than changes in aggregate diversity metrics (McKinney, 2008).

This distinction is further supported by the PERMANOVA results, which revealed significant differences in community composition across seasons and between sites, with season and locality jointly explaining a substantial proportion of the observed variation. These findings highlight that seasonal processes influence which species are present rather than how many, emphasizing the importance of multivariate approaches when assessing ecological change (Anderson, 2001). The strong site-specific seasonal structuring suggests that local habitat characteristics mediate species' responses to seasonal conditions, reinforcing the role of fine-scale environmental filters in urban ecosystems. Collectively, these results indicate that assessments based solely on diversity indices may underestimate ecologically meaningful seasonal turnover, and that conservation and management strategies should account for seasonal shifts in species composition to effectively support urban bird communities throughout the annual cycle.

The significant multivariate dispersion observed among seasons indicates that community heterogeneity also contributed to the detected differences in avian assemblage structure. Higher dispersion during September-November suggests greater variability in species composition among species sampled this season, potentially reflecting transitional ecological conditions associated with migratory influxes, breeding activity, or fluctuating habitat resources. Increased heterogeneity during transitional rainfall periods has been reported in avian communities where species respond differently to temporal changes in habitat quality and food availability. However, because PERMANOVA is sensitive to differences in dispersion, the significant betadisper result indicates that the observed seasonal differences may partly reflect unequal within-group variability in addition to true differences in community centroids. Nevertheless, the combined results strongly suggest that seasonal climatic dynamics and site-specific environmental characteristics play a major role in structuring avian communities within urban green spaces.

5.3. Summary of Main Findings

The bird assemblage data from NMK (Nairobi) and Karara (Karen) indicate clear temporal and spatial structuring in species composition across the study period (2014–2020). Multivariate analysis using Bray–Curti's dissimilarity (PERMANOVA) showed a significant effect of season and locality on community composition ($R^2 = 0.42$, $p = 0.001$), demonstrating that species assemblages differ meaningfully between sites and across seasons. This suggests that habitat characteristics and seasonal conditions jointly influence species turnover, even within relatively proximate urban and peri-urban environments.

However, analyses based on univariate diversity indices (Shannon diversity, H') revealed relatively stable diversity patterns across seasons and years. Seasonal comparisons using non-parametric tests (Kruskal–Wallis followed by Dunn post hoc tests) showed not statistically significant pairwise differences (adjusted $p > 0.05$), indicating that overall species diversity did not vary substantially between seasons. This apparent stability in diversity, despite shifts in species composition, suggests functional or numerical replacement of species across seasons rather than net gains or losses in diversity and can be attributed to unequal sampling disadvantaging Karen Karara.

Temporal trends further indicate modest inter-annual variability in diversity within each locality, with no consistent directional trend over time. NMK and Karara exhibited comparable diversity levels, although site-specific fluctuations were observed, likely reflecting differences in habitat structure, disturbance regimes, and resource availability and sampling effort per site. Collectively, these findings highlight that while seasonal and spatial dynamics significantly shape species composition, overall bird diversity remains relatively resilient, underscoring the importance of considering both compositional and diversity-based metrics in urban ecological assessments.

5.4. Conclusion

This study demonstrates a clear and persistent decline in avian diversity at both the National Museums of Kenya (NMK) and Karen Karara over the study period, with the magnitude and significance of change varying between sites. Although overall Shannon diversity values remained within a moderate range, temporal analyses revealed significant downward trends, particularly at Karen Karara, indicating sustained losses in species richness and/or evenness, however this can be attributed to unequal sampling as rarefaction analysis has shown and therefore more sampling is required to ascertain the findings. Species similarity between the two sites remained consistently low, suggesting that each locality supports a distinct avian assemblage shaped by site-specific environmental conditions. Seasonal analyses further showed that while overall diversity did not differ significantly among seasons, bird community composition varied markedly across seasons and between sites, highlighting strong seasonal and spatial structuring of avian communities. Collectively, these findings indicate that urban and peri-urban bird communities are undergoing gradual erosion, with changes in species composition providing a more sensitive indicator of ecological change than diversity indices alone.

The study demonstrates that avian community composition in Nairobi is significantly structured by seasonal dynamics and site-specific landscape attributes, revealing a high degree of ecological predictability within urban green spaces. By integrating multivariate community analysis with robust statistical validation, these results confirm that sites like the NMK and Karen Karara act as essential, stable refugia that support consistent yet seasonally responsive avian assemblages. Ultimately, these findings advocate for a landscape-scale approach to urban planning that prioritizes the maintenance of diverse habitat patches to preserve the compositional integrity and long-term viability of urban bird populations.

5.5. Recommendations

At the National Museums of Kenya, management efforts should prioritize maintaining and enhancing habitat heterogeneity, which may be contributing to the comparatively weaker decline in diversity. Protection of existing green spaces, enrichment planting with native vegetation, and minimization of habitat disturbance—particularly during key breeding and resource-rich seasons—would help sustain current avian assemblages. Continued long-term monitoring is also recommended to detect early warning signs of further declines, especially given the pronounced reduction in diversity observed after 2017.

The avian community at the NMK displays the classic hallmarks of urban biotic homogenization, characterized by higher fluctuations and lower species evenness compared to suburban-fringe sites. To improve the ecological quality of the museum grounds, management should shift focus toward enhancing structural habitat complexity, particularly by promoting native understory development to provide specialized niches. Furthermore, implementing a long-term strategy to manage dominant generalist species and providing consistent seasonal food resources will be essential to stabilize community structure and enhance the site's capacity to support a more diverse and equitable avian assemblage

Given the high compositional stability and equitable community structure observed at Karen Karara, conservation management should prioritize the preservation of existing vegetation complexity. To safeguard this site against the biotic homogenization common in urban landscapes, it is recommended that management focus on buffering the site perimeter with native flora to maintain habitat connectivity. Furthermore, implementing long-term, standardized avian monitoring will be critical to detecting shifts toward generalist-dominated communities, ensuring that the site continues to function as a high-quality ecological refugium within the Nairobi urban mosaic.

Across both sites, future management and research should incorporate seasonal dynamics of species composition rather than relying solely on aggregate diversity metrics. Conservation planning should account for seasonal turnover and site-specific species requirements to ensure year-round habitat suitability. Finally, integrating avian monitoring with assessments of vegetation structure, land-use change, and human activity would provide a more mechanistic understanding of the drivers of diversity loss and support evidence-based urban biodiversity conservation strategies.

5.6. Areas of Further Research

Building upon the baseline established in this study, future research should integrate functional trait-based analyses to move beyond taxonomic diversity and evaluate the functional resilience of these communities. Furthermore, exploring the role of urban green spaces as interconnected nodes through movement ecology—specifically assessing source-sink dynamics—would clarify how habitat quality in suburban areas supports the persistence of avian assemblages in the urban core. Finally, investigating the influence of fine-scale environmental stressors, such as acoustic pollution and localized microclimates, will provide mechanistic insights into the volatility observed at the more centrally located NMK site.

1**. Long-term monitoring of bird populations**

Future research should involve long-term monitoring of bird communities to detect changes in species composition, abundance, and seasonal patterns. Many studies note that, while urban birds are a subset of regional species pools, how these communities evolve over time is poorly understood. Research should be

i. Study of birds' populations throughout numerous years.
ii. Identify if a species is diminishing or expanding.
iii. Examine the seasonal and migration trends.

2. **The Impact of Green Space Characteristics**

Further studies should examine how certain elements of green places impact bird diversity, such as:

i. Size of the green space.
ii. Vegetation structure and plant diversity
iii. Connectivity of green patches
iv. Human disturbance levels.

Evidence shows that bigger and more regularly structured green areas support greater bird richness and variety.

3. The Role of Native vs. Exotic Vegetation

More research is needed on how plant composition affects avian communities. Future study might involve:

i. Compare native plant-dominated environments to invasive plants.
ii. Assess how plant diversity promotes eating and nesting sites.

According to research, green spaces with native flora sustain more bird species than those with alien plants.

References

Alberti, M., Correa, C., Marzluff, J. M., Hendry, A. P., Palkovacs, E. P., Gotanda, K. M., Hunt, V. M., Apgar, T. M., & Zhou, Y. (2017). Global urban signatures of phenotypic change in animal and plant populations. *Proceedings of the National Academy of Sciences*, 114(34), 8951–8956. https://doi.org/10.1073/pnas.1606034114

Aronson, M. F. J., La Sorte, F. A., Nilon, C. H., Katti, M., Goddard, M. A., Lepczyk, C. A., Warren, P. S., Williams, N. S. G., Cilliers, S., Clarkson, B., Dobbs, C., Dolan, R., Hedblom, M., Klotz, S., Kooijmans, J. L., Kühn, I., MacGregor-Fors, I., McDonnell, M., Mörtberg, U., Pyšek, P., Siebert, S., Sushinsky, J., Werner, P., & Winter, M. (2014). A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceedings of the Royal Society B*, 281, 20133330. https://doi.org/10.1098/rspb.2013.3330

Aronson, M. F. J., et al. (2017). Biodiversity in the city: Key challenges for urban green space management. *Frontiers in Ecology and the Environment*, 15(4), 189–196. https://doi.org/10.1002/fee.1480

Beninde, J., Veith, M., &Hochkirch, A. (2015). Biodiversity in cities needs space: A meta-analysis of factors determining intra-urban biodiversity variation. *Ecology Letters*, 18(6), 581–592. https://doi.org/10.1111/ele.12427

Bennun, L. A., & Njoroge, P. (1999). *Important Bird Areas in Kenya*. Nature Kenya.

Ibáñez-Álamo, J. D., Rubio, E., Benedetti, Y., & Morelli, F. (2017). Global loss of avian evolutionary uniqueness in urban areas. *Global Change Biology*, 23(8), 2990–2998. https://doi.org/10.1111/gcb.13566

Ikin, K., Le Roux, D. S., Rayner, L., Villaseñor, N. R., Eyles, K., Gibbons, P., Manning, A. D., & Lindenmayer, D. B. (2019). Key lessons for conserving biodiversity in urban environments. *Global Ecology and Conservation*, 20, e00767. https://doi.org/10.1016/j.gecco.2019.e00767

Lepczyk, C. A., Aronson, M. F. J., Evans, K. L., Goddard, M. A., Lerman, S. B., & MacIvor, J. S. (2017). Biodiversity in the city: Fundamental questions for understanding the ecology of urban green spaces. *Ecology Letters*, 20(1), 20–33. https://doi.org/10.1111/ele.12699

Morelli, F., Benedetti, Y., Ibáñez-Álamo, J. D., Jokimäki, J., Mänd, R., Tryjanowski, P., & Møller, A. P. (2016). Evidence of evolutionary homogenization of bird communities in urban environments across Europe. *Global Ecology and Biogeography*, 25(11), 1284–1293. https://doi.org/10.1111/geb.12486

Shwartz, A., Muratet, A., Simon, L., & Julliard, R. (2014). Local and management variables outweigh landscape effects in enhancing the diversity of different taxa in a big metropolis. *Biological Conservation*, 170, 285–294. https://doi.org/10.1016/j.biocon.2013.12.012

Shochat, E., Lerman, S. B., Anderies, J. M., Warren, P. S., Faeth, S. H., & Nilon, C. H. (2010). Invasion, competition, and biodiversity loss in urban ecosystems. *BioScience*, 60(3), 199–208. https://doi.org/10.1525/bio.2010.60.3.6

Sol, D., González-Lagos, C., Moreira, D., Maspons, J., & Lapiedra, O. (2014). Urbanisation tolerance and the loss of avian diversity. *Ecology Letters*, 17(8), 942–950. https://doi.org/10.1111/ele.12297

Bibby, C. J., Burgess, N. D., Hill, D. A., & Mustoe, S. H. (2000). *Bird census techniques* (2nd ed.). Academic Press, London.

Chace, J. F., & Walsh, J. J. (2006). Urban effects on native avifauna: A review. *Landscape and Urban Planning*, 74(1), 46–69. https://doi.org/10.1016/j.landurbplan.2004.08.007

Shochat, E., Lerman, S. B., Anderies, J. M., Warren, P. S., Faeth, S. H., & Nilon, C. H. (2010). Invasion, competition, and biodiversity loss in urban ecosystems. *BioScience*, 60(3), 199–208. https://doi.org/10.1525/bio.2010.60.3.6

Magurran, A. E. (2004). *Measuring biological diversity*. Blackwell Publishing, Oxford.

McKinney, M. L. (2008). Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystems*, 11, 161–176. https://doi.org/10.1007/s11252-007-0045-4

Anderson, M. J. (2001). A new method for non-parametric multivariate analysis of variance. *Austral Ecology*, 26(1), 32–46. https://doi.org/10.1111/j.1442-9993.2001.01070.pp.x

Adams, W. M. (2006). *Reconceptualizing sustainability for 21st century environmental and developmental challenges*. IUCN Report. https://portals.iucn.org/library/node/8909

Ait-El-Mokhtar, M., Baslam, M., Ben-Laouane, R., Anli, M., Boutasknit, A., &Meddich, A. (2022). Climate change threats to oasis agricultural systems in Morocco. *Agronomy, 12*(3), 646. https://doi.org/10.3390/agronomy12030646

Alerstam, T., Högstedt, G., & Åkesson, S. (2001). *Avian migration: Ecological patterns and evolutionary processes*. Springer Science & Business Media.

Asibey, M. O., Akakpo, E., &Kpeebi, Y. (2024). Re-evaluating garden city principles and green infrastructure approaches for sustainable urban development in Africa. *Local Environment, 29*(3), 1-18. https://doi.org/10.1080/13549839.2024.2386966

Blowes, S. A., Daskalova, G. N., Dornelas, M., Engel, T., Gotelli, N. J., Magurran, A. E., Martins, I. S., McGill, B., McGlinn, D. J., Sagouis, A., Shimadzu, H., Supp, S. R., & Chase, J. M. (2022). Analyzing biodiversity changes through abundance, evenness and richness interactions. *Ecology, 103*(e3820). https://doi.org/10.1002/ecy.3820

Bock, C. E., Jones, Z. F., & Bock, J. H. (2007). Examining relationships between avian species richness, evenness and abundance in southwestern savannas. *Ecology, 88*(5), 1322–1327.

Brown, S. (2020). Meta-analysis of climate change effects on urban biodiversity worldwide. *Global Environmental Change, 62*, 102063. https://doi.org/10.1016/j.gloenvcha.2020.102063

Byrne, J., & Sipe, N. (2010). *Review of urban green space planning strategies for densifying cities*. Urban Research Program Report. Griffith University.

Carothers, J. H., Jaksić, F. M., & Marquet, P. A. (1996). Geographic and ecological patterns in global bird species distribution. *Ecography, 19*(3), 293-298.

Cavarzere, V., & Silveira, L. F. (2012). Testing the mid-domain effect in Atlantic Forest bird communities. *Zoologia, 29*(4), 285-292.

Chapman, A. (2009). *Quantifying global species diversity* (2nd ed.). Australian Biological Resources Study.

Chong, K. Y., Teo, S., Kurukulasuriya, B., Chung, Y. F., Giam, X., & Tan, H. T. W. (2015). Singapore's botanical gardens as models for urban greening. *Gardens' Bulletin Singapore, 67*(1), 1-16.

Clements, J. F., Schulenberg, T. S., Iliff, M. J., Billerman, S. M., Fredericks, T. A., Sullivan, B. L., & Wood, C. L. (2022). *The eBird/Clement's checklist of world birds: v2022*. https://www.birds.cornell.edu/clementschecklist/updateindex/october-2022/

Cox, D. T., Hudson, H. L., Plummer, K. E., Siriwardena, G. M., Anderson, K., Hancock, S., & Gaston, K. J. (2014). Urban birds as providers of cultural ecosystem services. *Journal of Applied Ecology, 55*(5), 2308-2319.

Davies, Z. G., Edmondson, J. L., Heinemeyer, A., Leake, J. R., & Gaston, K. J. (2015). Quantifying urban carbon storage at city scale. *Journal of Applied Ecology, 48*(5), 1125-1134.

Dipeolu, A., Taiwo, A., & Adebara, T. (2025). Social cohesion impacts of green infrastructure in Lagos. *Acta Structilia, 31*(2), 123–149. https://www.ajol.info/index.php/actas/article/view/284234

Dreiseitl, H., &Wanschura, B. (2016). *Enhancing urban blue-green infrastructure systems*. Ramboll. https://ramboll.com/-/media/38fc23d12a5d47dcb7b3821716d69270.pdf

Elkington, J. (1997). *The triple bottom line: Business sustainability for the 21st century*. New Society Publishers.

Eriksen, S., Schipper, E. L. F., Scoville-Simonds, M., Vincent, K., Adam, H. N., Brooks, N., & West, J. J. (2021). Evaluating adaptation interventions in developing nations. *World Development, 141*, 105383. https://doi.org/10.1016/j.worlddev.2020.105383

Evans, K. L., Newson, S. E., & Gaston, K. J. (2009). Urban habitat influences on bird communities. *Ibis, 151*(1), 19-39. https://doi.org/10.1111/j.1474-919X.2008.00898.x

Firehock, K., & Walker, R. A. (2015). *Strategic planning approaches for green infrastructure at multiple scales*. Island Press.

Forero-Medina, G., Terborgh, J., Socolar, S. J., & Pimm, S. L. (2011). Climate warming impacts on tropical montane bird distributions. *PLoS ONE, 6*(12), e28535. https://doi.org/10.1371/journal.pone.0028535

Francis, J., Giles-Corti, B., Wood, L., &Knuiman, M. (2012). Public spaces and community formation. *Journal of Environmental Psychology, 32*(4), 401–409. https://doi.org/10.1016/j.jenvp.2012.07.002

Freund, D., & Bird, D. M. (2013). *Climate change impacts and conservation responses for avian species*. Cambridge University Press.

Fuller, R. A., Irvine, K. N., Devine-Wright, P., Warren, P. H., & Gaston, K. J. (2007). Biodiversity's role in psychological benefits from green spaces. *Biology Letters, 3*(4), 390–394. https://doi.org/10.1098/rsbl.2007.0149

Getachaw, S., Mekuria, W., & Tilahun, S. (2017). *Progress and challenges in Addis Ababa's green development strategy*. Ethiopian Environment and Forest Research Institute.

Gikungu, M. W., Karanja, T. N., & Njoroge, G. N. (2015). Community-based conservation in Karura Forest, Nairobi. *Journal of Natural Sciences Research, 5*(2), 2224-3186.

Harnik, P. (2010). *Innovative urban park designs for modern cities*. Island Press.

Hassell, J. M., Bettridge, J. M., Ward, M. J., Ogendo, A., Imboma, T., Muloi, D., Fava, F., Robinson, T. P., Begon, M., & Fèvre, E. M. (2021). Urban landscape impacts on biodiversity and human-animal interactions. *Global Change Biology, 27,* 781–792. https://doi.org/10.1111/gcb.15412

Ichimura, M. (2003). *Challenges in urban environments and land use management*. Asia-Pacific Forum for Environment and Development Expert Meeting. APFED3/EM/03/Doc.5.

IPCC. (2014). *Climate change impacts, adaptation and vulnerability assessment*. Cambridge University Press.

IPCC. (2022). *Climate change 2022: Comprehensive assessment of impacts and adaptation*. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/

Jetz, W., Wilcove, D. S., & Dobson, A. P. (2007). Projecting climate and land-use impacts on global avian diversity. *PLoS Biology, 5*(6), e157. https://doi.org/10.1371/journal.pbio.0050157

Kenya National Bureau of Statistics [KNBS]. (2019). *Kenya census 2019: Population distribution by administrative units*. Government Printer.

Kenya Red Cross Society [KRCS]. (2012). *Analysis of drought and flood cycles in Kenya*. KRCS Reports.

Kristensen, P. (2004). *The DPSIR analytical framework*. National Environmental Research Institute, Denmark.

Lamond, J., & Everett, G. (2019). Community perspectives on sustainable blue-green infrastructure. *Landscape and Urban Planning, 191*, 103639. https://doi.org/10.1016/j.landurbplan.2019.103639

Lepczyk, C. A., Flather, C. H., Radeloff, V. C., Pidgeon, A. M., Hammer, R. B., & Liu, J. (2008). Assessing human impacts on regional avian populations. *Conservation Biology, 22*(2), 405-416. https://doi.org/10.1111/j.1523-1739.2008.00881.x

Liao, K.-H., Deng, S., & Yok, P. (2017). Stormwater management through blue-green infrastructure. In P. Y. Tan & C. Y. Jim (Eds.), *Urban greening approaches* (pp. 203–226). Springer. https://doi.org/10.1007/978-981-10-4113-6_10

Lutta, A. O., Karanja, F. N., & Kithiia, J. (2024). Health impacts of urban green space reduction in Nairobi. *Urban Forestry & Urban Greening, 87*, 128035. https://doi.org/10.1016/j.ufug.2023.128035

Lyon, B., &Vigaud, N. (2017). Understanding East Africa's climate anomalies. *Climate Dynamics, 49*(1-2), 97-112. https://doi.org/10.1007/s00382-016-3328-8

Makworo, M., &Mireri, C. (2011). Threats to Nairobi's public open spaces. *Journal of Environmental Planning and Management, 54*(8), 1107–1123. https://doi.org/10.1080/09640568.2010.549631

McInnes, L. M., Purvis, A., & Orme, C. D. L. (2009). Geographic range limitations in species distributions. *Journal of Biogeography, 36*(5), 913-926.

McIntosh, R. P. (1967). Vegetation continuum analysis. *Botanical Review*, *33*(2), 130-187.

Miraza, M. (2017). Comparative analysis of greenspace loss in London and Nairobi. *KCL Blog*. https://blogs.kcl.ac.uk/eoes/2017/03/23/a-comparison-of-greenspace-loss-and-urban-expansion-over-time-in-london-and-nairobi/

Mundia, C. N., & Aniya, M. (2005). Remote sensing analysis of Nairobi's urban expansion. *International Journal of Remote Sensing, 26*(13), 2831–2849. https://doi.org/10.1080/01431160500117865

Muriuki, J. N. (2016). *Evolution of wildlife conservation approaches in Nairobi*. African Wildlife Foundation.

Myers, M. (1975). Metropolitan open space allocation strategies. *Transactions of the Kansas Academy of Science, 78*(3/4), 149–153. https://doi.org/10.2307/3627339

Nairobi City County Government. (2018). *Nairobi's integrated development plan 2018–2022*. Nairobi.

Ndolo, I. (2017). Diagnosis of Urbanization and seasonal Rainfall over the City of Nairobi. *Journal of Meteorology, 10*(1).

Newton, I. (1998). *Population dynamics of avian species*. Academic Press.

OECD. (2004). *Key indicators for environmental assessment*. Organisation for Economic Co-operation and Development.

Okech, E. A., &Nyadera, I. N. (2022). Pandemic impacts on Nairobi's urban green spaces. *GeoJournal, 87*(IV), 4931–4945. https://doi.org/10.1007/s10708-021-10540-0

Oyugi, M. O., Karanja, F. N., &Odenyo, V. A. (2017). Modelling the Effect of Land Use and Land Cover Variations on the Surface Temperature Values of Nairobi City, Kenya. *Resources and Environment*, *7*(6), 145-159.

Popy, S., Bordoni, A., &Prodon, R. (2010). Elevational shifts in Italian Alpine bird populations. *Journal of Biogeography, 37*(1), 57-67.

Rapport, D. J., & Friend, A. M. (1979). *Developing comprehensive environmental statistics frameworks*. Statistics Canada.

Rosaceae, M., Smith, T. B., & Kark, S. (2010). Urban impacts on species interactions. *Global Change Biology, 16*(2), 584-596.

Schweizer, M., & Liu, Y. (2018). Global patterns in avian biogeography. *Journal of Biogeography*, *45*(7), 1613-1626.

Şekercioĝlu, Ç. H., Primack, R. B., &Wormworth, J. (2012). Tropical birds and climate change impacts. *Biological Conservation, 148*(1), 1-18.

Shu-Yuan, P., Mengyao, G., Hyunook, K., Kinjal, J. S., Si-Lu, P., & Pen-Chi, C. (2018). Sustainable tourism development challenges. *Science of The Total Environment, 635*, 452–469. https://doi.org/10.1016/j.scitotenv.2018.04.134

Sieving, K. E., & Willson, M. F. (1998). Nest predation effects on forest bird diversity. *Ecology, 79*(7), 2391-2402. https://doi.org/10.1890/0012-9658(1998)079[2391:NPAASD]2.0.CO;2

Smith, R. M., Thompson, K., Hodgson, J. G., Warren, P. H., & Gaston, K. J. (2013). Biodiversity in urban domestic gardens. *Biological Conservation, 129*(3), 312-322. https://doi.org/10.1016/j.biocon.2005.10.045

Stanley, B. W., Stark, B. L., Johnston, K. L., & Smith, M. E. (2012). Historical analysis of urban open spaces. *Urban Geography, 33*(8), 1089–1117. https://doi.org/10.2747/0272-3638.33.8.1089

Stirling, G., & Wilsey, B. (2001). Species richness-evenness relationships. *The American Naturalist, 158*, 286–299.

Thao, N. T., Vromant, N., Hung, N. T., & Hens, L. (2019). Climate vulnerability in Vietnam's Mekong Delta. *Mitigation and Adaptation Strategies for Global Change*, *24*(5), 813-834.

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., & Williams, S. E. (2019). Climate-driven extinction risks. *Nature, 427*(6970), 145-148.

UNESCO. (2002). *Cultural diversity as sustainable development pillar*. UNESCO Publishing.

UN-Habitat. (2020). *State of African urbanization trends*. United Nations Human Settlements Programme.

Voinov, A., & Smith, C. (1994). Conceptualizing sustainability dimensions. *Futures, 26*(2), 197-205. https://doi.org/10.1016/0016-3287(94)90101-5

Vos, R. O. (2007). Theoretical foundations of sustainability. *Journal of Chemical Technology and Biotechnology, 82*(4), 334-339. https://doi.org/10.1002/jctb.1675

Whittaker, R. H. (1967). Vegetation gradient analysis. *Biological Reviews, 42*(2), 207-264.

WHO. (2005). *Ecosystem services for human health*. World Health Organization.

WHO. (2017). *Evidence reviews on urban green space benefits*. World Health Organization Regional Office for Europe.

World Economic Forum. (2024). *Global risk assessment report 2024* (19th ed.). https://www.weforum.org/reports/global-risks-report-2024/

Wormworth, J., & Mallon, K. (2006). *Global assessment of climate change impacts on bird species*. WWF Australia.

Zhang, H., John, R., Peng, Z., Yuan, J., Chu, C., Du, G., & Zhou, S. (2012). Plant community richness-evenness relationships along successional gradients. *PLoS ONE, 7*(11), e49024. https://doi.org/10.1371/journal.pone.0049024

Pielou EC. 1966. The measurement of diversity in different types of biological collections. Journal of Theoretical Biology 13:131–144

Yue Huang, Yazhou Zhao, Shuhua Li, Klaus von Gadow (2015). The Effects of habitat area, vegetation structure and insect richness on breeding bird populations in Beijing urban parks,

Urban Forestry & Urban Greening, Volume 14, Issue 4, 2015, Pages 1027-1039, https://doi.org/10.1016/j.ufug.2015.09.010

Christopher J.W. McClure, Allison C. Korte, Julie A. Heath, Jesse R. Barber (2015). Pavement and riparian forest shape the bird community along an urban river corridor, Global Ecology and Conservation, Volume 4, 2015, Pages 291-310, https://doi.org/10.1016/j.gecco.2015.07.004

Melese Genete Muluneh, Belachew Bogale Worku, (2022). Contributions of urban green spaces for climate change mitigation and biodiversity conservation in Dessie city, Northeastern Ethiopia. *Urban Climate, Volume* 46,2022,101-294, https://doi.org/10.1016/j.uclim.2022.101294

Benjamin James Barth, Sean Ian FitzGibbon, Robbie Stuart Wilson (2014).New urban developments that retain more remnant trees have greater bird diversity, Landscape and Urban Planning,Volume 136, 2015,Pages 122-129, https://doi.org/10.1016/j.landurbplan.2014.11.003.

Alerstam, T., Hedenström, A., & Åkesson, S. (2003). Long-distance migration: Evolution and determinants. *Oikos*, 103(2), 247–260.

Lee, A. T. K., Ottosson, U., Jackson, C., Shema, S., & others. (2021). Urban areas have lower species richness, but maintain functional diversity: Insights from the African Bird Atlas Project. *Ostrich: Journal of African Ornithology*, 92(1), 1–12.

Lepczyk, C. A., La Sorte, F. A., Aronson, M. F. J., Goddard, M. A., et al. (2017). Global patterns and drivers of urban bird diversity. In *Ecology and Conservation of Birds in Urban Environments* (pp. 13–33).

Leveau, L. M., Ruggiero, A., Matthews, T. J., & Bellocq, M. I. (2019). A global consistent positive effect of urban green area size on bird richness. *Avian Research*, 10(30).

Lin, B. B., Philpott, S. M., & Jha, S. (2017). Multiscale heterogeneity within and beyond Taipei city greenspaces and their relationship with avian biodiversity. *Landscape and Urban Planning*, 157, 138–150.

Newton, I. (1998). *Population limitation in birds*. Academic Press.

Nyambane, D. O., Njoroge, J. B., & Watako, A. O. (2016). Assessment of tree species distribution and diversity in the major urban green spaces of Nairobi city, Kenya. *Journal of Horticulture and Forestry*, 8(5), 61–68.

Silva, C. P., García, C. E., Estay, S. A., & Barbosa, O. (2015). Bird richness and abundance in response to urban form in a Latin American city: Valdivia, Chile as a case study. *PLoS ONE*, 10(9), e0138120.

Stagoll, K., Lindenmayer, D. B., Knight, E., Fischer, J., & Manning, A. D. (2017). Bird diversity in urban green space: A large-scale analysis of differences between parks and cemeteries in Central Europe. *Urban Forestry & Urban Greening*, 27, 264–271.

Toroitich, C., Njuguna, M., & Karanja, D. (2021). Effects of urban wetland patch pattern on the biodiversity of aquatic birds in Nairobi, Kenya. *Journal of Agriculture, Science and Technology,* 21(1), 112–128.

Both, C., Bouwhuis, S., Lessells, C. M., & Visser, M. E. (2006). Climate change and population declines in a long-distance migratory bird. *Nature*, 441(7089), 81–83.

Borrow, N., & Demey, R. (2014). *Birds of Western Africa*. Princeton University Press.

Crick, H. Q. P. (2004). The impact of climate change on birds. *Ibis*, 146(s1), 48–56.

Cunningham, S. J., Martin, R. O., Hojem, C. L., & Hockey, P. A. R. (2015). Temperatures in excess of critical thresholds threaten nestling growth and survival in a rapidly warming arid savanna: A study of common fiscals in southern Africa. *PLoS ONE*, 10(9), e0137229.

Newton, I. (2008). *The migration ecology of birds*. Academic Press.

Şekercioğlu, Ç. H., Primack, R. B., & Wormworth, J. (2012). The effects of climate change on tropical birds. *Biological Conservation*, 148(1), 1–18.

Aronson, M. F. J., La Sorte, F. A., Nilon, C. H., Katti, M., et al. (2014). A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceedings of the Royal Society B*, 281(1780), 20133330.

Chace, J. F., & Walsh, J. J. (2006). Urban effects on native avifauna: A review. *Landscape and Urban Planning*, 74(1), 46–69.

Lepczyk, C. A., Aronson, M. F. J., Evans, K. L., Goddard, M. A., Lerman, S. B., & MacIvor, J. S. (2017). Biodiversity in the city: Fundamental questions for understanding the ecology of urban green spaces for biodiversity conservation. *BioScience*, 67(9), 799–807.

MacArthur, R. H., & MacArthur, J. W. (1961). On bird species diversity. *Ecology*, 42(3), 594–598.

McKinney, M. L. (2008). Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystems*, 11, 161–176.

Shanahan, D. F., Possingham, H. P., Martin, T. G., & Fuller, R. A. (2011). The influence of patch area and connectivity on avian communities in urban revegetation. *Biological Conservation*, 144(2), 722–729.

Derdouri, A., Murayama, Y., Morimoto, T., Wang, R., & Haji Mirza Aghasi, N. (2025). Urban green space in transition: A cross-continental perspective from eight Global North and

South cities. *Landscape and Urban Planning*, *253*. https://doi.org/10.1016/j.landurbplan.2024.105220

Nussbaumer, R., L. Kirao, F. Liechti, and C. Jackson. 2022. Using ringing data to inform geolocator deployment: a case study of the Red-capped Robin-chat *Cossypha natalensis* in East Africa. Journal of Field Ornithology 93(2):8. https://doi.org/10.5751/JFO-00113-930208

Peter Odhengo, Alphayo I. Lutta, Philip Osano, Romanus Opiyo. (2024) Urban green spaces in rapidly urbanizing cities: A socio-economic valuation of Nairobi City, Kenya, Cities, Volume 155, 2024, https://doi.org/10.1016/j.cities.2024.105430

Peterson, A. T., Escalona-Segura, G., & Griffith, J. A. (1998). Distribution and Conservation of Birds of Northern Central America. *The Wilson Bulletin*, *110*(4), 534–543. http://www.jstor.org/stable/4164001

Hassell, J. M., et al. (2020). *Socio-ecological drivers of vertebrate biodiversity and human-animal interfaces across an urban landscape.* Global Change Biology, 27(4), 781-792. https://doi.org/10.1111/gcb.15412

Poff, N. L. (1997). Landscape filters and species traits: towards mechanistic understanding and prediction in stream ecology. *Journal of the North American Benthological Society*, 16(2), 391-409.

La Sorte FA, Graham CH. Phenological synchronization of seasonal bird migration with vegetation greenness across dietary guilds. J Anim Ecol.2021;90:343–355. https://doi.org/10.1111/1365-2656.13345

Gotelli, N. J., & Colwell, R. K. (2001). Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters*, 4(4), 379–391.

Oksanen, J., et al. (2022). *vegan: Community Ecology Package*. R package version 2.6-4.

Tattoni, D. J., and K. LaBarbera. 2022. Capture height biases for birds in mist-nets vary by taxon, season, and foraging guild in northern California. Journal of Field Ornithology 93(1):1. https://doi.org/10.5751/JFO-00021-930101

Appendix 1: Research Permits

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

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RESEARCH LICENSE

This is to Certify that Ms.. Maryann Wambui Wambui of Africa Nazarene University, has been licensed to conduct research as per the provision ofthe Science, Technology and Innovation Act, 2013 (Rev.2014) in Nairobi on the topic: Analysis of Avian Species Characteristics and Trends in an Urban Green Space Within the Nairobi National Museum, Kenya. for the period ending : 28/May/2026.

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Appendix 2: University Approval Letter

AFRICA NAZARENE
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22ndApril 2025

TOWHOMITMAYCONCERN

RE:RESEARCHPERMIT:MARYANNNGUGI

MaryannNgugiReg.No.(110062750)isaBonafidepostgraduatestudentat AfricaNazarene Universitypursuingamaster'sdegreeinEnvironmentandNaturalResourceManagement. This program entails Coursework and Thesis. She has successfully completed her coursework and defended her thesis proposal entitled:

"Analysis of AvianSpecies Characteristics and Trends in an Urban Green Space Within the Nairobi National Museum, Kenya."

Anyassistance accordedtoher tofacilitatedatacollection andcomplete her thesiswill be highly appreciated.

Sincerely.

Prof.OrphaK.Ongiti

Dean,PostgraduateStudies&Director,InstituteofResearch