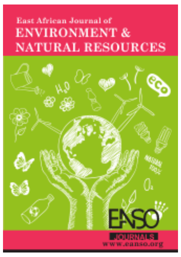

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Original Article

Avian Taxonomic and Functional Diversity in Contrasting Habitats: A Comparative Study of Urban and Remote Forests in Arusha, Tanzania

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ABSTRACT

Urbanisation globally transforms landscapes, impacting biodiversity significantly. In Arusha, Tanzania, rapid urban expansion accentuates the interplay between urbanisation and avian biodiversity. This study investigates urbanisation's influence on avian communities in two contrasting forested habitats: the urban "Themi River Forest" and the remote "Lake Duluti Forest." We explore taxonomic and functional avian diversity, elucidating underlying mechanisms. Taxonomic diversity analysis reveals "Lake Duluti Forest" with slightly higher species richness and "Themi River Forest" with a more even species distribution, reflecting urbanisation's influence. This aligns with global trends indicating reduced urban species richness due to habitat fragmentation. The urban forest, however, demonstrates avian adaptability to urbanised landscapes. Functional diversity analysis uncovers "Lake Duluti Forest" with greater functional richness, indicating a wider array of ecological roles. In contrast, "Themi River Forest" maintains comparable functional evenness, suggesting ecological balance despite urbanisation. Both forests exhibit distinct ecological niches, highlighting avian community flexibility. These findings hold significance for avian conservation and urban planning in Arusha and similar urbanising regions. Higher taxonomic diversity in remote forests underscores conservation importance. The urban forest showcases avian adaptability, emphasising green spaces in urban planning. Long-term conservation should protect both urban and remote forests, integrating strategies for avian habitat preservation and connectivity. This study advances understanding of urbanisation, forest type, and avian biodiversity's intricate relationship, offering insights for effective conservation in evolving urban landscapes.

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INTRODUCTION

Urbanisation has emerged as a potent force reshaping landscapes worldwide, with significant implications for biodiversity conservation (McDonnell & Hahs, 2015). In Arusha, Tanzania, where urbanisation is rapidly transforming natural habitats, the intricate relationship between urbanisation and biodiversity is particularly pronounced. The ongoing urban expansion in Arusha underscores the pressing need to comprehend how urbanisation influences biodiversity, specifically within contrasting forested habitats.

The dichotomy between natural forest ecosystems and the encroachment of human activities is increasingly evident. Urbanisation, accompanied by land use changes, poses a formidable challenge to the integrity of natural habitats, with forests often bearing the brunt of these alterations. These changes can trigger shifts in species composition, fundamentally affecting biodiversity dynamics (Chace & Walsh, 2006). As urban development encroaches upon natural forest habitats, species richness, distribution patterns, and ecological functions are under duress. This prompts urgent inquiries into the efficacy of conservation measures amid urbanisation.

Key among these inquiries is the concept of taxonomic and functional diversity, which assumes a pivotal role in understanding and conserving biodiversity. Taxonomic diversity, encompassing species richness, evenness, and diversity indices, offers insights into the variety and distribution of species (Magurran, 2004). Functional diversity, on the other hand, delves into the ecological role species play within ecosystems, encompassing functional richness, evenness, and divergence (Mason et al., 2005). The extent to which taxonomic and functional diversity vary across habitat types, especially within the context of urbanisation, remains a critical facet in contemporary biodiversity studies.

Against this backdrop, this study seeks to unravel the intricate interplay between urbanisation and avian biodiversity in Arusha. By comparing an urban forest, Themi Forest, with a remote forest, Lake Duluti Forest, our general objectives are twofold: firstly, to quantify the taxonomic and functional diversity of avian communities in these disparate habitats, and secondly, to pinpoint the mechanisms driving observed variations, particularly considering the influence of urbanisation.

Hypothesising that Themi Forest, subjected to urbanisation pressures, will exhibit reduced taxonomic diversity compared to the remote Lake Duluti Forest. Expecting the urban forest to house species adapted to human-modified landscapes, reflecting a shift in species composition. Concurrently, anticipating Lake Duluti Forest as a more pristine habitat to foster greater taxonomic diversity. In terms of functional diversity, predicting that the remote forest will harbour avian communities with higher functional richness and divergence due to reduced anthropogenic impacts. This study aims to deepen our understanding of the intricate relationships between urbanisation, forest type, and avian biodiversity, thereby informing effective conservation strategies for these unique ecosystems.

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STUDY METHODOLOGY

Study Area

This study was conducted in two distinct sites: Themi River Forest, an urban forest located within Arusha city, and Lake Duluti Forest, a remote forest situated in the Arusha region of Tanzania.

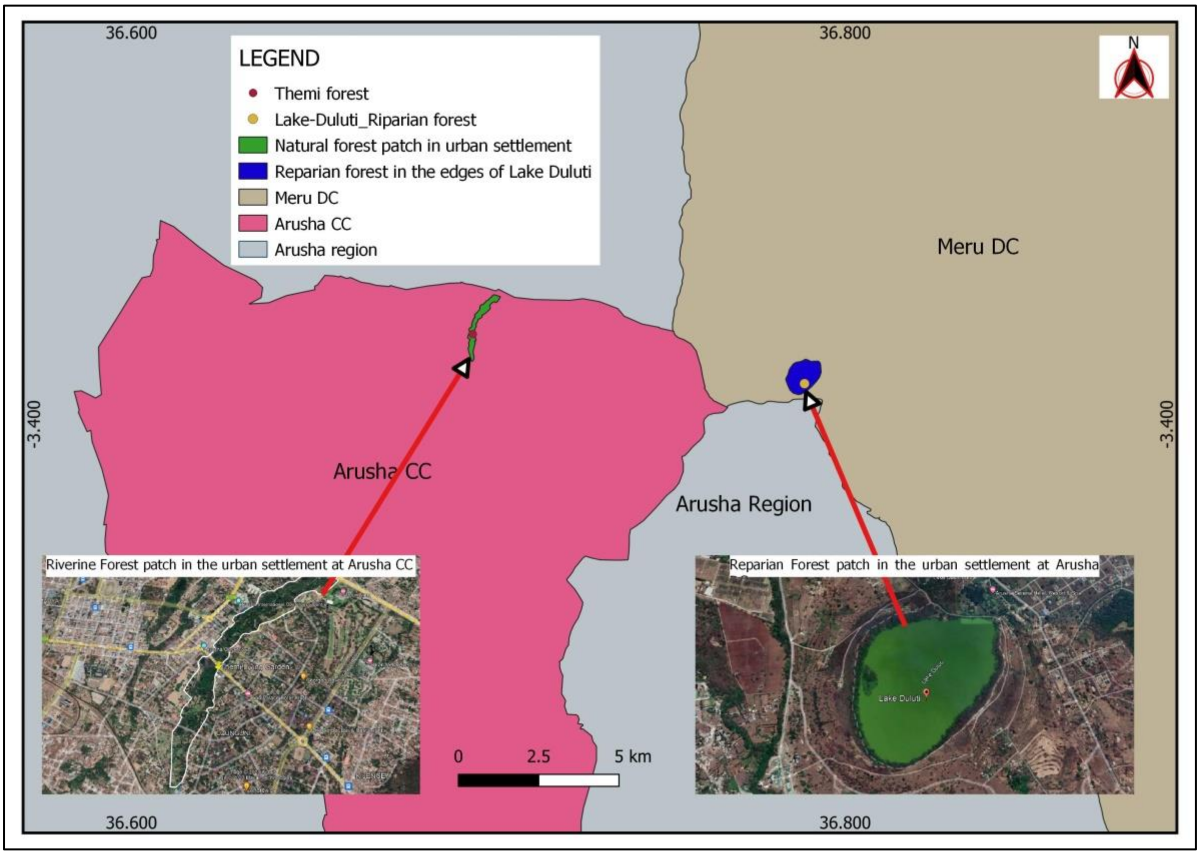
Themi River Forest

Themi River Forest, situated within the urban landscape of Arusha, covers an area of 409.2 km^2. Bordered by commercial and residential areas, this forest stands as a unique juxtaposition of nature and urbanisation (Chace & Walsh, 2006). The proximity to human activities exposes Themi River Forest to various urban pressures, including habitat fragmentation and recreational use. Despite these challenges, it remains a vital green space amid urban expansion. The forest's vegetation is a blend of indigenous and exotic species, reflecting the dynamic interplay between natural and human-altered elements (McDonnell & Hahs, 2015).

Lake Duluti Forest

Lake Duluti Forest, spanning an area of 851.2 km^2, offers a stark contrast as a remote and relatively untouched natural habitat in the Arusha region. Its dense canopy cover and diverse undergrowth characterise the ecosystem. Lake Duluti Forest enjoys a more pristine condition due to its remote location, with minimal exposure to direct urban pressures. The proximity to Lake Duluti enhances its ecological significance by fostering interactions between terrestrial and aquatic ecosystems. The forest serves as a refuge for various wildlife species, highlighting its importance for biodiversity conservation (Mason et al., 2005).

Figure 1: Location of Themi and Duluti forests in the Arusha Region



Contrasting Characteristics

Themi River Forest and Lake Duluti Forest represent divergent settings within the Arusha landscape. The former illustrates the interface between urban development and natural habitat, while the latter exemplifies a remote and

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undisturbed ecosystem. This dichotomy provides a unique opportunity to investigate the effects of urbanisation on avian taxonomic and functional diversity. The comparison between these habitats enables a deeper understanding of how different environments respond to urbanisation and the implications for biodiversity conservation strategies.

Bird Surveys

Data collection involved the utilisation of the point count method at designated sampling points within both Themi River Forest and Lake Duluti Forest. This established method facilitated the systematic assessment of avian species present in the study areas(Morelli et al., 2022; Thresher & Gunn, 1986). Observations were conducted during predefined time intervals, capturing both the sight and sound of avian species within a predetermined radius. At each sampling point, a skilled observer conducted the bird survey. The observer recorded all observed species, their counts, and notable behaviours. The point count method allowed for consistent data collection, reducing potential bias associated with different observation techniques (Morelli et al., 2022)

Selection of Functional Traits

Systematically categorising functional traits, encompassing key aspects of avian behaviour like feeding habits, foraging heights, habitat preferences, nesting behaviours, and migratory tendencies, has been documented in previous studies (Corbelli et al., 2015; Nava-Díaz et al., 2022). This categorisation aimed to simplify the complexities of avian behaviour, facilitating a comprehensive analysis of functional diversity. Functional trait data for each species were gathered from authoritative sources, field guides, and ornithological databases, creating a comprehensive dataset.

Eight functional traits with 43 distinct categories were selected, aligning with previous research on bird functional diversity and responses to habitat changes. These traits included ecological factors like primary foraging substrate and main habitat, as well as life-history traits such as dietary preferences and body mass. These traits were crucial for understanding how species react to environmental shifts and their impacts on ecosystem function. To standardise the trait data, established protocols were followed, treating traits as categorical and using a binary scale (0 or 1) to indicate their presence or absence in each species. For traits with multiple states, like diet, a subdivided approach was employed, assigning a binary score of 1 to each relevant state. This rigorous trait assessment process relied on reputable references, including Curzel et al. (2021), Germain et al. (2023a), Miller (2017), and Riegner (2021), ensuring methodological accuracy and rigour in trait data (*Supplemental Table 1*).

Data Analysis

Data Organization

The survey data were structured into two matrices to address the study objectives. The first matrix, representing sites by species abundance, provided a comprehensive overview of avian distribution in Themi River Forest and Lake Duluti Forest. Each row corresponded to a sampling site, and columns denoted the abundance of avian species recorded at each site. This matrix allowed us to explore spatial patterns of species distribution and richness (Legendre & Legendre, 2012) (*Supplement material Appendix A*)

The second matrix, characterised as species by traits, facilitated the examination of avian functional traits across the observed species (Legendre & Legendre, 2012). Each row represented a distinct avian species, and columns captured the selected functional traits, structured in binary format to indicate trait presence or absence (Germain et al., 2023b). This matrix enabled the investigation of how avian functional traits varied across species and between habitats (*Supplement material Appendix B*)

Taxonomic Diversity Analysis

To assess taxonomic diversity, species richness, evenness, and Simpson's diversity index were calculated using the 'vegan' package (Roswell et

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al., 2021). Subsequently, similarity indices (Jaccard Similarity Index, Bray-Curtis Similarity Index and Sørensen-Dice Similarity Index) were employed to compare the similarity or dissimilarity of species compositions between the two forest habitats.

Functional Diversity Analysis

In this study, the power of the "FD" package in R was harnessed to conduct an in-depth exploration of functional diversity (Legendre & Legendre, 2012; Villéger et al., 2008). This package offers a suite of tools tailored for computing various functional diversity indices, capturing diverse facets of trait dissimilarity within and between habitats (Legendre & Legendre, 2012).

The methodology was initiated by accurately curating two essential datasets: the trait matrix and the site matrix (Violle et al., 2007). The trait matrix summarised species traits, adopting a species-as-rows and traits-as-columns arrangement. Correspondingly, the site matrix recorded species abundance across different sites (presence/absence), adopting a site-as-rows and species-as-columns structure. This alignment of data structure with the FD package's requisites was vital.

At the core of our functional diversity analysis stood the eminent dbFD () function (Laliberte & Legendre, 2010; Legendre & Legendre, 2012). It leveraged the PCA-derived trait matrix and the site matrix to derive an array of functional diversity indices. These encompassed the comprehensive functional richness (FRic), the compelling functional evenness (FEve), the enlightening functional divergence (FDiv), and the insightful functional dispersion (FDis).

In an endeavour to effectively disseminate our findings, an elegant visualisation approach hinged on the "ggplot2" package was opted for (Wickham, 2016). This approach culminated in the creation of bar plots that facilitated a side-by-side comparison of FRic, FEve, FDiv, and FDis values across two distinctive habitat types: "Duluti Lake Forest" and "Themi River Forest." This narrative enriches comprehension of how species traits orchestrate ecosystem functioning, thereby invigorating conservation narratives and strategic ecological management.

RESULTS

Taxonomic Diversity

The investigation into the taxonomic diversity of avian communities within the contrasting forest habitats of "Lake Duluti Remote Forest" and "Themi River Urban Forest" uncovers intriguing patterns. Species richness, a fundamental measure of biodiversity, was found to be slightly higher in "Lake Duluti Forest," with 48 distinct avian species identified, in contrast to 44 species in "Themi River Forest."

Additionally, we evaluated the Shannon Diversity Index, which integrates both species richness and the evenness of species distribution. Our analysis reveals a Shannon Diversity Index of 4.03 for "Lake Duluti Forest" and 3.79 for "Themi River Forest (*Figure 2*) and Similarity indices to compare the similarity or dissimilarity of species compositions between the two forest habitats reveal close similarity (*Figure 3*).

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Figure 2: Comparative Shannon Diversity indices among contrasting habitats

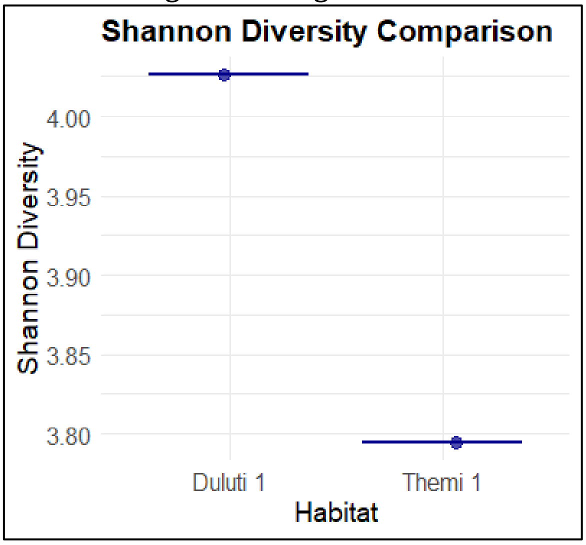
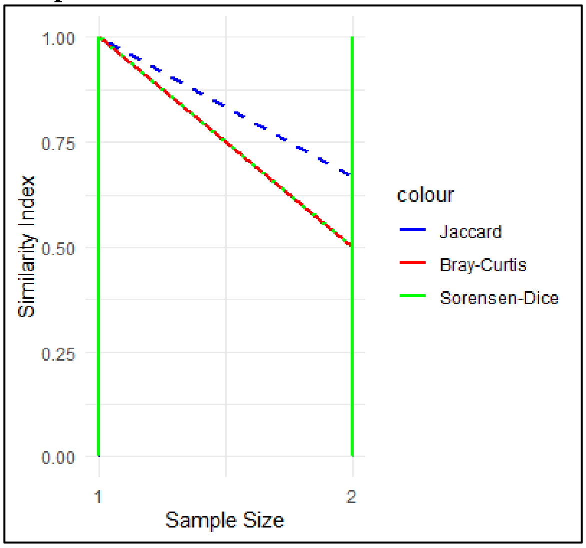


Figure 3: Similarity or dissimilarity of species compositions between Themi and Duluti

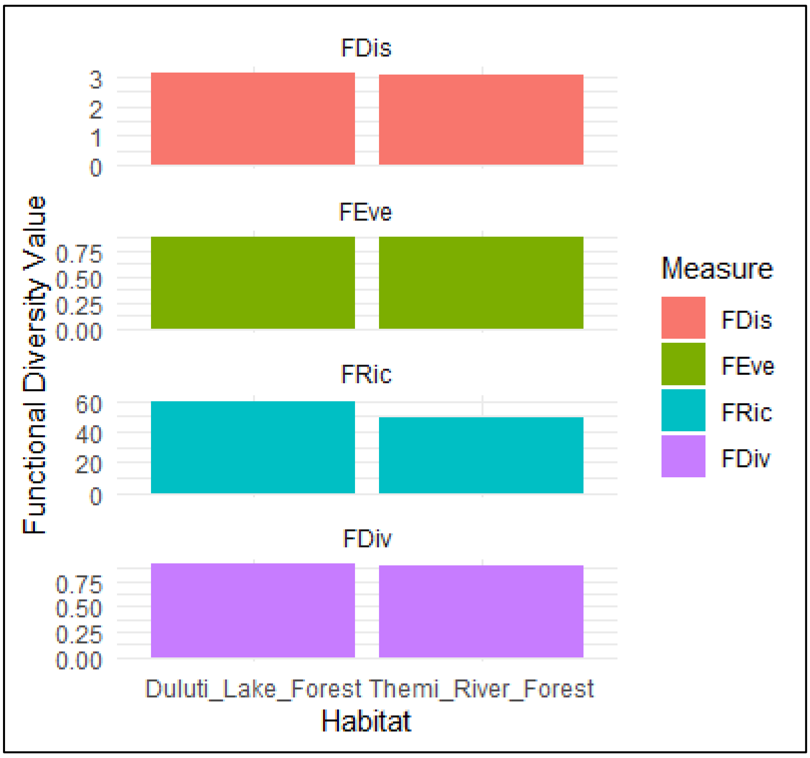


Functional Diversity Indices

In the quest for a deeper understanding of avian communities in the contrasting forest habitats of a remote forest, "Lake Duluti Forest," and an urban forest, "Themi River Forest," various functional diversity indices were explored, shedding light on intricate ecological patterns. First, functional Richness (FRic) quantifies the diversity of functional traits in avian communities, highlighting the remote forest's richness (FRic = 60.38) compared to the urban forest (FRic = 49.62). This contrast emphasises the remote forest's capacity to host a more diverse array of functional traits among its avian inhabitants. On the other hand, the evenness of functional trait distribution examined by functional Evenness (FEve) revealed remarkable similarity between the two habitats (Lake Duluti Forest FEve = 0.888, Themi River Forest FEve = 0.882), indicating comparable evenness in trait distribution.

A measure of ecological differentiation (Functional Dispersion (FDis) based on functional traits, subtly differentiating between the habitats (Lake Duluti Forest FDis = 3.13, Themi River Forest FDis = 3.08), highlighting distinct ecological niches within the remote forest. Lastly, functional Divergence (FDiv), which gauges functional disparities among species, showcasing similar levels in both habitats (Lake Duluti Forest FDiv = 0.91, Themi River Forest FDiv = 0.90), suggesting species have adapted to distinct niches. Our exploration of functional diversity reveals intricate ecological dynamics in these forests, with the remote forest's richness, evenness, and distinct niches standing out (*Figure 3*).

Figure 4: Comparative Functional Diversity Measures among contrasting habitats



DISCUSSION

Urbanisation, a widespread global phenomenon, casts its influence on natural habitats, including forests. In the case of "Themi River Forest," situated amidst the urban landscape of Arusha, the study adeptly sheds light on the tangible impact of urbanisation on avian biodiversity. It briefly articulates how the urban environment leads to a slightly lower species richness compared to the remote "Lake Duluti Forest," echoing trends observed in other urban areas worldwide (McDonnell & Hahs, 2015). This decrease in species richness serves as a foundational concept that sets the stage for a deeper exploration of avian responses to urbanisation.

Transitioning to the realm of functional diversity, the study delves into the ecological roles of avian species within these distinct forest types. Functional diversity, an essential complement to taxonomic diversity, offers a comprehensive understanding of how avian communities adapt to changing environments (Mouillot et al., 2013). The higher functional richness observed in the remote forest aligns with existing research, emphasising that less disturbed forests often harbour a broader spectrum of functional traits and ecological functions (Mouillot et al., 2013). This nuanced perspective expands the discourse beyond species counts and delves into the diverse ecological roles played by avian inhabitants. Intriguingly, the urban forest exhibits comparable functional evenness, indicating that despite the challenges posed by urbanisation, this habitat maintains a degree of ecological balance among avian species. This balance emerges from a confluence of factors, including urban forest management practices and the presence of species with diverse functional traits (Aronson et al., 2014). Observed forest specialist species such as Abyssinian Thrush (*Turdus olivaceus*) in a disturbed urban forest highlight the adaptability of avian communities within urban environments and their ability to find equilibrium despite habitat alterations.

Furthermore, the study's exploration of functional dispersion within the remote forest elucidates the presence of distinct ecological niches. Even in its remote state, this forest supports a mosaic of avian species, each contributing uniquely to ecosystem functioning (Flynn et al., 2009). The concept of intact natural habitats providing a spectrum of ecological niches aligns seamlessly with this finding. In contrast, while functional dispersion is slightly lower in the urban forest, the presence of distinct ecological niches underscores the adaptability of avian species to different facets of the urban ecosystem. This adaptability resonates with previous research that had observed certain bird species thriving in urban environments (Evans et al., 2010, 2011). Lastly, the study's examination of functional divergence, revealing similar levels in both habitats, underscores how avian species in both remote and urban forests have adapted to distinct niches. This adaptability showcases the flexibility of avian communities in responding to diverse environmental conditions (Aronson et al., 2014).

In essence, this study seamlessly weaves together the concepts of taxonomic and functional diversity, elucidating the intricate relationship between urbanisation, forest type, and avian biodiversity. It underscores the adaptability of avian communities and the resilience of certain species in the face of urbanisation, ultimately providing a nuanced understanding of the multifaceted responses of avian biodiversity to changing landscapes.

Implications for Conservation and Urban Planning

These findings carry significant implications for avian conservation and urban planning in Arusha and similar regions experiencing rapid urbanisation. The higher taxonomic diversity observed in the remote forests emphasises the importance of conserving remote and less disturbed habitats, as they harbour a wider variety of avian species (McDonnell & Hahs, 2015). In contrast, the urban forest showcases the adaptability of avian communities to urbanisation, emphasising the need for urban planners to consider green spaces within urban environments (Aronson et al., 2014). Long-term avian conservation efforts should prioritise the protection of both urban and remote forests. Urban areas should integrate conservation strategies that preserve and enhance avian habitats, recognising their ecological value and contribution to biodiversity (Evans et al., 2010, 2011). Additionally, maintaining green corridors connecting urban and remote forests can facilitate species movement and genetic exchange (van Strien et al., 2018). These strategies are crucial for sustaining avian biodiversity in the face of ongoing urbanisation and ensuring the coexistence of avian species with human communities in urban areas (Aronson et al., 2014)

CONCLUSION

This study delved into the complex dynamics of avian communities in urban and remote forests, shedding light on their responses to urbanisation. By contrasting the biodiversity and functional traits of birds in Arusha's "Lake Duluti Forest" and "Themi River Forest," valuable insights were uncovered. The remote forest exhibited higher taxonomic diversity, emphasising the importance of preserving less disturbed habitats for avian conservation. Conversely, the urban forest showcased the adaptability of avian communities to urbanisation, highlighting the need for green spaces in urban planning. Functional diversity analysis revealed nuanced ecological roles and adaptability, with the remote forest harbouring a diverse array of functional traits. These findings hold significant implications for conservation and urban planning, advocating for the protection of both urban and remote forests and the integration of sustainable strategies to maintain avian habitats in urban areas. The study contributes essential knowledge for safeguarding avian ecosystems in the face of urban expansion, underlining the urgency of holistic conservation efforts and urban planning that balance human development with the preservation of biodiversity.

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