UNIVERSITY OF CAPE COAST

BIRD ASSEMBLAGES AND VEGETATION STRUCTRE ALONG URBANIZATION GRADIENT IN CENTRAL REGION, GHANA

BY

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DECLARATION

Candidate's Declaration

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

Candidate 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……………………

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ABSTRACT

Ghana forest cover has decreased to less than 20% of the original continuous forest due to deforestation through urbanisation, agricultural intensification and infrastructure development. What are left are modified fragmented patches to serve as home for wild animals. This work focused on avian assemblages along an urban to forest gradient in southern Ghana to document how different species, species groups and feeding guilds respond to urbanization using point count method. Mean avian diversity and abundance increased with urbanization. There was variation in the vegetation structure along the gradient of urbanisation although theoretically vegetation structure tends to decrease with urbanisation as some vegetation parameters like flowering and fruiting plants were high in urban habitat. This resulted in nectarivore being the most abundant in the urban habitat while insectivore being the most abundant in the suburban habitat. The total abundance of species that make up the various feeding guild differed across the habitat types. Regarding the relationship between bird diversity, abundance and vegetation parameters; bird diversity and abundance were positively correlated to percentage ground cover and average tree height whiles they were negatively correlated to number of shrubs, number of small trees and number of flowering plants. There was no single species utilising a single habitat because different species utilised one or more component of the vegetation structure differently as seen from the (Canonical Correspondence Analysis) CCA plot. In conclusion, avian assemblages, the number of species that make up the various feeding guild and feeding guild

density are not limited by urbanisation but are represented spatially and temporary across the habitat gradient.

KEY WORDS

Avian Assemblages

Exurban

Fragmentation

Forest

Suburban

Urban

Vegetation structure

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DEDICATION

To my Father,

Nicholas Opoku

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LIST OF ACRONYMS

UCC	University of Cape Coast
KS	Kolmogorov-Smirnov
ISA	Indicator Species Analysis
CCA	Canonical Correspondence Analysis
IV	Indicator Value
ANOVA	Analysis of Variance
GLM	General Linear Models
DBH	Diameter at breast Height

CHAPTER ONE

INTRODUCTION

Background to the Study

Many of the world's forests are under threat. Despite national and international efforts, the annual loss of forest during the last decade amounted to approximately 15 million hectares worldwide (FAO, 2001).

Habitat fragmentation is the most important threat to forest ecosystems (Riitters *et al.*, 2002) and can occur through fire (Moritz, 2004), windfall (Sklenicka, 2016) and especially urbanization, which occurs on a large scale as human land use expands Convention on Biological Diversity, (CBD 2012). Urbanization has complex, direct and indirect effects on native biota (Alberti, 2008). For birds, urbanization can affect species abundance, diversity, richness, distribution, biomass and community composition (Blair, 1996; 1999; Clergeau, Jokimaki, & Snep, 2006; Meffert & Dziock, 2013). In addition, it results in an increase in local rates of extinction and loss of native species, and is a major cause of biotic homogenization (McKinney & Lockwood, 2011; Smart *et al.*, 2006) .

Habitat fragmentation is thought to be a primary factor in the loss of bird species (Johnson, 2001) but there are species that persist in a matrix of fragments, secondary undergrowth and large forest patches. The level of connectivity between fragmented forest patches has a strong influence on the population dynamics of species residing in these areas (Alberti, 2008). The two important consequences of fragmentation are; a reduction in total size of the habitat available and the breaking up of the remaining habitat into patches that are isolated to varying degrees

(Johnson, 2001), thereby increasing the vulnerability of biota to environmental and demographic threats (Wang, 2004). Reduction in habitat leads to species loss (Wethered & Lawes, 2003; 2005). Isolation of forest patches disrupts distribution patterns of species and forces individuals to transverse sub-optimal matrix habitat (which might be a threat) between suitable habitat patches, leading to local extinction of bird species (Ewers & Didham, 2006; Fraser, Ewers, & Cunningham, 2014). Fluctuating asymmetry, the most commonly used estimate of developmental stability is believed to reflect environmental stresses that may negatively affect the bird community better than estimates of population size (Camp, Brinck, Gorresen, & Paxton, 2016). Lens, Van Dongen, Norris, Githiru, & Matthysen, (2002) found that bird occupancy in a forest patch increased with mobility and the tolerance to deterioration of the habitat. Habitat fragmentation and disturbance may also have negative effect for biodiversity conservation and can affect a variety of population and community processes over a range of temporal and spatial scales (Cayuela, Golicher, Benayas, González-Espinosa, & Ramírez-Marcial, 2006; Henle *et al.*, 2007; Olff & Ritchie, 2002; Rey-Benayas *et al.*, 2007). However, separating the effects of each causal process can be challenging because the effects of habitat fragmentation often co-vary with the effects of local human disturbance (Bissonette & Storch, 2007; Cayuela *et al.*, 2006) and different organisms and ecosystems may experience the degree of fragmentation and disturbance in variable, even contradictory ways (Bissonette & Storch, 2007; Henle *et al.*, 2007).

Over the last three decades, Ghana's urban human population has more than tripled, rising from 4 million to nearly 14 million people, and outpacing rural population growth (Worldbank, 2016). The exponential growths of urban dwellers are mounting pressure on all amenities, including ecosystems and their wildlife. This work focused on how varying degrees of anthropogenic activities affect birds at different levels of urban settings as there is little information on the ecology of birds in the urban areas of Ghana. In particular, the study assessed the role of habitat patches in avian assemblages along urbanization gradient.

Statement of the Problem

Urban ecosystems have attracted more attention in the developed countries compared to the developing counterparts. Initially, they were analysed in terms of energy transfer with neighbouring ecosystems but are now examined more broadly, revealing that in spite of extreme urbanization they retained a variety of vegetative structures and supported several wildlife species (Lin & Grimm, 2015; Lundholm, 2006; Schnabel, 2009). They may still retain high habitat heterogeneity and dynamic nature, and a quasi-experimental set up to study several ecological processes (Clergeau *et al.*, 2006; Natuhara & Imai, 1996). The progressive urban expansion, the aging and modernization of neighbourhoods, and the modifications of the structure and functions of urban spaces can affect species abundance and composition (Blair, 1996; Lancaster & Rees, 1979). In Ghana, there is a knowledge gap on the influence of urbanisation on avian ecology and this work will examine how varying degrees of urbanization and vegetation structure affect the avian assemblages.

Justification

Majority of the human population reside in the urban centres and more facilities have been put in place to cater for such demand. Therefore, ecologists need to focus on the impact of urbanisation on wildlife to create possible ways on how human population can co-exist with wildlife in these urban centres (Hobson & Bayne, 2000; Johnson, 2001; Moritz, 2004). Thus, research data on the impact of urbanization on wildlife ecology will be necessary to provide pertinent information for the integration of wildlife conservation planning in urban landscapes management.

Aim and Objectives

The main aim of this study was to determine the effect of varying degrees of urbanization and vegetation structure on avian assemblages in the Central Region of Ghana.

The specific objectives were to:

1. Determine the differences in vegetation structure along the urbanization gradient
2. Investigate the differences in bird diversity and abundance
3. Determine the differences in feeding guild density, richness and abundance along urbanization gradient
4. Determine the relationship between vegetation structure and bird diversity, richness and abundance along the gradient of urbanization.

Null Hypotheses

1. There is no significant change in the vegetation structure along the urbanisation gradient
2. There is no significant change in bird diversity and abundance along the urbanization gradient
3. There is no significant change in feeding guilds density, richness and abundance along urbanisation gradient
4. There is no significant relationship between vegetation structure and bird diversity, richness and abundance along the gradient of urbanisation

Study Limitations

The goal of this work was to determine the distribution of avian assemblages along the gradient of urbanisation. But in every research, there is always limiting factors which affect the expected results one way or the other. In this study, environmental conditions such as bad weather like cloudy and rainy days affected the counting of birds. Also the study areas were in a constant change because trees were felled for charcoal production, there were bush fires, and there were infrastructure development like building houses and stores. All these could affect the results in the study areas.

CHAPTER TWO

LITERATURE REVIEW

The State of Ecosystem

Human populations continue to grow and dominate the world's ecosystems (Structure, Lerman, & Fernández-juricic, 2010). Wild portions of earth are urbanizing and humans are increasingly on the move in many parts of the world, shifting from rural regions to flourish in urban centres. As a result, the world's urban population multiplied tenfold last century. The United Nations estimates that by 2050, the global urban population will reach today's total population (Brockerhoff & Nations, 1998). Most urban growth is occurring in developing countries, where human populations are increasing at exponential rates (WRI, 1997). By 2025 the urban population in developing countries will reach 4 billion (three times the expected urban population of developed countries) (Brockerhoff & Nations). In those countries, urban growth will occur so rapidly that it will strain the ability of local governments to provide adequate housing, infrastructure, sanitation, public safety and other essential services. The result will be an increased human impact on ecosystems. Also in the developed world, a greater proportion of the land is urbanized and populations are moving away from traditional city centres. These gradients of urbanization become increasingly complex and multi-modal as suburbs take on increasingly urban characteristics (Alberti, 2008). These processes, collectively known as urbanization, had a staggering effect on native flora and fauna.

Urbanization is likely to be the single most important driver of extinction during this century. Already, urbanization is the second most frequently cited cause of species endangerment in the United States (Czech & Krausman, 1997). In the developing continents like Africa, the upper Guinea forest of West Africa is fifteenth in its world precedence list of 218 centres of bird endemism based on biological importance and recent intensity of threat according to Birdlife International, (Beier, Van Drielen, & Kankam, 2002). The problem of forest fragmentation is extremely severe in West Africa, although the vegetation of West Africa is typically described as consisting of forest and savannah; nearly all of the forest vegetation within populated areas such as Ghana has now been largely converted into savannah vegetation through cultivation and burning (Hopkins, 1966; 1970).

In Ghana, forest zones inhabit more or less 20% of their original area (Pouliot, Treue, Obiri, & Ouedraogo, 2012). The remaining fragments of moist semi-deciduous and dry semi-deciduous amount to 40% and 26% respectively. These zones have high richness in timber trees, in ever increasing human population, idyllic climate for cocoa production and persistent fires that have split a properly continuous forest into dissimilar fragments within non-forest medium (Hall & Swaine, 1981; Pouliot *et al.*, 2012).

Patches and matrixes as bird habitats

Habitat fragmentation research is based on island biogeography and meta-population theories, both assuming a binary or patch-matrix representation of landscapes, where the matrix is seen as inhospitable, homogeneous and ecologically irrelevant (Amaral Nascimento, Neves, Martins, & Coutinho, 2012). Such a dichotomous view of landscapes guided most of the research during the last decades, resulting in much emphasis on patch-level characteristics (mainly patch size and isolation), ignoring the landscape context (Heilman, Strittholt, Slosser, & Dellasala, 2002). Matrix is one important aspect of landscape context, especially in human-dominated landscapes (Bissonette & Storch, 2007). Nowadays, it appears to be common sense that the ‘‘matrix matters’’ (Oliver, Roy, Hill, Brereton, & Thomas, 2010), and affects both within- and between-patch processes in heterogeneous landscapes (Lovett, Jones, Turner, & Weathers, 2005). Much of the current research in landscape ecology intends to understand how different matrix types influences biodiversity (Fortin & Agrawal, 2005). Depending on its nature, the matrix can be alternative or secondary habitat (Ramankutty & Rhemtulla, 2012), source of perturbations and exotic species (Harrison, 2011), and conduct or hinder dispersal (Herrera & García, 2009). Matrix type thus may control the nature and magnitude of edge (Da Silveira, Niebuhr, Muylaert, Ribeiro, & Pizo, 2016), area (Wethered & Lawes, 2005), and isolation effects (Schüepp, Herrmann, Herzog, & Schmidt-Entling, 2011), and may regulate the use of corridors and stepping stones (Hodgson, Thomas, Dytham, Travis, & Cornell, 2012). Some studies suggested that matrix quality, in terms of occurrence and dispersal of organisms, increases as the structural similarity with the patch increases (Bailey *et al., 2010),* but this remains largely speculative for most groups.

Edges are predicted to be one of the most destructive factors that result from habitat fragmentation (Ochoa-Gaona, González-Espinosa, Meave, & Bon, 2004).

According to Howard & Barr (2000), edge is described as "junction of different landscape elements (e.g. plant community type, successional stage and land use)". This means that, habitat becomes more fragmented into smaller patches, and eventually become contiguous to different type of habitats. Edge species like being at the edge for feeding benefits and as result they become exposed to predation and brood parasitism. Within tropical rain forest, lots of environmental characteristics are changed close to forest edges that border agricultural clearings, in particular in the first 100 m of the edge (Natuhara & Imai, 1996). Environmental variables such as temperature, solar radiation, and wind turbulence increase obviously in clearings and beside forest borders (Croci, Butet, & Clergeau, 2008). In response to these changes, vegetation structure, floristic composition and wildlife communities also may perhaps be distorted in forest close to edges (Karr & Roth, 1971). Habitat edges can have an effect on disease dynamics in functioning as obstructions or strains to the movement and spreading of disease propagation (Fraser et al., 2014). Birds like songbirds e.g. warblers, flycatchers, and thrushes that nest close to forest edges are incapable of coping with the negative impact of the Brown-headed Cowbirds' parasitism (Ladin, 2015). It has been observed that the Brown-headed Cowbird's population seems to be higher in fragmented landscapes than it is in forest patches, this is due to food availability (Pimentel, Lach, Zuniga, & Morrison, 2000) regardless of the abundance of host species. Thus the closer the host species are to the edges, the higher the probability that they will suffer parasitism by Brown-headed Cowbirds (Gustafson, Knutson, Niemi, & Friberg, 2002).

Urban areas are highly modified and complex landscapes, within which green or open areas (patches) are seen as valuable for human well-being as well as wildlife (Collins *et al.,* 2000; Pickett *et al.,* 2001). The biological processes of dispersal interact with the landscape structure in determining the distribution of populations of species present (Croci et al., 2008). Several studies have focused attention on the conservation significance of elements of the urban landscape, such as brownfield sites (Miller, Fraterrigol, Hobbs, David, & Wiens, 2001) and gardens (Kookhaie & Masnavi, 2014). An essential first step to managing urban environments more effectively is a fuller understanding of the interplay between landscape (matrix effects) and local factors (patch effects) that affect urban biodiversity. Many cities have a network of habitat fragments or urban greenways comprising areas of semi-natural habitats, secondary succession, ruderal and pioneer environments and open areas. These habitats may be important features for biodiversity both as stable and as transient habitats (Sefidi, Tabibian, & Toghyani, 2016; Weiss, Zucchi, & Hochkirch, 2013), and may also be valuable for their possible function as Corridors and stepping stones to facilitate species dispersal (Gonzalez-Oreja et al., 2012; Hodgson et al., 2012) and they are therefore a key part of current ecological planning (Ratih & Febrianto, 2016). In urban landscape planning, urban greenways and wildlife corridors are increasingly advocated to encourage animals and plants to move around urban areas and thus to preserve or enhance urban biodiversity.

Birds in Urban System

The effect of urbanization on bird communities has been an area of research since 1950 (Marzluff, 2001). One of the useful research approach has been to study avian community composition along a gradient of urbanization (Blair, 1996; Clergeau, Jokimäki, & Snep, 2006). Studies across urban-rural gradients suggest that species richness and diversity peak at intermediate levels of urbanization and that avian biomass increases with urbanization (Beissinger & Osborne, 1982; Blair, 1999; Lancaster & Rees, 1979). Some workers have correlated structure of environments with some measure of biotic diversity (Karr & Roth, 1971; Wiens & Rotenberry, 1981) ; others have considered environmental structure and its relation to habitat utilization in individual species or groups of species (Estabrook & Dunham, 1976; Welsh & Lougheed, 1996). As the structural complexity of the habitat (especially the vegetation component) increases in marine (Baker & Harris, 2011; Goodsell & Connell, 2008) and terrestrial environments, the number of species in many animal groups increases. This relationship is well documented in birds as avian species diversity generally increases with increased floral diversity, however plant species composition may also strongly affect avian communities. Furthermore, individual bird species often show strong preferences for certain vegetation types (Estabrook & Dunham, 1976; Karr & Roth, 1971). Some researchers have compared the pre- and post-development bird communities at a site (Beaver, 1976) , whereas others have compared two sites with different levels of development (Beissinger & Osborne). A few have attempted to examine a range of development intensities by comparing residential areas of different ages (Carley, Pasternack, Wyrick & Barker, 2012) or by comparing areas with different land uses (Czech & Krausman, 1997). Recently, some researchers have turned to assessing bird communities across a range of urban land uses to examine the effects of spatial pattern (Heilman et al., 2002), habitat fragmentation (Riitters *et al.*, 2002), adjacent landscapes (Clergeau *et al.*, 2006), and scale (Wiens & Rotenberry). These studies suggest that it is important to examine the composition of the community and the distribution of individual birds as well as overall measures of the avian community such as species richness. Different groups of birds appear to be affected in different ways, and this has distinct conservation implications. Besides diversity, urbanization also influences species composition of the avifauna. According to the terminology of Blair (1996), bird species of urban areas can be categorized as urban avoiders, urban adapters and urban exploiters, differing e.g. in the degree to which they can tolerate disturbance and utilize and rely on human-provided resources (Threlfall, 2011). Typical urban avoiders are often long-term migrants, habitat specialists (e.g. exclusively feeding on arthropods), or species that are very sensitive to human-related disturbances (e.g. large raptors), because, for example they are nesting on the ground (Blair; Shanahan, Strohbach, Warren, & Fuller, 2014). These birds are mostly native in a community and can be found in relatively undisturbed habitats (covered mainly of native vegetation) outside of cities. Urban avoiders are the most adversely affected by urbanization, resulting in their abundance to be the lowest in urban areas. Urban adapters are often edge species, residing in areas with intermediate levels of disturbance (e.g. suburbs), and besides natural resources they facultatively utilize a remarkable proportion of human provided resources, e.g. food from garbage or bird feeders. Cavity or shrub nesters and omnivore species are typical in this category, such as members of families Corvidae or Paridae (Croci et al., 2008), or some ground feeding finch species. Similarly, several gull species are also successfully established colonies in coastal cities, nesting on roof-tops (Calladine & Park, 2006). Urban adapters include both native and non-native species, and they tend to be dominant in the rural to urban transition areas, where land-use is the most heterogeneous. The group with highest urban abundance, the urban exploiters or synurbic species (Francis & Chadwick, 2012) can be found in the most urbanized areas, where native habitats are scarce and human-altered conditions are predominant. These species not only tolerate but prefer urbanized areas, proven by that, their populations typically reach higher densities in urban compared to more natural habitats. It is important to keep in mind however, that a species can labelled as synurbic in one location, but not in other, therefore it is more appropriate to speak of synurbic populations, rather than entire species, except if a species is synurbic across all of its range (Francis & Chadwick,). The communities of urban exploiters are frequently characterized by a few prevailing and often alien species (Durak & Holeksa, 2015), and by few native ones; furthermore, their diversity and abundance is usually not dependent upon natural vegetation (Threlfall,). Synurbic species not only exploit but often have become dependent on sources provided by humans (Leveau, Jokimäki, & Kaisanlahti-Jokimäki, 2017), e.g. the Feral Pigeon *Columba livia*, House Sparrow or European Starling *Sturnus vulgaris* can be termed to be world widely synurbic. Other species, like the House Crow *Corvus splendens*, Common Myna

Acridotheres tristis in Australia or India, the Blackbird in many parts of Europe, the House Finch *Haemorhous mexicanus* in North America are also good examples of this category. Compared to urban adapters which are often early successional species from more natural habitats adjacent to cities, exploiters are well adapted to human-dominated landscapes, often sharing a long common history with humans (e.g. the House Sparrow (*Passer domesticus*), Bengtson, Eliasen, Jacobsen, & Magnussen, 2010; Ericson, Tyrberg, Kjellberg, Jonsson, & Ullén, 1997).These studies also suggest that urbanization affects the heterogeneity of the landscape and, consequently, the distribution, abundance, and resources upon which birds depend. Typically, moderate development (disturbance) increases heterogeneity, the cover of ornamental vegetation, the availability of water sources, primary productivity, and the amount of edge between habitats while as extreme development or disturbance, however, decreases heterogeneity and the availability of resources as they are permanently replaced with pavement and structures. This is due to Intermediate Disturbance Hypothesis which states that the proposition that the highest diversity of species in an ecosystem is maintained by a level of disturbance intermediate between frequent and rare disturbance. If disturbance is frequent the succession may fail to develop beyond the pioneer phase. If disturbance is rare, the climax will be established and diversity reduced according to the competitive exclusion principle. At intermediate levels of disturbance, the arrival of new species will increase diversity in proportion to the interval between disturbances (Bissonette & Storch, 2007; Connell, 1979; Johnson, 2001; Weithoff, 2001).

Urbanization: Effects on Environmental Components

Effects on weather conditions

Perhaps the most well-known feature of the urbanized environments is their substantively altered local weather conditions (Giles, 2005). For example, precipitation is often enhanced in cities due to the higher concentration of particulates serve as condensation nuclei (Crutzen, 2004). The phenomenon called urban heat island effect is one of the best documented climatic feature of cities, referring to the higher temperatures of urban areas compared to their surroundings (EPA, 2008; Wong Nyuk, 2002). The difference between urban and non-urban temperatures can be several degrees on average and especially evident after sunset when the absorbed heat during daytime is reemitted (Suomi & Kayhko, 2012).

Animal and plant populations may respond to the higher urban temperature, for example, by earlier blooming dates and extended vegetation growth period, in which phenomena the reduced risk of springtime frost in cities plays a remarkable role (Neil & Wu, 2006) . The altered vegetation phenologies (e.g. earlier bud burst, flowering, fruiting) affect the life cycles of insects which, in turn affect the arthropod food availability for bird species. If birds cannot respond as quickly to changes in spring phenology as their invertebrate prey, then the earlier appearance of arthropods may decouple the interactions in predator-prey relationships, i.e. by causing asynchrony between the peak abundance of phytophagous insects (e.g. caterpillars) and the timing of breeding of insectivorous birds (Leech, Crick, & Rehfisch, 2004). On the other hand, however, warmer climate in the city may also influence birds' overwinter survival, leading to increased breeding populations (Chace & Walsh, 2006).

Effects of pollution

Urban areas are also sources of many types of chemical pollution, with concentrations several times higher than the global average. Air, soil and water pollution (due to emissions from industry, traffic and heating, or nutrient loads to water bodies) cause changes in biogeochemical and nutrient cycles and primary production (Cheng, Yin, Xie, Zhang, & Yang, 2014); however, pollutants' exact mode of action are still not well understood (Li, Poon, & Liu, 2001). Their effects may expand well beyond city boundaries and once entered to the food chain, they can be detrimental for a wide range of organisms, including birds (Padoch et al., 2008). Small, insectivorous songbirds are good indicators of chemical pollution, since they occupy high trophic levels and have high metabolic rate. In urban areas enhanced levels of bioaccumulation of heavy metals has already been demonstrated in many common bird species, e.g. in the House Sparrow (*Passer domesticus)* (Göbel, Zimmermann, Klinger, Stubbe, & Coldewey, 2008) the House Wren (*Troglodytes aedon)* or the American Robin (*Turdus migratorius)* (Focardi *et al*., 2006). The detrimental, synergistic effects of such pollutants on birds' physiology is also documented by several studies (AMAP, 1998) and it also known that young individuals are more sensitive in general (Rosivall, Szöllosi, Hasselquist, & Török, 2010), suffering from higher mortality, reduced body mass and condition (Ross *et al., 2001).* Heavy metal pollution may pose both direct and indirect detrimental effects on birds' reproductive success. To assess their relative importance, a recent study manipulated the dietary lead levels at Great Tit (*Parus major)* nests, and compared these nestlings' physiological, biometrical and plumage traits to those of the nestlings living in a heavily polluted area (Eeva & Lehikoinen, 2010) . Despite of the similar exposure of lead in the treatment group and in the birds of the highly polluted area, chicks of the latter exhibited lower survival, decreased size and also the signs of inferior health state, compared to the treatment groups. This result underlines the potential indirect effects pollutants e.g. by affecting the arthropod fauna serving as food for the birds.

Ecological light pollution is another characteristic disturbance related to urban settlements which is caused by the high number of artificial light sources used in the cities. It has complex and subtle effects mainly on animal behaviour via affecting animals' orientation, migration, foraging, reproduction and communication (Longcore, Rich, & Gauthreaux, 2008). It may also result in forming new interactions between competitors or predators and their preys (Duncan, 1997) that would not meet normally. Artificial night lighting has demonstrable effects on a wide range of animal taxa from flying insects (Pugh & Pawson, 2016) to several vertebrate groups, including birds (Dingle & Drake, 2007). In birds, especially migrant species are susceptible to light pollution as many migrate during night, and hypothesized to use light sources as visual references instead of natural clues on the horizon, especially on nights with heavy clouds and fog (Pugh & Pawson, 2016). Once being attracted, they can either become trapped and/or die from collision or exhaustion, and may additionally suffer from other consequences, e.g. reduced energy stores or delayed arrival at wintering or breeding areas. As light is supposed to initiate singing behaviour in birds, artificial night time illumination should also affect territorial and courtship behaviour (Pugh & Pawson,). In line with this, males of several bird species has been demonstrated to start their dawn choruses (anthropomorphism) earlier in sites with more pronounced light pollution compared to their conspecifics of darker territories (Eisenbeis & Hänel, 2009). A recent study on captive Eurasian Blackbird (*Turdus merula)* found that, when exposed to low light levels during nights, individuals started to moult and developed their reproductive system earlier compared to birds kept under dark night conditions, similar to forest nights (Leech *et al.*, 2004). The underlying physiological mechanisms were investigated on urban dweller Blackbird kept under constant conditions (Geue & Partecke, 2008). It turned out that forest and urban birds differed both in their chronotype and circadian clock, as the urban birds had longer daily activity (i.e. woke up before dawn) and shorter circadian period length, whereas forest birds' timing of starting and ending the day was more closely related to the natural twilight.

Luniak, Mulsow, & Walasz, (1990) also demonstrated that urban Blackbird exposed to higher levels of night lighting forage longer after dusk, a difference especially notable in early spring when daylight hours are short. However, the authors did not find any positive correlation between light intensity and body condition, suggesting that birds might not profit from the extended foraging time (but they may have more time for mating or other activities during day time). From all of these studies it seems clear, that artificial light pollution has a substantial effect on behaviour and modifies the endogenous circadian rhythmicity of urban birds.

Anthropogenic noise pollution refers to the altered acoustic environment of cities and transportation networks. It has impacts on animal communication systems and behaviour by masking acoustic signals related to territorial defence, mate attraction, alarm calls, pair-bond maintaining calls, and begging calls of nestlings (Siriwardena, 1995). For example, in European robin (*Erithacus rubecula)* it has been experimentally demonstrated that noise level influences both spatial distribution of males (they avoid noise-emitting sources) and their singing behaviour (Shanahan *et al.*, 2014).

The assumption that elevated noise levels affect birds' breeding success negatively has gained support on a few species so far. For example, a study conducted in the proximity of a highway showed that Great tits breeding in noisier areas had smaller clutches and raised fewer chicks independent of clutch size (Maziarz & Broughton, 2015). Other studies found that males of noisy territories are often lower quality, younger ones that are less successful in attracting mates, presumably because females either avoid these sites or the song of these males are masked, or both (Coleman, 2000). The latter phenomenon can be a handicap for males owning noisier territories, since song repertoire and characteristics are known to be important cues for females to assess a potential partner's quality.

A study of House Sparrows suggests acoustic interference by noise in parent-offspring communication:(Schroeder, Nakagawa, Cleasby, & Burke, 2012) has found that parents breeding in chronic noise reach lower reproductive success compared to parents of control areas – supposedly because elevated noise masks parent-offspring vocal communication, e.g. begging calls of nestlings. Noise pollution may also cause physiological stress, or affect other aspects of behaviour, e.g. it may interfere with sounds playing important roles in predator-prey interactions (Crino, Johnson, Blickley, Patricelli, & Breuner, 2013). For example, in elevated background noise Chaffinches (*Fringilla coelebs*) increase their vigilance and reduce their pecking rate during foraging (Pezzanite, Rockwell, Davies, Loonen, & Seguin, 2005), and in Tree Swallows (*Tachycineta bicolor)* the experimentally elevated static noise reduced nestlings' ability to respond parental alarm calls properly (McIntyre, Leonard, & Horn, 2014).

Since anthropogenic noise is concentrated mainly at low frequencies (Bissonette & Storch, 2007), bird species using high-frequency songs (i.e. masked less by urban noise) supposed to be in selective advantage compared to species with lower frequency songs, proposing the idea that the former could be preadapted to inhabit urban environments. This hypothesis has gained some support from within-genera comparisons in more than a hundred avian genera (Mclaughlin & Kunc, 2013) outlining the role that noise pollution may play in the success or failure of certain species in urban environments. However, it seems that at least some bird species are able to compensate for elevated noise levels by altering their singing characteristics e.g. amplitude or frequency, as it was found in Common Nightingale (*Luscinia megarhynchos)* (Brumm, 2002), Great Tits (Zollinger, Slater, Nemeth, & Brumm, 2017), Song Sparrows (*Melospiza melodia)* (Henry & Lucas, 2009) or Grey-shrikethrush (*Colluricincla harmonica)* (Beaver, 1977), due to either behavioural plasticity or evolutionary adaptation. Interestingly, noise pollution may also offer an alternative explanation to the phenomenon of nocturnal singing of diurnal birds in cities: this behaviour could be an adaptive response by which birds try to avoid daytime acoustic interference while singing (Patricelli & Blickley, 2006).

Effects of man-made structures

Roads are prominent features of urbanized landscapes that are sources of various traffic-related pollutants, alter hydrological systems (Lackstrom & Stroup, 2009) and also increase collision mortality (Heilman et al., 2002). Road avoidance in animals, especially due to traffic noise is a well-known phenomenon. In their meta-analysis, Gomes *et al.*, (2009) found a general decrease in bird population densities with the increased proximity of roads. However, the species abundance of Accipitriformes and Falconiformes were higher nearby the infrastructure, probably because of the extra foraging opportunities that roadkill carcasses offer. This study also proved that road-effect zones may expand up to a kilometer in most of the studied bird species, and this effect is more prominent in open areas compared to forest habitats. Interestingly, birds also show behavioural adaptations to road traffic, for example Benítez-López Legagneux and Ducatez (2013) found that individuals of common European species adjusted their flight initiation distance (an indicator of escape propensity) to the speed limits of roads, with earlier escape (longer flight initiation distances) on roads with higher speed limits. Perhaps the most characteristic components of urbanized landscapes are buildings.

Building-covered patches are unsuitable areas for many birds because they cannot use these as foraging or breeding sites. In addition, buildings are usually associated with increased human activity, pets, pollution, elevated noise and light levels, reduced vegetation, thus, might be avoided by species susceptible to disturbance. However, more tolerant species may gain benefits from their presence (Carrascal, Palomino, Seoane, & Alonso, 2008). For example, the proximity of buildings may serve as a thermal shelter for overwintering arthropods (Nelson & Sanchez, 2005) and certain bird species preferentially roost or breed in houses. Collision mortality in birds is also highly increased by the presence of buildings. Long distant migrants during their annual spring and fall routes are especially vulnerable to such risks; however, a recent study on North-American birds failed to find positive correlation between collision mortality and long-term population trends (Arnold & Zink, 2011). Last but not least, with increasing building density the surface covered by vegetation is necessarily reduced and spatially more heterogeneous, adversely affecting the distribution, abundance and species richness of many native animal taxa. Reduced vegetation is also one of the major factors responsible for urban heat islands, as vegetation cover decreases the amount of absorbed solar radiation, and cools air temperature by evapotranspiration (Mcdonnell, Pickett, & Pouyat, 1993).

CHAPTER THREE

MATERIALS AND METHODS

Study Area

The study was carried out in Cape Coast Metropolis in the Central Region of Ghana (7.9465° N, 1.0232° W) (Figure 1). This area lies in the semi-deciduous vegetation zone of West Africa with an annual mean rainfall of 1310 mm and an elevation of 300 m above sea level (Ekpe, Hinkle, Quigley, & Owusu, 2014). The common trees in the study area are Wawa (*Entadrophragma utile*), African mahogany (*Khaya ivorensis*), silk cotton tree (*Ceiba pentandra*), palm trees (Arecaceae) (Hall & Swaine, 1981). Non-forest matrix, including farm lands, comprising small farms and fallows with scattered local and exotic trees are common in the study area. Prevailing crops in the farms were: corn (*Zea mays*), plantain (*Musa paradisiaca*), cocoyam (*Xanthosoma sagittifolium*), tomatoes (*Solanum lycopersicum*), garden eggs (*Solanum melogena*) and cassava (*Manihot esculantum*) (FAO,). Other human activities such as silviculture, selective logging, charcoal production and frequent fire at the study sites led to the conversion of forest into vegetation dominated by elephant grass (*Pennisetum purpureum*), Guinea grass (*Panicum maxima*), Centro (*Centrosema pubescens*), Siam weed (*Chromolaena odorata*) and many more weedy species (FAO, 2015; Poku, 2002).

Land Cover and Gradient of Urbanization

In this study, land cover in terms of vegetation and built-up matrices were used as measures of urbanization. Built-up areas were buildings, roads and other urban structures. Nineteen study sites were demarcated and characterized by using digital aerial photographs produced by the application of Quantum Geographic Information System (QGIS) from the study area. Each site was at least 1 km away from the nearest site. At each site, the percentage built-up area (to the nearest whole number) within a 500 m radius was calculated using the extension features of the QGIS and the sites classified into habitats within various levels of urbanization, based on the guidelines of Marzluff (2001) as follows; (1) 0–4% = wildland or forest habitat), (2) 5–20% = exurban, (3) 21–50% = suburban, and (4) > 50% = urban habitat (Figure 2). Wildlands or forests are unsettled lands that may occasionally (especially at large scales) include dwellings. Exurban lands are sparsely settled by individual homesteads, recreational developments, small towns, and villages; the unsettled land is much more abundant than the settled land, but the actual pattern of settlement can vary widely. Settlements in exurban areas are surrounded by a natural matrix. Suburban lands are characterized by moderate to high-density, single-family housing with sizes of 0.1 to 1.0 hectares. Lawns and gardens are common. Basic services, light industry, and multi-family housing are interspersed with the typical single-family dwellings. Most buildings are single-or double-storied. Urban lands are areas where the majority of the land is covered by buildings. In urbanized areas, the remnants of the forest are called patches (Alberti, 2008; Berry, 1990; Marzluff, Bowman, & Donnelly, 2001).

GPS readings of the patches' locations were taken and the spatial data downloaded onto a computer and converted to a database file and exported to QGIS to interpret the GPS readings. The area of each patch was calculated using the extension features of the QGIS.

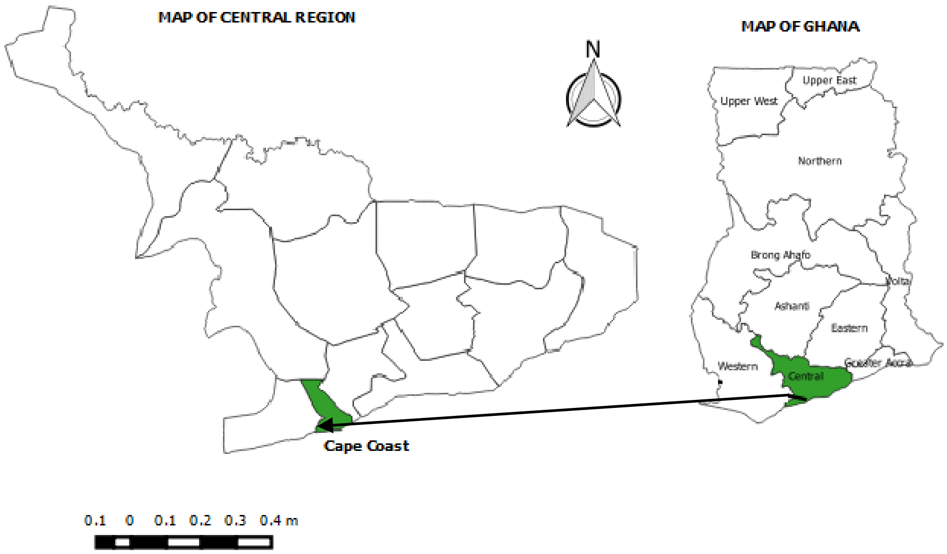

Figure 1 : Map of Ghana showing the location of Central Region and Cape Coast.

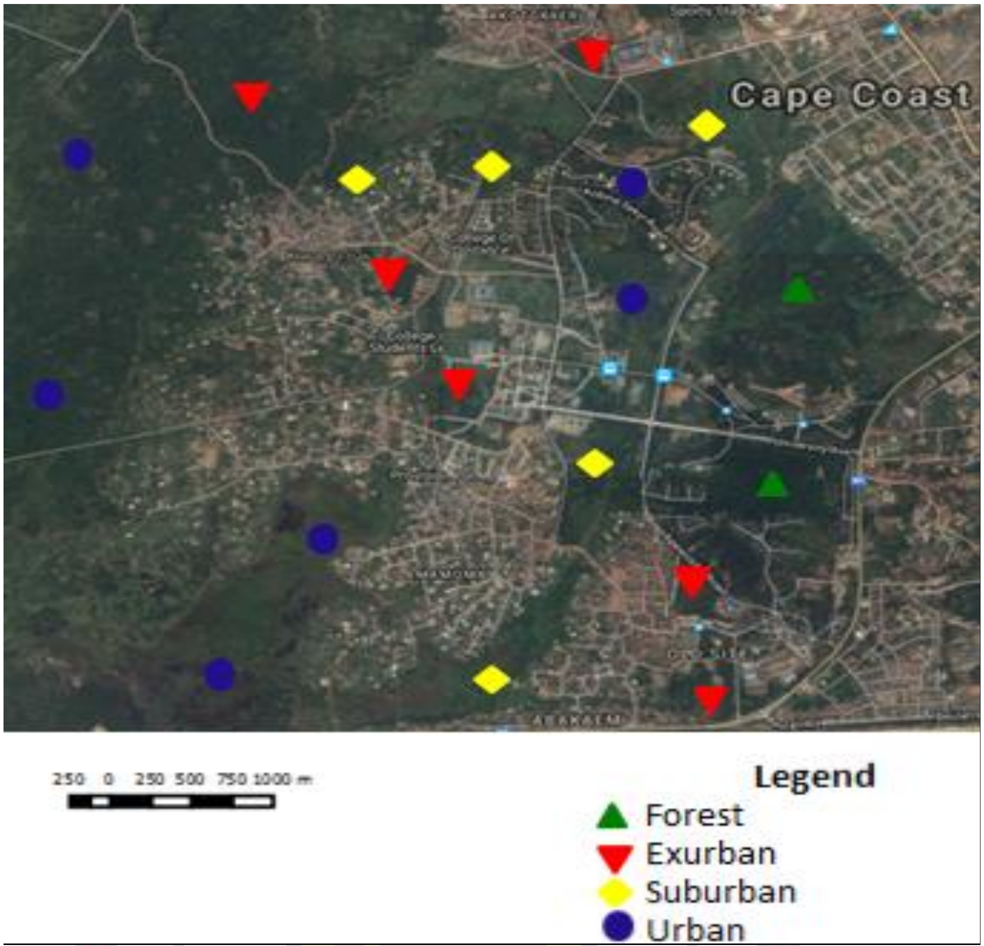

Figure 2 : Map of study area showing the four habitat types.

Bird Survey

The point count technique was used to census birds in the patches (Kissling, Garton & Handel, 2006; Marty & Mossoll-Torres, 2012). Point locations of 50 m radius were randomly established in each of the habitat types in a patch, and each point was at least 100 m away from the nearest point. Birds were counted using visual or auditory at each point for 7 minutes, in the morning from 6:30 to 9:30 am and in the evening from 3:00 to 6:00 pm and were repeated four times per season. Birds were recorded as occurring within a 50 m radius and the densities of various feeding guilds were calculated using the DISTANCE software (Buckland *et al*, 2001).

Vegetation Measurement

At the centre of each point, four 10 m x 10 m quadrats were randomly selected. Where, the following measurements were taken and averaged, following the procedure by Manu, Peach, & Cresswell (2007); (1) by viewing through the canopy from the objective lens of a binoculars, the percentage canopy cover was estimated to the nearest 1 %, (2) the diameter at breast height (DBH) of each tree was measured and the number of big trees and small trees were recorded (Trees having DBH greater than 20 cm were regarded as big trees while those less than 20 cm were regarded small trees), (3) percentage ground cover was estimated by the eye to the nearest 1 % (Manu *et al.*,), (4) number of shrubs, (5) number of flowering and fruiting trees and 6) tree height determined by a range finder.

Data Analysis

All data were organised in Microsoft Excel and imported to R software, version 3.3.1 (R Development Core Team, 2015) for analysis. Normality test for all response variables in the data were conducted using Shapiro-Wilk test for normality and frequency distribution of histogram. Shannon-Wiener diversity index was calculated to determine the diversity of the birds using the vegan package in R statistical software (Oksanen, 2015), which is based on the formula:

$H = -\sum pi \log b\, pi$ ……………………………………………….1

where pi is the proportional abundance of species, i and b are the bases of the logarithm.

Species accumulation curves were generated using vegan package, for all the sites to determine the rate of species accumulation and Kolmogorov-Smirnov test was used to check for differences in the accumulation curves. Analysis of variance (ANOVA), a parametric test and Kruskal Wallis, a non-parametric test were used to evaluate the differences in bird diversity and bird abundance respectively across the four habitat types (forest, exurban, suburban and urban). Bar plots were used to illustrate the results.

Birds were classified into various feeding guilds based on their major diets (Birds of Africa) (Sinclair *et al.*, 2003). Feeding guilds are groups of species in a community that exploit the same set of resources in a similar manner, but are not necessarily closely related taxonomically. From the above statement, birds of prey were grouped into carnivores, seed or grain-eaters into granivores, fruit-eaters into frugivores, insect seeking birds into insectivores, feeds on both plant and animal matter into omnivores, nectar feeders into nectarivores and fish predators into piscivores. The number of species that made up the various feeding guilds, their abundances and densities were calculated. That is, mean number of species and mean abundance of various feeding guilds. Analysis of Variance (ANOVA) was used to test for variation in the number of species in each feeding guild, their respective densities across the habitat types where as Kruskal Wallis test was used to test for total abundance in each feeding guild across the habitat types and were used to assess the variation in vegetation structure across habitat types.

Collinearity tests on the eight vegetation parameters were conducted to check for any correlation among predictor variables. Only one of any pair of variables with correlation coefficient greater than 0.5 was retained for further analysis. To check for the relationship between vegetation structure and bird diversity and abundance, mixed effect models were used with habitat types as random factors. Akaike Information Criterion (AIC) was used to identify the best model. Canonical Correspondence Analysis (CCA), a multivariate analysis which relies on multidimensional scaling, was implemented by the vegan package in R software to show how individual birds interacted with vegetation structure across the habitat types. The Indicator Species Analysis (ISA) (Marzluff, 2001), which is implemented by the labdsv package in R (Oksanen, 2015) was used to contrast the distribution of individual species along the urban gradient. This method combined information on the concentration of species abundance in a particular group (in this case, habitat type) and the faithfulness of occurrence of a species in a particular group. The Indicator Values (IV) ranged from 0 (no indication) to 100 (perfect indication). Perfect indication meant particular species group was associated to a particular habitat type.

CHAPTER FOUR

RESULTS

Characteristics of the Levels of Urbanization

A total of 15,314 individual birds belonging to 17 orders, 50 families, and 144 species were recorded across the four study sites. The rate of species accumulation across the habitat types did not reach asymptote or level up with the sampling effort but exurban accumulated the highest species followed by suburban, forest and the least being the urban habitat (Figure 3). Also, from the Kolmogorov-Smirnov test (KS), the rate at which species accumulated differed significantly between four out of six possible pairings from the four habitat types: Exurban, Urban, Suburban and Forest. (Table 1).

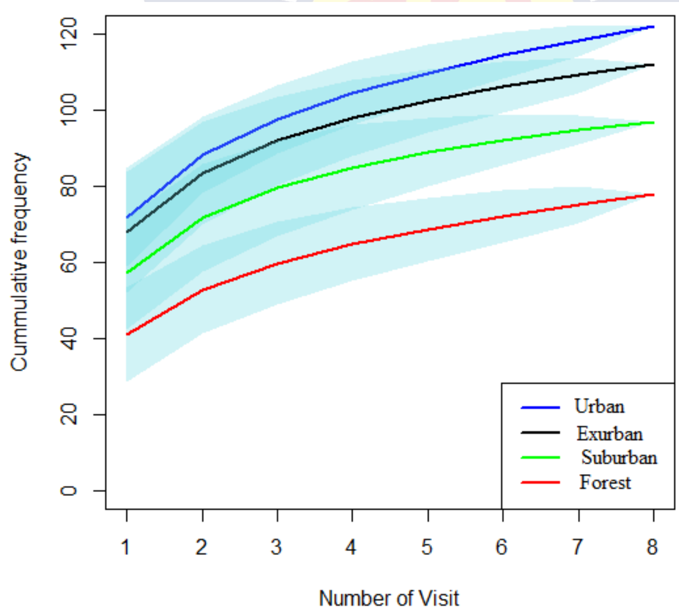

Figure 3 : The rate of species accumulation with sampling effort (number of visit) by the different habitat types.

Table 1: Differences in species accumulation between the habitat types using Kolmogorov-Smirnov Test

Habitat types	p-value
Exurban-Suburban	0.7
Exurban-Forest	0.01*
Exurban-Urban	0.07
Suburban-Forest	0.01*
Suburban-Urban	0.01*
Forest-Urban	0.01*

*p<0.05 i.e. significant difference

All the vegetation parameters differed significantly across the habitat types (Table 2). Tree height and percentage ground cover were recorded the highest in suburban habitat with mean values (X±SE) of 13.8m±1.0 and 70.0%±1.0 respectively. Forest and suburban habitats recorded the highest number of big trees (4.2±1.1). The highest number of small trees 7.6±1.0 and percentage canopy cover 43.7±1.0 were seen in the forest habitat. Urban habitat recorded the highest in the following vegetation parameters; number of shrubs (17.3±1.0), number of fruiting plants (5.0±1.1) and number of flowering plants (5.0±1.1) among the habitat types.

Table 2: Variation in vegetation parameters across the habitat types.

Vegetation parameters	Exurban	Forest	Suburban	Urban	p-value
Tree height	12.5±1.0	13.6±1.0	13.8±1.0	13.0±1.0	0.001*
No. of Big trees	1.8±1.1	4.2±1.1	4.2±1.1	3.2±1.1	0.001*
No. of Small trees	6.3±1.0	7.6±1.0	7.1±1.0	6.8±1.1	0.001*
% Canopy cover	42.3±1.0	43.7±1.0	43.3±1.0	43.6±1.0	0.001*
% Ground cover	68.0±1.0	69.0±1.0	70.0±1.0	69.0±1.0	0.001*
No. of Shrubs	16.4±1.0	17.2±1.0	17.1±1.0	17.3±1.0	0.001*
No. of Fruiting plants	4.0±1.0	4.7±1.1	4.9±1.1	5.0±1.1	0.001*
No. of Flowering plants	4.0±1.0	4.8±1.1	4.9±1.1	5.0±1.1	0.001*

Variation in bird diversity and abundance along the gradient of urbanization

There was a significant difference in bird diversity across the habitat types (GLM: $F_{3, 687} = 20.65$, p: <2e-16, Table 3). The highest diversity of birds was recorded in the urban followed by suburban, exurban and the least in the forest habitat. There was a significant difference in bird abundance across the habitat types ($DF_{3: 693}$, $p < 0.001$, Table 4), with the urban and suburban recording higher abundance than exurban and forest.

Table 3 : Variation in bird diversity across the four habitat types.

Habitat types	Estimate	Std. Error	t-value	p-value
Exurban	2.213	0.035	64.101	<0.001*
Forest	-0.236	0.047	-4.953	<0.001*
Suburban	0.153	0.052	2.915	0.004*
Urban	0.02	0.066	0.297	0.767

Adjusted R-squared: 0.079, F-statistic: 20.65, 3 and DF: 687, p-value: <2e-16

Table 4 : Variation in bird abundance across the four habitat types.

Habitat types	Estimate	Std. Error	t-value	p-value
Exurban	54.764	1.029	224.321	<0.001*
Forest	0.583	1.045	-18.045	<0.001*
Suburban	1.491	1.044	11.701	<0.001*
Urban	1.43	1.062	-8.858	<0.001*

Adjusted R-squared: 0.084, DF: 3 and 687, p-value: <2e-16

Distribution in Feeding Guilds along the Gradient of Urbanization

The densities of the feeding guilds did not differ significantly along the gradient of urbanisation (Table 5) likewise the number of species in each feeding guild (Table 6). However mean abundance of feeding guilds in the various habitat types varied significantly. For example, insectivores were the most abundant, reaching mean abundance of 137.7±1.0 in the suburban and urban habitat types whereas Nectarivores recorded 12.7±1.1 as the most abundant feeding guild in the urban setting (Table 7). A checklist of all the birds reordered can be seen in the Appendix

Table 5: Mean density for avian feeding guild conducted in forest, exurban, s suburban and urban areas based on one-way ANOVA.

Feeding guild	Exurban	Forest	Suburban	Urban	p-value
Carnivore	1.7±0.9	2.2±1.8	1.9±1.4	4.2±1.3	0.239
Granivore	9.8±4.1	8.2±8.3	9.1±6.1	10.0±5.8	0.100
Frugivore	1.9±1.1	3.0±2.1	4.1±1.6	3.9±1.5	0.480
Insectivore	5.9±2.2	8.9±4.5	8.5±3.3	14.5±3.2	0.092
Nectarivore	1.5±0.8	1.5±1.6	1.7±1.2	3.6±1.1	0.270
Piscivore	1.0±1.0	1.7±2.7	1.4±1.5	4.0±2.0	0.540
Omnivore	6.9±2.3	7.1±4.7	7.7±3.5	14.4±3.3	0.140

Table 6: Mean species richness for avian feeding guild conducted in forest, exurban, suburban and urban areas based on Kruskal Wallis test.

Feeding guild	Exurban	Forest	Suburban	Urban	p-value
Carnivore	2.8±0.4	2.4±0.5	3.2±0.7	4.3±1.0	0.150
Granivore	6.1±0.7	4.7±0.9	6.5±1.1	7.4±1.7	0.182
Frugivore	5.0±0.4	5.2±0.6	5.2±0.7	5.3±1.0	0.975
Insectivore	19.3±2.6	16.8±3.4	25.5±4.1	24.4±6.1	0.146
Nectarivore	1.9±0.2	2.5±0.3	2.2±0.3	2.7±0.5	0.147
Piscivore	3.1±0.6	1.0±0.9	3.8±0.9	2.0±1.9	0.062
Omnivore	4.5±0.5	4.5±0.7	5.4±0.8	0.2±1.2	0.613

Table 7: Mean abundance for avian feeding guild conducted in forest, exurban, suburban and urban areas based on Kruskal Wallis test.

Feeding guild	Exurban	Forest	Suburban	Urban	p-value
Carnivore	21.6±1.1	22.5±1.1	24.1±1.1	23.3±1.1	0.136
Granivore	77.4±1.0	77.9±1.1	78.9±1.0	78.5±1.1	0.806
Frugivore	26.2±1.1	27.1±1.1	27.8±1.1	28.4±1.1	0.056
Insectivore	136.3±1.0	136.7±1.0	137.7±1.0	137.4±1.1	0.034*
Nectarivore	9.1±1.1	10.4±1.1	10.9±1.1	12.7±1.1	0.042*
Piscivore	8.8±1.1	9.6±1.2	11.0±1.2	11.7±1.3	0.264
Omnivore	84.9±1.0	85.5±1.1	86.2±1.0	86.3±1.1	0.187

Relationship between vegetation structure and bird diversity, richness and abundance along the gradient of urbanization

Of all the vegetation parameters recorded, it is only the number of small trees and the number of flowering plants that had a significant negative relationship with bird diversity. Birds were less diverse in areas with more small trees and flowering plants (Figures 4 & 5). Figures 6 & 7 show that there was high bird diversity at high tree and percentage ground cover. In Figure 8 & 9, the number of flowering plants and number of shrubs are indirectly proportional to bird abundance thus an increase in number of shrubs and flowering plants corresponded to a decrease in bird abundance significantly whereas high percentage ground cover and high proportion of average tree height resulted in high bird abundance are (Figures 10 &11).

A plot of bird species and vegetation parameters against the axes of the CCA plot (Figure 12) showed that, cumulatively, the two axes represented 46.34% of the composition variation for which axes 1 and 2 accounted for 24.62% and 21.71% of the bird composition respectively. Majority of birds were clustered around the center of vegetation parameters and tended to utilize all the vegetation parameters in their own way. For instance, the carnivorous African harrier hawk was mostly found around tall big trees whereas the frugivorous and cavity nester, piping hornbill were found around fruiting trees and big trees. Warblers like the yellow-mantled widowbird, winding cisticola and the laughing dove, blue spotted wood-dove and red-eyed dove were associated with ground cover. Common bulbul, common wattle-eye and little greenbul were associated with all the vegetation parameters. The IAS showed that none of the bird species had significant IV, which suggested there was no preference of a particular habitat by a particular species; thus every species utilized all the habitat types similarly (Appendix C).

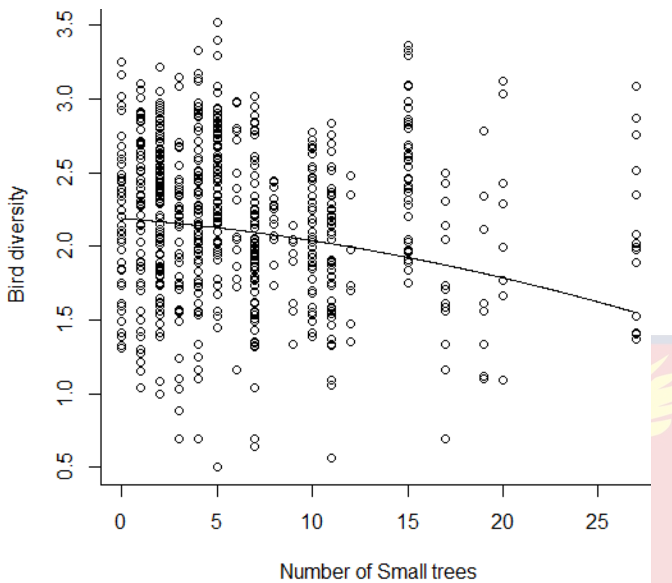

Figure 4: Relationship between number of small trees and bird diversity

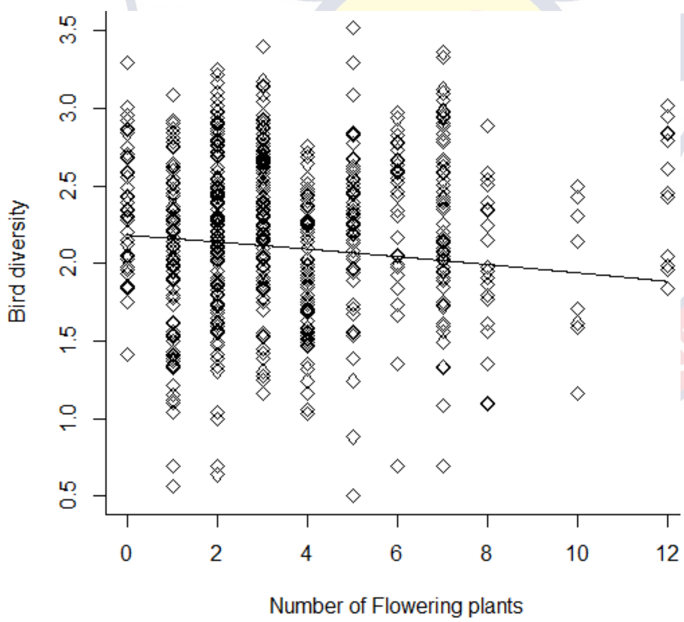

Figure 5: Relationship between number of flowering plants and bird diversity

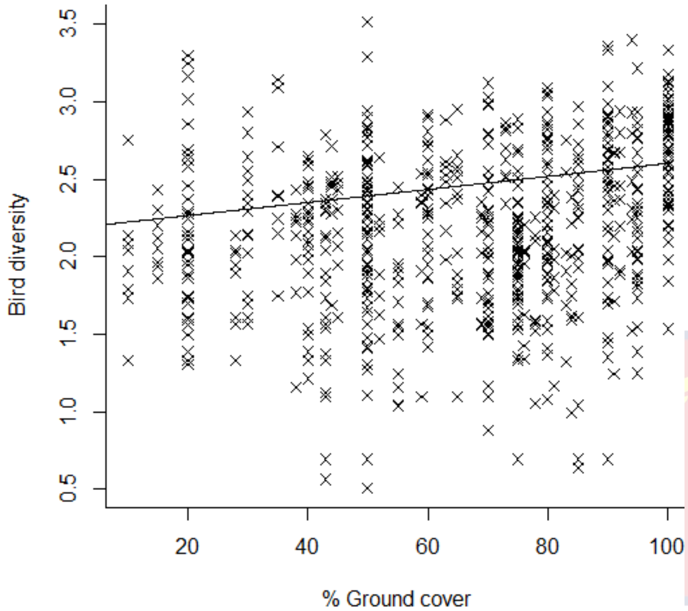

Figure 6: Relationship between percentage Ground cover and bird diversity

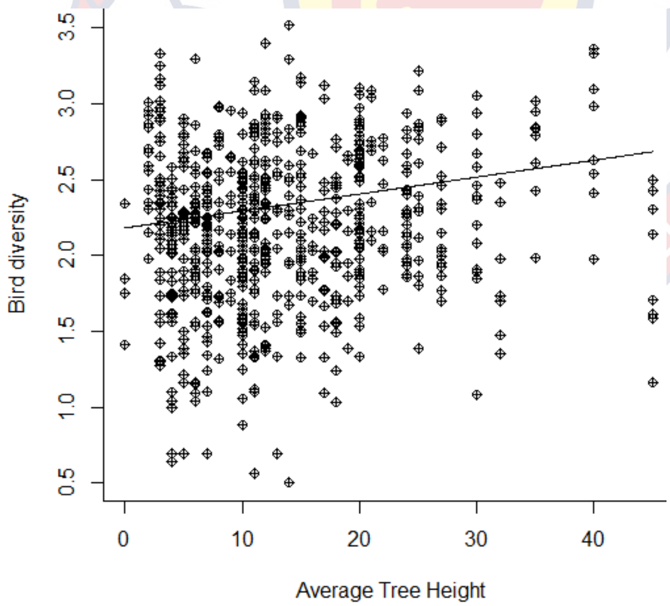

Figure 7: Relationship between average tree height and bird diversity

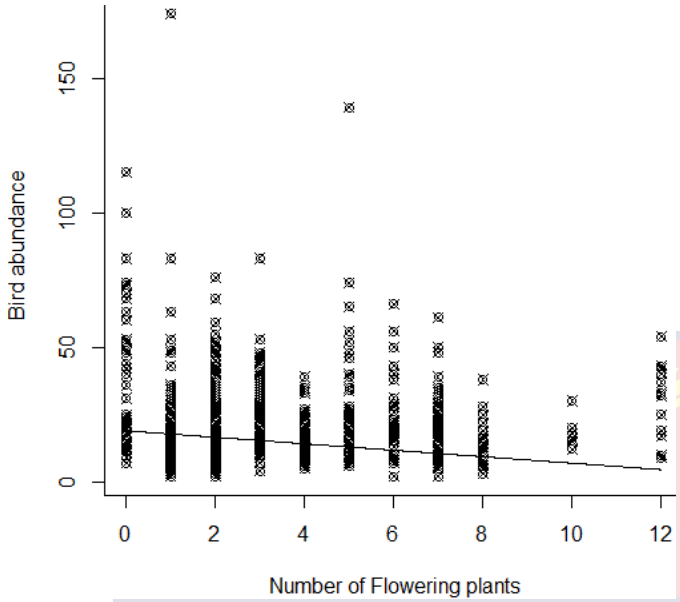

Figure 8 : Relationship between number of flowering plants and bird abundance

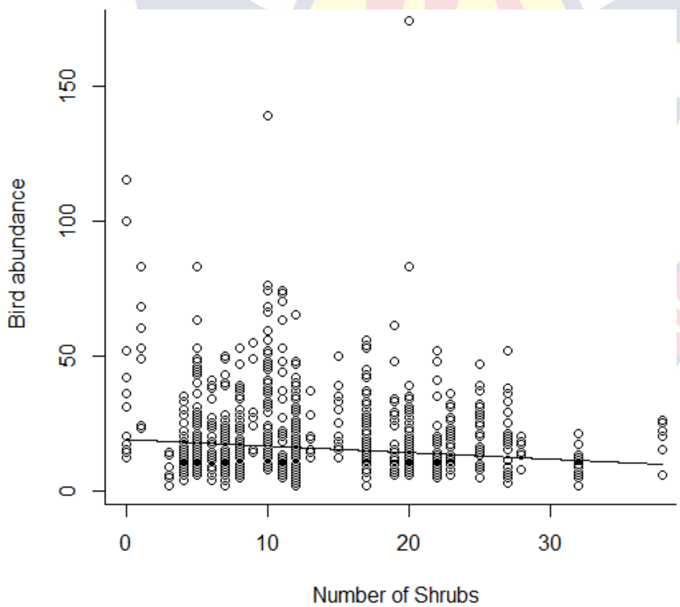

Figure 9: Relationship between number of shrubs and bird abundance

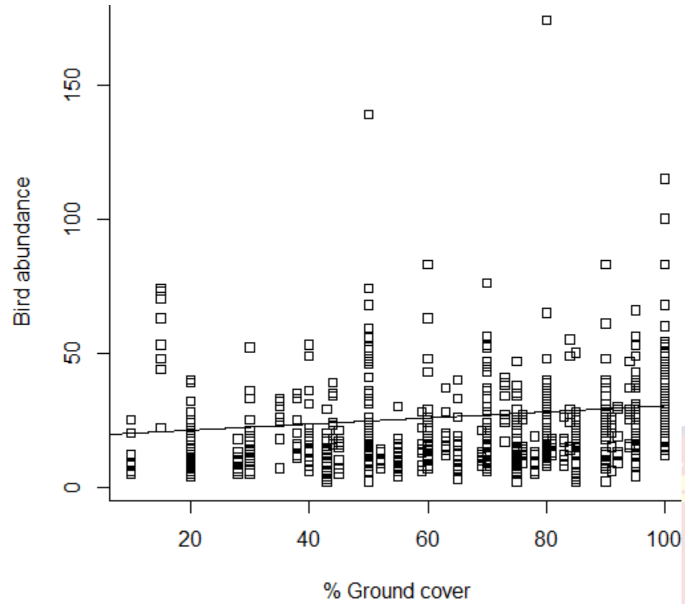

Figure 10 : Relationship between percentage ground cover and bird abundance

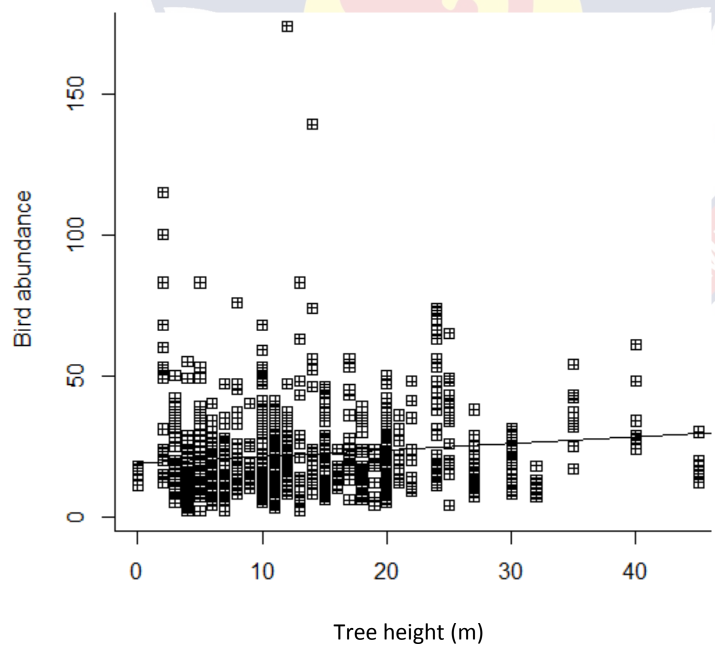

Figure 11 : Relationship between average tree height and bird abundance

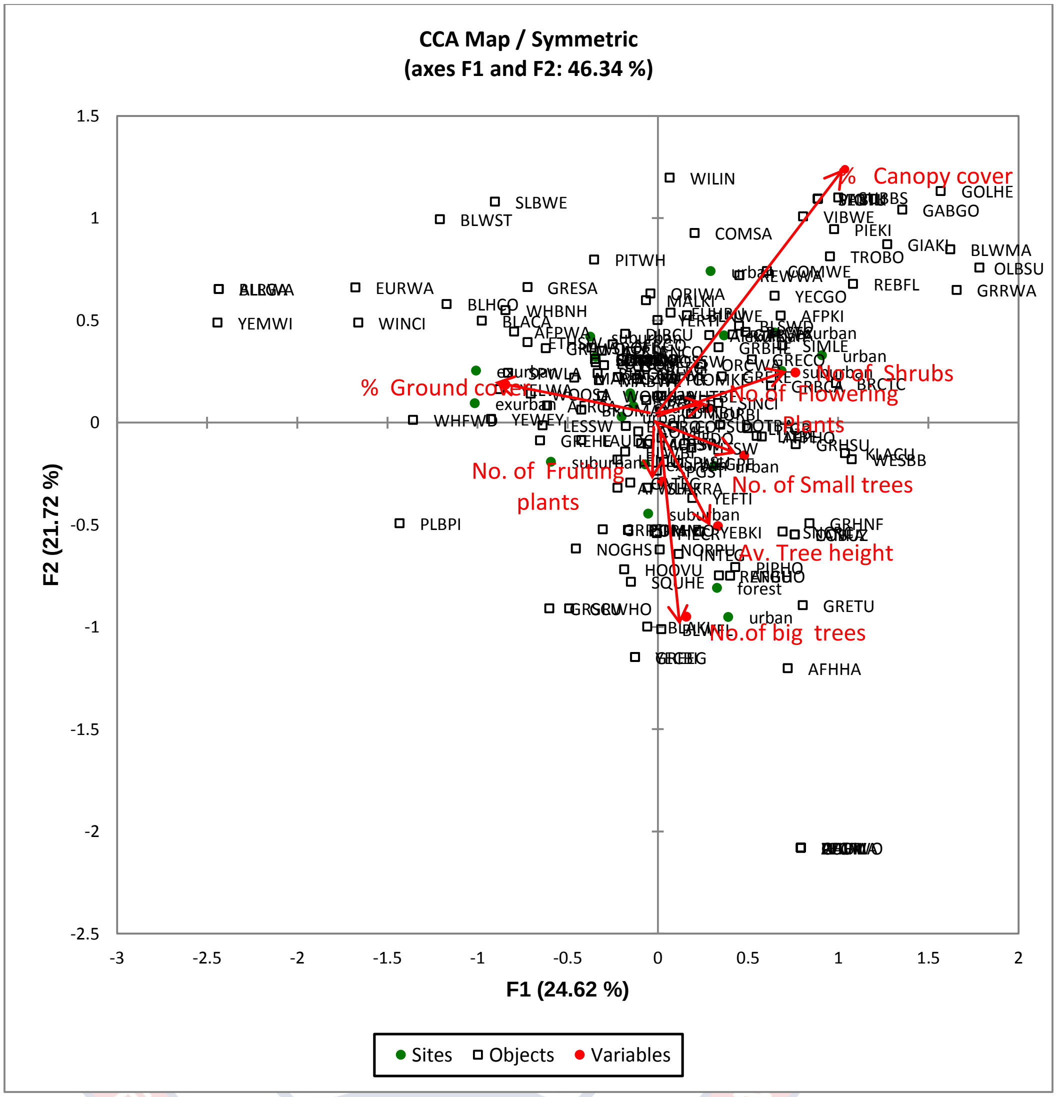

Figure 12: Non-Metric Multidimensional Scaling (Canonical Correspondence Analysis) of bird species versus vegetation variables measured across an urbanization gradient.

CHAPTER FIVE

DISCUSSION

There is a decrease in vegetation and an increase in human made structures along a gradient from the forest to the urban setting. Thus there is an urbanization gradient, which implies that environmental variability is spatially structured into a pattern that influences ecological processes and annual population dynamics of wildlife (Blair, 1996; Mcdonnell, Pickett, & Pouyat, 1993). The gradient concept in urban areas applies as well also to social, demographic, and physical characteristics (Marcus, 1972).

Species accumulation not reaching asymptote might be influenced by the behaviour of some bird species in the study areas. Thus time and design of the study had influence on the species accumulation. In particular, intra-African migrants were many prior to the survey (dry season) but later followed the rains back to Sudan and Guinea savannah during the survey (Elgood, Fry, & Dowsett, 1973; Nwaogu & Cresswell, 2015). Notably, the great spotted and Levaillant cuckoos were seen in high numbers in the dry season at the start of the survey and their numbers decreased as the rainy season progressed. Also, some resident species had high accumulation but decreased with time, but some of these e.g. were most at times around their nests or breeding sites as observed.

The disturbance created in exurban habitat was less than that of urban habitat but more than forest habitat. The exurban habitat accumulated high species which confirms the intermediate disturbance hypothesis that moderate disturbances create a mosaic of microhabitats which support more species than the extremes of the disturbances. Suburban which is next to exurban followed the same principles but due to less disturbances created by human settlement and activities accumulated, lower species than exurban habitat. The forest habitat had the lowest species accumulation which deviated from generality that the more diverse trees, there are more resources for birds, but due to the high structural complexity of the floral species, it became very difficult seeing birds in such a thick vegetation. This made detection function high (thus very difficult), which obscure the observer from identifying more birds compared to other habitat types. Also forest bird species are cryptic species which add up to having few species accumulated. In the urban habitat, low structural complexity of the tree species resulted in low detection function which resulted in seeing more birds which lead to highest bird species accumulated.

Variation in Vegetation Structure along the Gradient of Urbanization

The results highlighted the variation of vegetation structure across the study areas. A once continuous deciduous vegetation has been fragmented by varying degrees of anthropogenic activities over a long period of time, creating modified habitats of different vegetation structures. The forest habitat having less human influence maintained higher proportion of big trees, small trees, high canopy cover, few shrubs, a significant proportion of both fruiting and flowering plants which conform to the vertical structure of forest habitat. The opposite is the urban habitat, which human activities like building, road construction, farming and charcoal burning, have resulted in the loss of the majority of both big and small trees an increase medicinal plants and commercial tress like teak *Tectona grandis* through silviculture. The urban habitat still retains high proportion of shrubs, notably *Anogeissus leiocarpus*, which serve as raw material in charcoal production. Urban habitats have been known to have a higher number of ornamental plants resulting in high numbers of both fruiting and flowering plants. Due to moderate degree of human influence, exurban and suburban tend to have moderate proportion of the vegetation parameters (Menaa *et al.*; Ross *et al.*, 2001).

Variation in Bird Diversity and Abundance

In urban ecosystems, bird assemblages are affected by both the abundance and diversity of vegetation and by habitat heterogeneity (Lovett *et al.*, 2005). However, the highest richness is not always in the most natural habitats but often occurs in moderately perturbed ones (Marzluff, Bowman, & Donnelly, 2000). There are many studies that have found increasing species richness with increasing urbanisation at regional or global scales (Ewers & Didham, 2006). In this work, the same patterns were observed in which increasing urbanization resulted in increased species richness. As birds diversities and species' abundances were highest in more urbanised habitats. In the urban sites, wastes generated by humans served as the feeding sites for most birds, and human made structures as breeding sites and roosting sites. Birds prefer to use previous artificial breeding sites if it achieved over 85% reproductive success (Structure *et al.*, 2010). For example northern grey-headed sparrow, bronze mannikin and pied crow were seen using man-made structures as breeding sites over trees and might be because man-made structures in the urban settings increases their reproductive output compared to natural habitats. Some bird species like the vultures tend to cluster around the urban waste areas as they get more food resources than the natural habitats.

Distribution Status of Feeding Guilds along the Gradient of Urbanization

It was expected that diet requirements would undoubtedly play an important role in determining avian distribution across the urban gradient (Welsh & Lougheed, 1996), however, in this study the results of mean density and species richness of various feeding guilds didn't vary significantly across the habitat types.

The carnivores' guild was dominated by yellow-billed kite, which accounted for 80% of all carnivore abundance, with low species richness and without variations in mean density and abundance. The piscivores also had low species richness and were expected to show no variation across the habitat types. Though many studies (Beissinger and Osborne 1982) have reported increases in abundance of most omnivores with urbanization, in this study the omnivore guild accounted for approximately 26% of the total guild abundance but did not increase in species richness or abundance with urbanisation. It appeared that urbanisation favoured the frugivores, which recorded the highest abundance and species richness in the urban areas, because fruiting trees became more common as you move from the forest habitats to the urban areas and majority of the urban areas had backyards of fruiting trees. Insectivores were most abundant in suburban and urban habitats, where they likely benefitted from insects attracted to outdoor lights and safe nest sites provided by utility structures although the number of species did not change across the habitat types. Nectarivore guild was more abundant in the urban and suburban habitats than exurban and forest which were less developed. Ornamental flowers like *Hibiscus* spp, *Jasmium* spp and *Tropaeolum majus*) were popular in urban and suburban areas which attracted nectarivores as it the nectar in flowers is their food.

Relationship between Vegetation Structure and Bird Diversity, Richness and Abundance along the Gradient of Urbanization

Various species were seen to cluster around the centre of CCA plot showing the generality of resource acquisition. However some species show trends with respect to the vegetation variables. For example, Raptors and big birds like African harrier hawk (*Polyboroides typus*), black kite (*Milvus migrans*), and green turaco (*Tauraco persa*) were associated with big trees whereas yellow billed kite (*Milvus parasitus*), piping hornbill (Bycanistes fistulator) were seen on tall trees. Yellow fronted tinker (*Pogoniulus chrysoconus*), klass' cuckoo (*Chrysococcyx klaas*) were seen around small trees. The sunbirds utilised flowering plants. Warblers like European reed warbler (*Acrocephalus scirpaceus*), winding cisticola (*Cisticola marginatus*) and waders like the green sandpiper (*Tringa ochropus*) together with ducks found around areas of bare or muddy ground. The tchagras and kingfisher were seen utilising shrubs whiles the shrikes like tropical boubou (*Laniarius aethiopicus*), sulphur-breasted bush-shrike (*Chlorophoneus sulfureopectus*) and others were most at times found on top of the canopy. Thus there are multiple factors like physical features, ecological processes, seasonality and indirect processes which influenced how species utilised resources along the urbanisation gradient. E.g. the availability of food sources affect the movement and cost of searching for foods, this indirectly affect the predation rate of birds. Birds with good food acquisition skills will maximise this opportunity and have better body condition of birds. This better body condition will help males to get more breeding mates and will increase the number of clutches and therefore their survival. This will increase the overall reproduction rates

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Wild habitats will continue to be encroached as human population is on the edge of increasing exponentially. With this, wildlife needs to be in-cooperated into cities planning and areas of less human influence identified for wildlife conservation. Using aerial view of QGIS, 19 patches were located around University of Cape Coast and its environs which were grouped based on percentage of built structures within 500 meter radius as forest, exurban, suburban and urban habitats. Point count method was used to recorded birds for 7 minutes and the following vegetation parameters were measured: average tree height, number of large trees , number of small trees, number of shrubs, percentage canopy cover, percentage ground cover and numbers of flowering and fruiting plants. The results showed that avian diversity and abundance increased with urbanisation but the vegetation parameters did not; they were scattered almost spatially similar among the habitat types. Nectarivore and insectivore were most abundant in urban and suburban habitats, respectively. The result of the Indicator Species Analysis showed that birds utilised all the habitats without hindrances, but the results of the canonical correspondent analysis indicated that they were clustered around the vegetation parameters they utilised.

Conclusions

Knowledge of wildlife ecology in urban areas is extremely limited in Ghana but it is important in providing an understanding of how wildlife species respond to anthropogenic pressures and a potential opportunity to plan conservation issues within the Cape Coast metropolis. In this study, majority of the specific objectives tested supported the alternate hypotheses which are in consistent with other studies in demonstrating that;

- Avian diversity and abundance increased with urbanisation
- The varying degrees of human activities created a vegetation structure not distinct or unique to each habitat type.
- The total abundance of species that made up the various feeding guild differed across the habitat types. That is, nectarivore and insectivore increased along urbanization whereas the other feeding guilds abundance did not increased along urbanisation.
- As percentage ground cover and average tree height increases, bird diversity and abundance increases accordingly whereas decreasing number of shrubs, number of small trees and number of flowering plants caused a decline or reduction in bird diversity and abundance.
- Various species tend to utilise one or more components of the vegetation structure in each habitat type without constraints which is contrary to other studies

However, feeding guild density and richness did not change across the habitat types which supported the null hypotheses that there is no significant change in feeding guilds density and richness along urbanisation gradient

Recommendations

The urban habitat showed a surprisingly high abundance and high diversity because of more resources such as wastes to serve as feeding grounds and man-made structures to serve as breeding and roosting sites. However, it is not evident that the urban zone provides sufficient resources for all species that were abundant during the January – May censuses and did not serve as an ecological trap. Therefore breeding aspects of the most abundant species such as village weavers, pied crow, bronze manikin and northern grey-headed sparrow needs to be quantified by institutions like University of Cape Coast, Environmental Protection Agency (EPA) and Ghana Wildlife Society to determine if urban bird populations have adequate reproductive success for their own maintenance rather than being rescued by dispersal from populations with excess production of offspring from forest habitats. Although availability of nearby undeveloped habitats may be critical for maintaining avian abundance and species richness in urban areas, research is needed to substantiate this hypothesis.

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APPENDICES

Appendix A

Code name	Common name	Scientific name	family	feeding guild	exurban	forest	suburban	urban
AFGHO	African grey hornbill	Lophoceros nasutus	Bucerotidae	Granivore	27	64	12	14
AFGPI	African green pigeon	Treron calvus	Columbidae	Frugivore		7		
AFHHA	African harrier hawk	Polyboroides typus	Accipitridae	Carnivore	4	9	2	
AFMWA	African moustache warbler	Melocichla mentalis	Macrosphenidae	Insectivore			1	
AFPHO	African pied hornbill	Lophoceros semifasciatus	Bucerotidae	Frugivore	83	70	86	26
AFPKI	African pied Kingfisher	Ceryle rudis	Alcedinidae	Insectivore	28	6	27	18
AFPSW	African palm Swift	Cypsiurus parvus	Apodidae	Insectivore	16	9	22	16
AFPWA	African pied wagtail	Motacilla aguimp	Motacillidae	Insectivore	9	3	4	15
AFRCA	African crake	Crex egregia	Rallidae	Omnivore		2		
AFRGO	African Goshawk	Accipiter tachiro	Accipitridae	Carnivore	1	1	3	
AFRJA	African jacana	Actophilornis africanus)	Jacanidae	Insectivore	51	1	305	2
AFRTH	African thrush	Turdus pelios	Turdidae	Insectivore	118	42	81	42
AFWLA	African wattled lapwing	Vanellus senegallus	Charadriidae	Insectivore	28	7	45	
ALLGA	Allen's gallinule	Porphyrio alleni	Rallidae	Omnivore	1			
BABFF	Bar breasted firefinch	Lagonosticta rufopicta	Estrildidae	Granivore	101	26	73	31
BLACA	Black crake	Zapornia flavirostra)	Rallidae	Omnivore	21	4	38	
BLACO	Black coucal	Centropus grillii	Cuculidae	Insectivore	2	1		
BLAKI	Black kite	Milvus migrans	Accipitridae	Carnivore	1		14	
BLASP	Black sparrowhawk	Accipiter melanoleucus	Accipitridae	Carnivore		1		
BLCTC	Black crowned tchagra	Tchagra senegalus	Malaconotidae	Insectivore	28	10	15	7

BLHCO	Blue headed coucal	Centropus monachus	Cuculidae	Omnivore	3	1	4	1
BLNWE	Black-necked weacer	Ploceus nigricollis	Ploceidae	Granivore	88	20	61	27
BLRWA	Black rumped waxbill	Estrilda troglodytes	Estrildidae	Granivore	88	20	61	27
BLSWD	Blue spotted wood-dove	Turtur afer	Columbidae	Granivore	103	51	54	30
BLWBI	Black winged bishop	Euplectes hordeaceus	Ploceidae	Granivore	38	16	69	
BLWFL	Black and white flycatcher	Bias musicus	Vangidae	Insectivore	2	9	15	
BLWMA	Black and white mannikin	Spermestes bicolor	Estrildidae	Granivore	7		10	
BLWST	Black winged stilt	Himantopus himantopus	Recurvirostridae	Piscivore	1		4	
BRCTC	Brown crowned tchagra	Tchagra australis	Malaconotidae	Insectivore	20	10	2	2
BROMA	Bronze mannkin	Spermestes cucullata	Estrildidae	Granivore	423	409	436	120
BRORO	Broadbill roller	Eurystomus glaucurus	Coraciidae	Insectivore	4	31	13	16
CATEG	Cattle egret	Bubulcus ibis	Ardeidae	Insectivore	163	69	137	24
COBUZ	Common buzzard	Buteo buteo	Accipitridae	Carnivore				1
COMBU	Common bulbul	Pycnonotus barbatus	Pycnonotidae	Omnivore	299	287	290	149
COMFI	Common fiscal	Lanius collaris	Laniidae	Insectivore	30	15	26	2
COMKE	Common kestrel	Falco tinnunculus	Falconidae	Carnivore	2			1
COMMO	Common moorhen	Gallinula chloropus	Rallidae	Piscivore	1			
COMSA	Common sandpiper	Actitis hypoleucos	Scolopacidae	Insectivore	14	1	9	
COMSN	Common snipe	Gallinago gallinago	Scolopacidae	Insectivore		2		
COMSW	Common swift	Apus apus	Apodidae	Insectivore		4		
COMWE	Common wattle eye	Platysteira cyanea	Platysteiridae	Insectivore	69	14	43	24
COPSU	Copper sunbird	Cinnyris cupreus	Nectariniidae	Nectarivore	107	110	88	62
DIRCU	Diederik Cuckoo	Chrysococcyx caprius	Cuculidae	Insectivore	4	6	11	
DOTBA	Doubled-toothed barbet	Pogonornis bidentatus	Lybiidae	Frugivore	31	7	4	5
ETHSW	Ethiopian swallow	Hirundo aethiopica	Hirundinidae	Insectivore	51	49	100	20
EUHBU	European honey buzzard	Pernis apivorus	Accipitridae	Carnivore	2	1		
EURWA	European reed warbler	Acrocephalus scirpaceus	Acrocephalidae	Insectivore	1		1	
GABGO	Gabar goshawk	Micronisus gabar	Accipitridae	Carnivore	8	1		

GABWO	Gabon woodpecker	Dendropicos gabonensis	Picidae	Insectivore		1		
GARWA	Garden warbler	Sylvia borin	Sylviidae	Insectivore	5	1	1	
GIAKI	Giant kingfisher	Megaceryle maxima	Alcedinidae	Piscivore	1		1	
GOLHE	Goliath heron	Ardea goliath	Ardeidae	Piscivore	1			
GRBCA	Grey backed camaroptera	Camaroptera brachyura	Cisticolidae	Insectivore	171	99	74	78
GRBHE	Green backed heron	Butorides striata	Ardeidae	Piscivore	2	2	1	
GRECO	Green crombec	Sylvietta virens	Macrosphenidae	Insectivore	4	4	5	1
GREEG	Great egret	Ardea alba	Ardeidae	Piscivore			1	
GREHE	Grey heron	Ardea cinerea	Ardeidae	Piscivore	3		4	
GREKE	Grey kestrel	Falco ardosiaceus	Falconidae	Carnivore	5		2	
GRESA	Green sandpiper	Tringa ochropus	Scolopacidae	Piscivore	2	16	16	
GRETU	Green turaco	Tauraco persa	Musophagidae	Frugivore	16	28	3	1
GREWO	Grey woodpecker	Dendropicos goertae	Picidae	Insectivore		1	7	
GRHNF	Grey headed nigrita	Nigrita canicapillus	Estrildidae	Granivore	9	9		
GRHSU	Green headed sunbird	Cyanomitra verticalis	Nectariniidae	Nectarivore	7	10	5	3
GRPSN	Greater painted snipe	Rostratula benghalensis	Rostratulidae	Piscivore	8		1	
GRRWA	Great reed warbler	Acrocephalus arundinaceus	Acrocephalidae	Insectivore			1	
GRSCU	Great spotted cuckoo	Clamator glandarius	Cuculidae	Nectarivore			11	
GRWHO	Green wood-hoopoe	Phoeniculus purpureus	Phoeniculidae	Insectivore	2		5	1
HOOVU	Hooded vulture	Necrosyrtes monachus	Accipitridae	Carnivore	10	10	97	8
INTEG	Intermediate egret	Ardea intermedia	Ardeidae	Piscivore	9		16	
KLACU	Klass cuckoo	Chrysococcyx klaas	Cuculidae	Insectivore			1	1
LANFA	Lanner falcon	Falco biarmicus	Falconidae	Carnivore				11
LAUDO	Lauging dove	Spilopelia senegalensis	Columbinae	Omnivore	221	21	78	22
LECFL	Lead coloured flycatcher	Fraseria plumbea	Muscicapidae	Insectivore		9		
LEICU	Leivant cuckoo	Clamator levaillantii	Cuculidae	Insectivore	1		2	
LESSW	Lesser strpied swallow	Cecropis abyssinica	Passeriformes	Insectivore	3	11	15	3
LITBE	Little bee-eater	Merops pusillus	Meropidae	Insectivore	12	1	25	5

LITGR	Little greenbul	Eurillas virens	Pycnonotidae	Frugivore	86	20	35	5
LITSW	Little swift	Apus affinis	Apodidae	Insectivore	1	14	4	23
LIZBU	Lizzard buzzard	Kaupifalco monogrammicus	Accipitridae	Carnivore	1	7	1	1
LOTCO	Long tailed cormorant	Microcarbo africanus	Phalacrocoracidae	Piscivore	10	40	2	24
LOTGS	long tailed glossy starling	Lamprotornis caudatus	Sturnidae	Insectivore	1	6		
LOTNI	Long tailed nightjar	Caprimulgus climacurus	Caprimulgidae	Insectivore		2		
MALKI	Malachite kingfisher	Corythornis cristatus	Alcedinidae	Insectivore	2		8	
MARTC	Marsh tchagra	Bocagia minuta	Malaconotidae	Insectivore	6	3	5	1
MOSSW	Mosque swallow	Cecropis senegalensis	Hirundinidae	Insectivore	20	5	6	6
MOTSP	Mottled spinetail	Telacanthura ussheri	Apodidae	Insectivore	25	64	11	19
NOGHS	Northen grey headed sparrow	Passer griseus	Passeridae	Omnivore	38	11	145	7
NORBI	Northern red bishop	Euplectes franciscanus	Ploceidae	Granivore	87	27	60	3
NORPU	Northen puffback	Dryoscopus gambensis	Malaconotidae	Omnivore	56	72	24	9
OLBSU	Olive bellied sunbird	Cinnyris chloropygius	Nectariniidae	Nectarivore	1		5	2
ORCWA	Orange cheeked waxbill	Estrilda melpoda	Estrildidae	Granivore	5	9	16	
ORIWA	Oriole warbler	Hypergerus atriceps	Cisticolidae	Insectivore	26	11	18	2
PABIL	Pale breasted illadopsis	lladopsis rufipennis	Pellorneidae	Insectivore	2			
PIECR	Pied crow	Corvus albus	Corvidae	Omnivore	152	289	124	133
PIEKI	Pied kingfisher	Ceryle rudis	Alcedinidae	Piscivore	8	1	2	
PIPHO	Piping hornbill	Bycanistes fistulator	Bucerotidae	Frugivore	20	43	14	13
PIAPI	Piapiac	Ptilostomus afer	Corvidae	Omnivore	1			
PITWH	Pin tailed whydah	Vidua macroura	Viduidae	Granivore	22		1	
PLBPI	Plain backed pipit	Anthus leucophrys	Motacillidae	Insectivore			2	
PURHE	Purple heron	Ardea purpurea	Ardeidae	Piscivore	1			
PUVIL	Puvel's illadoposis	Illadopsis puveli	Pellorneidae	Insectivore		20		
REBFL	Red bellied Paradise flycatcher	Terpsiphone rufiventer	Monarchidae	Insectivore	19	6	21	8
REEDO	Red eyed dove	Streptopelia semitorquata	Columbidae	Granivore	126	176	117	26
REFCI	Red faced citicola	Cisticola erythrops	Cisticolidae	Insectivore	46	44	61	17

RENBU	Red necked buzzard	Buteo auguralis	Accipitridae	Carnivore			4	1
REWWA	Red winged warbler	Prinia erythroptera	Cisticolidae	Insectivore	11	4		
SENCO	Senegal coucal	Centropus senegalensis	Cuculidae	Insectivore	94	37	48	16
SENPA	Senegal parrot	Poicephalus senegalus	Psittacidae	Frugivore		1		
SENTK	Senegal thick-knee	Burhinus senegalensis	Burhinidae	Insectivore	1			
SHIKRA	Shikra	Accipiter badius	Accipitridae	Carnivore	11	17	5	7
SIMLE	Simple leaflove	Chlorocichla simplex	Pycnonotidae	Frugivore	19	27	16	9
SINCI	Singing cisticola	Cisticola cantans	Cisticolidae	Insectivore	15		14	1
SLBWE	Slender billed weaver	Ploceus pelzelni	Ploceidae	Granivore			5	
SNCRC	Snowy crowned robin-chat	Snowy-crowned Robin-chat	Muscicapidae	Insectivore	20	24	11	1
SPGST	Splendid glossy starling	Lamprotornis splendidus	Sturnidae	Insectivore	76	128	123	53
SPLSU	Splendid sunbird	Cinnyris coccinigastrus	Nectariniidae	Nectarivore	52	101	49	30
SPOFL	Spotted flycatcher	Muscicapa striata	Muscicapidae	Insectivore				1
SPWLA	Spurred winged lapwing	Vanellus spinosus	Charadriidae	Insectivore	44	5	24	2
SQUHE	Squacco heron	Ardeola ralloides	Ardeidae	Piscivore			23	
SUBBS	Sulfur breasted bush-shrike	Chlorophoneus sulfureopectus	Malaconotidae	Insectivore	5			
TAFPR	Tawny flanked prinia	Prinia subflava	Cisticolidae	Insectivore	47	10	82	24
TROBO	Tropical boubou	Laniarius aethiopicus	Malaconotidae	Insectivore	18		1	3
VIBWE	Viellot's black weaver	Ploceus nigerrimus	Ploceidae	Granivore	99		1	1
VILWE	Village weaver	Ploceus cucullatus	Ploceidae	Granivore	368	247	377	42
VIOTU	Violet turaco	Musophaga violacea	Musophagidae	Frugivore	4			
WEGPE	Western grey plantain eater	Crinifer piscator	Musophagidae	Frugivore	164	170	94	77
WESBB	Western bluebill	Spermophaga haematina	Estrildidae	Granivore	19	20	4	9
WHBNH	White backed night heron	Calherodius leuconotus	Ardeidae	Piscivore	1		6	
WHFWD	White faced whistling duck	Dendrocygna viduata	Anatidae	Piscivore	61		26	
WHICI	Whistling cisticola	Cisticola lateralis	Cisticolidae	Insectivore	2			
WHTBE	White throated beeeater	Merops albicollis	Meropidae	Insectivore	119	80	130	17
WILIN	Wilson's indigobird	Vidua wilsoni	Viduidae	Granivore	6		4	4

WILWA	Willow warbler	Phylloscopus trochilus	Phylloscopidae	Insectivore		1		
WINCI	Winding cisticola	Cisticola marginatus	Cisticolidae	Insectivore	36		25	
WOOKI	Woodland kingfisher	Halcyon senegalensis	Alcedinidae	Insectivore	31	33	64	9
WOOSA	Wood sandpiper	Tringa glareola	Scolopacidae	Insectivore	33		51	1
YEBKI	Yellow billed kite	Milvus migrans	Accipitridae	Carnivore	254	338	361	81
YECBI	Yellow crowned bishop	Euplectes afer	Ploceidae	Granivore			12	
YECGO	Yellow crowned gonolek	Laniarius barbarus	Malaconotidae	Insectivore	191	52	57	13
YEFTI	Yellow fronted tinkerbird	Pogoniulus chrysoconus	Lybiidae	Frugivore	15	12	9	2
YELWA	Western Yellow wagtail	Motacilla flava	Motacillidae	Insectivore	27		100	6
YEMWI	Yellow mantled widowbird	Euplectes macroura	Ploceidae	Insectivore	5			
YERTI	Yellow rumped tinkerbird	Pogoniulus bilineatus	Lybiidae	Frugivore	2	1	1	
YEWEY	African Yellow white-eye	Zosterops senegalensis	Zosteropidae	Insectivore	2	5	8	1

Appendix B

I. *Results of a linear mixed model determining the relationship between bird diversity and vegetation parameters. Full model estimates are presented along with the best model.*

Full model				Best model		
Bird Diversity						
Random effect:						
Group	Variance	Std.Dev.		Variance	Std.Dev.	
Protection status	0.484	0.138		0.483	0.139	
Fixed effects:						
	Estimate	Std.E	*P*	Estimate	Std.E	*P*
(Intercept)	1.860	0.103	0.000	2.188	0.092	0.000
No. of Flowering Plants	-0.021	0.008	0.018	-0.021	0.008	0.012
No. of Big trees	-0.005	0.006	0.393			
No. of Small trees	-0.011	0.004	0.007	-0.010	0.004	0.008
No. of Shrubs	-0.000	0.002	0.973			
% Ground cover	0.004	0.000	0.000	0.004	0.000	0.000
% Canopy cover	0.004	0.000	0.409			
Av. Tree height	0.012	0.000	0.000	0.011	0.002	0.000

II. *Results of a non-linear mixed model determining the relationship between bird abundance and vegetation parameters. Full model estimates are presented along with the best model.*

Full model				Best model		
Bird Abundance						
Random effect:						
Group	Variance	Std.Dev.		Variance	Std.Dev.	
Protection status	15.277	5.009		15.277	5.431	
Fixed effects:						
	Estimate	Std.E	*P*	Estimate	Std.E	*P*

(Intercept)	20.347	3.486	0.000	18.939	3.397	0.000
No. of Flowering Plants	-1.099	0.280	0.000	-1.202	0.272	0.000
No. of Big trees	-0.170	0.191	0.373			
No. of Small trees	-0.021	0.130	0.874			
No. of Shrubs	-0.239	0.079	0.003	-0.242	0.077	0.002
% Ground cover	0.102	0.0271	0.000	0.114	0.026	0.000
% Canopy cover	-0.040	0.031	0.200			
Av. Tree height	0.359	0.106	0.000	0.235	0.072	0.001

Appendix C

Results showing Indicator value for each species

Species code	group	indval	P-value	freq
ALLGA	1	1	1	1
BLRWA	1	1	1	1
COMMO	1	1	1	1
GOLHE	1	1	1	1
MABWE	1	1	1	1
PABIL	1	1	1	1
PIPIA	1	1	1	1
PURHE	1	1	1	1
SENTK	1	1	1	1
SUBBS	1	1	1	1
VIOTU	1	1	1	1
WHICI	1	1	1	1
YEMWI	1	1	1	1
VIBWE	1	0.980198	1	3
PITWH	1	0.956522	1	2
GABGO	1	0.888889	1	2
GRPSN	1	0.888889	1	2
TROBO	1	0.818182	1	3
REWWA	1	0.733333	1	2
PIEKI	1	0.727273	1	3
GARWA	1	0.714286	1	3
GREKE	1	0.714286	1	2
WHFWD	1	0.701149	1	2
BLACO	1	0.666667	1	2
COMKE	1	0.666667	1	2
EUHBU	1	0.666667	1	2

DOTBA	1	0.659574	1	4
LAUDO	1	0.646199	1	4
YECGO	1	0.610224	1	4
WINCI	1	0.590164	1	2
BRCTC	1	0.588235	1	4
SPWLA	1	0.586667	1	4
COMSA	1	0.583333	1	3
LITGR	1	0.572414	1	4
MOSSW	1	0.540541	1	4
EURWA	1	0.5	1	2
GIAKI	1	0.5	1	2
GRHNF	1	0.5	1	2
SINCI	1	0.5	1	3
YERTI	1	0.5	1	3
NORBI	1	0.491525	1	4
SENCO	1	0.482051	1	4
BLCTC	1	0.466667	1	4
ORIWA	1	0.45614	1	4
BLNWE	1	0.44898	1	4
COMWE	1	0.442308	1	4
BABFF	1	0.437229	1	4
BLSWD	1	0.432773	1	4
WILIN	1	0.428571	1	3
AFRTH	1	0.419014	1	4
CATEG	1	0.414758	1	4
COMFI	1	0.410959	1	4
GRBCA	1	0.405213	1	4
GRBHE	1	0.4	1	3
MARTC	1	0.4	1	4

YEFTI	1	0.394737	1	4
AFPKI	1	0.35443	1	4
COMBU	1	0.293774	1	4
BLASP	2	1	1	1
COMSN	2	1	1	1
COMSW	2	1	1	1
GABWO	2	1	1	1
GAWOO	2	1	1	1
LECFL	2	1	1	1
LOTNI	2	1	1	1
PUVIL	2	1	1	1
SENPA	2	1	1	1
WILWA	2	1	1	1
LOTGS	2	0.857143	1	2
LIZBU	2	0.7	1	4
AFHHA	2	0.6	1	3
GRETU	2	0.583333	1	4
MOTSP	2	0.537815	1	4
LOTCO	2	0.526316	1	4
AFRCA	2	0.5	1	3
BRORO	2	0.476923	1	4
PIPHO	2	0.472527	1	4
GRESA	2	0.470588	1	3
NORPU	2	0.447205	1	4
SPLSU	2	0.435345	1	4
SNCRC	2	0.428571	1	4
SHIKRA	2	0.425	1	4
PIECR	2	0.41404	1	4
AFPWA	2	0.40625	1	4

GRHSU	2	0.4	1	4
REEDO	2	0.395506	1	4
WESBB	2	0.384615	1	4
SIMLE	2	0.380282	1	4
WEGPE	2	0.344828	1	4
SPGST	2	0.340426	1	4
COPSU	2	0.299728	1	4
GREEG	3	1	1	1
GRRWA	3	1	1	1
GRSCU	3	1	1	1
PLBPI	3	1	1	1
SLBWE	3	1	1	1
SQUHE	3	1	1	1
YECBI	3	1	1	1
BLAKI	3	0.933333	1	2
GREWO	3	0.875	1	2
WHBNH	3	0.857143	1	2
AFRJA	3	0.849582	1	4
BLWST	3	0.8	1	2
MALKI	3	0.8	1	2
RENBU	3	0.8	1	2
HOOVU	3	0.776	1	4
YELWA	3	0.75188	1	3
NOGHS	3	0.721393	1	4
LEICU	3	0.666667	1	2
INTEG	3	0.64	1	2
GRWHO	3	0.625	1	3
OLBSU	3	0.625	1	3
AFRGO	3	0.6	1	3

WOOSA	3	0.6	1	3
BLWMA	3	0.588235	1	2
LITBE	3	0.581395	1	4
BLWFL	3	0.576923	1	3
GREHE	3	0.571429	1	2
BLACA	3	0.567164	1	3
BLWBI	3	0.560976	1	3
AFWLA	3	0.555556	1	3
ORCWA	3	0.533333	1	3
DIRCU	3	0.52381	1	3
TAFPR	3	0.503067	1	4
KLACU	3	0.5	1	2
YEWEY	3	0.5	1	4
LESSW	3	0.46875	1	4
WOOKI	3	0.467153	1	4
ETHSW	3	0.454545	1	4
BLHCO	3	0.444444	1	4
REBFL	3	0.392857	1	4
WHTBE	3	0.375723	1	4
VILWE	3	0.364603	1	4
REFCI	3	0.363095	1	4
GRECO	3	0.357143	1	4
AFPSW	3	0.349206	1	4
YEBKI	3	0.34913	1	4
AFPHO	3	0.322097	1	4
BROMA	3	0.312994	1	4
COBUZ	4	1	1	1
LANFA	4	1	1	1
SPOFL	4	1	1	1

LITSW	4	0.547619	1	4