UNIVERSITY OF CAPE COAST

EFFECTS OF URBAN LAND-USE TYPE ON AVIFAUNA ASSEMBLAGE STRUCTURE IN CAPE COAST METROPOLITAN ASSEMBLY

JOSEPH KWASI AFRIFA

2021

UNIVERSITY OF CAPE COAST

EFFECTS OF URBAN LAND-USE TYPE ON AVIFAUNA ASSEMBLAGE STRUCTURE IN CAPE COAST METROPOLITAN ASSEMBLY

BY

JOSEPH KWASI AFRIFA

THESIS SUBMITTED TO THE DEPARTMENT OF CONSERVATION BIOLOGY AND ENTOMOLOGY OF THE SCHOOL OF BIOLOGICAL SCIENCES, COLLEGE OF AGRICULTURE AND NATURAL SCIENCES, UNIVERSITY OF CAPE COAST, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN WILDLIFE MANAGEMENT

DECEMBER 2021

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my original research and that no part of it has been presented for another degree at this university or elsewhere.

Candidate's Signature ……………………………… Date…………………...

Name: ……………………………………………………………………..............

Supervisor's Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature ……………………Date……………................

Name:………………………………………………………………………………

Co-Supervisor's Signature…………………………...Date………………………

Name: ……………………………………………………………………………...

ABSTRACT

Given the global trend of increasing urbanization, the need to preserve and improve urban biodiversity has become critical. This study examines the relative influence of different land-use types as well as environmental resources (small trees, large trees, flowering trees, fruiting trees, shrubs, telecommunication mast, pylons, electric poles, buildings) on bird diversity indicators in the Cape Coast Metropolitan Assembly in Ghana. Remote sensing was used to estimate the extent of conversion of natural habitats into urban settlements. Using point count survey, bird species were recorded and compared in randomly selected plots of four land-use types of farmlands, remnant forest, residential and commercial areas. The relative influence of habitat resources on bird diversity indicators as well as the comparative use of natural and artificial resource by birds in built-up areas within the study area was also evaluated. The study found a significant extension of built-up areas into natural habitats in the study area with a significant increase in sparse vegetation coupled with a drop in the area covered by dense vegetation over the last three decades. Avifauna diversity indicators differ significantly across the four land-use types with urban farmlands being the most species diverse, followed by remnant forest, then residential and finally commercial areas. Findings from the study suggest that avian species diversity indicators decreased significantly with increasing land-use intensity and revealed that the study area still possesses significant conservation potentials for urban birds and by extension biological diversity as long as vegetation fragments are maintained within a sustained urban expansion framework. Biodiversity can be improved by

improving the complexity and quantity of plant cover in residential areas by supporting citizens to establish private yards to increase the city's green network.

KEYWORDS

Artificial resources

Avifauna diversity indicators

Land-use types

Natural resources

Urbanization

Urban land use

ACKNOWLEDGEMENTS

I want to express my sincere appreciation to the A. P. Leventis Foundation for financing this research. My supervisors, Dr. Justus P. Deikumah and Prof. K. A. Monney, deserve my sincere appreciation for their invaluable contributions and encouragement to this study. A big thank you to the Department of Conservation Biology and Entomology for the wonderful support and guidance.

DEDICATION

To my parents: Mr. and Mrs. Tabirih

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

Chapter Overview

This chapter introduces the study. It spells out the background of the study, statement of the problem and justification. The purpose of the study, research objectives, research hypothesis, significance of the study, and limitations of the study are presented in this chapter.

Background to the study

The world human population has surpassed 7.9 billion people and is anticipated to increase by 1.05 per cent per year (United Nations, 2021). In this regard, it is predicted that by 2030, more than 60% of the global population will be living in cities, with emerging nations accounting for the majority of this increase (United Nations, 2021). Consequently, human population distributions in time and space will become more unevenly distributed with a concentration in the urban areas (Leveau & Leveau, 2012; United Nations, 2021). This increase in human population and distribution could present several challenges to biodiversity as there would be a proportional increase in demand for natural resources to support this population (Ganaie et al., 2020; Guan et al., 2020). This suggests that habitats for biodiversity will be destroyed as urban and its suburbs continue to expand into natural habitats (Leveau & Leveau, 2016). Therefore, understanding how biodiversity within urban areas responds to the changes in their environment is crucial in the conservation planning and management of urban landscape so as not to eliminate biodiversity that thrives within these areas.

The level of urbanization and the kind of land use can alter the distribution of animal populations, including birds (Clergeau et al., 2006; Stratford & Robinson, 2005). Evidence shows that urban development reduces the richness and relative abundance of species such as arthropods (Fenoglio et al., 2020) reptiles and amphibians (Delaney et al., 2021), birds (Chamberlain et al., 2017) and also for most biodiversity elements (Callaghan et al., 2021; Leveau, 2021; Piano et al., 2020). Many studies on birds in urban settlements reported declining trends in the population of species and an increase in the risks of extinction as urbanization increases (Chamberlain et al., 2017; Dri et al., 2021; Leveau, 2019). This is because urbanization causes the conversion of forests, grasslands, pastures, and, in certain cases, wetlands and water bodies into built habitats (Solecka et al., 2017; Vasenev et al., 2019). These converted habitats consequently become hostile and uninhabitable to most original native species (Xu et al., 2018). However, biodiversity in urban areas contributes significantly to improving the human population's quality of life through the provision of ecological services (Wu, 2014), enhances emotional well-being of people (Hausmann et al., 2016), provides educational and economic values (Hanley & Perrings, 2019). Thus, the need to protect such valuable biodiversity and their habitat is critical.

Statement of Problem and Justification

Given the rapid growth of urban areas across the world, the need to preserve the biodiversity that occurs in urban areas is becoming increasingly crucial. In developed countries, land use and species response to urbanization have been widely investigated (Schwarz et al., 2017). However, little is known about population dynamics and decrease patterns in tropical Africa, particularly for birds. Although population growth triggers global environmental change, which leads to land-use changes, which in turn contributes to the conversion of the natural environment into a built-up environment in many regions of Africa, there are no or few established guidelines for the acquisition and development of lands in many parts of Africa.

In Ghana, like in many other Sub-Saharan African nations, land ownership is vested in clan heads and traditional chiefs rather than the central government; as a result, rules controlling land acquisition and development are either weak or non-existent. Few individuals get the necessary permits before beginning any type of building work (Agbosu, 2000; Mersha et al., 2021). As a result, significant sections of forest loss are due to unregulated commercial and infrastructure development (Boon et al., 2009). In cases where forest loss is due to unregulated commercial and infrastructure development, species inhabiting such environments lose their native habitats overnight and must either leave or adapt (Lowry et al., 2013). The impact of this sudden loss of habitat is aggravated for habitat-sensitive species, who may face increased risks of population declines and, eventually, local extinction (Brewster et al., 2018; Morante-Filho et al., 2015).

Furthermore, it is unknown how resource available in urban landscape influences the presence and persistence of wildlife, particularly birds, in urbanizing areas in Ghana. Our understanding of bird species response and use of man-made structures and patchy vegetation within urban areas in Ghana is limited by this knowledge gap. Understanding how urban land-use patterns shape bird populations, as well as how bird species occupy and exploit urban resources, is critical. This knowledge, if available can assist in finding ways to lessen the negative impacts of fluctuations in urban landscape for animals whiles providing the advantage of harnessing potential opportunities for the conservation of biodiversity in urban settlements.

Also, urban landscape designers and managers are increasingly aiming to build eco-friendly regions that sustain biodiversity and allow species to freely move across urban landscapes (MacGregor-Fors et al., 2016). To achieve this, there is the need to understand land-use changes, and the effects of the current land-use types on urban bird diversity indicators as well as evaluate how environmental resources influence avifauna. This knowledge could be useful in the planning and management, as well as in the conservation of biodiversity in urban settings in general.

Purpose of the study

The study examines the rate of urbanization based on landcover change and the relative influence of land-use types on avifauna assemblage structure in Cape Coast Metropolitan (CCMA) in Ghana.

Research objectives

1. To investigate trends in land use/cover change in CCMA over the last three decades.

2. To examine the influence of urban land-use types on avifauna abundance, diversity, and richness (diversity indicators) in a rapidly developing urban settlement in Ghana.
3. To determine the relationship between diversity indicators (response variables) and environmental resources (explanatory covariates) in the study area.
4. Investigate the comparative use of artificial and natural resources by birds in a built-up area of tropical urban settlement in Ghana.

Hypothesis

The study hypothesized that environmental resources will differ significantly among urban land-use types hence natural land-use types (remnant forest and farmlands) would have a significantly higher bird diversity indicator than build-up environments and that natural native vegetation covariates would positively influence avifauna assemblage structure in the study area.

Also, the study hypothesized that certain groups of birds are adapted to the urban environment hence birds in built-up areas would utilize man-made structures more than they would utilize natural structures.

Significance of the Study

The study provides clear evidence of considerable land cover temporal and geographical changes over the previous three decades within the study area.

The study also gives first-hand information on avifauna composition, community assemblage within various land use types, and the effect of environmental resources on bird diversity indicators.

The study also contributes to our understanding of how urban bird species are structured, how bird species inhabit and use urban habitats and resources relevant to conservation, urban planning and management, and biodiversity conservation in general.

This research also helps urban area management and conservationist to plan future actions by improving our understanding of the distribution and abundance of birds of conservation concern in the CCMA.

Limitations of the study

Birds are very mobile species hence double counting of the same bird at different count stations was a potential key barrier during data collection. However, setting sites at least 1.8 km apart and sampling points 200 m apart was deemed ideal to reduce this limitation.

Four classes of land cover were pre-defined with consideration to area falling within the following; built-up, sparse vegetation, dense vegetation, and water (rivers, streams, lakes, lagoons, wetlands) during remote sensing, however, wetlands were not surveyed due to inaccessibility at the time of data collection.

CHAPTER TWO

LITERATURE REVIEW

Overview of literature review

This section presents synthesized scholarly literature on topics relating to the research by evaluating a selection of sources on previous knowledge as well as identifying gaps in the research. The literature is broken down into sections to cover the entire research by focussing on urbanization and its impact on wildlife, birds community and response to urbanization and birds in an urban landscape.

Urbanisation: trends, causes and effects

Urbanization as a process is characterized by the fast and sometimes unregulated movement of people from rural to urban areas, which is typically prompted by economic causes (Kumar & Navodaya, 2014). This uncontrolled influx of human population in an area can lead to landscape alteration through resource extraction (Blair, 2001), unsustainable agricultural practices (Duran et al., 2012), the use of remnant forests for recreation (Nikolaenko, 1992), and industrial development (Krausmann, 2001; Marzluff, 2001) to meet the needs of the population.

These previously stated human activities often fragment, alter and occasionally replace natural habitats with pavements and structures (McKinney, 2006). As a result of this process, wetlands, other peri-urban ecosystems and protected areas of natural vegetation get fragmented, degraded or invaded by non-native species (Elmqvist et al., 2016). Many of these changes may have an impact on the lives of sensitive wildlife communities within these human-dominated landscapes, resulting in their loss (Buczkowski & Richmond, 2012; Elmqvist et al., 2016), population decline (Czech, 2000; Gaynor et al., 2018; McKinney, 2008; Steidl & Powell, 2006) and subsequent direct local extinction (Fattorini, 2011).

Urbanization and its impact on the natural environment

The demand to create additional cities and agricultural fields has already consumed vast quantities of land in certain parts of the world (McKinney, 2006). This has led to the loss of numerous species and puts the survival of others in jeopardy, particularly ground-nesting species, habitat specialists, and species that require large areas of undisturbed habitat (Magura et al., 2020; Reynolds et al., 2019). For example, in the United Kingdom, almost one-tenth of the land area is urbanized (Haines-Young et al., 2000), which has resulted in the local extinction of wildlife species such as birds: (Eskimo curlew *Numenius borealis*, Balearic shearwater *Puffinus mauretanicus*); reptiles: (Leatherback turtle *Dermochelys coriacea*); and vascular plants: (*Sorbus wilmottiana*) among others (England, 2010). In addition, between 1982 and 1992, rapid urbanization in the United States resulted in the loss of more than 2.1 million hectares of forest, 1.5 million hectares of agricultural lands, and 0.94 million hectares of pasture (World Resource Institute, 1994). Urbanization has resulted in biodiversity loss not just in developed nations but also in developing countries (Güneralp et al., 2017), though the pace, severity, and intensity of urbanization in advanced and underdeveloped countries appear to differ (Lambin et al., 2001). For example, in Latin America, urbanization and the need for agricultural resources has resulted in the development of cities into nearly two-thirds of the forest, but in Africa and Asia, agricultural growth is responsible for more than one-third of forest loss (Gibbs et al., 2010; Gockowski & Sonwa, 2011; Waltert et al., 2005).

Wildlife response to land cover changes

For a long time, scientists have been researching the impact of urbanization on wildlife species (Marzluff, 2001; Piano et al., 2020). The usual and beneficial research technique has been to analyse species community composition along a gradient of urbanization, from densely populated city centres to outlying rural areas with agricultural land mixed with forest fragments (McKinney, 2008; Piano et al., 2020).

Generally, research has shown that one of the most common consequences of urban growth is a decrease in species richness (number of species present) and abundance (total number of individuals of all species present) of biodiversity elements (McKinney, 2008; Piano et al., 2020). Many of these studies on how species react to urban systems have found that species population decreases, extinctions and biodiversity loss have a positive correlation with rising urbanization (Ahrne et al., 2009; Czech, 2000; Kharel, 2011; Magura et al., 2020; Melles et al., 2003; Pauchard et al., 2006).

Although these effects cannot be disregarded, there is also a potential for species from many taxonomic groups to use and adapt to newly created habitats resulting from human activity in the environment (Fuller et al., 2013; MacGregor-Fors et al., 2016). For example, urban environments have been shown to provide food and nesting structures for some bird species as well as shelter and protection from natural predators (Evans & Gawlik, 2020; Kurucz et al., 2021). In some cases, the fragmented habitats that arise are the sole refuge for the isolated or entrapped urban species (Demeyrier et al., 2016). For ecologically confined birds in metropolitan areas, pylons and power poles provide ideal hunting and feeding grounds for raptors, scavengers, and carrion eaters (Moreira et al., 2018).

Birds in an urban landscape

Researchers have studied avian communities across a variety of urban land uses to evaluate the influence of spatial patterns (Batáry et al., 2018; Heilman et al., 2002), habitat fragmentation (Riitters et al., 2002), and landscape alterations (Clergeau et al., 2006) on bird species composition. These studies suggest that it is critical to investigate the community composition and dispersion of individual birds, as well as overall avian community parameters such as species richness and abundance. This is due to the fact that various bird groups tend to be affected in different ways, which has varied conservation consequences.

Human activities are predicted to have a substantial influence on the environment hence, the constitution of urban species populations (Aronson et al., 2016). Birds are frequently used as markers of how biodiversity is responding to urbanisation because they are prominent, exist in many ecosystems, are reasonably straightforward to monitor, and their great movement allows them to follow their preferred environment (Vandewalle et al., 2010). Furthermore, the reaction of birds is crucial to the human population since birds have a big influence on people in urban settings, both positively and negatively (Cox et al., 2018).

Blair (1996) and Tryjanowski et al. (2020) classified urban bird species into three categories: avoiders, adapters, and exploiters. These classifications were made based on how well birds can survive habitat disturbance and how much they use and tend to depend on resources provided by humans. Typical urban avoiders are often long-term migrants, habitat specialists, or species that are very sensitive to human-related disturbances e.g., some large raptors (Shanahan et al., 2014). These birds are mostly native to a community and can be found in relatively undisturbed habitats (covered mainly by native vegetation) outside of built-up areas. Urban avoiders are the most adversely affected by urbanization, resulting in their abundance being the lowest in urban areas (Blair, 1996).

Urban adapters are frequently edged species, living in places with intermediate degrees of disturbance (e.g., suburbs and farmlands), and they facultatively use a significant amount of human-provided resources, such as food from rubbish or bird feeders, in addition to natural resources (Tryjanowski et al., 2020). Cavity or shrub nesters and omnivorous species, as well as certain ground-feeding finch species, are common in this group (Croci et al., 2008). Urban adapters comprise both native and non-native species, and they tend to predominate in rural-to-urban transition zones with the most diverse land use (Blair, 1996).

The urban exploiters are the most numerous groups of birds in urban environments (Francis & Chadwick, 2012). These species can be found in the most densely populated locations, where native habitats are few and human-made conditions predominate (Kark et al., 2007). These species can endure urban areas since their numbers tend to be denser in urban areas (Palacio, 2020). The communities of urban exploiters are typically characterized by a few dominant and often foreign species, as well as a few local species whose diversity and abundance are not dependent on natural vegetation (Durak et al., 2015; Threlfall et al., 2016). These species are also frequently reliant on human-provided resources (Leveau et al., 2017).

CHAPTER THREE

MATERIALS AND METHODS

This chapter presents the methods and procedures chosen by the researcher to carry out the research. This session spells out a description of the study area, the landcover classification procedure, research design, sampling technique and variables measured as well as the method for data processing and analysis.

Study area

Cape Coast Metropolitan Assembly (CCMA) (5°6′23.4″N 1°14′29.04″W) in the Central Region of Ghana (one of the 16 administrative regions in Ghana) (Fig.1.), covers a geographical area of approximately 122 square kilometres, with a settlement population of about 189,925 people and an annual population growth rate of 1.0 % (Ghana Statistical Service, 2021). Cape Coast Metropolitan Assembly is dominated by urban areas with three-quarters of the population residing in these areas (Ghana Statistical Service, 2021). Located within the Guinea-Congo vegetation zone of West Africa, CCMA has double maxima rainfall pattern ranging from 750 mm to 1000 mm, with the major wet season from May to July (Ghana Meteorological Agency, 2021). It is a humid environment, with monthly relative humidity ranging between 85% and 99%. Shrubs, meadows, natural forest remnants, and coastal thickets make up the city's current vegetation. The common trees in the forest fragments and coastal thickets include African mahogany (*Khaya ivorensis*), silk cotton tree (*Ceiba pentandra*), oil palm trees (*Elaeis guineensis*), and other species of the Family Arecaceae. Because of clearance for farming, charcoal burning, and other human activities, the original vegetation of thick bushes, which was nourished by rainfall, has been replaced by sparse secondary vegetation. Elephant grass (*Pennisetum purpureum*), Guinea grass (*Panicum maxima*), Centro (*Centrosema pubescens*), the invasive weed siam weed (*Chromolaena odorata)* and many more weedy species dominate the secondary vegetation. The core of the metropolis is built-up and is a mosaic of residential areas, car parks, open markets and offices of corporate bodies. Interspersed among these is vegetation which consists of shrubs and, grasses, native forest fragments and coastal thickets (Ghana Statistical Service, 2013). Other areas such as farmlands are restricted to the periphery with active farmlands dominated by maize (*Zea mays*), plantain (*Musa paradisiaca*), cocoyam (*Xanthosoma sagittifolium*), tomatoes (*Solanum lycopersicum*) and cassava (*Manihot esculenta*). Abandoned farmlands are dominated by shrubs and small trees that are occasionally cut down for charcoal production. Green spaces, usually remnant forests are restricted within the campuses of two universities and a number of second-cycle schools. These remnant forests also retain some of the original vegetation of the metropolis (Deikumah & Kudom, 2010).

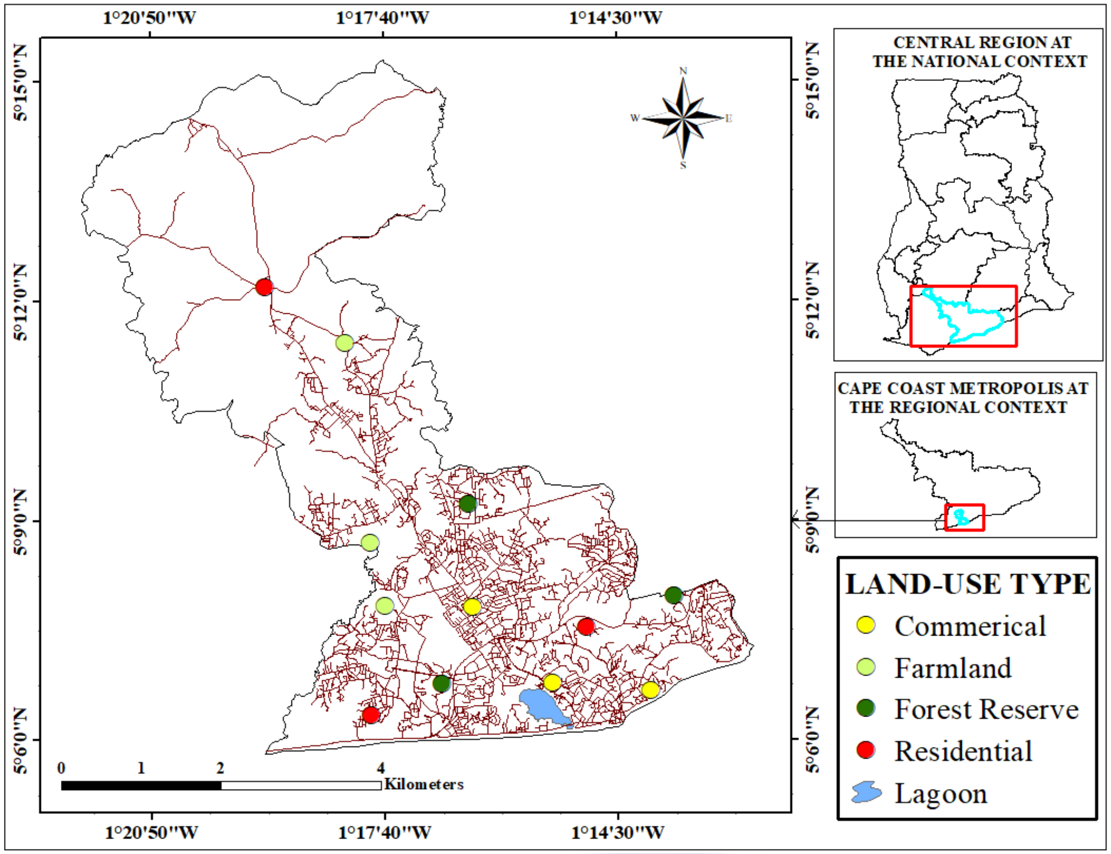


Figure 1: Map of the study area (Cape Coast Metropolitan Assembly) showing the distribution of study sites and land-use types

Satellite data, land use/landcover classification and change analysis

Landsat satellite data (20% Cloud Free) of four dates in the past three decades were downloaded from the United States Geological Survey (USGS) Earth Explorer website. All the data were pre-processed and projected to the Universal Transverse Mercator (UTM) projection system. The satellite data collected are presented in Appendix A.

The image processing was done with ENVI (Excelis) version 5.3 and ArcGIS version 10.6. Image classification was used to assign pixels to a distinct category of land use and land cover described within the CCMA. Four classes of land cover were pre-defined with consideration to area falling within the following; dense vegetation (forest reserves and remnant forests), sparse vegetation (shrub, grassland, farmland), built-up (including residential and commercial), and water (rivers, streams, lakes, lagoons, wetlands)

The land use/cover classification was done using the ENVI 5. 3 program and a supervised classification approach utilising the Support Vector Machine algorithm. Support Vector Machine makes use of a user-defined kernel function to plot a set of non-linear decision boundaries in the original dataset into linear boundaries of a higher-dimension construct. The algorithm used by the Support Vector Machine Classification tool is based on statistical learning theory, which determines a hyperplane that optimally separates two classes. Training data is used to determine the optimum hyperplane and generalize its ability to verify using validation data (Han et al., 2007).

Experimental design and landscape categorization for data collection

Three of each of the four main land categories within the research area were chosen for this study based on dominating vegetation, land use, and intensity. These include:

1. Commercial area- These are areas of high human activities with commercial buildings, marketplaces, lorry parks and areas with a high concentration of shops. The land cover in these areas are close to completely without natural vegetation.
2. Residential areas-These are areas where people live; occupied primarily by private residences. They include organized village settlements and rural types of settlements.
3. Farmlands- these are areas dominated by croplands and farm bushes as well as recently abandoned farmlands.
4. Remnant forests- These are urban remnant forests preserved within universities and secondary school campuses with less active human activities.

The size of the land-use types ranges from 1.88 to 2.01 km^2 while the study sites were located at least 1.5 km apart. Forty-five grid points, 200 meters apart were generated using QGIS version 3.14.1 and distributed among the three replicates of each land use category. This was done to ensure the independence of sample points within each site and reduce the chance of double-counting of birds. The coordinates of the generated points were transferred to a Garmin eTrex 10® GPS device which was used to locate them on the field.

Avifauna survey

A point count survey with a specified radius of 50 meters was used in recording birds twice, from January to February and June to July, to document the avifaunal composition of CCMA. Bird surveys were conducted at these two times of year to better understand the influence of seasons on bird assemblage structure as well as seasonal resource fluctuations in the research area.

Bird surveys were conducted twice daily, from 06:00 to 10:00 hours and 15:00 to 18:00 hours, to coincide with peak activity times for birds. During each survey, 10 minutes were spent counting birds at the point count station. Using a pair of binoculars (Nature-Trek 8x42) and a field guide to birds of western Africa (Borrow & Demey, 2014), bird species and the number of individuals seen or heard were recorded. Also, activities performed by birds seen such as perching, singing, nesting, or feeding and the substrate as well as part of the substrate on which the birds are found performing such activities were recorded for each species. These observations were recorded within the time of the bird survey at each sampling point. All environmental variables encountered that were being used by birds during the sampling period were grouped as either artificial or natural resources for further analysis. In addition, all birds encountered opportunistically during other field research within the survey were documented. Data from these encounters were not used in the final analyses but were used to build the species list for the CCMA.

Vegetation survey

Natural vegetation for this study is defined as photosynthetic plants that developed with little or no human interference (Ramankutty et al., 2010). It includes artificially created green plants and exotic plant species. Details of natural vegetation that potentially influence bird assemblage structure quantified in this study are presented in Table 1.

Vegetation surveys at each site were conducted to characterize the composition and structure of vegetation in the study area. Vegetation characteristics were quantified following protocols from Naidoo, (2004). At each bird survey location, a 30 x 30 m quadrat was randomly placed, and the number of small trees, flowering trees, and large trees, as well as the estimated percentage of vegetation cover, were recorded. Shrubs were counted within a 10 x 10 m quadrat within the area. Percentage vegetation cover representing the total area within the 30 x 30 m quadrat that is covered by vegetation, whether it is lawns, grasses, herbs, or any other natural vegetation, was estimated by sight to the closest 5%. Large trees were defined as those with a diameter at breast height (DBH) higher than 40 cm, while small trees were defined as those with a DBH less than 40 cm. Shrubs were defined as plants with several stems emerging from the root level (Hawthorne & Lawrence, 2013). Within each sampling point, the presence or lack of crops or gardens was also documented.

Table 1: Description of environmental variables and measuring units

Environmental Variable	Description	Unit
Natural		
Large trees	The total number of photosynthetic plants with a diameter at breast height greater than 40cm, (Hawthorne and Lawrence, 2013).	Count
Small trees	The total number of photosynthetic plants with a diameter at breast height is less than 40cm, (Hawthorne and Lawrence, 2013).	Count
Shrubs	The total number of photosynthetic plants within the 30 x 30m having multiple stems emanating from the root level (Hawthorne and Lawrence, 2013).	Count
Flowering plants	The total number of photosynthetic shrubs and trees within the 30 x 30m that were producing flowers at the time of data collection.	Count
Fruiting plants	The total number of photosynthetic shrubs and trees within the 30 x 30m that were producing fruits at the time of data collection.	Count
Vegetation cover	Percentage of the total area within the 30 x 30m that is covered by vegetation such as lawns, grasses, herbs, etc., estimated by eye to the nearest 5% (Manu, 2003)	Percentage
Crop/gardens	Presence or absence of plant that is grown to be harvested within the 30x30m	Presence/absence
Artificial		
Number of buildings	The total number of buildings within the 30x30m quadrat. These include houses, shops, offices, etc.	Count
Electric poles	Number of electric and television poles within the area	Count
Telcom mast/Pylons	Number of pylons and mast within the area	Count
Paved roads	Roads with a concrete surface	Presence/absence
Dump site/Refuse	Refuse dumping sites	Presence/absence

Artificial resource surveys

In this study, artificial resources are resources that are not natural but might be useful to birds in the lack of natural vegetation in an urban context. The number of telecom masts, power poles, and buildings were counted within a 50-meter radius at each sample station. The presence or lack of paved roads, as well as garbage dumps, were also noted and used for further analysis.

Data and statistical analysis

Land use/cover changes detection and analysis

To compare changes in land use/cover within the CCMA, post-classification comparison change detection was conducted. On a pixel-by-pixel basis, the post-classification technique was applied to compare the land classification findings of the four images from the comparison years. A resultant change detection matrix was utilized to separate the areas of change and magnitude in each land cover category. Linear regression was further used to test for significant changes in the observed land cover changes over the years.

Avifauna data analysis

For each study site and land-use type, the total number of individuals of all species indicating bird abundance and overall species richness (i.e., the number of species detected during the survey) were calculated using the vegan package in R statistical software. Avian species diversity was calculated using the Shannon-Wiener index,

$$H' = -\sum\left(\frac{n_i}{N}\, x\, In\frac{n_i}{N}\right)$$

where n_i is the number of individuals of each of the i species and N is the total number of individuals for the study area. Species diversity indicators were calculated in the vegan package (Oksanen et al., 2007).

Species accumulation curve was used to illustrate the rate of species accumulation among land-use types and within CCMA. Shapiro Wilks test was used to test for normality of the response variables (i.e., abundance, richness, and diversity). The response variables at the site level were found to be normally distributed (Shapiro-Wilk normality test $W = 0.91$, p-value $= 0.06$) hence Analysis of Variance (ANOVA) was used to test for variations in mean abundance, richness, and diversity of birds among the four land-use types and between seasons. This was followed by a post hoc test using a Tukey-HSD test at 95% confidence level for multiple comparisons of means of the avian diversity indicators across land-use types. Similarly, ANOVA was used to test for variations in quantified environmental variables (both natural and artificial) across land-use types. A multi-collinearity test was conducted on all explanatory variables to eliminate strongly correlated variables. Explanatory variables were taken as strongly correlated when Pearson's correlation coefficient exceeds 50% (i.e., $r > \pm 0.50$). Only one of the two correlated variables was maintained in the final model based on its ecological importance and potential influence on the relevant response variable.

Because there was over-dispersion in the data, the relationship between the response variables and the explanatory variables was modelled using a General Linear Model (GLM) with the quasi-Poisson family. The main predictors were land-use type and season while other covariates were small trees, large trees, flowering trees, shrubs, percentage vegetation cover, telecommunication mast/pylons, electric poles, number of buildings, presence or absence of a paved road, crops, and refuse. Using stepwise deletion, explanatory variables that had no significant relationship with the response variables were dropped from the model. Model residual plots from regression models were used to check whether the model assumptions were met using the function *check_model(model)* in the "performance" package (Lüdecke et al., 2021). The explanatory variables were then ranked according to their relative influence on each of the response variables using their parameter estimates.

Also, to investigate the comparative use of artificial and natural resources use by birds in built-up areas within CCMA, an analysis of variance was used to test for variation in activities performed by birds and the substrate category used within built-up areas in CCMA. Also, indicator species analysis (ISA) was carried out to determine species that were strongly associated with a particular substrate category.

Spatial autocorrelation was tested on the sampling points using a spline correlogram. The sampling points were found not to be spatially correlated (Appendix B). All analyses were done in R statistical software 4.1.0. (R Core Team & Core Team, 2021).

CHAPTER FOUR

RESULTS

This session presents the results of the findings of the study. This chapter is divided into four main sessions in line with the objectives. The first section i.e., objective one presents the findings of lands/cover changes within CCMA over the last three decades. The second session i.e., objective two presents the influence of urban land-use types on avifauna abundance, diversity, and richness in a CCMA. The third section i.e., objective three presents the findings on the relationship between diversity indicators and environmental resources in the study area. The final session presents the findings on the comparative use of artificial and natural resources by birds in a built-up area of tropical urban settlement in Ghana.

Objective one

Trends in land use/cover change in CCMA over the last three decades

Land cover within CCMA has changed significant ($F_{4,12} = 35.01$, $p < 0.001$). Built-up areas have increased significantly ($F_{1,2} = 53.75$, $p < 0.001$) from 1990 to 2020 in CCMA (Table 2). Dense vegetation cover within CCMA has decreased significantly by 38% as a result of the increase in areas now covered with buildings. The land area covered by water in 1990 has also reduced by 0.39% while areas with sparse vegetation have increased significantly by 24% over the last three decades (Fig 2.).

Table 2: Results of land use and land cover change detection analysis within CCMA from 1990 to 2020. Values in bold characters indicate significant change, + or – indicate an increase or decrease respectively

	Area Coverage (km^2)				Changes in land use/cover between years				
Land cover type	1990	2000	2010	2020	1990-2000	2000-2010	2010-2020	1990-2020	% LULC change (1990-2020)
Built-Up Areas	16.25	24.39	26.80	33.87	+8.14	+2.41	+7.07	**+17.61**	14.53
Dense Vegetation	99.77	68.01	58.80	52.97	-31.76	-9.21	-5.83	**-46.80**	38.60
Sparse Vegetation	2.89	27.15	34.16	32.56	+24.25	+7.01	-1.60	**+29.67**	24.47
Water	2.32	1.69	1.48	1.84	-0.63	-0.21	+0.36	-0.48	0.39

*Model statistics for the test of significance in trend in land-use changes are shown in Appendix C

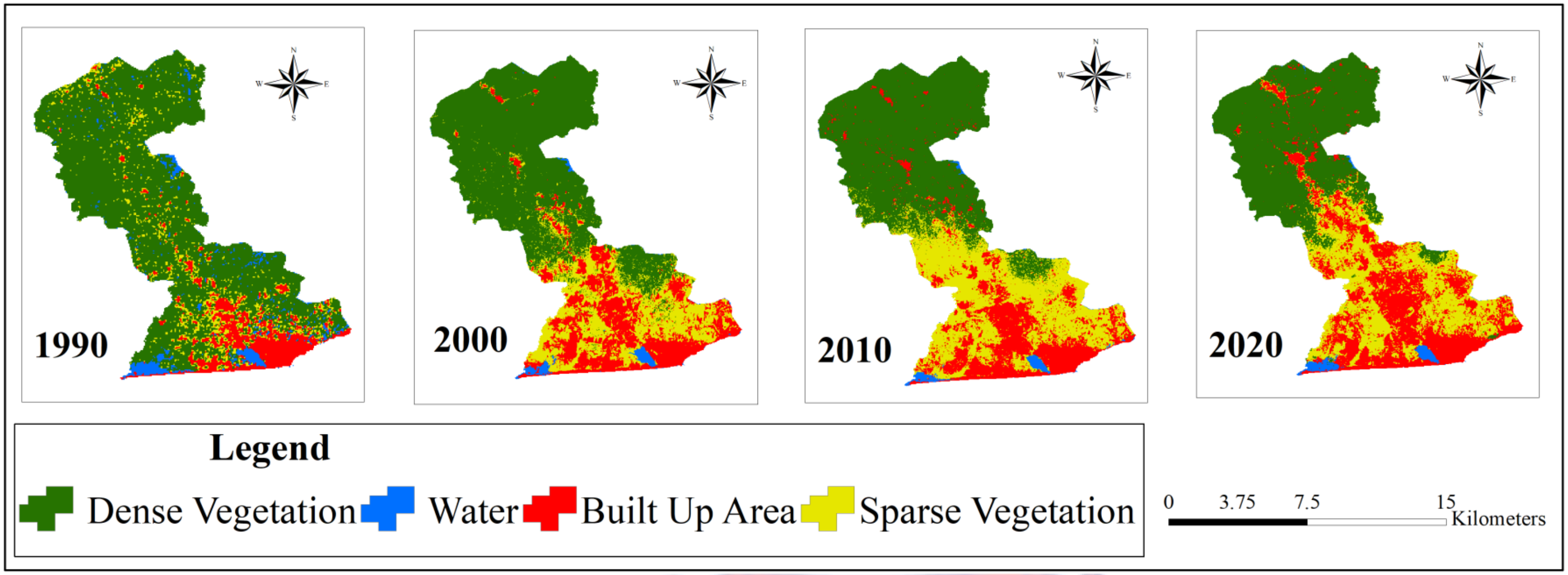


Figure 2: Land Use and Land Cover change in Cape Coast Metropolitan Assembly between 1990 to 2020

Objective two

Overview of bird survey in CCMA

The species accumulation curves approached an asymptote for the entire study area (Appendix D), as well as for individual land-use types (Appendix E) suggesting that each study landscape was adequately surveyed and most species in the study area were detected. Overall, 8,583 individual birds comprising 154 species from 50 families were recorded within the four land-use types in Cape Coast Metropolitan Assembly (Appendix F). These include 127 common residents, 18 intra-African migrants, and nine Afro-Palearctic migrants. The highest number of individuals, 1160 representing 13.5% were recorded from the family Ploceidae, 1016 (11.8%) from the Estrildidae, and 838 (9.8%) were from the Pycnonotidae family. Family Scolopacidae and Sylviidae had the lowest record of only one individual each in the entire study area.

Across land-use types, Family Corvidae (22.0%) had the highest relative abundance in commercial areas followed by Pycnonotidae (10.4%) and Passeridae (10.3%) respectively (Fig. 3a) while Family Bucerotidae together with 12 other families contributed less than 1% to the abundance. In farmlands and residential areas, the family Ploceidae was the highest with 19.4% (Fig. 3b), and 12.5% (Fig. 3c) relative abundance respectively followed by family Estrildidae with 13.7% while family Alcedinidae together with 21 other families had less than 1% relative abundance. In urban remnants forests, Family Pycnonotidae had the highest relative abundance with 10.6% (Fig. 3d).

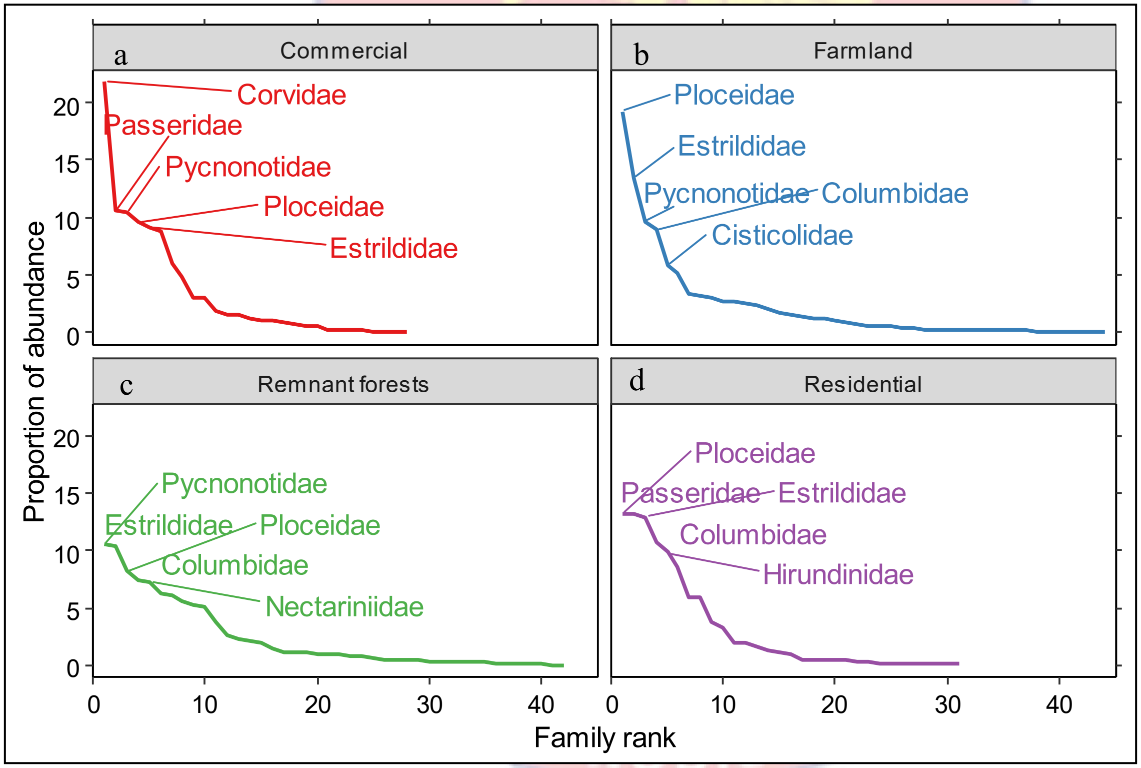


Figure 3: Relative abundance ranking of avian families across four selected land-use types within the Cape Coast Metropolis.

Variations in bird diversity indices within land-use types

Species diversity

Mean species diversity for the entire survey was estimated as (mean±Standard Error= 3.28± 0.11). ANOVA results shows that species diversity differed significantly across land-use types ($F_{3,19} = 32.01$, $p < 0.001$) but not between seasons ($F_{1,19} = 2.87$, $p = 0.10$). Comparatively, farmland was the most species diverse with mean species diversity of 3.69±0.13 while commercial land-use type had the lowest species with a mean of 2.82±0.08 as illustrated with the bar chart in Figure 4. A post hoc test using Tukey HSD test was conducted to find out where the difference in means lies between the land use types. The results of the post hoc test show that the difference in means between farmlands and commercial centres is significant (difference in means =0.829, p<0.001). The difference in means between remnant forest and commercial areas was also found to be significant with the difference in means =0.829 and p<0.001. Also, the difference in means between residential areas and farmland was found to be significant with a difference in means =-0.653 and p<0.001 as presented in Table 3 and also illustrated with alphabets in Figure 4.

Table 3: Results for Tukey HSD multiple comparisons of bird diversity between land-use types

Land-use Type		Difference in Means	Lower Limit	Upper Limit	Adjust P-value
Farmland	Commercial	0.829	0.548	1.109	<0.001
Remnant forests	Commercial	0.694	0.414	0.974	<0.001
Residential	Commercial	0.176	-0.105	0.456	0.321
Remnant forests	Farmland	-0.135	-0.415	0.145	0.542
Residential	Farmland	-0.653	-0.933	-0.373	<0.001
Residential	Remnant forests	-0.518	-0.798	-0.238	<0.001

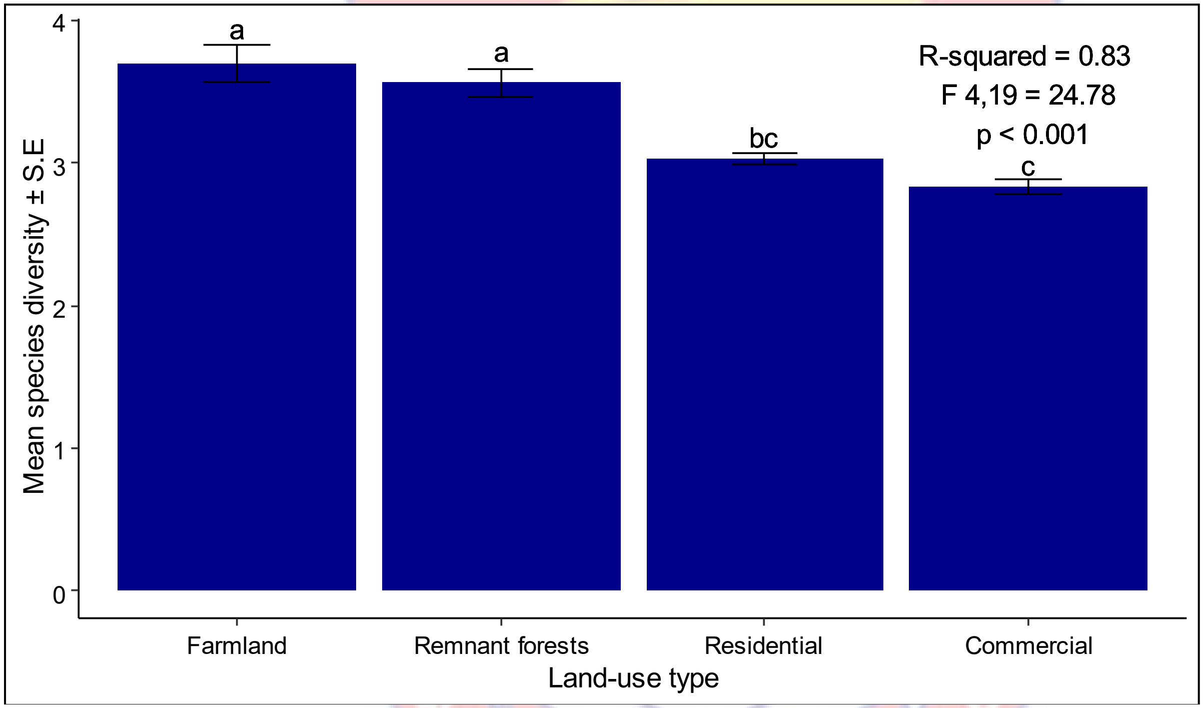


Figure 4. Variation in species diversity within land-use types in the Cape Coast Metropolis. Similar alphabets on standard error bars do not differ significantly

Species abundance

Mean abundance in the CCMA was estimated at (mean±standard error=715±91). Comparatively, more birds were encountered on farmlands 1065±243 with commercial areas having the least number of individuals 506±82 (Fig.5). The results of analyses of variance revealed significant variations in avifaunal abundance across land-use types ($F_{3,19} = 5.35$, $p < 0.01$) but not between seasons ($F_{1,19} = 2.8$, $p = 0.11$). However, a post hoc test using Tukey-HSD test shows that the significant variation lies between farmland-commercial and residential-farmland with difference in means of 278.33, p=0.01 and -253.33, p=0.02 respectively as presented in Table 4 and also illustrated with alphabets in Figure 5.

Table 4: Results for Tukey HSD multiple comparisons of bird abundance between land-use types

Land-use Type		Difference in Means	Lower Limit	Upper Limit	Adjust P-value
Farmland	Commercial	278.33	53.50	503.17	0.012
Remnant forests	Commercial	109.83	-115.00	334.67	0.533
Residential	Commercial	25.00	-199.84	249.84	0.989
Remnant forests	Farmland	-168.50	-393.34	56.34	0.188
Residential	Farmland	-253.33	-478.17	-28.50	0.024
Residential	Remnant forests	-84.83	-309.67	140.00	0.719

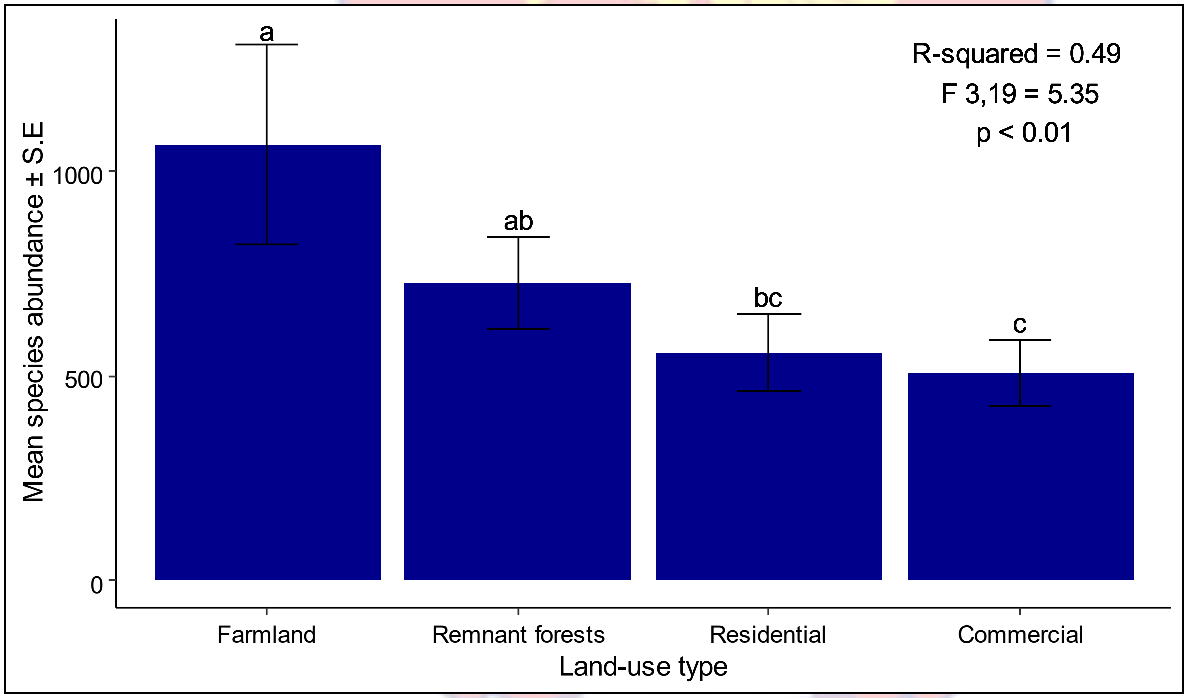


Figure 5: Variation in the relative abundance of birds within land-use types within the Cape Coast Metropolitan Assembly. Similar alphabets on standard error bars do not differ significantly

Species richness

Overall mean species richness was estimated as (mean±standard error = 58±6) and varied significantly across land-use types in the CCMA ($F_{3,19} = 21.96$, $p < 0.01$) but not between season ($F_{1,19} = 1.58$, $p = 0.22$), with farmlands being the most species-rich land use type with a mean value of 82±6 and commercial centres the least with a mean value of 37±4 as illustrated in Figure.6. A post hoc test using Tukey HSD test was conducted to find out where the difference in means lies between the land use types. The results of the post hoc test shows that the difference in means between farmlands and commercial centres is significant (difference in means =33.66, $p<0.001$). The difference in means between remnant forest and commercial areas was also found to be significant with difference in means =23.16 and $p<0.001$. Also, the difference in means between residential areas and farmland was found to be significant with difference in means =-10.500 and $p<0.001$ as presented in Table 5 and also illustrated with alphabets in Figure 6.

Table 5: Results for Tukey HSD multiple comparisons of bird richness between land-use types

Land-use Type		Difference in Means	Lower Limit	Upper Limit	Adjust P-value
Farmland	Commercial	33.667	20.372	46.961	< 0.001
Remnant forests	Commercial	23.167	9.872	36.461	<0.001
Residential	Commercial	5.833	-7.461	19.128	0.617
Remnant forests	Farmland	-10.500	-23.795	2.795	0.154
Residential	Farmland	-27.833	-41.128	-14.539	<0.001
Residential	Remnant forests	-17.333	-30.628	-4.039	0.008

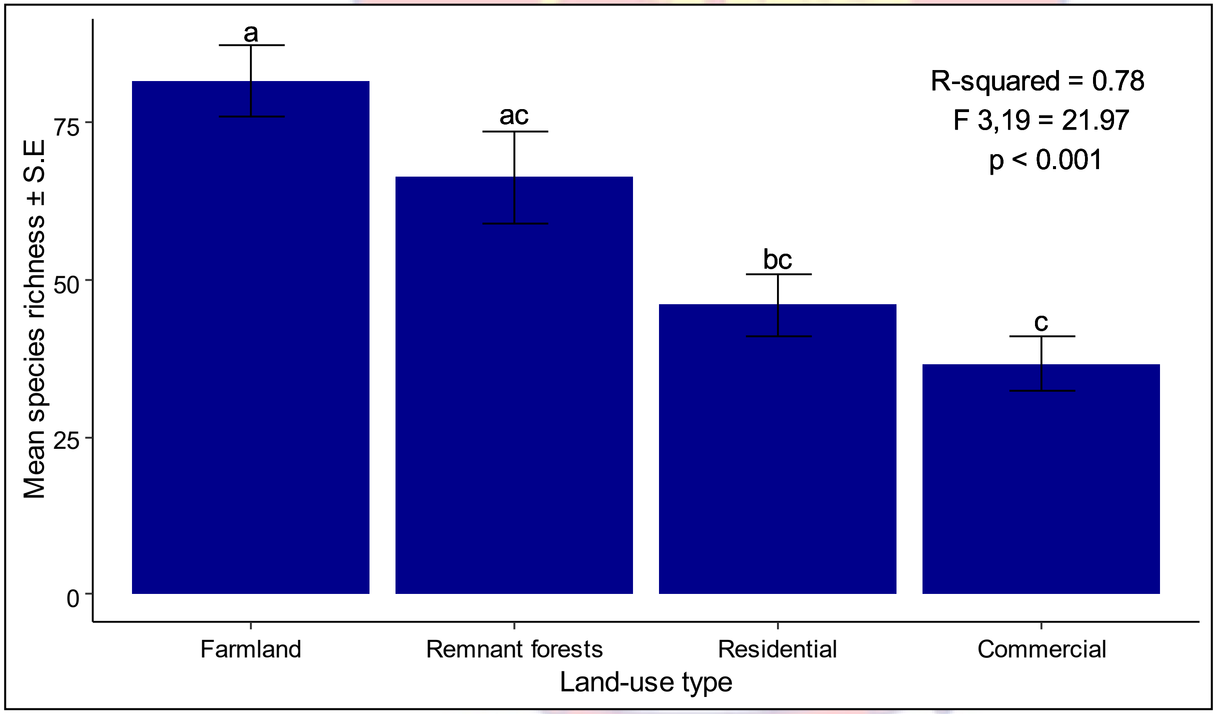


Figure 6. Variation in avifauna richness within land-use types within the Cape Coast Metropolis. Similar alphabets on standard error bars do not differ significantly

Objective three

Landscape and site scale variations in environmental variables in the CCMA

Estimated environmental resources comprising both natural stand vegetation covariates and artificial support for birds in the study landscape differed significantly across land-use types as shown in Table 6. The number of small trees, large trees, and flowering plants were higher in remnant forests as predicted with mean values (mean±standard error) of 5.33±0.32, 8.62±0.33, and 1.16 ±0.12 respectively, while shrub density and percentage vegetation cover were highest in farmlands with mean values of 8.92±0.33 and 77.61%±2.14 respectively. The number of buildings, electric poles, and telecommunication masts were more in commercial centres with mean values of 6.06±0.17, 5.55±0.32, and 0.22±0.05 respectively. According to the results of the T-test, only number of flowering trees (t =-5.96, df = 287.04, $p < 0.001$) and fruiting trees (t =-4.04, df = 287.37, $p < 0.001$) were found to vary significantly between seasons.

Table 6: Variation in (mean ± standard error) of environmental resources across land-use types within the Cape Coast Metropolitan Assembly

Environmental Variables	Commercial	Farmland	Remnant forests	Residential	F value	p-value
Small trees	0.87±0.32	4.78±0.32	5.33±0.32	2.20±0.32	135.9	< 0.001
Large trees	1.19±0.16	2.23±0.16	2.78±0.16	1.87±0.16	166.7	< 0.001
Flowering trees	0.30±0.12	1.10±0.12	1.16±0.12	0.44±0.12	45.1	< 0.001
Fruiting trees	0.35±0.14	1.35±0.14	1.22±0.14	0.73±0.14	46.63	< 0.001
Shrubs	3.0±0.33	8.92±0.33	8.62±0.33	3.42±0.33	384.8	< 0.001
% Vegetation cover	15.11±2.14	77.61±2.14	75.44±2.14	29.11±2.14	694.3	< 0.001
Telcom mast/pylons*	0.22±0.05	0.02±0.05	0.31±0.05	0.20±0.05	17.15	< 0.001
Electric poles*	5.55±0.32	0.00±0.32	1.31±0.32	5.07±0.32	136.2	< 0.001
Number of buildings*	6.06±0.17	0.02±0.17	0.77±0.17	5.28±0.17	529.2	< 0.001

* Denote artificial environmental variables

The multi-collinearity test on the explanatory variables revealed little collinearity among variables (Appendix G). Although percentage vegetation cover and number of buildings were negatively correlated ($r = -0.86$), they were both used in the final model because the presence of buildings was treated as an artificial resource while vegetation cover as a natural variable, and also, they influenced species diversity indicators differently.

Relationship between environmental variables and species diversity indicators in CCMA

Generally, the results of the Generalized Linear Model (Appendix H) shows that the main predictors (i.e., land use type and season) and environmental covariates (i.e., presence of crops, flowering trees, number of buildings, and the interaction between buildings and vegetation cover) showed a significant relationship with species diversity ($F_{10, 349} = 29.92$, $p < 0.001$). The presence of crops and flowering trees showed a significantly positive relationship with species diversity ($F_{10, 349} = 4.35$, $p < 0.001$) and ($F_{10, 349} = 2.56$, $p < 0.001$) respectively. Although number of buildings ($F_{10, 349} = -4.52$, $p < 0.001$) and vegetation cover ($F_{10, 349} = -1.27$, $p < 0.001$) showed a significant negative relationship with species diversity, an interaction between buildings and vegetation cover showed a significant positive relationship with species diversity ($F_{10, 349} = 4.82$, $p < 0.001$) (Appendix H).

Similarly, the main predictors, presence of crops, large trees, flowering trees, and the interaction between buildings and vegetation cover showed a significant relationship with species abundance ($F_{12, 347} = 13489$, $p < 0.001$).

Species abundance was found to have a positive significant relationship with flowering trees ($F_{12, 347} = 3.25$, $p < 0.001$) and the presence of crop or garden ($F_{12, 347} = 5.51$, $p < 0.001$) within the landscape as well as the interaction between buildings and vegetation cover ($F_{12, 347} = 6.04$, $p < 0.001$) (Appendix H). Large trees ($F_{12, 347} = -2.86$, $p < 0.001$), number of buildings ($F_{12, 347} = -5.59$, $p < 0.001$), and percentage vegetation cover ($F_{12, 347} = -3.92$, $p < 0.001$) had a significant negative relationship with species abundance. From the model estimates, a unit increase in flowering trees and the presence of crops or gardens increases bird species abundance, while a unit increase in large trees, buildings, and percentage vegetation cover results in a decrease in species abundance.

Furthermore, the main predictors and presence of crops, large trees, flowering trees, and the interaction between the number of buildings and vegetation cover showed a significant relationship with species richness ($F_{10, 349} = 3874$, $p < 0.001$). Flowering trees ($F_{10, 349} = 3.27$, $p < 0.001$) and the presence of crops or gardens ($F_{10, 349} = 5.47$, $p < 0.001$) in an area as well as the interaction between buildings and vegetation cover ($F_{10, 349} = 6.36$, $p < 0.001$) were found to have a positive significant relationship with species richness as presented in Appendix H. From the estimates of the model, an increase in these covariates increases bird species richness. While large trees, number of buildings, and percentage of vegetation cover had a significant negative relationship with species richness.

Generally, from the parameter estimates of all final models, crops had the highest positive significant effect on all species diversity indicators while the interaction between buildings and percentage vegetation cover had the least positive influence within the CCMA (Fig. 7.). Number of buildings and large trees had the highest and lowest significant negative influence on species diversity indicators respectively.

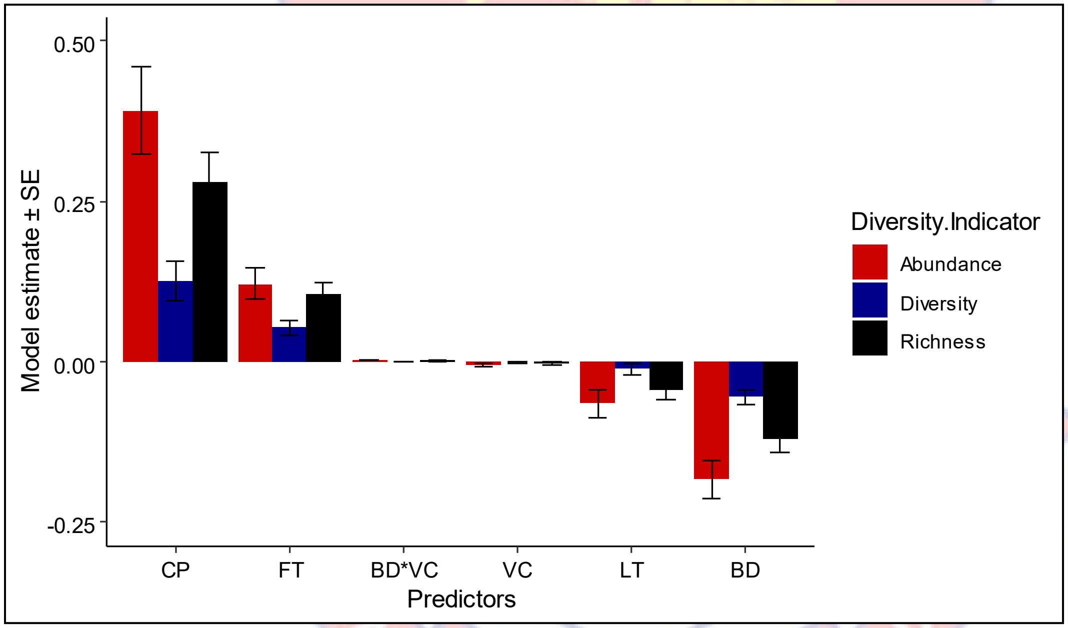


Figure 7: Rank of final model parameter estimates, effect size, and direction of significant predictors (covariates) on avian diversity indicator (response variables). *CP=crop, BD= buildings, VC=percentage vegetation cover, FT=flowering trees, LT=large trees.

Relationship between environmental variables and species diversity indicators within land-use types

In commercial areas, farmlands, and residential areas, only percentage vegetation cover, presence of crops, and flowering trees were found to have a significant positive influence on species diversity respectively (Table 7). Within remnant forests, flowering trees were found to have a significant positive relationship with species diversity while electric poles were found to have a significant negative relationship with species diversity. Only flowering trees had a positive significant relationship with species diversity within residential areas (Table 7).

Similarly, vegetation cover and the presence of crops had a significant positive relationship with species abundance within commercial areas while large trees had a significant negative relationship with species abundance within farmlands. Within remnant forests, flowering trees were found to have a significant positive effect on bird abundance while vegetation cover had a significant negative effect on bird abundance. Flowering trees and vegetation cover were all found to have a positive influence on bird abundance in residential areas (Table 7).

Percentage vegetation cover had a significant positive effect on species richness within commercial areas. Within farmlands number of flowering plants and the presence of crops had a significant positive influence on species richness while an increase in large trees caused a significant decrease in the species richness. Flowering trees also positively influenced bird species richness while percentage vegetation cover within remnant forests significantly influenced species richness negatively. Within residential areas, flowering trees showed a significant positive effect on species richness (Table 7).

Table 7: Summary table of model estimate (SE) of avian diversity indices as a function of environmental resource within land-use types. Values in bold characters indicate significant coefficient estimates

	Land-use type			
	Commercials	Farmlands	Reserves	Residential areas
Predictors	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)
Diversity				
Flowering trees	0.040(0.064)	0.019(0.016)	**0.059(0.014)**	**0.124(0.037)**
Vegetation cover	**0.009(0.004)**	-0.002(0.001)	-0.002(0.001)	0.002(0.002)
Electric poles	-0.009(0.014)	NA	**-0.027(0.012)**	-0.008(0.010)
Crop present	0.067(0.131)	**0.117(0.042)**	0.073(0.056)	0.099(0.089)
Abundance				
Large trees	0.030(0.077)	**-0.135(0.046)**	0.028(0.038)	0.002(0.047)
Flowering trees	0.139(0.087)	0.092(0.050)	**0.115(0.033)**	**0.194(0.069)**
Vegetation cover	**0.015(0.005)**	-0.009(0.004)	**-0.013(0.003)**	**0.010(0.004)**
Crop present	**0.301(0.190)**	0.420(0.150)	0.214(0.137)	0.061(0.176)
Richness				
Large trees	0.041(0.060)	**-0.083(0.028)**	0.024(0.029)	-0.002(0.034)
Flowering trees	0.054(0.070)	**0.064(0.031)**	**0.112(0.026)**	**0.207(0.049)**
Vegetation cover	**0.013(0.004)**	-0.005(0.003)	**-0.007(0.003)**	0.005(0.003)
Crop present	0.231(0.148)	**0.294(0.090)**	0.107(0.109)	0.137(0.125)

NA= Undefined estimates due to singularity of values.

Objective four

Comparative use of artificial and natural resources by birds in a built-up area in CCMA

A total of 3,486 individuals comprising 82 species of birds from 33 families were recorded in built-up areas within CCMA (Appendix E). These included 71 common residents, eight intra-African migrants, and three Palearctic migrants. The species accumulation approached an asymptote this shows that most of the bird species in the survey area appear to have been recorded. A total of 1753 (46.2%) individuals of 52 species belonging to 23 families were found using artificial structures and resources while 1731 (45.6%) individuals of 48 species belonging to 33 families were found using natural structures and resources (Fig.8). Three hundred and ten individuals (8.17%) of 31 species belonging to 18 families were recorded flying around without using any of the structures in the study area.

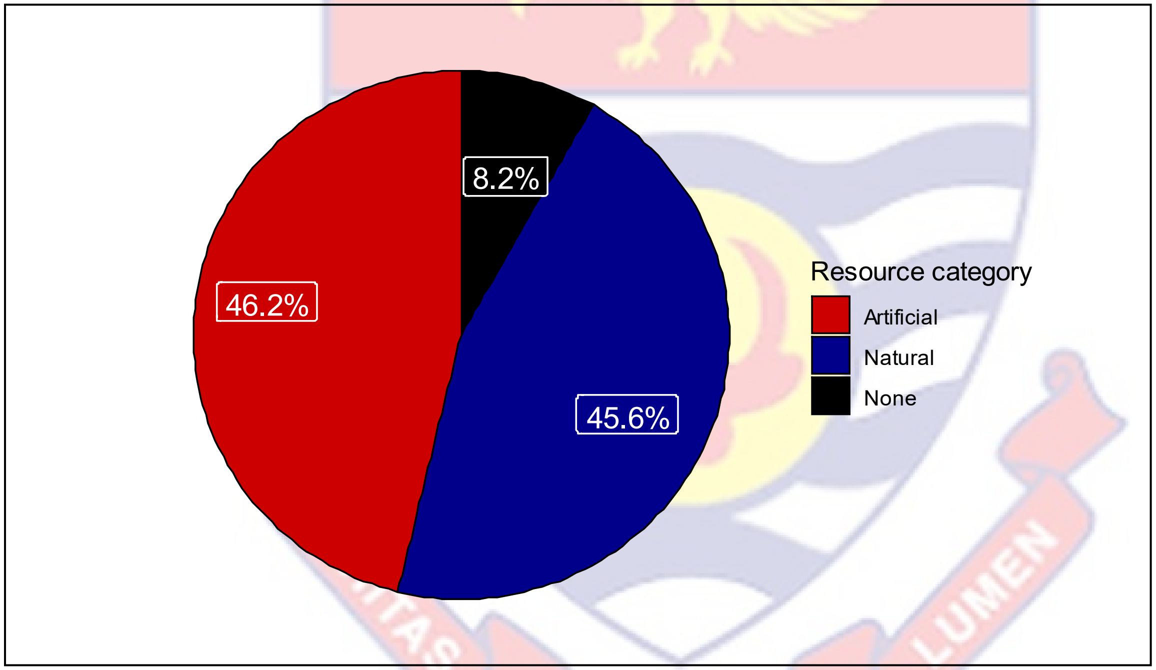


Figure 8: Percentage proportion of resource use by birds in built-up areas in Cape Coast Metropolitan Assembly

Family Corvidae represented by two species (i.e., Pied Crow *Corvus albus* and Piapiac *Ptilostomus afer*) had the highest number of individuals, contributing 16.9% to the total bird population in CCMA (Table 8). Family Passeridae, Estrildidae and Ploceidae contributed 14.7%, 11.4% and 11.1% respectively while Family Acrocephalidae, Rallidae, and Scolopacidae had a single species as well as an individual record.

Table 8: List of bird families, the number of species (richness) and their relative abundance in built-up areas within CCMA

Family	Richness	Rank Abundance	Abundance	Proportion (%)
Corvidae	2	1	588	16.9
Passeridae	2	2	512	14.7
Estrildidae	5	3	397	11.4
Ploceidae	6	4	388	11.1
Columbidae	4	5	383	11
Pycnonotidae	5	6	350	10
Nectariniidae	4	7	183	5.2
Hirundinidae	3	8	156	4.5
Cisticolidae	7	9	93	2.7
Musophagidae	2	10	68	2
Accipitridae	5	11	64	1.8
Sturnidae	2	12	50	1.4
Motacillidae	2	13	43	1.2
Cuculidae	3	14	33	0.9
Apodidae	2	15	24	0.7
Alcedinidae	2	16	23	0.7
Turdidae	1	17	20	0.6
Ardeidae	1	18	18	0.5
Bucerotidae	3	19	18	0.5
Falconidae	1	20	17	0.5
Platysteiridae	1	21	10	0.3
Viduidae	1	22	10	0.3
Meropidae	2	23	7	0.2
Lybiidae	2	24	6	0.2
Zosteropidae	1	25	6	0.2
Laridae	1	26	5	0.1
Macrosphenidae	1	27	4	0.1
Malaconotidae	2	28	3	0.1
Fringillidae	1	29	2	0.1
Phoeniculidae	1	30	2	0.1
Acrocephalidae	1	31	1	0
Rallidae	1	32	1	0
Scolopacidae	1	33	1	0

Variation in resource use by the total number of individual bird species on artificial structures and natural vegetation in the CCMA

The results of the ANOVA show no significant difference between artificial and natural resource use by the total number of individual birds (species abundance) in built-up areas within CCMA ($F_{1,98} = 0.36$, $p = 0.7$) as well as between seasons ($F_{1,98} = 1.47$, $p = 0.15$). However, there was a significant difference in activities performed by birds and the substrate type used ($F_{9,91} = 14.96$, $p < 0.001$). The highest average number of individuals (mean ± SE = 195.00 ± 32.49) were found perching on artificial vegetation while 112.83 ± 12.22 were found on natural vegetation. Most of the individuals found preening did so on artificial structures (26.17 ± 15.95) while most of them found feeding used natural vegetation (125.00 ±20.34). Nesting individuals were recorded more on natural structures (26.17 ± 6.63) as well as most of the individuals found singing used natural structures (24.17 ± 5.19) (Fig.9).

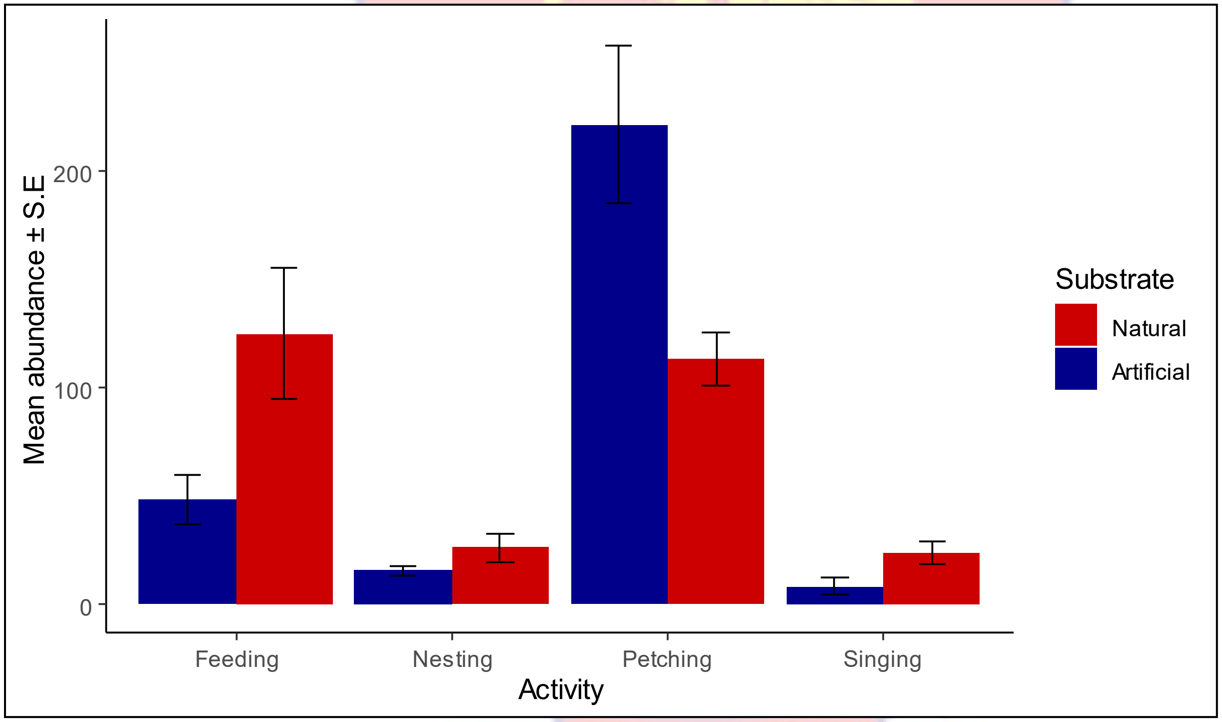


Figure 9: Variations in the frequency of activities performed by birds on artificial and natural substrates

Variation in activities performed by bird species on artificial structures and natural vegetation in the CCMA

A significant difference was found between artificial and natural resource use by bird species (species richness) in built-up areas within CCMA ($F_{2,98} = 8.30$, $p < 0.001$). The highest number of species (53) were found using artificial substrates while the lowest number of species (48) were found using natural structures. Also, a significant difference was found in activities performed by the number of bird species and the substrate type used ($F_{9,91} = 26.39$, $p < 0.001$). The highest average number of species (mean ± SE = 20.33 ± 1.26) were found perching on natural vegetation while 14.67 ± 1.71 were found on artificial vegetation. Most of the species found preening did so on artificial structures (2.00 ± 0.52) while most of the species found feeding used natural vegetation (17.17 ± 2.54). Nesting species were recorded more on artificial structures (4.00 ± 0.58) while most of the individuals found singing used natural structures (10.00 ± 1.91) (Fig. 10).

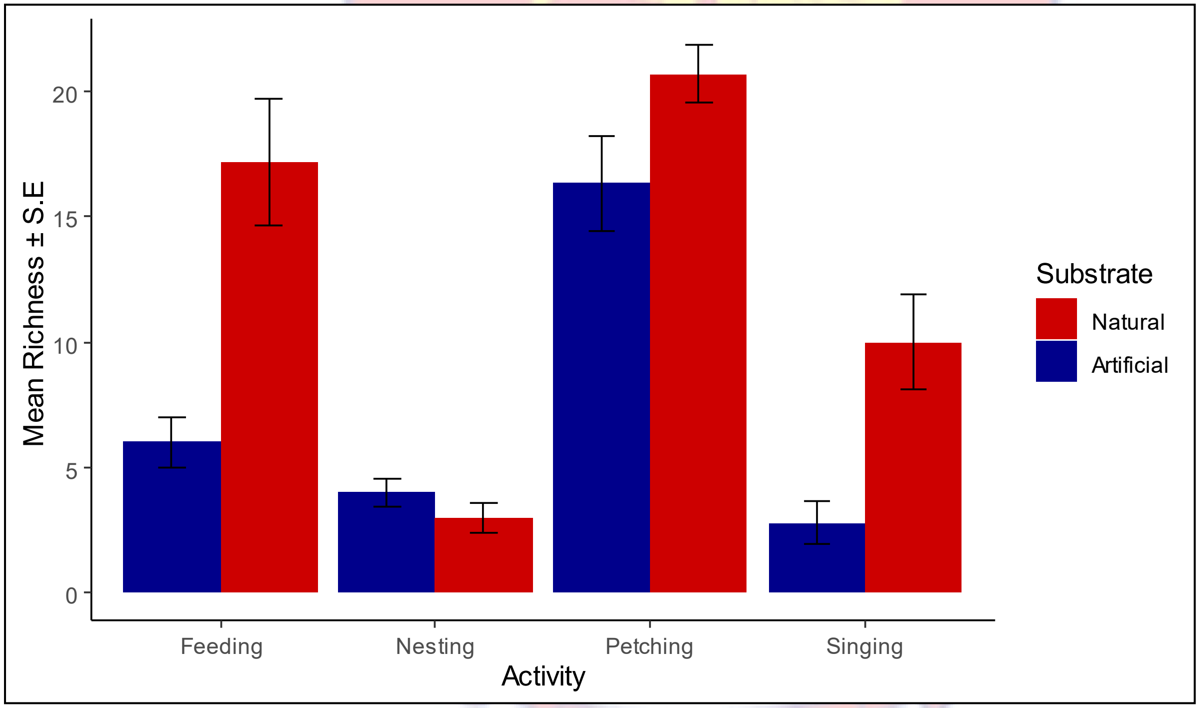


Figure 10: Mean number of bird species and the activities performed on artificial and natural substrates

Indicator Species Analysis (ISA) on birds' association with artificial and natural resources

Indicator Species Analysis (ISA) on birds' use of artificial and natural resources shows a significant association of some species with specific substrate categories. Among the 82 species tested, 17 species were selected (Table 9). Three species (Laughing dove *Spilopelia senegalensis*, Northern Grey-headed Sparrow *Passer griseus* and African Pied Wagtail *Motacilla aguimp*) were identified as significantly associated with artificial resources, eight species (Splendid Sunbird *Cinnyris coccinigastrus*, Copper Sunbird *Cinnyris cupreus*, Village Weaver *Ploceus cucullatus*, Black-necked Weaver *Ploceus nigricollis*, Tawny-flanked Prinia *Prinia subflava*, Senegal Coucal *Centropus senegalensis*, Western Plantain-eater *Crinifer piscator*, Grey-backed Camaroptera *Camaroptera brevicaudata*, and Brown-throated Wattle-eye *Platysteira cyanea*) significantly associated with natural resources and five species significantly (African Palm Swift *Cypsiurus parvus*, Little Swift *Apus affinis*, Ethiopian Swallow *Hirundo aethiopica*, and the critically endangered Hooded Vulture *Necrosyrtes monachus*) associated with flying at the time of data collection (Table 9).

Table 9: Indicator species significantly associated with a category of resource

Resources	Species common name	Scientific name	Stat.	P-value
Artificial				
	Laughing Dove	*Spilopelia senegalensis*	0.48	< 0.01
	African Pied Wagtail	*Motacilla aguimp*	0.30	0.01
	Northern Grey-headed Sparrow	*Passer griseus*	0.41	0.02
Natural				
	Splendid Sunbird	*Cinnyris coccinigastrus*	0.54	< 0.01
	Copper Sunbird	*Cinnyris cupreus*	0.53	< 0.01
	Village Weaver	*Ploceus cucullatus*	0.52	< 0.01
	Black-necked Weaver	*Ploceus nigricollis*	0.50	< 0.01
	Tawny-flanked Prinia	*Prinia subflava*	0.46	< 0.01
	Senegal Coucal	*Centropus senegalensis*	0.41	0.02
	Western Plantain-eater	*Crinifer piscator*	0.41	0.02
	Grey-backed Camaroptera	*Camaroptera brevicaudata*	0.36	0.02
	Brown-throated Wattle-eye	*Platysteira cyanea*	0.32	0.05
None (flying)				
	African Palm Swift	*Cypsiurus parvus*	0.72	< 0.01
	Little Swift	*Apus affinis*	0.58	< 0.01
	Ethiopian Swallow	*Hirundo aethiopica*	0.43	0.01
	Hooded Vulture	*Necrosyrtes monachus*	0.35	0.03

CHAPTER FIVE

DISCUSSION

This chapter delves into the meaning, importance and relevance of the research results. It also focuses on explaining and evaluating what the research findings mean, how it relates to other literature, and making an argument in support of the conclusions and recommendations from the study.

Land use/land cover changes within CCMA

The results of the land cover change analysis provide concrete evidence of extensive land cover temporal changes within CCMA. Built-up areas and sparse vegetation have increased, resulting in a decrease in areas with dense vegetation and water cover. The observed increase in built-up area and sparse vegetation could be attributed to a growing human population. CCMA had a settlement population of 170,000 people and a growth rate of 3.5% per annum in 2010 according to the 2010 population and housing census (Ghana Statistical Service, 2013). However, physical observation and remote sensing data as demonstrated in the current study revealed extensive expansion of human settlements as new lush infrastructure is located deeper into areas that were previously covered by forests and natural vegetation. Also, the rising need for agricultural goods to feed the growing population of the metropolis has accelerated the conversion of natural terrestrial areas to agricultural fields, especially on the CCMA's outskirts, perhaps contributing to the increase in sparse vegetation as revealed in earlier studies in other regions (Pérez-Hernández & Gavilán, 2021).

CCMA is characterized by a mosaic landscape with remnant forests found within the enclave of senior high schools and university campuses with a minimal level of disturbance to wildlife. This landscape supports a considerable diversity of avifauna including a globally threatened species "Hooded vulture *Necrosyrtes monachus*" that were recorded in all the land use types. These findings confirm earlier studies (eg., Demeyrier et al., 2016; Mason, 2000; Stratford & Robinson, 2005), that revealed that urban landscapes support biodiversity, particularly avifauna populations including species of conservation concern.

Variations in bird species diversity measures within land-use types

Although not surprising, this study revealed that diversity indicators decreased with increasing land-use intensity, providing a better understanding of habitat resources available to birds as well as their distribution within the study landscape. Suggesting that farmlands and urban forest reserves offer the widest spectrum of resources for birds compared to residential and commercial areas. This finding is consistent with the findings of Millard et al. (2021), who discovered that increasing the intensity of land use causes a significant reduction in overall pollinator biodiversity in an area.

The study shows that farmlands recorded the highest number of species and individuals which confirms the intermediate disturbance hypothesis (IDH). IDS states that moderate disturbances in a habitat can create a mosaic of microhabitats that support more species than the extremes of the disturbances (Shea et al., 2004; Wilkinson, 1999). Consequently, fewer species were recorded in residential and commercial areas which are next to farmlands in terms of disturbance intensity. This finding is consistent with the findings of previous studies by Newbold et al.(2013) and de Lima et al., (2013), which indicated a significant worldwide influence of land-use intensity on the local abundance of bird species as well as the findings of numerous other studies on a variety of species such as fishes (Ortega et al., 2021), butterflies, (Kuussaari et al., 2021), reptiles and amphibians (Delaney et al., 2021; Hof et al., 2011).

Surprisingly the forest habitat recorded the second-highest species diversity indicators which deviated from the general known trend that an area with more diverse trees will have more resources for birds, hence more bird species (Jakobsson & Lindborg, 2017). However, the forest habitat within the CCMA has received high levels of degradation from hunters, wood fuel collectors, illegal chain saw activities, and refuse dumps, as well as no active protection measures, are in place for these sites. These activities may have depleted the resources for birds, hence habitat-sensitive species may have found the place uninhabitable. Also, the remnant forest has received further encroachment rendering the sizes too small to support biodiversity. This could be the reason for relatively few species recorded in this habitat. The farmlands retain a high proportion of shrubs, crops, and a few large and small trees. These vegetation parameters have been found to contribute positively to the abundance, richness, and diversity of birds (MacGregor-Fors, 2008).

Relationships between environmental resources and variation in avian diversity indicators

Generally, the presence of crops and flowering trees showed a significant positive relationship with species diversity within CCMA. An increase in the flowering trees and the presence of crops could translate into the availability of nectar, pollen, and other foraging materials for farmland birds and insects. This conclusion is not surprising, given that MacGregor-Fors (2008) previously found a positive relationship between natural vegetation variables and bird species diversity. Birds benefit from these vegetation resources in a variety of ways, including feeding, shelter, and nesting sites (Melles et al., 2003). Species diversity indicators showed a significant negative relationship between percentage vegetation cover and large trees. This finding, however, contradicts earlier research by Kebrle et al. (2021) who found large trees as a key factor for bird diversity as well as a study by Rico-Silva et al. (2021) who found native bird richness and abundance to be positively influenced by woody vegetation cover. However, this finding can be attributed to the fact that vegetation cover within the study area was mostly lawns that are managed regularly through weeding and occasionally spraying with herbicides. This may have reduced available food for specialist species and hence provided resources for only a few categories of birds like the Cattle Egret *Bubulcus ibis* and other insectivorous species that were constantly found foraging for arthropods in the lawns. Also, the present vegetation of CCMA is a coastal thicket, which supports mostly savanna birds and a few forest specialists that uses large trees more often for roosting and nesting.

The number of buildings had a significant negative relationship with species diversity indicators. This result confirms findings in previous studies by Rodrigues et al. (2018) who found a negative effect of buildings on both species richness and abundance. In CCMA, the density of buildings appears to be related to urbanization and is a good indicator of the level of urbanization. However, the interaction between buildings and vegetation cover showed a significant positive relationship with all three species diversity indicators. This suggests that bird diversity would be maintained within the study area as long as vegetation fragments are maintained within areas with buildings.

Comparative use of artificial and natural resources by birds in a built-up area in CCMA

Bird species recorded showed to be dominated by urban exploiters and few urban adopters as found in studies across different continents in urban landscapes (Marzluff, 2001). These urban species have been described as synanthropic species and are quite adapted to benefit from artificial habitats and resources that people create around themselves (Dipineto et al., 2013). This study found no significant difference between artificial and natural resource use as well as resource use across seasons by the total number of birds in built-up areas within the study area. This could be influenced by the dominance of species like the Pied Crow *Corvus albus* of the Family Corvidae that dominated the species' abundance. The Pied Crow *Corvus albus* has been reported to be an urban adaptor that is adapted to utilizing artificial resources very well (Londei, 2010). Hence their dominance of abundance could influence the number of birds found using the artificial and natural resources in the study area. Also, the patches of natural vegetation such as trees and shrubs provide nesting material and nesting sites for Village Weavers *Ploceus cucullatus* of the Family Ploceidae which were also found to be significantly associated with natural vegetation. It is therefore not surprising that no significant difference was found between artificial and natural resource use by urban birds as these two species influenced the abundance of species, hence skewing the data.

However, there was a significant difference in activities performed by birds and the substrate type used. The highest average number of individuals found perching and preening used artificial vegetation while the highest individuals found feeding, singing and nesting used natural vegetation. The high concentration of buildings, electric poles, pylons, telecommunication mast and other artificial structures provides a conducive substrate for these urban birds to perch and perform daily time budget activities. This finding confirms finding from studies in other regions by Pike et al. (2017), who found more species using artificial structures during time budget activities, although the proximity of such artificial resources to natural vegetation has an influence.

A significant difference was found between artificial and natural resource use by bird species (species richness) in built-up areas. The highest number of species (53) were found using artificial substrates. This study also found significantly more species using artificial than natural substrates for nesting, similar to the report of Mainwaring (2015) who found that a wider range of birds used man-made structures as nesting sites. This could be due to the fact that most of the natural vegetation in the study area has been replaced by artificial ones hence urban birds have adapted to using man-made structures during an important part of their life such as nesting. Surface and substrate such as pylons and telecommunication mast are used frequently for nesting by Pied Crows *Corvus albus*, Yellow-billed Kites *Milvus aegyptius* and Common Kestrel *Falco tinnunculus* in the absence of natural tall trees. This finding is consistent with studies in other regions that found pylons to provide numerous nesting sites for species such as storks (Balmori, 2005), ravens (Howe et al., 2014), vultures (Anderson & Hohne, 2007) and fourteen species of raptors in South Africa (Anderson, 2000). Other species such as Bronze Mannikin *Spermestes cucullata*, Laughing Dove *Spilopelia senegalensis*, Northern Grey-headed Sparrow *Passer griseus* and House Sparrow *Passer domesticus* also used artificial substrates such as roofs of buildings, openings in air conditions, electric metres and windows of some buildings during the breeding season for nesting.

The availability of adequate nesting sites for breeding populations of birds can sometimes restrict species survival, making nesting a crucial element of the life cycle of birds. The principal benefit of man-made structures in the urban setting is that they frequently provide nesting sites in locations where they are scarce (Mainwaring, 2015). However, one of the principal downsides of using man-made structures for nesting is that they might operate as ecological traps by luring birds to nest in undesirable locations. According to studies, the breeding success of White Storks on man-made structures such as pylons is lower (Balmori, 2005; Tryjanowski et al., 2009). Furthermore, the hazards of nesting on man-made buildings include the deconstruction of nests as a result of routine maintenance and cleaning of these structures, resulting in the loss of nests and in some cases chicks.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATION

Summary

The study examines the rate of urbanization based on land use/landcover change and the relative influence of land-use types on urban bird diversity, abundance and richness as well as evaluates the influence of habitat resources (natural and artificial) on avifauna assemblage structure in a rapidly developing urban settlement in Cape Coast Metropolitan in Ghana. Two hypotheses were set to guide the study:

1. Environmental resources will differ significantly among urban land uses hence natural land-use types (remnant forests and farmlands) would have a significantly higher bird diversity indicator than build-up environments and natural native vegetation covariates would positively influence avifauna assemblage structure in the study area.
2. Certain groups of birds are adapted to the urban environment hence birds in built-up areas would utilize man-made structures more than they would utilize natural structures.

Remote sensing was used to estimate the extent of conversion of natural habitats into urban settlements. Using a 50 m fixed-radius point count, a bird species survey was conducted twice, from January to February and June to July from 06:00 to 10:00 hours and 15:00 to 18:00 hours. Birds recorded were compared in randomly selected plots of four land-use types of farmlands, remnant forest, residential and commercial areas.

Built-up areas within CCMA have expanded and are still expanding into natural habitats. Areas with sparse vegetation have increased coupled with a drop in the area covered by dense vegetation over the last three decades. Also, estimated environmental resources comprising both natural stand vegetation covariates and artificial support for birds in the study landscape differed significantly across land-use types. Avifauna diversity, abundance and richness differ significantly across the four land-use types with urban farmlands being the most species diverse, followed by remnant forests, then residential and finally commercial areas as hypothesized.

The study also found a significant difference in activities performed by the number of individual birds and the type of resource used. The highest average number of individuals found perching, preening did so on artificial structures while feeding, nesting and singing were done on natural structures. A significant difference was also found between artificial and natural resource use by bird richness as well as activities performed and the type of resource used. Natural resources were used by more species (species richness) for perching, singing and feeding while artificial resources were used more for preening and nesting.

Implications for bird conservation, urban planning, and management

The relationship between urban land-use changes and species distribution and abundance has been extensively studied in landscape and ecology studies, and the literature on urban ecology is rich with studies describing the relationship between urban land-use changes and organism distribution and abundance (Concepción et al., 2016; Lee et al., 2021; Murgui & Hedblom, 2017). However, few studies have investigated bird use of man-made structures in an urban landscape and its implications for ecological restoration (Vogel et al., 2018). This study is among the first to empirically test the comparative use of natural and man-made structures by birds in an urban settlement. The study has demonstrated that the CCMA is expanding into habitats for wildlife with inadequate consideration of urban biodiversity. Land acquisition and development are poorly regulated, as a result, enormous areas of forest are being lost every day to unregulated cultivation and development, resulting in a rapid loss of biodiversity. This overnight loss of forest has led to fragmented landscapes with varying land-use intensity from heavily disturbed commercial centres to relatively least disturbed remnant forests. This study also revealed that bird diversity indicators decrease with increasing land-use intensity offering an insight into the distribution of habitat resources available to birds within the study landscape while suggesting that farmlands and urban forest reserves offer the widest spectrum of resources for birds compared to residential and commercial areas.

This study has also demonstrated that although not a replacement for natural resources, artificial resources contribute significantly to the survival of the urban bird breeding population in the absence of natural ones and that some species are adapted to using man-made structures for different activities. Incorporating these study findings into landscape design and management will help to reduce biodiversity loss while preserving ecosystem function in increasingly fragmented landscapes.

Recommendations

1. First, we propose that the CCMA urban planning policies should adopt an environmental sustainability framework that focuses on regulating land clearing within the Metropolis. This policy should also focus on increasing the quantity and complexity of the vegetation cover in residential areas by establishing urban green networks. This could be in the form of supporting citizens in maintaining residential vegetation (e.g., private yards), this would increase the city's green areas and promote biodiversity conservation. Also, urban area management and planning activities should continuously be evaluated to measure their effectiveness and amended where necessary.
2. The study also suggests that conservation practitioners could use artificial structures as tools to conserve and restore populations of urban birds. This can be done by not destroying nests of birds found on artificial structures during maintenance activities on these structures.
3. Further local scale research aimed at determining artificial features that are important for the maintenance of bird diversity is required.

4. Furthermore, further research is needed to investigate the costs and advantages of man-made structures as bird nesting sites. Studies that assess the population state and reproductive success of birds on man-made buildings, in particular, would be particularly useful for conservation practitioners and urban landscape managers.

REFERENCES

Agbosu, L. K. (2000). Land law in Ghana: Contradiction between Anglo-American and customary conceptions of tenure and practices. In *Istitute for research andeducation on social structure, rural resource use and development*. Land Tenure Center, University of Wisconsin-Madison.

Ahrne, K., Bengtsson, J., & Elmqvist, T. (2009). Bumble bees (Bombus spp) along a gradient of increasing urbanization. *PloS One*, *4*(5), e5574.

Anderson, M.D. (2000). Raptor conservation in the Northern Cape Province, South Africa. *Ostrich*, *71*(1–2), 25–32.

Anderson, M.D., & Hohne, P. (2007). African White-backed Vultures nesting on electricity pylons in the Kimberley area, Northern Cape and Free State provinces, South Africa. *Vulture News*, *57*, 45–50.

Aronson, M. F. J., Nilon, C. H., Lepczyk, C. A., Parker, T. S., Warren, P. S., Cilliers, S. S., Goddard, M. A., Hahs, A. K., Herzog, C., & Katti, M. (2016). Hierarchical filters determine community assembly of urban species pools. *Ecology*, *97*(11), 2952–2963.

Balmori, A. (2005). Possible effects of electromagnetic fields from phone masts on a population of white stork (Ciconia ciconia). *Electromagnetic Biology and Medicine*, *24*(2), 109–119.

Batáry, P., Kurucz, K., Suarez-Rubio, M., & Chamberlain, D.E. (2018). Non-linearities in bird responses across urbanization gradients: A meta-analysis. *Global Change Biology*, *24*(3), 1046–1054.

Blair, R. B. (1996). Land use and avian species diversity along an urban gradient.

Ecological Applications, *6*(2), 506–519.

Blair, R. B. (2001). Birds and butterflies along urban gradients in two ecoregions of the United States: is urbanization creating a homogeneous fauna? *Biotic Homogenization*, 33–56.

Boon, E., Ahenkan, A., & Baduon, B. N. (2009). An assessment of forest resources policy and management in Ghana. *Proceedings of the 29th Annual Conference of the International Association for Impact Assessment, Accra, Ghana*, 16–22.

Borrow, N., & Demey, R. (2014). *Birds of western Africa* (Second). Christopher Helm. London.

Brewster, C. L., Beaupre, S. J., & Willson, J. D. (2018). Habitat loss and local extinction: linking population declines of eastern collared lizards (*Crotaphytus collaris*) to habitat degradation in Ozark glades. *Journal of Herpetology*, *52*(3), 352–360.

Buczkowski, G., & Richmond, D. S. (2012). The effect of urbanization on ant abundance and diversity: a temporal examination of factors affecting biodiversity. *PloS One*, *7*(8), e41729.

Callaghan, C. T., Liu, G., Mitchell, B. A., Poore, A. G. B., & Rowley, J. J. L. (2021). Urbanization negatively impacts frog diversity at continental, regional, and local scales. *Basic and Applied Ecology*, *54*, 64–74.

Chamberlain, D., Kibuule, M., Skeen, R., & Pomeroy, D. (2017). Trends in bird species richness, abundance and biomass along a tropical urbanization gradient. *Urban Ecosystems*, *20*(3), 629–638.

Clergeau, P., Croci, S., Jokimäki, J., Kaisanlahti-Jokimäki, M. L., & Dinetti, M. (2006). Avifauna homogenisation by urbanisation: analysis at different European latitudes. *Biological Conservation*, *127*(3), 336–344.

Concepción, E. D., Obrist, M. K., Moretti, M., Altermatt, F., Baur, B., & Nobis, M. P. (2016). Impacts of urban sprawl on species richness of plants, butterflies, gastropods and birds: not only built-up area matters. *Urban Ecosystems*, *19*(1), 225–242.

Cox, D. T. C., Hudson, H. L., Plummer, K. E., Siriwardena, G. M., Anderson, K., Hancock, S., Devine-Wright, P., Gaston, K. J., Devine-Wright, P., & Gaston, K. J. (2018). Covariation in urban birds providing cultural services or disservices and people. *Journal of Applied Ecology*, *55*(5), 2308–2319.

Croci, S., Butet, A., & Clergeau, P. (2008). Does urbanization filter birds on the basis of their biological traits. *The Condor*, *110*(2), 223–240.

Czech, B. (2000). Economic growth as the limiting factor for wildlife conservation. *Wildlife Society Bulletin*, *28*(1), 4–15.

de Lima, R. F., Dallimer, M., Atkinson, P. W., & Barlow, J. (2013). Biodiversity and land-use change: Understanding the complex responses of an endemic-rich bird assemblage. *Diversity and Distributions*, *19*(4), 411–422.

Deikumah, J. P., & Kudom, A. A. (2010). Biodiversity status of urban remnant forests in Cape Coast, Ghana. *Journal of Science and Technology (Ghana)*, 30(3).

Delaney, K. S., Busteed, G., Fisher, R. N., & Riley, S. P. D. (2021). Reptile and Amphibian Diversity and Abundance in an Urban Landscape: Impacts of

Fragmentation and the Conservation Value of Small Patches. *Ichthyology & Herpetology*, *109*(2), 424–435.

Demeyrier, V., Lambrechts, M. M., Perret, P., & Grégoire, A. (2016). Experimental demonstration of an ecological trap for a wild bird in a human-transformed environment. *Animal Behaviour*, *118*, 181–190.

Dipineto, L., Borrelli, L., Pepe, P., Fioretti, A., Caputo, V., Cringoli, G., & Rinaldi, L. (2013). Synanthropic birds and parasites. *Avian Diseases*, *57*(4), 756–758.

Dri, G. F., Fontana, C. S., & de Sales Dambros, C. (2021). Estimating the impacts of habitat loss induced by urbanization on bird local extinctions. *Biological Conservation*, *256*, 109064.

Durak, T., Żywiec, M., Kapusta, P., & Holeksa, J. (2015). Impact of land use and climate changes on expansion of woody species on subalpine meadows in the Eastern Carpathians. *Forest Ecology and Management*, *339*, 127–135.

Duran, C., Gunek, H., & Sandal, E. K. (2012). Effects of urbanization on agricultural lands and river basins: Case study of Mersin (South of Turkey). *Journal of Environmental Biology*, *33*(2), 363.

Elmqvist, T., Zipperer, W., & Güneralp, B. (2016). Urbanization, habitat loss, biodiversity decline: solution pathways to break the cycle. *In, Seta, Karen; Solecki, William D.; Griffith, Corrie A.(Eds.). Routledge Handbook of Urbanization and Global Environmental Change. London and New York: Routledge.*, *2016*, 139–151.

England, N. (2010). Lost life: England's lost and threatened species. *Natural*

England, Peterborough, UK.

Evans, B. A., & Gawlik, D. E. (2020). Urban food subsidies reduce natural food limitations and reproductive costs for a wetland bird. *Scientific Reports*, *10*(1), 1–12.

Fattorini, S. (2011). Insect extinction by urbanization: a long term study in Rome. *Biological Conservation*, *144*(1), 370–375.

Fenoglio, M. S., Rossetti, M. R., & Videla, M. (2020). Negative effects of urbanization on terrestrial arthropod communities: A meta-analysis. *Global Ecology and Biogeography*, *29*(8), 1412–1429.

Francis, R. A., & Chadwick, M. A. (2012). What makes a species synurbic? *Applied Geography*, *32*(2), 514–521.

Fuller, R. A., Irvine, K. N., Davies, Z. G., Armsworth, P. R., & Gaston, K. J. (2013). Interactions between people and birds in urban landscapes. *Urban Bird Ecology and Conservation*, 249–266.

Ganaie, T. A., Jamal, S., & Ahmad, W. S. (2020). Changing land use/land cover patterns and growing human population in Wular catchment of Kashmir Valley, India. *GeoJournal*, 1–18.

Gaynor, K. M., Hojnowski, C. E., Carter, N. H., & Brashares, J. S. (2018). The influence of human disturbance on wildlife nocturnality. *Science*, *360*(6394), 1232–1235.

Ghana Meteorological Agency (2021). *Ghana Meteorological Agency's Seasonal Forecast for the Northern Sector and Seasonal Forecast Update for Southern Sector of Ghana*. Accra, Ghana.

Ghana Statistical Service (2021). *Ghana Population and housing census, Ganeral report, Cape Coast municipality*. Ghana Statistical Service, Accra, Ghana

Ghana Statistical Service (2013). *2010 population and housing census district analytical report, Cape Coast Municipality*. Ghana Statistical Service, Accra, Ghana.

Gibbs, H. K., Ruesch, A. S., Achard, F., Clayton, M. K., Holmgren, P., Ramankutty, N., & Foley, J. A. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences*, 107(38), 16732–16737.

Gockowski, J., & Sonwa, D. (2011). Cocoa intensification scenarios and their predicted impact on CO 2 emissions, biodiversity conservation, and rural livelihoods in the Guinea rain forest of West Africa. *Environmental Management*, *48*(2), 307–321.

Guan, J., Kirikkaleli, D., Bibi, A., & Zhang, W. (2020). Natural resources rents nexus with financial development in the presence of globalization: is the “resource curse” exist or myth? *Resources Policy*, *66*, 101641.

Güneralp, B., Lwasa, S., Masundire, H., Parnell, S., & Seto, K. C. (2017). Urbanization in Africa: Challenges and opportunities for conservation. *Environmental Research Letters*, *13*(1), 15002.

Haines-Young, R. H., Barr, C. J., Black, H. I. J., Briggs, D. J., Bunce, R. G. H., Clarke, R. T., Cooper, A., Dawson, F. H., Firbank, L. G., & Fuller, R. (2000). *Accounting for nature: assessing habitats in the UK countryside*. DETR.

Han, D., Chan, L., & Zhu, N. (2007). Flood forecasting using support vector machines. *Journal of Hydroinformatics*, *9*(4), 267–276.

Hanley, N., & Perrings, C. (2019). The economic value of biodiversity. *Annual Review of Resource Economics*, *11*, 355–375.

Hausmann, A., Slotow, R. O. B., Burns, J. K., & Di Minin, E. (2016). The ecosystem service of sense of place: benefits for human well-being and biodiversity conservation. *Environmental Conservation*, *43*(2), 117–127.

Hawthorne, W., & Lawrence, A. (2013). *Plant identification: creating user-friendly field guides for biodiversity management*. Routledge.

Heilman, G. E., Strittholt, J. R., Slosser, N. C., & Dellasala, D. A. (2002). Forest Fragmentation of the Conterminous United States: Assessing Forest Intactness through Road Density and Spatial Characteristics: Forest fragmentation can be measured and monitored in a powerful new way by combining remote sensing, geographic information. *BioScience*, *52*(5), 411–422.

Hof, C., Araújo, M. B., Jetz, W., & Rahbek, C. (2011). Additive threats from pathogens, climate and land-use change for global amphibian diversity. *Nature*, *480*(7378), 516–519.

Howe, K. B., Coates, P. S., & Delehanty, D. J. (2014). Selection of anthropogenic features and vegetation characteristics by nesting Common Ravens in the sagebrush ecosystem. *The Condor: Ornithological Applications*, *116*(1), 35–49.

Jakobsson, S., & Lindborg, R. (2017). The importance of trees for woody pasture bird diversity and effects of the European Union's tree density policy. *Journal of Applied Ecology*, *54*(6), 1638–1647.

Kark, S., Iwaniuk, A., Schalimtzek, A., & Banker, E. (2007). Living in the city: can anyone become an 'urban exploiter''?' *Journal of Biogeography*, *34*(4), 638–651.

Kebrle, D., Zasadil, P., Hošek, J., Barták, V., & Šťastný, K. (2021). Large trees as a key factor for bird diversity in spruce-dominated production forests: Implications for conservation management. *Forest Ecology and Management*, *496*, 119460.

Kharel, G. (2011). *Impacts of urbanization on environmental resources: A land use planning perspective*. University of Texas at Arlington.

Krausmann, F. (2001). Land use and industrial modernization: an empirical analysis of human influence on the functioning of ecosystems in Austria 1830–1995. *Land Use Policy*, *18*(1), 17–26.

Kumar, D., & Navodaya, A. R. (2014). Urbanization process, trend, pattern and its consequences in India. *Neo Geographia*, *3*(4), 54–77.

Kurucz, K., Purger, J. J., & Batáry, P. (2021). Urbanization shapes bird communities and nest survival, but not their food quantity. *Global Ecology and Conservation*, *26*, e01475.

Kuussaari, M., Toivonen, M., Heliölä, J., Pöyry, J., Mellado, J., Ekroos, J., Hyyryläinen, V., Vähä-Piikkiö, I., & Tiainen, J. (2021). Butterfly species' responses to urbanization: differing effects of human population density and built-up area. *Urban Ecosystems*, *24*(3), 515–527.

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O. T., Dirzo, R., Fischer, G., & Folke, C. (2001). The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change*, *11*(4), 261–269.

Lee, A. T. K., Ottosson, U., Jackson, C., Shema, S., & Reynolds, C. (2021). Urban areas have lower species richness, but maintain functional diversity: insights from the African Bird Atlas Project. *Ostrich*, *92*(1), 1–15.

Leveau, L. M., & Leveau, C. M. (2012). The role of urbanization and seasonality on the temporal variability of bird communities. *Landscape and Urban Planning*, *106*(3), 271–276.

Leveau, L. M., & Leveau, C. M. (2016). Does urbanization affect the seasonal dynamics of bird communities in urban parks? *Urban Ecosystems*, *19*(2), 631–647.

Leveau, L. M. (2019). Urbanization induces bird colour homogenization. *Landscape and Urban Planning*, *192*, 103645.

Leveau, L. M. (2021). Big cities with small green areas hold a lower species richness and proportion of migrant birds: A global analysis. *Urban Forestry & Urban Greening*, *57*, 126953.

Leveau, L. M., Jokimäki, J., Kaisanlahti-Jokimäki, M. L., & Kaisanlahti Jokimäki, M. L. (2017). Scale dependence of biotic homogenisation by urbanisation: A comparison of urban bird communities between central Argentina and northern Finland. *European Journal of Ecology*, *3*(2), 1–18.

Londei, T. (2010). How the most widespread African crow, the Pied Crow *Corvus* *albus*, depends on man. *Ostrich*, *81*(3), 243–246.

Lowry, H., Lill, A., & Wong, B. B. M. (2013). Behavioural responses of wildlife to urban environments. *Biological Reviews*, *88*(3), 537–549.

Lüdecke, D., Ben-Shachar, M. S., Patil, I., Waggoner, P., & Makowski, D. (2021). performance: An R package for assessment, comparison and testing of statistical models. *Journal of Open Source Software*, *6*(60).

MacGregor-Fors, I. (2008). Relation between habitat attributes and bird richness in a western Mexico suburb. *Landscape and Urban Planning*, *84*(1), 92–98.

MacGregor-Fors, I., Escobar, F., Rueda-Hernández, R., Avendaño-Reyes, S., Baena, M. L., Bandala, V. M., Chacón-Zapata, S., Guillén-Servent, A., González-García, F., & Lorea-Hernández, F. (2016). City "green" contributions: the role of urban greenspaces as reservoirs for biodiversity. *Forests*, *7*(7), 146.

Magura, T., Ferrante, M., & Lövei, G. L. (2020). Only habitat specialists become smaller with advancing urbanization. *Global Ecology and Biogeography*, *29*(11), 1978–1987.

Mainwaring, M. C. (2015). The use of man-made structures as nesting sites by birds: a review of the costs and benefits. *Journal for Nature Conservation*, *25*, 17–22.

Marzluff, J. M. (2001). Worldwide urbanization and its effects on birds. *Avian ecology and conservation in an urbanizing world* (pp. 19–47). Springer, Boston, MA.

Mason, C. F. (2000). Thrushes now largely restricted to the built environment in eastern England. *Diversity and Distributions*, *6*(4), 189–194.

McKinney, M. L. (2006). Urbanization as a major cause of biotic homogenization. *Biological Conservation*, *127*(3), 247–260.

McKinney, M. L. (2008). Effects of urbanization on species richness: a review of plants and animals. *Urban Ecosystems*, *11*(2), 161–176.

Melles, S., Glenn, S., & Martin, K. (2003). Urban bird diversity and landscape complexity: species–environment associations along a multiscale habitat gradient. *Conservation Ecology*, *7*(1), 5.

Mersha, S., Gebremariam, E., & Gebretsadik, D. (2021). Drivers of informal land transformation: perspective from peri-urban area of Addis Ababa. *GeoJournal*, 1–14.

Millard, J., Outhwaite, C. L., Kinnersley, R., Freeman, R., Gregory, R. D., Adedoja, O., Gavini, S., Kioko, E., Kuhlmann, M., & Ollerton, J. (2021). Global effects of land-use intensity on local pollinator biodiversity. *Nature Communications*, *12*(1), 1–11.

Morante-Filho, J. C., Faria, D., Mariano-Neto, E., & Rhodes, J. (2015). Birds in anthropogenic landscapes: the responses of ecological groups to forest loss in the Brazilian Atlantic Forest. *PLoS One*, *10*(6), e0128923.

Moreira, F., Martins, R. C., Catry, I., & D'Amico, M. (2018). Drivers of power line use by white storks: A case study of birds nesting on anthropogenic structures. *Journal of Applied Ecology*, *55*(5), 2263–2273.

Murgui, E., & Hedblom, M. (2017). Ecology and conservation of birds in urban environments. *Ecology and Conservation of Birds in Urban Environments*, Cham: 1–525.

Naidoo, R. (2004). Species richness and community composition of songbirds in a tropical forest-agricultural landscape. *Animal Conservation Forum* 7,(93-105).

Newbold, T., Scharlemann, J. P. W., Butchart, S. H. M., Şekercioğlu, Ç. H., Alkemade, R., Booth, H., & Purves, D. W. (2013). Ecological traits affect the response of tropical forest bird species to land-use intensity. *Proceedings of the Royal Society B: Biological Sciences*, *280*(1750), 20122131.

Nikolaenko, V. T. (1992). Urbanization and the use of forests for recreation. *Lesnoe Khozyaĭstvo*, *11*, 25–28.

Oksanen, J., Kindt, R., Legendre, P., O'Hara, B., Stevens, M. H. H., Oksanen, M. J., & Suggests, M. (2007). The vegan package. *Community Ecology Package*, *10*(631–637), 719.

Ortega, J. C. G., Bacani, I., Dorado-Rodrigues, T. F., Strüssmann, C., Fernandes, I. M., Morales, J., Mateus, L., Silva, H. P. da, & Penha, J. (2021). Effects of urbanization and environmental heterogeneity on fish assemblages in small streams. *Neotropical Ichthyology*, *19*.

Palacio, F. X. (2020). Urban exploiters have broader dietary niches than urban avoiders. *Ibis*, *162*(1), 42–49.

Pauchard, A., Aguayo, M., Peña, E., & Urrutia, R. (2006). Multiple effects of urbanization on the biodiversity of developing countries: the case of a fast-growing metropolitan area (Concepción, Chile). *Biological Conservation*, *127*(3), 272–281.

Pérez-Hernández, J., & Gavilán, R. G. (2021). Impacts of land-use changes on vegetation and ecosystem functioning: Old-field secondary succession. *Plants*, *10*(5), 990.

Piano, E., Souffreau, C., Merckx, T., Baardsen, L. F., Backeljau, T., Bonte, D., Brans, K. I., Cours, M., Dahirel, M., & Debortoli, N. (2020). Urbanization drives cross-taxon declines in abundance and diversity at multiple spatial scales. *Global Change Biology*, *26*(3), 1196–1211.

Pike, M., Spennemann, D. H. R., & Watson, M. J. (2017). Building use by urban commensal avifauna in Melbourne central business district, Australia. *Emu-Austral Ornithology*, *117*(3), 284–289.

R Core Team (2021). *A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna Austria*. https://www.r-project.org/

Ramankutty, N., Foley, J. A., Hall, F. G., Collatz, G. J., Meeson, B. W., Los, S. O., Brown De Colstoun, E., & Landis, D. R. (2010). ISLSCP II potential natural vegetation cover. *ORNL DAAC*.

Reynolds, S. J., Ibáñez Álamo, J. D., Sumasgutner, P., Mainwaring, M. C., Ibáñez-Álamo, J. D., Sumasgutner, P. M., & Mainwaring, C. (2019). Urbanisation and nest building in birds: a review of threats and opportunities. *Journal of Ornithology*, *160*, 841–860.

Rico-Silva, J. F., Cruz-Trujillo, E. J., & Colorado Z, G. J. (2021). Influence of environmental factors on bird diversity in greenspaces in an Amazonian city. *Urban Ecosystems*, *24*(2), 365–374.

Riitters, K. H., Wickham, J. D., O'neill, R. V, Jones, K. B., Smith, E. R., Coulston, J. W., Wade, T. G., & Smith, J. H. (2002). Fragmentation of continental United States forests. *Ecosystems*, *5*(8), 815–822.

Rodrigues, A. G., Borges-Martins, M., & Zilio, F. (2018). Bird diversity in an urban ecosystem: the role of local habitats in understanding the effects of urbanization. *Iheringia. Série Zoologia*, *108*.

Schwarz, N., Moretti, M., Bugalho, M. N., Davies, Z. G., Haase, D., Hack, J., Hof, A., Melero, Y., Pett, T. J., & Knapp, S. (2017). Understanding biodiversity-ecosystem service relationships in urban areas: A comprehensive literature review. *Ecosystem Services*, *27*, 161–171.

Shanahan, D. F., Strohbach, M. W., Warren, P. S., & Fuller, R. A. (2014). The challenges of urban living. *Avian Urban Ecology*, 3–20.

Shea, K., Roxburgh, S. H., & Rauschert, E. S. J. (2004). Moving from pattern to process: coexistence mechanisms under intermediate disturbance regimes. *Ecology Letters*, *7*(6), 491–508.

Solecka, I., Sylla, M., & Świąder, M. (2017). Urban sprawl impact on farmland conversion in suburban area of Wroclaw, Poland. *IOP Conference Series: Materials Science and Engineering*, *245*(7), 72002.

Steidl, R. J., & Powell, B. F. (2006). Assessing the effects of human activities on wildlife. *The George Wright Forum*, *23*(2), 50–58.

Stratford, J. A., & Robinson, W. D. (2005). Distribution of neotropical migratory bird species across an urbanizing landscape. *Urban Ecosystems*, *8*(1), 59–77.

Threlfall, C. G., Williams, N. S. G., Hahs, A. K., & Livesley, S. J. (2016).

Approaches to urban vegetation management and the impacts on urban bird and bat assemblages. *Landscape and Urban Planning*, *153*, 28–39.

Tryjanowski, P., Kosicki, J. Z., Kuźniak, S., & Sparks, T. H. (2009). Long-term changes and breeding success in relation to nesting structures used by the white stork, *Ciconia ciconia*. *Annales Zoologici Fennici*, *46*(1), 34–38.

Tryjanowski, P., Morelli, F., & Møller, A. P. (2020). Urban birds: Urban avoiders, urban adapters, and urban exploiters. In *The Routledge Handbook of Urban Ecology* (pp. 399–411). Routledge.

United Nations Department of Economic and Social Affairs Population Dynamics (2021). *World Population Clock: 7.9 Billion People (2021)*. Worldometer. Retrieved July 2, 2021 https://www.worldometers.info/world-population/#ref-1

Vandewalle, M., De Bello, F., Berg, M. P., Bolger, T., Doledec, S., Dubs, F., Feld, C. K., Harrington, R., Harrison, P. A., & Lavorel, S. (2010). Functional traits as indicators of biodiversity response to land use changes across ecosystems and organisms. *Biodiversity and Conservation*, *19*(10), 2921–2947.

Vasenev, V. I., Yaroslavtsev, A. M., Vasenev, I. I., Demina, S. A., & Dovltetyarova, E. A. (2019). Land-use change in New Moscow: First outcomes after five years of urbanization. *Geography, Environment, Sustainability*, *12*(4), 24–34.

Vogel, H. F., McCarron, V. E. A., & Zocche, J. J. (2018). Use of artificial perches by birds in ecological restoration areas of the Cerrado and Atlantic Forest biomes in Brazil. *Neotropical Biology and Conservation*, *13*(1), 24–36.

Waltert, M., Bobo, K. S., Sainge, N. M., Fermon, H., & Mühlenberg, M. (2005). From forest to farmland: habitat effects on Afrotropical forest bird diversity. *Ecological Applications*, *15*(4), 1351–1366.

Wilkinson, D. M. (1999). The disturbing history of intermediate disturbance. *Oikos*, 84(1), 145-147.

World Resource Institute (1994). *World Resources 1994-95: A Report*. Oxford University Press.

Wu, J. (2014). Urban ecology and sustainability: The state-of-the-science and future directions. *Landscape and Urban Planning*, *125*, 209–221.

Xu, X., Xie, Y., Qi, K., Luo, Z., & Wang, X. (2018). Detecting the response of bird communities and biodiversity to habitat loss and fragmentation due to urbanization. *Science of the Total Environment*, *624*, 1561–1576.

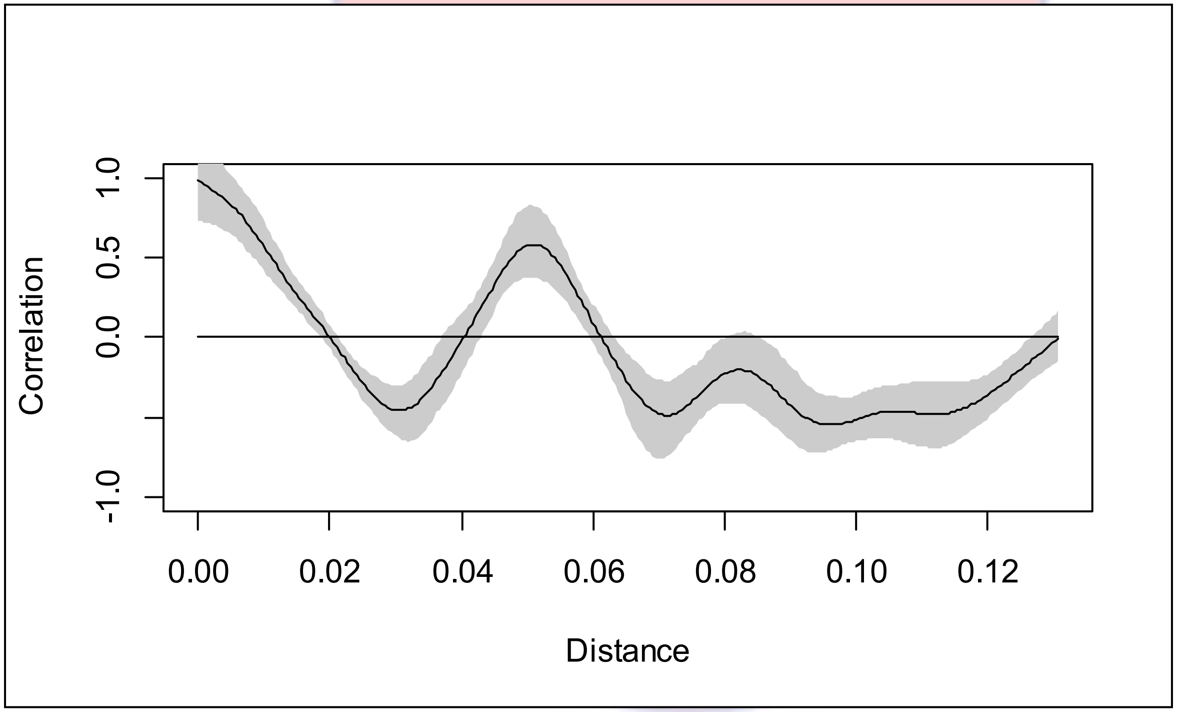
APPENDICES

Appendix A

Source and characteristics of satellite imagery downloaded from USGS website

Date of Image	Satellite/ Sensor	Reference system/Path/ Row	Spatial Resolution
1990	Landsat1 /MSS	WRS-1/194/56	30m
2000	Landsat5 /TM	WRS-1/194/56	30m
2010	Landsat7 /ETM+	WRS-1/194/56	30m
2020	Landsat5 /OLI/TIRS	WRS-1/194/56	30m

Appendix B



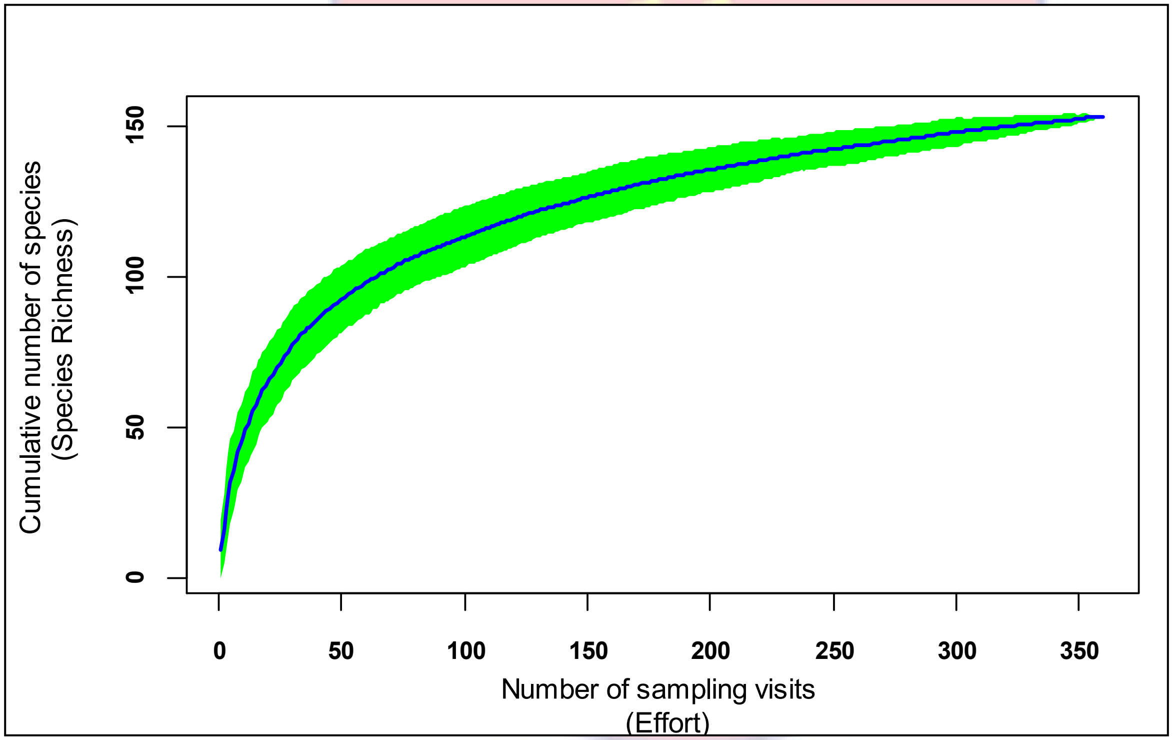
Spatial autocorrelation (Spline correlogram) of sampling points within the sampling area

Appendix C

Results of regression model for the test of trend in land-use changes in the past three decades

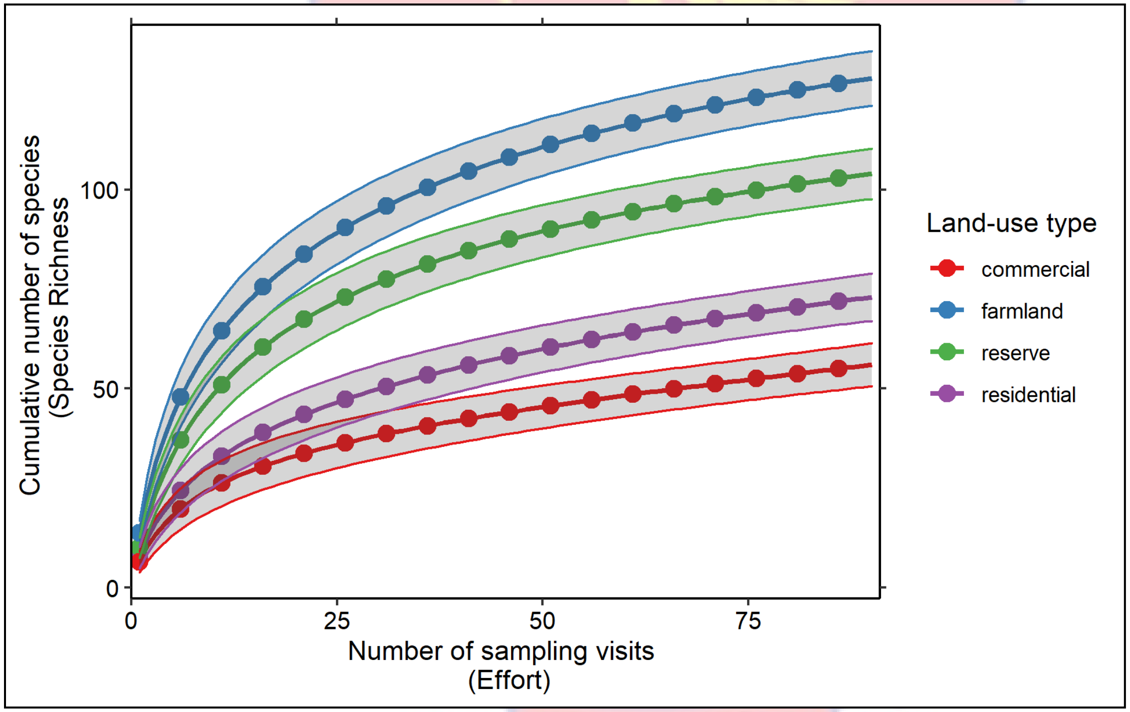
Land-use types	Estimate	Std. Error	t value	Pr(>|t|)
Built-Up Areas	0.013	0.002	7.137	0.006
Dense Vegetation	0.035	0.005	6.560	0.007
Sparse Vegetation	0.012	0.004	3.373	0.043
Water	0.001	0.000	10.059	0.002

Appendix D



Overall species accumulation curve showing the rate of species accumulation per sample visit in the Cape Coast Metropolis

Appendix E



Species accumulation curve showing the rate of species accumulation per sample visit in the Cape Coast Metropolitan Assembly

Appendix F

Avifaunal species recorded in CCMA during the study period

No.	Species common name	Species scientific name	Species family	Status
1	African Crake	*Crex egregia*	Rostratulidae	Intra-African migrant
2	African Cuckoo-Hawk	*Aviceda cuculoides*	Accipitridae	Resident
3	African Firefinch	*Lagonosticta rubricata*	Estrildidae	Resident
4	African Goshawk	*Accipiter tachiro*	Accipitridae	Resident
5	African Green Pigeon	*Treron calvus*	Columbidae	Resident
6	African Grey Hornbill	*Lophoceros nasutus*	Bucerotidae	Intra-African migrant
7	African Grey Woodpecker	*Dendropicos goertae*	Picidae	Resident
8	African Harrier-Hawk	*Polyboroides typus*	Accipitridae	Intra-African migrant
9	African Hobby	*Falco cuvierii*	Falconidae	Resident
10	African Jacana	*Actophilornis africanus*	Jacanidae	Resident
11	African Palm Swift	*Cypsiurus parvus*	Apodidae	Resident
12	African Paradise Flycatcher	*Terpsiphone viridis*	Monarchidae	Intra-African migrant
13	African Pied Hornbill	*Lophoceros fasciatus*	Bucerotidae	Resident
14	African Pied Wagtail	*Motacilla aguimp*	Motacillidae	Resident
15	African Pygmy Kingfisher	*Ispidina picta*	Alcedinidae	Intra-African migrant
16	African Thrush	*Turdus pelios*	Turdidae	Resident
17	African Wattled Lapwing	*Vanellus senegallus*	Charadriidae	Resident
18	African Yellow White-eye	*Zosterops senegalensis*	Zosteropidae	Resident
19	Ahanta Francoline	*Pternistis ahantensis*	Phasianidae	Resident
20	Bar-breasted Firefinch	*Lagonosticta rufopicta*	Estrildidae	Resident
21	Barn Swallow	*Hirundo rustica*	Hirundinidae	Migrant

Appendix F (Continued)

No.	Species common name	Species scientific name	Species family	Status
22	Bearded Barbet	*Lybius dubius*	Lybiidae	Resident
23	Black Crake	*Amaurornis flavirostra*	Rallidae	Resident
24	Black-and-white Mannikin	*Lonchura bicolor*	Estrildidae	Resident
25	Black-and-white Shrike-flycatcher	*Bias musicus*	Vangidae	Resident
26	Black-crowned Tchagra	*Tchagra senegalus*	Malaconotidae	Resident
27	Black-necked Weaver	*Ploceus nigricollis*	Ploceidae	Resident
28	Black-rumped Waxbill	*Estrilda troglodytes*	Estrildidae	Resident
29	Black-winged Kite	*Elanus caeruleus*	Accipitridae	Resident
30	Black-winged Red Bishop	*Euplectes hordeaceus*	Ploceidae	Resident
31	Blue Malkoha	*Ceuthmochares aereus*	Cuculidae	Resident
32	Blue-breasted Kingfisher	*Halcyon malimbica*	Alcedinidae	Intra-African migrant
33	Blue-spotted Wood Dove	*Turtur afer*	Columbidae	Resident
34	Broad-billed Roller	*Eurystomus glaucurus*	Coraciidae	Intra-African migrant
35	Bronze Mannikin	*Lonchura cucullata*	Estrildidae	Resident
36	Brown-crowned Tchagra	*Tchagra australis*	Malaconotidae	Resident
37	Brown-throated Wattle-eye	*Platysteira cyanea*	Platysteiridae	Resident
38	Buff-spotted Woodpecker	*Campethera nivosa*	Picidae	Resident
39	Caspian Tern	*Hydroprogne caspia*	Laridae	Resident
40	Cassian's Flycatcher	*Muscicapa cassini*	Muscicapidae	Resident
41	Chestnut-breasted Nigrita	*Nigrita bicolor*	Estrildidae	Resident
42	Chestnut-winged Starling	*Onychognathus fulgidus*	Sturnidae	Resident
43	Common Bulbul	*Pycnonotus barbatus*	Pycnonotidae	Resident

Appendix F (Continued)

No.	Species common name	Species scientific name	Species family	Status
44	Common Kestrel	*Falco tinnunculus*	Falconidae	Resident
45	Common Nightingale	*Luscinia megarhynchos*	Muscicapidae	Migrant
46	Common Redshank	*Tringa totanus*	Scolopacidae	Migrant
47	Common Sand Piper	*Actitis hypoleucos*	Scolopacidae	Migrant
48	Compact Weaver	*Ploceus superciliosus*	Ploceidae	Resident
49	Copper Sunbird	*Cinnyris cupreus*	Nectariniidae	Resident
50	Diederik Cuckoo	*Chrysococcyx caprius*	Cuculidae	Intra-African migrant
51	Double-spurred Francolin	*Pternistis bicalcaratus*	Phasianidae	Resident
52	Double-toothed Barbet	*Lybius bidentatus*	Lybiidae	Resident
53	Ethiopian Swallow	*Hirundo aethiopica*	Hirundinidae	Resident
54	Fanti Saw-wing	*Psalidoprocne obscura*	Hirundinidae	Resident
55	Garden Warbler	*Sylvia borin*	Sylviidae	Migrant
56	Goliath Heron	*Ardea goliath*	Ardeidae	Resident
57	Greater Painted Snipe	*Rostratula benghalensis*	Rostratulidae	Intra-African migrant
58	Green Crombec	*Sylvietta virens*	Macrosphenidae	Resident
59	Green Hylia	*Hylia prasina*	Hyliidae	Resident
60	Green Wood Hoopoe	*Phoeniculus purpureus*	Phoeniculidae	Resident
61	Green-headed Sunbird	*Cyanomitra verticalis*	Nectariniidae	Resident
62	Grey Kestrel	*Falco ardosiaceus*	Falconidae	Resident
63	Grey-backed Camaroptera	*Camaroptera brevicaudata*	Cisticolidae	Resident
64	Grey-headed Bristlebill	*Bleda canicapillus*	Pycnonotidae	Resident
65	Grey-headed Bushshrike	*Malaconotus blanchoti*	Malaconotidae	Resident

Appendix F (Continued)

No.	Species common name	Species scientific name	Species family	Status
66	Grey-headed Nigrita	*Nigrita canicapillus*	Estrildidae	Resident
67	Greyish Eagle-Owl	*Bubo cinerascens*	Strigidae	Resident
68	Guinea Turaco	*Tauraco persa*	Musophagidae	Resident
69	Hooded Vulture	*Necrosyrtes monachus*	Accipitridae	Resident
70	House Sparrow	*Passer domesticus*	Passeridae	Resident
71	Intermediate Egret	*Ardea intermedia*	Ardeidae	Resident
72	Kemp's Longbill	*Macrosphenus kempi*	Macrosphenidae	Resident
73	Klaas's Cuckoo	*Chrysococcyx klaas*	Cuculidae	Intra-African migrant
74	Lanner Falcon	*Falco biarmicus*	Falconidae	Resident
75	Laughing Dove	*Spilopelia senegalensis*	Columbidae	Resident
76	Lesser Striped Swallow	*Cecropis abyssinica*	Hirundinidae	Resident
77	Levaillant's Cuckoo	*Clamator levaillantii*	Cuculidae	Intra-African migrant
78	Little Bee-eater	*Merops pusillus*	Meropidae	Resident
79	Little Egret	*Egretta garzetta*	Ardeidae	Resident
80	Little Greenbul	*Eurillas virens*	Pycnonotidae	Resident
81	Little Grey Greenbul	*Eurillas gracilis*	Pycnonotidae	Resident
82	Little Swift	*Apus affinis*	Apodidae	Resident
83	Lizard Buzzard	*Kaupifalco monogrammicus*	Accipitridae	Resident
84	Long-tailed Hawk	*Urotriorchis macrourus*	Accipitridae	Resident
85	Long-tailed Nightjar	*Caprimulgus climacurus*	Caprimulgidae	Intra-African migrant
86	Magpie Mannikin	*Lonchura fringilloides*	Estrildidae	Resident
87	Marsh Tchagra	*Bocagia minuta*	Malaconotidae	Resident

Appendix F (Continued)

No.	Species common name	Species scientific name	Species family	Status
88	Melodious Warbler	*Hippolais polyglotta*	Acrocephalidae	Migrant
89	Mosque Swallow	*Cecropis senegalensis*	Hirundinidae	Resident
90	Mottled Spinetail	*Telacanthura ussheri*	Apodidae	Resident
91	Narrow-tailed Starling	*Poeoptera lugubris*	Sturnidae	Resident
92	Northern Grey-headed Sparrow	*Passer griseus*	Passeridae	Resident
93	Northern Puffback	*Dryoscopus gambensis*	Malaconotidae	Resident
94	Northern Red Bishop	*Euplectes franciscanus*	Ploceidae	Resident
95	Olive Sunbird	*Cyanomitra olivacea*	Nectariniidae	Resident
96	Olive-bellied Sunbird	*Cinnyris chloropygius*	Nectariniidae	Resident
97	Orange-breasted Bushshrike	*Chlorophoneus sulfureopectus*	Malaconotidae	Resident
98	Orange-cheeked Waxbill	*Estrilda melpoda*	Estrildidae	Resident
99	Oriole Warbler	*Hypergerus atriceps*	Cisticolidae	Resident
100	Pale Flycatcher	*Melaenornis pallidus*	Muscicapidae	Resident
101	Piapiac	*Ptilostomus afer*	Corvidae	Resident
102	Pied Crow	*Corvus albus*	Corvidae	Resident
103	Pied Kingfisher	*Ceryle rudis*	Alcedinidae	Resident
104	Pin-tailed Whydah	*Vidua macroura*	Viduidae	Resident
105	Piping Hornbill	*Bycanistes fistulator*	Bucerotidae	Resident
106	Plain-backed Pipit	*Anthus leucophrys*	Motacillidae	Resident
107	Puvel's Illadopsis	*Illadopsis puveli*	Pellorneidae	Resident
108	Red-bellied Paradise Flycatcher	*Terpsiphone rufiventer*	Monarchidae	Resident
109	Red-billed Firefinch	*Lagonosticta senegala*	Estrildidae	Resident

Appendix F (Continued)

No.	Species common name	Species scientific name	Species family	Status
110	Red-breasted Swallow	*Cecropis semirufa*	Hirundinidae	Intra-African migrant
111	Red-cheeked Wattle-eye	*Platysteira blissetti*	Platysteiridae	Resident
112	Red-eyed Dove	*Streptopelia semitorquata*	Columbidae	Resident
113	Red-faced Cisticola	*Cisticola erythrops*	Cisticolidae	Resident
114	Red-necked Buzzard	*Falco chicquera*	Accipitridae	Intra-African migrant
115	Red-winged Prinia	*Prinia erythroptera*	Cisticolidae	Resident
116	Reichenbech's Sunbird	*Anabathmis reichenbachii*	Nectariniidae	Resident
117	Senegal Coucal	*Centropus senegalensis*	Cuculidae	Resident
118	Shikra	*Accipiter badius*	Accipitridae	Resident
119	Short-winged Cisticola	*Cisticola brachypterus*	Cisticolidae	Resident
120	Simple Greenbul	*Chlorocichla simplex*	Pycnonotidae	Resident
121	Singing Cisticola	*Cisticola cantans*	Cisticolidae	Resident
122	Snowy-crowned Robin-Chat	*Cossypha niveicapilla*	Muscicapidae	Resident
123	Southern Fiscal	*Lanius collaris*	Laniidae	Resident
124	Speckled Tinkerbird	*Pogoniulus scolopaceus*	Lybiidae	Resident
125	Splendid Starling	*Lamprotornis splendidus*	Sturnidae	Resident
126	Splendid Sunbird	*Cinnyris coccinigastrus*	Nectariniidae	Resident
127	Spotted Flycatcher	*Muscicapa striata*	Muscicapidae	Migrant
128	Tambourine Dove	*Turtur tympanistria*	Columbidae	Resident
129	Tawny-flanked Prinia	*Prinia subflava*	Cisticolidae	Resident
130	Thick-billed Weaver	*Amblyospiza albifrons*	Ploceidae	Resident
131	Tropical Boubou	*Laniarius major*	Malaconotidae	Resident

Appendix F (Continued)

No.	Species common name	Species scientific name	Species family	Status
132	Vieillot's Black Weaver	*Ploceus nigerrimus*	Ploceidae	Resident
133	Village Weaver	*Ploceus cucullatus*	Ploceidae	Resident
134	Violet-backed Starling	*Cinnyricinclus leucogaster*	Sturnidae	Intra-African migrant
135	Western Bluebill	*Spermophaga haematina*	Estrildidae	Resident
136	Western Cattle Egret	*Bubulcus ibis*	Ardeidae	Resident
137	Western Nicator	*Nicator chloris*	Nicatoridae	Resident
138	Western Plantain-eater	*Crinifer piscator*	Musophagidae	Resident
139	Western Reef Heron	*Egretta gularis*	Ardeidae	Resident
140	Western Yellow Wagtail	*Motacilla flava*	Motacillidae	Migrant
141	White-throated Bee-eater	*Merops albicollis*	Meropidae	Intra-African migrant
142	Willow Warbler	*Phylloscopus trochilus*	Phylloscopidae	Migrant
143	Wilson's Indigobird	*Vidua wilsoni*	Viduidae	Resident
144	Winding Cisticola	*Cisticola marginatus*	Cisticolidae	Resident
145	Wood Warbler	*Phylloscopus sibilatrix*	Phylloscopidae	Migrant
146	Woodland Kingfisher	*Halcyon senegalensis*	Alcedinidae	Intra-African migrant
147	Yellow-billed Kite	*Milvus aegyptius*	Accipitridae	Intra-African migrant
148	Yellow-crowned Gonolek	*Laniarius barbarus*	Pycnonotidae	Resident
149	Yellow-fronted Canary	*Crithagra mozambica*	Fringillidae	Resident
150	Yellow-fronted Tinkerbird	*Pogoniulus chrysoconus*	Lybiidae	Resident
151	Yellow-mantled Widowbird	*Euplectes macroura*	Ploceidae	Resident
152	Yellow-rumped Tinkerbird	*Pogoniulus bilineatus*	Lybiidae	Resident
153	Yellow-throated Leaflove	*Atimastillas flavicollis*	Pycnonotidae	Resident
154	Yellow-whiskerd Greenbul	*Eurillas latirostris*	Pycnonotidae	Resident

Appendix G

Pearson correlation coefficients between independent variables and their Variance Inflation Factors (VIF). Correlated values are in bold fonts.

Independent variables		1	2	3	4	5	6	7	8	9	VIF
1	Small trees	1									1.77
2	Large trees	0.34	1								1.24
3	Flowering trees	0.43	0.28	1							1.78
4	Fruiting trees	0.44	0.22	**0.63**	1						1.78
5	Shrubs	0.47	0.33	0.23	0.25	1					2.06
6	% Vegetation cover	**0.55**	0.36	0.27	0.27	**0.69**	1				4.39
7	Telcom mast/pylons*	-0.07	0.06	0.01	-0.06	-0.08	-0.09	1			1.06
8	Electric poles*	-0.37	-0.19	-0.2	-0.2	-0.48	**-0.62**	0.22	1		1.86
9	Number of buildings*	**-0.54**	-0.32	-0.28	-0.28	**-0.68**	**-0.86**	0.11	**0.65**	1	4.37

* Denote artificial environmental variables

Appendix H

Summary table of parameter estimates of avian diversity indicators as a function of environmental variables. Values in bold characters indicate significant coefficients of estimation

Explanatory variables	Response variables					
	Diversity		Abundance		Richness	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
(Intercept)	**1.669**	0.152	**3.335**	0.208	**2.146**	0.144
Farmland	**0.405**	0.127	**0.580**	0.164	**0.492**	0.113
Residential	0.085	0.069	0.029	0.104	0.079	0.071
Remnant forest	**0.235**	0.119	**0.346**	0.157	**0.277**	0.109
Season wet	**0.282**	0.050	**0.184**	0.066	**0.264**	0.045
Small trees	-0.002	0.009	0.001	0.011	0.001	0.007
Large trees	-0.015	0.016	**-0.060**	0.021	**-0.037**	0.014
Flowering trees	**0.058**	0.023	**0.076**	0.026	**0.053**	0.018
Shrubs	0.004	0.008	-0.008	0.011	0.001	0.008
Telcom mast/pylons	0.076	0.049	0.017	0.072	0.055	0.047
Number of buildings	**-0.080**	0.020	**-0.158**	0.029	**-0.104**	0.019
Vegetation cover	-0.002	0.002	**-0.008**	0.002	**-0.004**	0.001
Electric poles	-0.010	0.008	0.018	0.011	-0.002	0.008
Paved road present	0.056	0.060	0.025	0.082	0.003	0.056
Crop present	**0.227**	0.056	**0.377**	0.069	**0.244**	0.047
Refuse present	0.035	0.135	-0.006	0.179	0.065	0.115
Number of buildings*Vegetation cover	**0.002**	0.000	**0.003**	0.001	**0.002**	0.000