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Species

Patterns of avian diversity in a tropical urban area provide valuable lessons for setting up urban green spaces

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ABSTRACT

Rapid land conversion, mainly driven by urbanization, poses a serious threat to biodiversity across the world. To address this, urban green spaces are often created in temperate regions, to support biodiversity and improve human well-being. However, there is an opportunity to advocate for the protection of existing green spaces in tropical Africa that support biodiversity and to avoid the challenges of urbanization faced by developed countries. We assessed the abundance and richness of bird species in ten completely engulfed natural habitat patches in the Cape Coast metropolis, a rapidly growing urban area in southern Ghana. We assessed the taxonomic, functional, and phylogenetic diversity of avian species in ten habitat patches. Also, we also investigated the influence of green space attributes on abundance and diversity. We recorded a total of 100 avian species belonging to 39 families. The Hooded Vulture (*Necrosyrtes monachus*), was the only species of conservation concern being Critically Endangered. We found that both the diversity and abundance of birds positively correlated with larger habitat areas and the presence of water, but did not vary significantly across seasons. We recorded more species and a higher richness index in the wet season than the dry season. We caution that most of the present green spaces are at risk of dying out if not protected, and as such, strongly advocate for the protection of these sites, especially those supporting endangered species.

Keywords: Tropical urban ecosystem, urbanization, avian diversity, land change, Hill numbers

1. INTRODUCTION

About 50% or more of the Earth's land resource has already been altered due to human activities (Hooke et al., 2012). This unprecedented transformation of natural habitats is driven by the increasing demand for land resources, exacerbated by a growing human population, which is projected to reach 8.5 billion by 2030 (Bujang, 2017; United Nations, 2022). This challenge is particularly pronounced in Africa where rapid population growth and urban expansion has led to extensive land conversion (United Nations, 2022). Urbanization, identified as a major driver of habitat loss Mensah, (2014), is particularly concerning for biodiversity conservation in developing regions, including Ghana.

The impact of urbanization on biodiversity is well-documented, with many studies highlighting adverse effects such as habitat loss, fragmentation, and declines in species abundance. McKinney, (2008) found that extreme urbanization often leads to lower species richness across various taxa. Nonetheless, the creation of urban green spaces, well championed in temperate regions, can mitigate some of these adverse effects by providing critical habitat for wildlife. In tropical urban areas, existing unprotected green spaces play a crucial role in supporting biodiversity and enhancing human well-being (Pasanen et al., 2023). These already existing green spaces eliminate the need to create artificial ones.

Hill numbers provide a unified framework for assessing diversity, incorporating species abundance to give a more complete picture of community composition (Chao et al., 2014; Napoleone et al., 2021). Functional diversity, refers to the different roles' species play in an ecosystem, is especially important in urban areas, where ecosystem services help sustain ecological balance. Phylogenetic diversity, reflecting evolutionary relationships among species, offers insights into community resilience and adaptability to environmental changes (Moore, 2013; Napoleone et al., 2021). Albeit their importance, these approaches have been underutilized in West African urban ecology studies to describe species assemblages.

Key green space attributes such as patch size, habitat complexity, and surrounding land use influence avian diversity. While patch size has been extensively studied Thompson et al., (2022), other variables, such as vegetation structure, habitat connectivity, and urban disturbance levels, require further investigation, particularly in African cities. Research on metropolitan areas in Australia (Shanahan et al., (2011) has shown that patch size and habitat connectivity have a strong influence on bird diversity, highlighting the need to preserve structurally diverse green spaces. Normalized Difference Vegetative Index (NDVI), a widely used indicator of vegetation health, has been shown to correlate with avian diversity, as greener areas tend to support higher species richness and abundance due to increased resource availability (Leveau and Isla, 2021; Benedetti et al., 2023).

Similarly, urbanization gradients influence biodiversity by shaping microclimates and habitat diversity thus leading to variations in species composition across urban landscapes. Urbanization intensity, often measured by impervious surface cover, negatively impacts avian diversity by reducing habitat quality and fragmenting populations. Some species are able to adapt to urban environments, which can alter community composition. Water bodies are especially important for avian diversity, offering essential resources like drinking water, foraging areas, and nesting sites for species that depend on them. Additionally, seasonal variations play a role in shaping urban bird communities with studies indicating higher species richness during the wet season due to increased resource availability (Abrahamczyk et al., 2011; Cox et al., 2011).

This study examined the role of ten abandoned and fully engulfed green spaces in supporting avian diversity within Cape Coast, Ghana. Using total functional diversity and log abundance as response variables, we investigated key predictors of bird diversity in these urban patches. We hypothesize that diversity will increase with patch size, consistent with the island biogeography theory MacArthur and Wilson, (1967), but also that vegetation complexity and surrounding urban intensity will significantly influence bird assemblages. This study helps address gaps in tropical urban ecology research by highlighting the conservation importance of overlooked green spaces in fast-growing cities and guiding future strategies for managing urban biodiversity in Africa.

2. MATERIALS AND METHODS

Study area

The study was done in the Cape Coast Metropolitan Area (CCMA), situated between coordinates 5° 07′ to 5° 20′ N and 1° 11′ to 1° 41′ W within the Central Region of Ghana. The CCMA covers an area of 12,200 hectares (ha) under the current 260 metropolis and municipal classification of Ghana. The area has undergone significant urbanization since the 1990s. In 2010, CCMA had a population of 169,894, and according to the 2021 census, it now has 189,925 residents. CCMA is situated within the Guinea-Congo vegetation zone of West Africa, characterized by high humidity and monthly relative humidity ranging from 85% to 99%. The study area experiences two main seasons: a bi-modal rainy season (April to July and September to October) and has a dry season (November to March). North of the region lies the Kakum National Park, a significant area for biodiversity protection in Ghana.

The current Google satellite images of the study area from May 2023 were analyzed to identify patches of green space within the urban landscape that are wholly engulfed by roads or buildings (QGIS Development Team, 2023). We identified ten green habitat patches for the study, varying in size from 0.5 ha to 38 ha. Our inclusion criteria required sites to be large enough to support populations of several species—but isolated from other patches or forest fragments. We classified the sites as either large or small based on their total area. Large sites were those that exceeded 4 ha; this categorization resulted in a sample size of five small sites (N = 5) and five large sites (N = 5). We also visually classified the sites' surrounding urbanization into two levels based on the surrounding landscape and categorization from several studies (Appendix 1, 2 & 3). Sites in the core built-up area were surrounded by higher densities of settlements and roads, while those in moderate built-up areas had fewer buildings but were still.

Experimental design

Two-point count locations were randomly generated using QGIS 3.30.2 along the perimeter of the ten study sites, with distances between points ranging from 84 to 800 meters. In the three smallest sites (War Memorial Museum, Ayikoayikoo, and Fort William habitat patches), the distance between points ranged from 84 to 130 meters, reflecting their smaller size. We used point counts along the perimeter because some patches had been converted into dump sites, making them unsuitable for walking through. The 20 generated points were located in the field using a handheld Garmin GPS device (Garmin® Extrex HC). Bird sampling was conducted using a pair of binoculars (Focus 8x42). Each of the 20 points was sampled twice each in the wet and dry seasons (Figure 1).

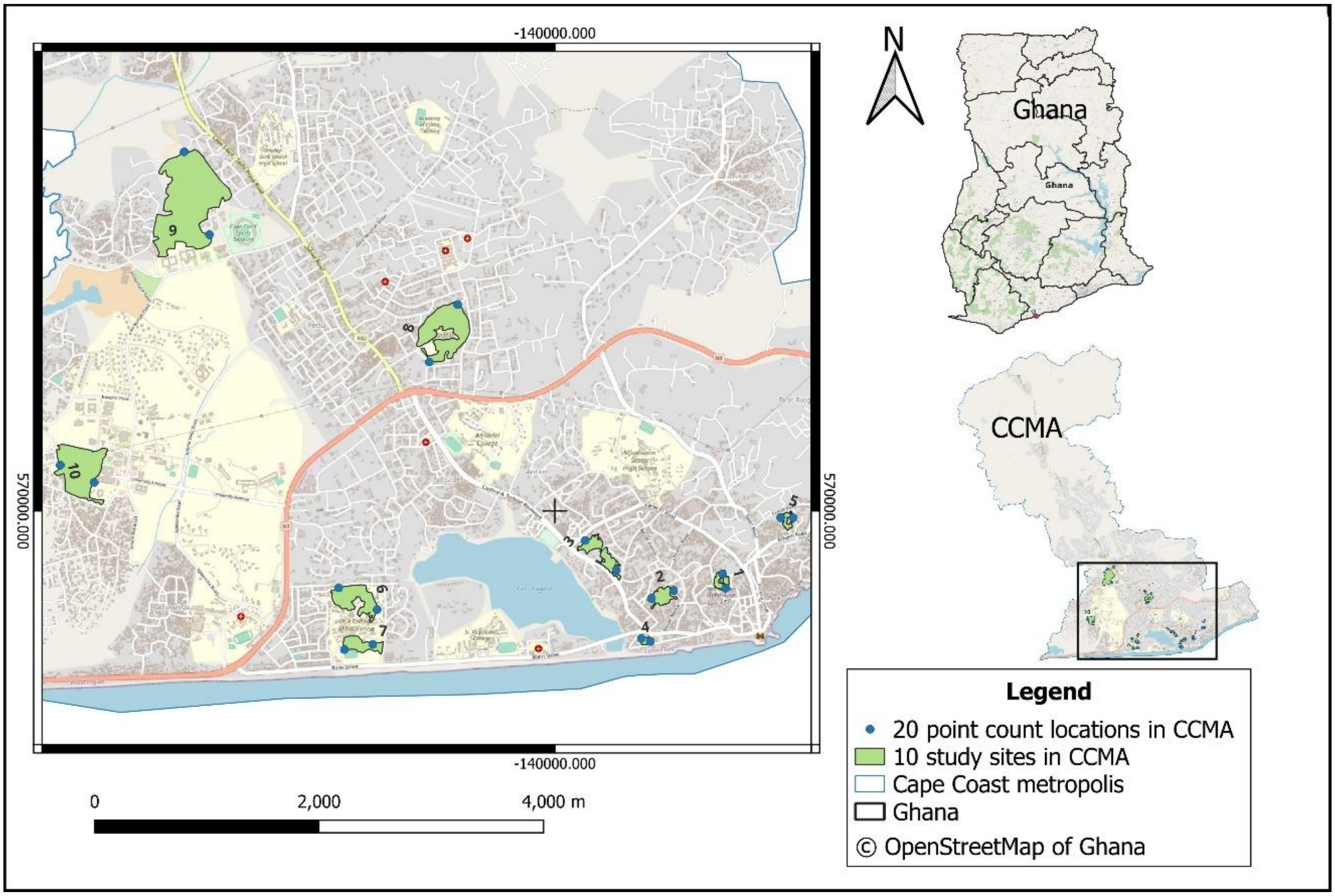


Figure 1 Map showing Ghana (top right), Cape Coast metropolis (down right), and study sites in green with point count locations in blue. Generated with QGIS 3.30.2 with imagery from OpenStreetMap contributors (https://www.openstreetmap.org/copyright)

Despite the small sample size, the four replicates per point allowed us to obtain a more accurate reflection of the diversity and abundance at the sites. Additionally, because birds are highly mobile, increasing the number of points relative to habitat size would have resulted in significant double-counting. Bird counts were performed over 80 days, within four months during the wet season and three during the dry season. Point counts began at 06:00 hours GMT and lasted for one hour. Bird activity is generally highest early in the morning due to their drive to forage (Bonter et al., 2013). We avoided counting bird flyovers at all sites. Data collection was paused during rain. Avian richness and abundance were recorded using the Merlin eBird app, which is dedicated to recording avian species observations (Sullivan et al., 2009).

Avian richness for each species at each site was recorded at its two-point count locations with the aid of a field guide (Borrow and Demey, 2020). Abundance in all sites, except the three smallest, was calculated by adding the maximum bird counts across visits at both point count locations to obtain the overall abundance. This aggregation was necessary due to the distance between points being above 210 meters (Morrison and Peitz, 2021). For the three smallest sites we did not aggregate but used highest abundance per species across all four visits due to the small size and because birds are highly mobile species. Incidental species recorded outside count times were not included in the analysis. The four incidental species are— the Mosque Swallow, Cecropis senegalensis, Black-winged Kite, Elanus caeruleus, Western Yellow Wagtail, Motacilla flava, and Pin-tailed Whydah, Vidua macroura.

Diversity indices

We calculated diversity using Hill numbers, setting q to 0 to account for rare species Chao et al., (2014), Chiu and Chao, (2014), using the "hillR" package in RStudio (Li, 2018). The package gives resultant indices and values for taxonomic, functional, and phylogenetic alpha index (Li, 2018). To quantify the functional diversity of the sites, we incorporated four biological and ecological traits of birds, including plumage, diet, ecological services provided by each species, and body mass as a proxy for body size. We classified species by feeding guild, plumage color, and ecosystem service primarily based on the Birds of Ghana guide Borrow and Demey, (2020) and other internet sources for each species.

Plumage was described based on the number of colors (single, dual and multi-color) and its attractiveness (drab or bright). The ecosystem services provided by birds play a crucial role in conservation decisions. They include insect control, frugivores, pollinators, fruit or seed dispersal, bio-indicator, crop pest, predator, pseudo-scavenger, and scavenger. Feeding guild classification follows established methods from previous studies and include; carnivore, frugivore, granivore, insectivore, nectarivore, omnivore and piscivore (Mariano-Neto and Santos, 2023; Shafie et al., 2023). Lastly, we included body mass as a biological trait representing size as it influences the visibility of birds to visitors in green spaces, particularly those without binoculars.

Body mass data was obtained from the AVONET database on all bird species (Tobias et al., 2022). The "hiilR" packages outputs a several indices including Rao's Q (a measure of functional diversity based on multiple traits), D_q (functional hill number), MD_q (mean functional diversity per species) and FD_q, the effective total functional distance between species of the assemblages. It also includes an overall phylogenetic alpha diversity value. FD_q and log abundance were considered as response variables to investigate the influence of some selected variables' diversity and abundance.

Variables for the study

To investigate how certain common green space attributes correlate with diversity, we selected and measured variables of interest that typically play a role based on previous studies in both temperate and tropical regions (Mbiba et al., 2021; Thompson et al., 2022). The Normalized Difference Vegetation Index (NDVI) is an index used to quantify the amount of greenness and plant health, which can serve as a proxy for food productivity (Leveau et al., 2020). We used NDVI values to differentiate the greenness of the sites across seasons. These NDVI values were derived on Google Earth Engine from Sentinel-2 images with less than 10% cloud cover using a script (https://code.earthengine.google.com/ca7719afa295ad6c0bff772d3f6a46f0). The habitat patch area was calculated in QGIS using polygon shapefiles with the correct georeferenced units in square meters.

Elevation has been found to influence bird distribution in some studies (Villegas and Garitano-Zavala, 2010; Zhong et al., 2024). Since the study area ranged from -2 to 117 meters above sea level, we sought to determine whether the elevation of the sites influenced bird diversity. Elevation data for this study was generated from Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) images in QGIS. The distance to refuse site was measured as the distance between the midpoint of the patch area and the nearest refuse site. Categorical variables included the level of urbanization (with two factors: core built-up and moderate), the presence of water, and season. A multicollinearity test was performed to eliminate highly correlated variables (> 0.7). Distance to refuse and log habitat area were positively correlated, so we removed distance to refuse from the analysis.

Data analysis

The data was stored in Microsoft Excel sheets and the analysis was conducted within an Rmarkdown script in RStudio Team, (2022), working on R software version 4.2.3 (R Core Team, 2022). We created generalized mixed models using "lme4 package" in R to investigate influence with (location only) and (location + season) as random effects. We also selected final models based on the lowest Akaike Information Criteria and interpreted the results with the "report" package.

3. RESULTS

Avian diversity across the study sites

A total of 100 avian species were recorded as belonging to 39 families in the selected habitat patches. Total abundance of the ninety-six species was 5,882 individuals excluding incidental species. A total of 87 species and 73 species were recorded in the wet season and dry season, respectively. The most represented families were Cisticolidae, Nectariniidae, and Estrildidae, with six species each. Except for the Hooded Vulture Necrosyrtes monachus, which is critically endangered, all other species were of no conservation concern (International Union for Conservation of Nature, 2023).

Out of the 100 species, there were 88 predominantly resident bird species and 12 migrant species. The only nocturnal species recorded was the Long-tailed Nightjar Caprimulgus climacurus observed during morning counts. Although some owl species were encountered, they were recorded outside count times and not identified and included in the species list for subsequent analysis. The most abundant species was the Pied Crow Corvus albus with 10.4% of the total abundance. It was followed by Bronze Mannikin Spermestes cucullata at 7.0%, and Common Bulbul Pycnonotus barbatus at 6.5%. The descriptions of the sites, including richness across seasons, log abundance, and total functional diversity for all ten sites where birds were sampled, are presented in (Table 1).

Overall, functional diversity was highest in the University of Cape Coast Botanical Garden (UCC) despite being the second largest area. This was followed by the largest area, the Cape Coast Stadium, and then Ola Roman Catholic Park. Sixty-five species were recorded in both the University of Cape Coast Botanical Garden and Cape Coast Stadium, while sixty species were recorded in Ola Roman Catholic Park. The three smallest sites—War Memorial, Fort William, and Ayikoayiko—had the lowest FD_q values.

Table 1 Habitat name, size, and corresponding variation in richness, log abundance, and functional diversity across the sample sites.

Location	**Area (ha)**	**Richness**		**Log Abundance**	**Log FD_Q**
		Dry	**Wet**		
Cape Coast stadium	37.6	45	56	6.2	7.7
University of Cape Coast	14.6	54	47	6.3	7.8
St. Peters Seminary	14.0	34	44	6.1	7.2
Ola boarding	7.0	36	48	6.2	7.4
Aboom	4.2	37	45	6.1	7.3
Ola roman catholic park	3.3	40	54	6.2	7.7
Fort Victoria	2.3	35	38	6.0	6.9
Fort William	1.4	20	27	5.0	6.3
Ayikoayikoo	1.0	23	37	5.7	6.7
War Memorial Museum	0.5	20	28	5.1	6.2

Table 2 Level of association of significant variables to the four response variables (Log abundance, Rao's Q, Log FD_Q, and Log Phylogenetic alpha diversity).

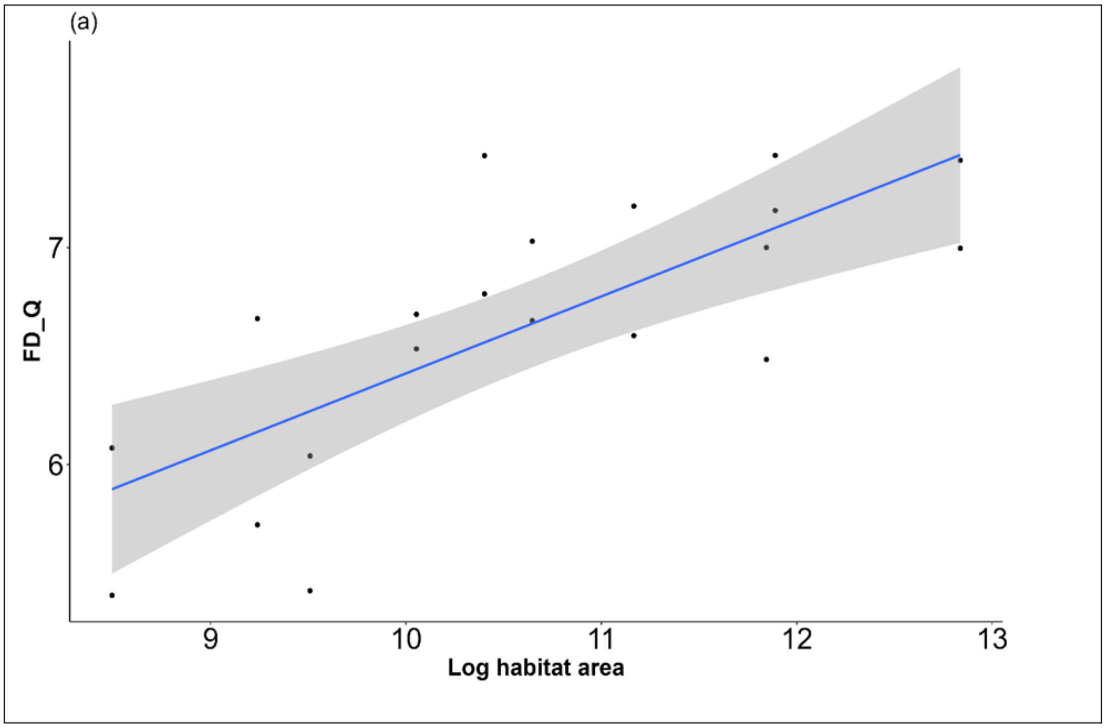
Variables	**Log Abundance**	**Log FD_Q**
Log Area	+	+
Season x Rainy	-	+
Log NDVI	-	+

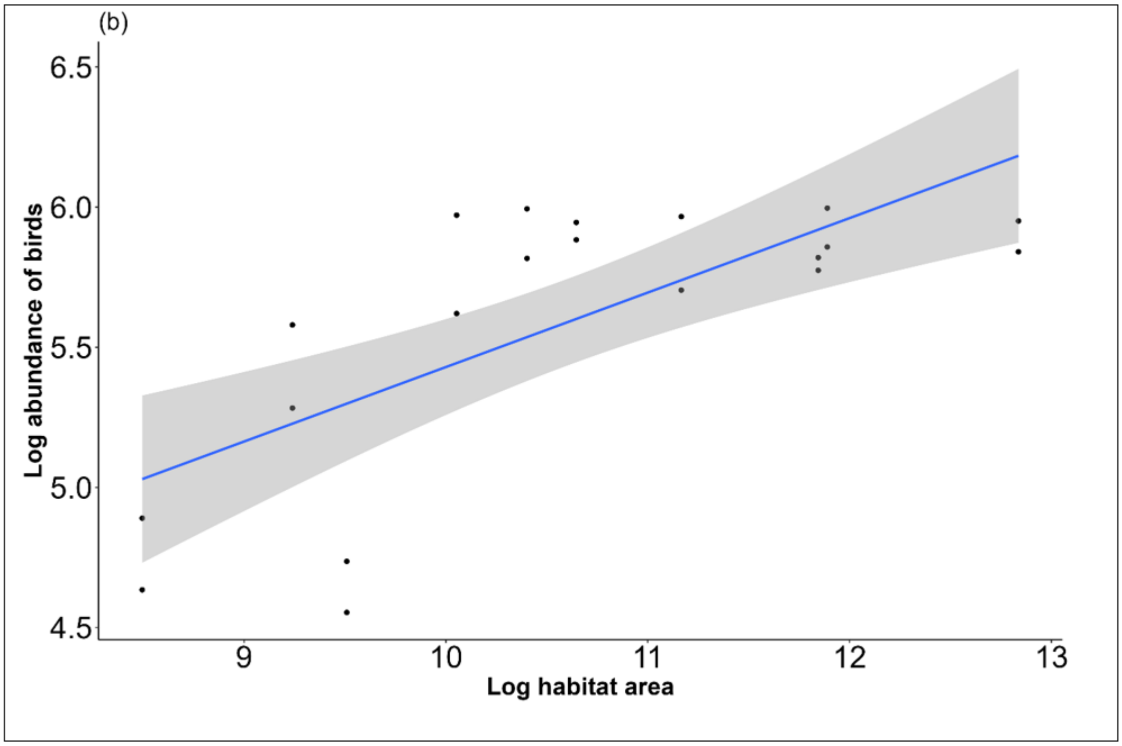
Water presence x Yes	+ +	+ +
Log x Elevation	+	+
Urbanization x Moderate	-	-

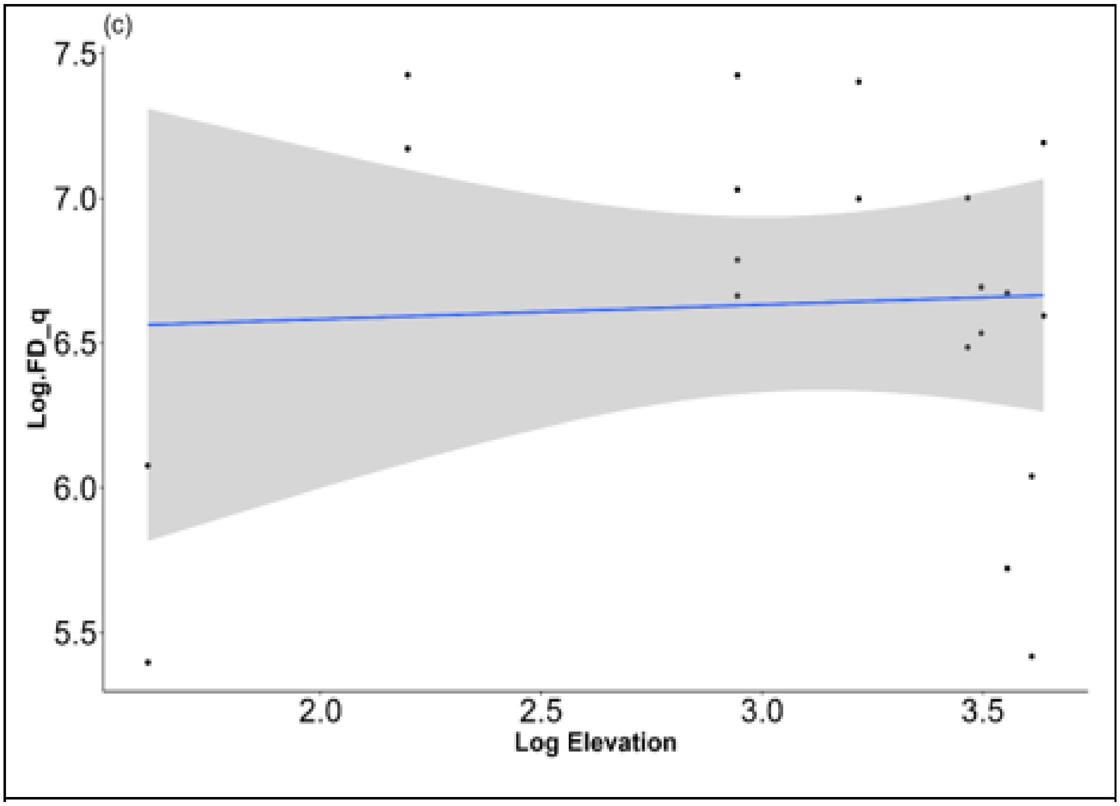
Positive (+) and negative (-) denotes the strength of association. Negative sign shows non-significant or reduced association. Positive means strong association. The number of plus signs indicates the strength of association obtained from the model with the lowest AIC per mixed model.

Influence of selected variables

We found that the presence of water was strongly associated with all two response variables investigated within the best-mixed models. The presence of water significantly influenced abundance, total functional diversity (log abundance: Estimate ± SE = 0.45 ± 0.55, t = 1.00; FD_Q: Estimate ± SE = 0.50 ± 0.30, t = 1.67, Table 2). For abundance, log area (Estimate ± SE = 0.28 ± 0.19, t = 1.48) was the second strongest predictor. Overall, six variables—log area, presence of water, log elevation, log NDVI, rainy season, and moderate urbanization—showed close associations with the response variables. We also explored differences in all four response variables across seasons and their relation to habitat area. There were no significant variations across seasons (log abundance: W = 71, p = 0.12; FD_Q: t = -1.76, df = 16.51, p = 0.09). The relationships of variables and response variables are expressed in (Table 2 & Figure 2).




(b)
6.5
6.0
5.5
5.0
4.5
Log abundance of birds
9
10
11
12
13
Log habitat area


(c)
7.5
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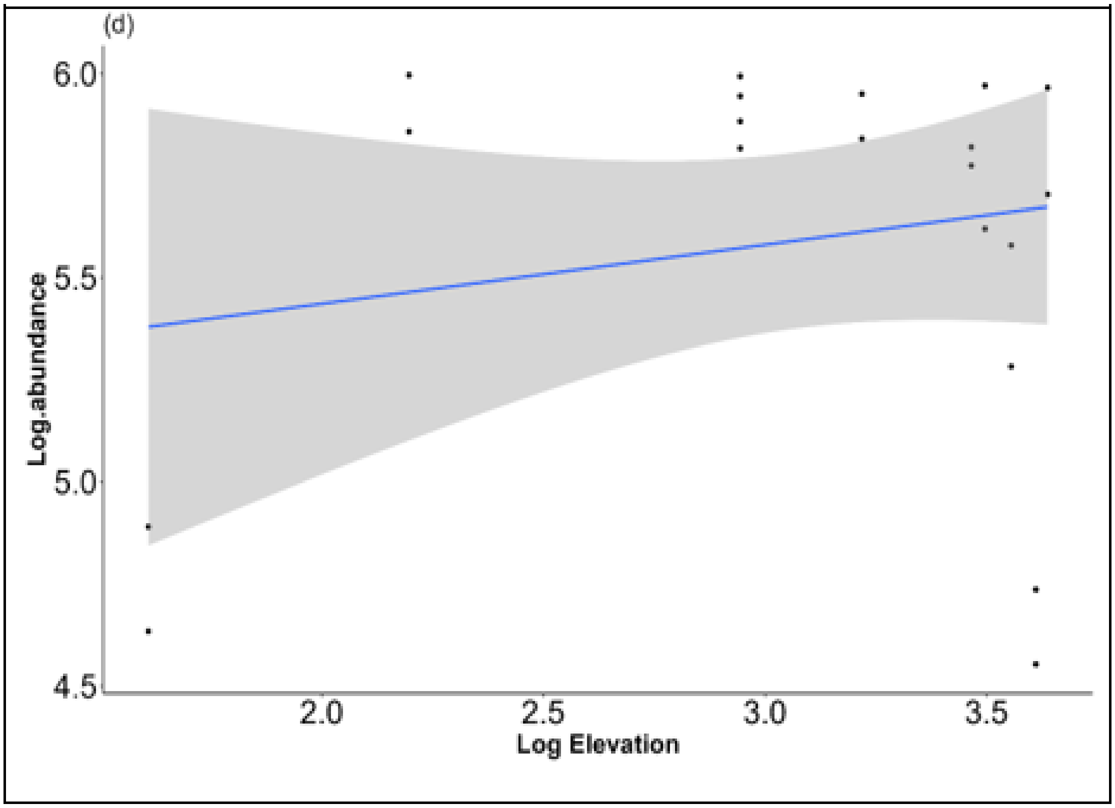
Log.FD_q
2.0
2.5
3.0
3.5
Log Elevation


(d)
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Log.abundance
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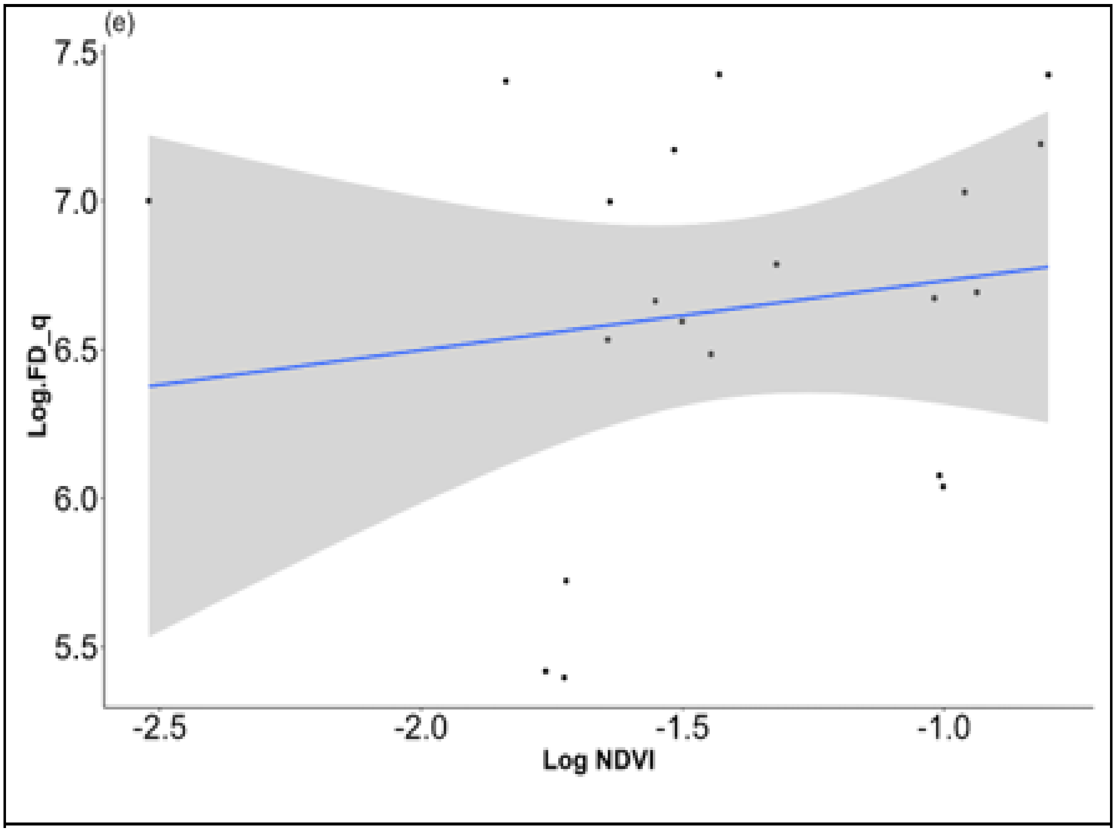
2.5
3.0
3.5
Log Elevation


(e)
7.5
7.0
6.5
6.0
5.5
Log.FD_q
-2.5
-2.0
-1.5
-1.0
Log NDVI

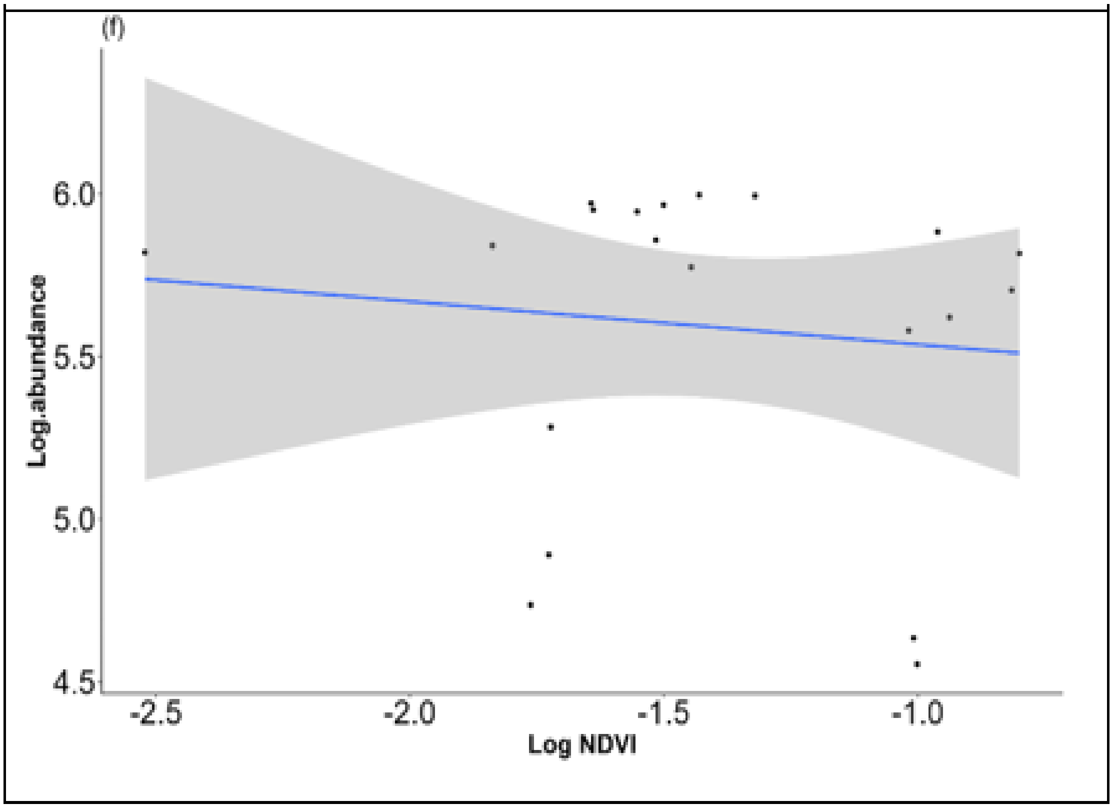


Figure 2 The relationship between (a) log area and log FD_Q, (b) log area and log abundance, (c) log elevation and log FD_Q, (d) log elevation and log abundance, (e) log NDVI and log FD_Q, (d) log NDVI and log abundance.

4. DISCUSSION

This study revealed species diversity and abundance positively correlated with habitat area in a typical urban ecosystem, as observed in several studies (Dale, 2018; Peris and Montelongo, 2014). The presence of water was significant for higher avian diversity and abundance. Diversity and abundance were slightly higher in the wet season than in the dry. This study revealed that present green spaces support a diverse and huge number of avian species, including endangered species, and therefore need to be protected.

Avian diversity and lessons for green space creation

Traditionally, urban ecosystems hold a many avian species, as evidenced from this study. Species richness and abundance positively correlated to habitat area, as observed in several studies (Dale, 2018). It is essential to note that this study did not assess nocturnal species, and we did not cover an estuary with a significant presence of waterbirds; hence, the actual species count for the area is likely higher than reported. Similar to the global context observed in other studies, urban regions can support biodiversity and improve human well-being. Tropical urban areas, in particular, can support more biodiversity than temperate ones, aligning with a similar trend seen in the biodiversity presence of pristine forests in both areas. This study also revealed that the presence of a water body and an ample green space can significantly support more bird species.

This is because a water body provides another micro-habitat for several water-dependent birds to thrive. The results of this study provide valuable lessons for the creation of urban green spaces in the future. This study reinforced the importance patch area and also highlighted the need for water to accommodate water dependent species. Though the wet season correlated with more species, we will refrain from suggesting it had a significant influence on species diversity as our study was constrained to a year of data collection. Should a similar pattern arise if data from several years are accounted for, then we can confidently associate wet season to host more species. Moderate urbanization was associated with a higher diversity of species. This is supported by past studies that show that extreme urbanization always reduces diversity.

Management implications

Urban ecosystems can die out rapidly, and bird groups may only utilize a habitat patch for a short time before it is cleared for a development project. Across the study area, green spaces have diminished. However, compared to other metropolises like Accra, CCMA retains a substantial amount of its green spaces. During the study, the second visit to the Ola Boarding patch revealed that the previously forested area for birds had been cleared, fragmenting the research area. This is a prime example of the risk birds face when nesting or roosting in such sites. Unfortunately, this site is one of three that housed a roost and feeding site for the critically endangered Hooded Vulture.

While stakeholders of these urban sites have the right to clear the land, it highlights how volatile resources for birds and other species are in the urban setting. It underscores the need for research to communicate the importance of these sites. A similar fate could be predicted for three more patches owned by private entities. Two habitat patches were found around historical forts (Fort William and Fort Victoria), which are government-owned and serve a cultural role by attracting visitors. They can be predicted to last longer as they are government-owned. Encroachment was, however, detected at the rear end of Fort Victoria, where locals were degrading the patch by harvesting wood for charcoal. Birds were strangely found utilizing burnt trees as perches to hunt in the freshly degraded environment.

Only the University of Cape Coast Botanical Garden can be reliably predicted to exist for the next five years to support biodiversity, as it is managed by the University and used for scientific and spiritual purposes. With various human threats present, the Cape Coast metropolis could soon mimic the Greater Accra metropolis, where full-blown urbanization has ensured few habitat patches remain in the core urban area. This study will, however, serve as a baseline for which other studies in the future can refer to and compare when urbanization has been fully achieved in tropical urban areas. Additionally, with the increase in human population comes a rise in waste, which is being utilized by bird species that traditionally did not associate with garbage. Most bird species observed in the study area were found to frequent the local refuse dump, picking at available food resources.

Common species include Common Bulbul, Village Weaver *Ploceus cucullatus*, Cattle Egret *Bubulcus ibis*. Surprisingly, Yellow-billed Kites *Milvus migrans parasitus,* and Woodland Kingfishers *Halcyon senegalensis* were also found to use refuse dumps frequently to pick food. Most study sites (6) had been converted into illegal refuse dump sites. This means birds did not need to travel long to utilize the food source. With an apparent absence of scavengers across the metropolis, species like Pied Crows have assumed that role. However, there is a health risk associated with these pseudo-scavengers, as they lack the adaptations of vultures to prevent the spread of diseases from the carcasses they feed on. This situation could lead to outbreaks of diseases such as cholera and others.

5. CONCLUSIONS AND RECOMMENDATIONS

Our findings suggest that within a typical urban area, the species-area theory holds true. Larger habitat patches support a higher diversity of birds and may host a greater abundance of individuals per species than smaller patches. Building on existing research, we propose that the presence of a water body can significantly influence the richness and abundance of bird species. We acknowledge the potential for existing urban patches supporting biodiversity to quickly disappear for the subsequent development project. As tropical Africa continues to urbanize, preserving existing green spaces that support diverse species is essential.

We emphasize the need for protective measures and aim to engage urban planners and stakeholders by presenting relevant findings and context. This approach is more beneficial than creating urban green spaces after extensive destruction. Additionally, we emphasize the need to support true scavengers in African urban environments, considering the risk of disease spread by species not adapted to dispose of diseased carcasses. Raising awareness and educating stakeholders is crucial for vulture conservation. The findings of this study can help guide future efforts in developing urban green spaces, promoting a more sustainable and biodiverse urban landscape.

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Author contributions

JKD conceived the idea for the project and conducted the analysis. Both authors made equal contributions in data collection, curation and preparing the manuscript.

Informed consent

Not applicable.

Ethical approval & declaration

In this article, the animal regulations followed as per the ethical committee guidelines of Department of Conservation Biology and Entomology, School of Natural Sciences, University of Cape Coast, Ghana; the authors observed the patterns of avian diversity in a tropical urban area provide valuable lessons for setting up urban green spaces. The Animal ethical guidelines are followed in the study for species observation & identification.

Conflicts of interests:

The authors declare that there are no conflicts of interests.

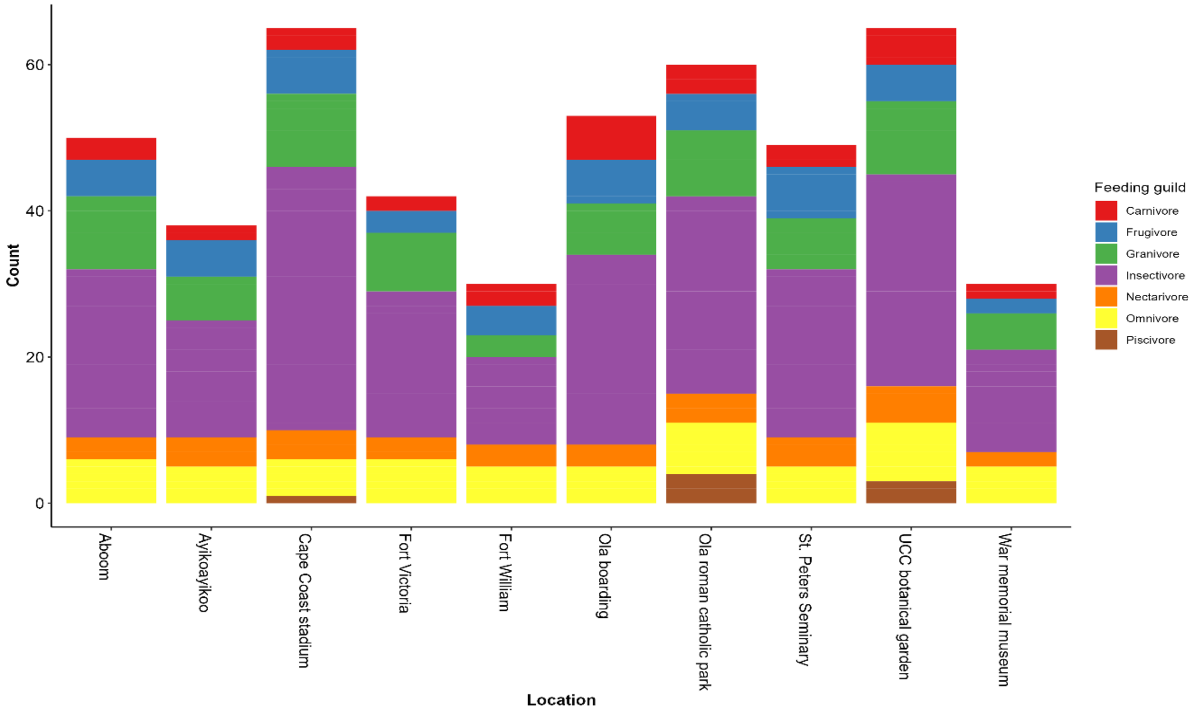
Funding:

The study has not received any external funding.

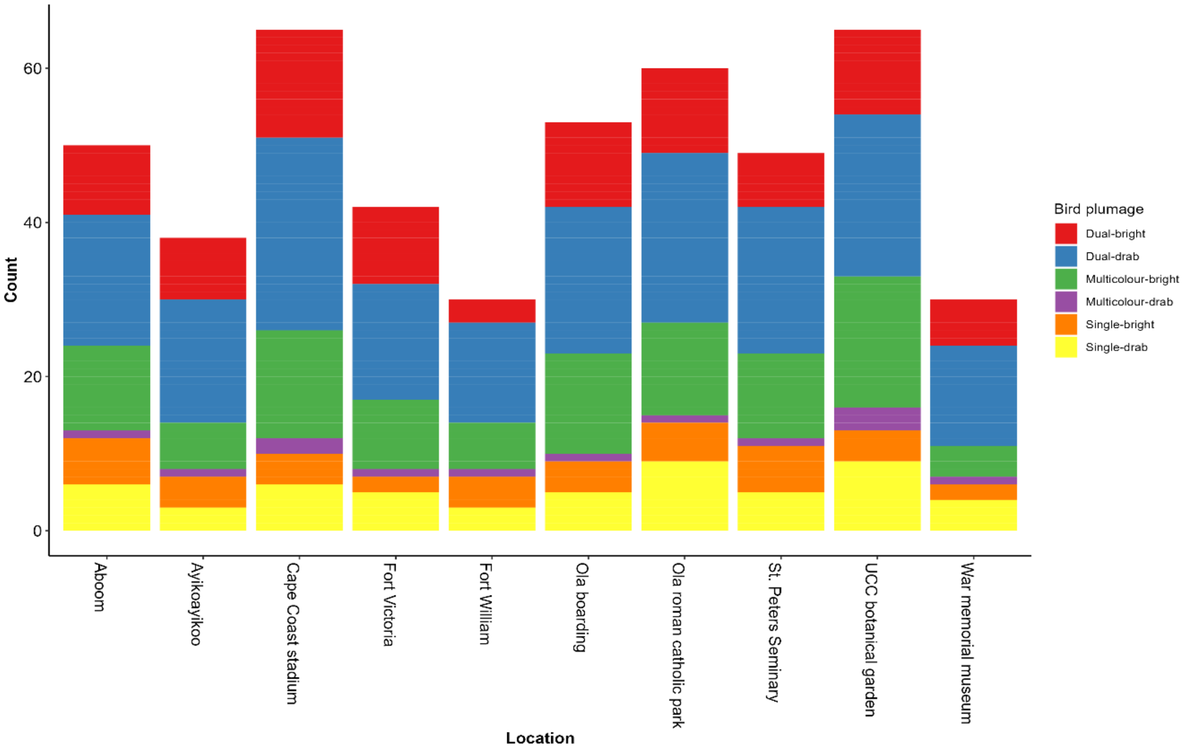
Data and materials availability

All data associated with this study are present in the paper.

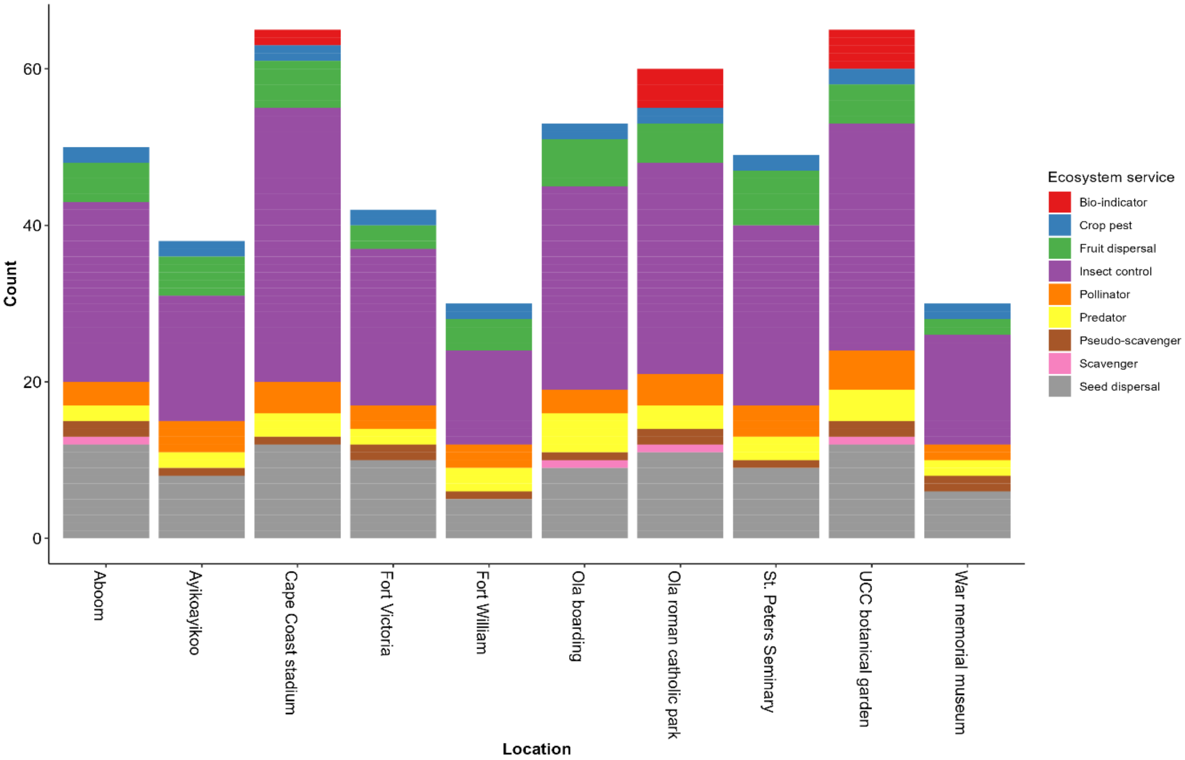
APPENDICES



Appendix 1 Feeding guild of species and their distribution across the ten selected study sites.



Appendix 2 Species plumage categories and their distribution among the ten study sites.



Appendix 3 Ecosystem role of species categories and their distribution among the ten study sites.

REFERENCES

1. Abrahamczyk S, Kluge J, Gareca Y, Reichle S, Kessler M. The influence of climatic seasonality on the diversity of different tropical pollinator groups. PLoS One 2011; 6(11):e27115. doi: 10.1371/journal.pone.0027115
2. Benedetti Y, Callaghan CT, Ulbrichová I, Galanaki A, Kominos T, Abou-Zeid F, Ibáñez-Álamo JD, Suhonen J, Díaz M, Markó G, Bussière R, Tryjanowski P, Bukas N, Mägi M, Leveau L, Pruscini F, Jerzak L, Ciebiera O, Jokimäki J, Kaisanlahti-Jokimäki ML, Møller AP, Morelli F. EVI and NDVI as proxies for multifaceted avian diversity in urban areas. Ecol Appl 2023; 33(3):e2808. doi: 10.1002/eap.2808
3. Bonter DN, Zuckerberg B, Sedgwick CW, Hochachka WM. Daily foraging patterns in free-living birds: exploring the predation-starvation trade-off. Proc Biol Sci 2013; 280(1760):20123087. doi: 10.1098/rspb.2012.3087
4. Borrow N, Demey R. Field Guide to Birds of Western Africa. 2nd Edition Bloomsbury Publishing, 2020.
5. Bujang A. Technical Empowerment of Agricultural Cooperatives in Malaysia. Enhancing Agricultural Cooperatives' Roles in Response to Changes in Food Consumption Trends, 2017.
6. Chao A, Gotelli NJ, Hsieh TC, Sander EL, Ma KH, Colwell RK, Ellison AM. Rarefaction and extrapolation with Hill numbers: A framework for sampling and estimation in species diversity studies. Ecol Monogr 2014; 84(1):45-67. doi: 10.1890/13-0133.1
7. Chiu CH, Chao A. Distance-based functional diversity measures and their decomposition: a framework based on Hill numbers. PLoS One 2014; 9(7):e100014. doi: 10.1371/journal.pone.0100014. Erratum in: PLoS One 2014; 9(11):e113561.
8. Cox DTC, Brandt MJ, Mcgregor R, Ottoson U, Stevens MC, Creswell W. Patterns of seasonal and yearly mass variation in West African tropical savannah birds. Ibis 2011; 153(4):672-83. doi: 10.1111/j.1474-919X.2011.01150.x
9. Dale S. Urban bird community composition influenced by size of urban green spaces, presence of native forest, and urbanization. Urban Ecosyst 2018; 21(1):1-14. doi: 10.1007/s11252-017-0706-x
10. Hooke R, Martin DJ, De-Pedraza J. Land transformation by humans: A review. GSA Today 2012; 22(12):4-10. doi: 10.1130/GSAT151A.1
11. International Union for Conservation of Nature. The IUCN Red List of Threatened Species. IUCN 2023.
12. Leveau LM, Isla FI, Isabel Bellocq M. From town to town: Predicting the taxonomic, functional and phylogenetic diversity of birds using NDVI. Ecol Indic 2020; 119. doi: 10.1016/j.ecolind.2020.106703
13. Leveau LM, Isla FI. Predicting bird species presence in urban areas with NDVI: An assessment within and between cities. Urban For Urban Green 2021; 63:127199. doi: 10.1016/j.ufug.2021.127199
14. Li D. hillR: taxonomic, functional, and phylogenetic diversity and similarity through Hill Numbers. J Open Source Softw 2018; 3(31):1041. doi: 10.21105/joss.01041
15. MacArthur RH, Wilson EO. The Theory of Island Biogeography. Princeton NJ: Princeton University Press, 1967; 203.
16. Mariano-Neto E, Santos RAS. Changes in the functional diversity of birds due to habitat loss in the Brazil Atlantic Forest. Front For Glob Change 2023; 6. doi: 10.3389/ffgc.2023.1041268
17. Mbiba M, Mazhude C, Fabricius C, Fritz H, Muvengwi J. Bird species assemblages differ, while functional richness is maintained across an urban landscape. Landsc Urban Plan 2021; 212. doi: 10.1016/j.landurbplan.2021.104094
18. McKinney ML. Effects of urbanization on species richness: A review of plants and animals. Urban Ecosyst 2008; 11(2):161-76. doi: 10.1007/s11252-007-0045-4
19. Mensah CA. Destruction of urban green spaces: A problem beyond urbanization in Kumasi city (Ghana). Am J Environ Prot 2014; 3(1):1-9.
20. Moore J. Diversity, Taxonomic Versus Functional. In Encyclopedia of Biodiversity, 2013; 648-56. doi: 10.1016/B978-0-12-384719-5.00036-8
21. Morrison LW, Peitz DG. Spacing of point counts for grassland bird surveys in small geographical areas: Biases and tradeoffs. Wilson J Ornithol 2021; 132(4):810-819. doi: 10.1676/19-00117
22. Napoleone F, Giarrizzo E, Burrascano S. Habitat conservation state and plant diversity respond to different drivers in semi-natural grasslands. J Veg Sci 2021; 32(4):e13055. doi: 10.1111/jvs.13055
23. Pasanen TP, White MP, Elliott LR, Van-den-Bosch M, Bratman GN, Ojala A, Korpela K, Fleming LE. Urban green space and mental health among people living alone: The mediating roles of relational and collective restoration in an 18-country sample. Environ Res 2023; 232:116324. doi: 10.1016/j.envres.2023.116324
24. QGIS Development Team. QGIS Geographic Information System. Open-Source Geospatial Foundation Project. In QGIS Inc. 2023 http://qgis.org

25. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, 2022. https://www.R-project.org/
26. RStudio Team. RStudio: Integration Development Environment for R. PBC 2022. http:www.rstudio.com
27. Shafie NJ, Anuar H, David G, Ahmad A, Abdullah MT. Bird species composition, density and feeding guilds in contrasting lowland dipterocarp forests of Terengganu, Peninsular Malaysia. Trop Ecol 2023; 64(2):238-48. doi: 10.1007/s42965-022-00267-5
28. Shanahan DF, Miller C, Possingham HP, Fuller RA. The influence of patch area and connectivity on avian communities in urban revegetation. Biol Conserv 2011; 144(2):722-729. doi: 10.1016/j.biocon.2010.10.014
29. Sullivan BL, Wood CL, Iliff MJ, Bonney RE, Fink D, Kelling S. eBird: A citizen-based bird observation network in the biological sciences. Biol Conserv 2009; 142(10):2282-2292. doi: 10.1016/j.biocon.2009.05.006
30. Thompson R, Tamayo M, Sigurðsson S. Urban bird diversity: does abundance and richness vary unexpectedly with green space attributes? J Urban Ecol 2022; 8(1). doi: 10.1093/jue/juac017
31. Tobias JA, Sheard C, Pigot AL, Devenish AJM, Yang J, Sayol F, Neate-Clegg MHC, Alioravainen N, Weeks TL, Barber RA, Walkden PA, MacGregor HEA, Jones SEI, Vincent C, Phillips AG, Marples NM, Montaño-Centellas FA, Leandro-Silva V, Claramunt S, Darski B, Freeman BG, Bregman TP, Cooney CR, Hughes EC, Capp EJR, Varley ZK, Friedman NR, Korntheuer H, Corrales-Vargas A, Trisos CH, Weeks BC, Hanz DM, Töpfer T, Bravo GA, Remeš V, Nowak L, Carneiro LS, Moncada R AJ, Matysioková B, Baldassarre DT, Martínez-Salinas A, Wolfe JD, Chapman PM, Daly BG, Sorensen MC, Neu A, Ford MA, Mayhew RJ, Fabio Silveira L, Kelly DJ, Annorbah NND, Pollock HS, Grabowska-Zhang AM, McEntee JP, Carlos T Gonzalez J, Meneses CG, Muñoz MC, Powell LL, Jamie GA, Matthews TJ, Johnson O, Brito GRR, Zyskowski K, Crates R, Harvey MG, Jurado Zevallos M, Hosner PA, Bradfer-Lawrence T, Maley JM, Stiles FG, Lima HS, Provost KL, Chibesa M, Mashao M, Howard JT, Mlamba E, Chua MAH, Li B, Gómez MI, García NC, Päckert M, Fuchs J, Ali JR, Derryberry EP, Carlson ML, Urriza RC, Brzeski KE, Prawiradilaga DM, Rayner MJ, Miller ET, Bowie RCK, Lafontaine RM, Scofield RP, Lou Y, Somarathna L, Lepage D, Illif M, Neuschulz EL, Templin M, Dehling DM, Cooper JC, Pauwels OSG, Analuddin K, Fjeldså J, Seddon N, Sweet PR, DeClerck FAJ, Naka LN, Brawn JD, Aleixo A, Böhning-Gaese K, Rahbek C, Fritz SA, Thomas GH, Schleuning M. AVONET: morphological, ecological and geographical data for all birds. Ecol Lett 2022; 25(3):581-597. doi: 10.1111/ele.13898
32. United Nations. World Population Prospects. Summary of Results. United Nations, New Fork, 2022.
33. Villegas M, Garitano-Zavala Á. Bird community responses to different urban conditions in La Paz, Bolivia. Urban Ecosyst 2010; 13(3):375-91. doi: 10.1007/s11252-010-0126-7
34. Zhong Y, Luo Y, Zhu Y, Deng J, Tu J, Yu J, He J. Geographic variations in eco-evolutionary factors governing urban birds: The case of university campuses in China. J Anim Ecol 2024; 93(2):208-220. doi: 10.1111/1365-2656.14038