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Investigating The Impact of Land Use on Avian Diversity and Abundance in Areas Surrounding Mabamba Swamp, Uganda

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SIT Study Abroad

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Abstract

The primary objective of this study was to investigate the impact of wetland-adjacent land use on avian species richness and abundance areas surrounding Mabamba Swamp, Uganda. Four types of land use were investigated: *Eucalyptus* plantations, wetland-edge agricultural fields, residential areas, and mature secondary forests. A total of 40-morning point counts were conducted for ten days in late November and late December of 2021. One-way ANOVA tests and Tukey's HSD tests revealed significant differences in mean avian richness and abundance between all sites except residential areas and Nkima Forest. Additionally, Nkima Forest was found to contain the most number of specialist species. Findings indicate that habitat complexity is an important driver of avian richness and that *Eucalyptus* plantations and monoculture agricultural fields significantly limit local avian biodiversity. Findings have the potential to inform the conservation and regulation of wetland-adjacent resource use.

Keywords: *birds, diversity, agriculture, wetlands*

1.0 Introduction

1.1 Background

Despite covering only 7% of the earth's surface, 40% of all plants and animals live or breed in wetlands (Mumba, 2020). Wetlands encompass all areas that are saturated with water permanently or seasonally, from saltwater marshes and rice paddies to coral reefs and rivers. In addition to supporting remarkable biodiversity, wetlands play an essential role in combatting global climate change through the absorption of carbon dioxide and storage of phosphorus and nitrogen (USEPA, n.d.). These biologically rich habitats are disappearing almost three times faster than forests worldwide, threatening the wildlife and communities that rely on their persistence (Akwetaireho and Getzner, 2010).

In Uganda, wetlands cover 11% of the country's area and provide essential socio-economic and biological benefits—from sustaining hunting and fishing livelihoods to harboring vulnerable wildlife populations (Aryamanya-Mugisha, 2011). One of nine watershed management areas in the country, Mabamba Wetland is located southwest of Entebbe on the shores of Lake Victoria (MBWETA, 2014). The 17,000-ha swamp is recognized under the 2014 RAMSAR convention as an Important Bird Biodiversity Area (IBA) and a Wetland of International Importance, due to its "special value for maintaining the genetic and ecological diversity" of the region (Timoshenko, 1988). The swamp is home to over 300 bird species and is a refuge for many migratory and globally threatened species: it hosts 38% of the global population of Blue Swallow (*Hirundo atocerulea*), as well as populations of Papyrus Gonolek (*Laniarius mufumbri*), Papyrus Yellow Warbler (*Chloropeta grcilirostris*), and approximately 150 pairs of the elusive Shoebill Stork (*Balaeniceps rex*) (MBWETA, 2014).

Despite its significance as a biodiversity hotspot, Mabamba Wetland is not legally protected. As per the 1994 Constitution of Uganda and the 1997 Local Government Act, wetlands are held in trust for the people and are managed by local governments (Uganda Const., 1984; The Local Governments Act, 1997). Mabamba is therefore under the authority of the Wakiso District Local Government (Ziba subcounty). Though written legislation exists, regulations are not well-known to local communities (MBWETA, 2014).

The lack of communication between district administrators and local communities, coupled with unregulated sand mining, dependence on wetland resources, and poor agricultural practices, have led to the accelerated degradation of Mabamba in the past few decades (MBWETA, 2014). The catchment now exhibits noticeable signs of anthropogenic damage, as the slope separating the wetland from Nkima Forest is partially deforested and heavily affected by soil erosion. Additionally, fish populations are depleted, agricultural fields continue to encroach into the wetland edge, and *Eucalyptus* plantations continue to increase (Zake, 2014).

To effectively preserve this biologically rich area, it is necessary to understand the impact of anthropogenic development on avian community composition and behavior. This study, therefore, will investigate the impact of *Eucalyptus* plantations, agricultural fields, residential areas, and secondary forest on avian abundance and diversity in the areas surrounding Mabamba Swamp, with hopes of understanding how continued landscape encroachment may influence vulnerable populations of wetland-associated birds.

1.2 Problem Statement

Unregulated use of the Mabamba Swamp has led to habitat degradation, accelerating in the past few decades due to rapid population increase. Land-use change and agricultural intensification are among the most imminent threats to the wildlife that rely on the swamp for shelter and food (MBWETA, 2014). In addition to uncontrolled wetland-edge subsistence farming, flower farms are beginning to take root on the shores of Lake Victoria. Effective wetland management requires understanding how these anthropogenic disturbances influence the structure of Uganda’s wildlife communities (MBWETA, 2014).

With their role in disease regulation, seed dispersal, and biomass recycling, birds are a critical component of ecosystem health and stability (Gatesire et al. 2014) and are frequently used as bioindicators (Egwumah et al., 2017). Previous studies have explored long-term population trends in wetland-associated avian communities in the Mediterranean, Spain, and Turkey. (Liordos et al., 2014; Martinex-Abrain et al., 2016; Keten et al., 2020). Within Uganda, studies have cataloged resident and migratory birds that inhabit a variety of wetlands, including Mabamba (Egane, 2021; Byaruhanga and Kigoolo, 2005). No previous research, however, has integrated the impact of changing land use on bird diversity in and around Mabamba Swamp. Therefore, the purpose of this study is to assess how *Eucalyptus* plantations, agricultural fields, residential areas, and secondary forests near Mabamba Bay Wetland influence avian diversity and richness. Findings have the potential to inform management that effectively balances human well-being and wildlife persistence.

1.3 Objectives

The primary objective of this study is to investigate the impact of land use surrounding Mabamba Swamp on avian abundance and avian species richness. Specific objectives are to:

i. Measure the species richness, evenness, and abundance of birds in four different land-use areas (*Eucalyptus* plantations, agricultural fields, residential areas, and mature secondary forest)

ii. Assess the impact of land use type on avian richness, evenness, and abundance

1.4 Hypothesis

Land use may significantly influence the composition of avian communities due to the impacts of vegetation cover and monoculture agriculture. If areas with higher vegetation cover support greater richness, Nkima forest will exhibit the greatest avian diversity and abundance, followed by agricultural fields. Timber plantations and residential areas will contain the lowest species abundance and diversity. Additionally, lower abundance and diversity in monoculture plantations may suggest that more diverse croplands harbor more birds than monoculture enterprises.

1.5 Significance & Justification

Following the global trend, Uganda's wetlands are in rapid decline. According to the Ministry of Water and Environment, the natural area of wetlands declined by 30% between 1994 and 2008, largely due to agricultural and industrial intensification (Turyahabwe et al., 2013A). Unsustainable resource exploitation is rooted in explosive population growth, as 80% of people living adjacent to wetlands depend on wetland resources for food security needs (Turyahabwe et al., 2013B).

Conservation is a delicate balance between managing human needs and protecting biological resources. As populations increase and the conditions of IBAs continue to decline, it is critical that we understand how human land use is altering the structure of wildlife communities (Odull and Byaruhanga, 2009). Mabamba Swamp is a prime location for research at the intersection of human livelihoods and ecological well-being: while recent agricultural encroachment is well-documented, the ecological consequences of this land-use change are unknown. This study would be the first in Mabamba Swamp to uncover relationships between land use and avian assemblages, which is a critical first step in preserving the area's rich biodiversity.

1.6 Scope of the Study

This study was conducted for 10 days and will only involve the northeastern shore of Mabamba Wetland, just south of the village of Ziba. The study area is constrained by approximately the following coordinates: 32˚36' - 32˚34' E and 00˚080' - 00˚088' N. Due to temporal constraints, the study did not assess long-term changes in avian communities. Instead, the study focused on current differences between avian assemblages in different land-use areas.

2.0 Literature Review

2.1 Avian Habitat and Global Wetland Decline

Ecological degradation due to wetland loss is a global issue. Bolca et al. (2014) investigated long-term changes in land use and wetland habitat availability in Turkey. From 1963-to 2010, researchers found an 84% increase in urban and industrial settlements, which was associated with a 37.65% decrease in avian habitat (Bolca et al., 2014). Similar relationships between agricultural and industrial intensification and avian decline have been noted in wetland habitats in Argentina, China, and the United States (Sica et al., 2018; Wang and Yang, 2021; Ward et al., 2010). More specifically related to differences in land use, numerous papers have found urban, suburban, and rural wetland habitats to contain significantly different avian assemblages, with richness generally peaking in rural landscapes (Mao et al., 2019; Andrade et al., 2017; Luo et al. 2019).

2.2 Wetland Modification and Avian Assemblages in East Africa

In the past decade, a collection of studies has assessed the impact of wetland modification on waterbird assemblages in East Africa. For example, in Uganda, many studies have investigated the effect of rice schemes and other forms of flooded agriculture on waterbird diversity and abundance. A study by Nachuha and Quinn (2012) found an insignificant relationship between proximity to the Doho rice scheme and the size of waterbird colonies. (Nachuha and Quinn, 2012). These findings are contrary to relationships found in other regions, like the Mediterranean (Hafner and Fasola, 1992; Parejo and Sanchez-Guzman, 1999). On the other hand, Sarah et. al (2020) found species richness to be greater in rice paddies than in wetlands and swamps (Sarah et al., 2020), indicating a positive relationship between artificial wetlands and avian richness.

2.3 Wetland-Adjacent Land Use and Avian Assemblages

There appears to be a significant difference, however, in the impact of wetland-interior agriculture—like rice paddies—and wetland-adjacent land use. A handful of other studies have explored the impact of this kind of land use on East African waterbird communities, often finding that disturbance negatively impacts avian communities. Egane (2020) found less modified habitats and garden patches to harbor greater richness than more modified habitats in and around Lubigi Wetland in Uganda. In a similar study, Soka et al. (2013) found that terrestrial environments around Hombolo Wetland in Tanzania contributed more to total species richness than aquatic habitats, potentially due to flooding of the wetland. In addition, they found anthropogenic disturbance—through settlement expansion, agriculture, and livestock grazing, to be the main threats to long-term avian survival (Soka et al. 2013).

2.4 Impact of Silviculture and Agriculture on Avian Diversity

Outside of wetland habitats, agricultural disturbance and timber plantations have been shown to limit avian diversity. In Tanzania, John and Kabigumila (2007) found that breeding bird communities have failed to adapt to *Eucalyptus* plantations (John & Kabigumila, 2007). This negative relationship between *Eucalyptus* silviculture and avian diversity is supported by findings from studies in China (Liao et al., 2020), Spain (Goded et al., 2019), and Argentina (Phifer et al., 2017). Findings appear more varied for plantations with other tree species: in a global synthesis of the effect of agroforestry on biodiversity, Bohada-Murillo et al. coffee, and cacao plantations had no significant effect on avian diversity. These findings are supported by a study on closed-canopy fruit plantations in Madagascar (Evans et al. 2020).

Similarly, monoculture agriculture has been found to limit avian diversity. A study conducted in Kenya found that crop diversity had significant positive effects on avian richness (Ndang'ang'a et al., 2013), a relationship that was supported by a study on farmland birds in central Chile (Munoz-Saez et al., 2017).

Although anthropogenic disturbance is known to threaten bird survival, human settlements and wetland-adjacent agriculture provide essential habitat for some disturbance-dependent species, such as the Common Bulbul, Bronze Mannikin, and Red-cheeked Cordonbleu (Gatesire et al. 2014). Additionally, while plantations and agricultural areas have persistently been shown to harbor fewer birds than near-natural areas, these disturbed habitats contain unique assemblages of granivorous and omnivorous bird species (Mulwa et al., 2021; Evans et al., 2020; Munoz-Saez et al., 2017).

3.0 Methodology

3.1 Mabamba Wetland

Mabamba Bay Wetland is a 17,000-hectare marsh an hour west of Entebbe in southwestern Uganda and is designated as a Ramsar Wetland of International Importance (MBWETA, 2014). Located on the northern shores of Lake Victoria, the swamp is dominated by papyrus (*Cyperus papyrus*) and silver grass (*Miscanthus sp.*) with some areas of the sedge *Cladium* interspersed (BirdLife International, 2014). There is an open-water channel that cuts through the vegetation, dotted with patches of water-Lillies (*Nymphaea*). The Bay forms part of the Waiya Bay, which is located southwest of Nakiwogo Bay (MBWEA, 2021). The Ramsar Site and catchment also contain a 337-ha forest reserve—Kalangalo Forest Reserve— which provides invaluable biological and economic resources for the local community, from the regulation of the microclimate to the provision of firewood. Approximately 21,000 people live in or around the wetland (Zake, 2014). Climactically, Mabamba receives an average annual rainfall of 1200-1500mm with an average minimum temperature of 17˚C and an average maximum temperature of 26˚C (Byaruhanga and Kigoolo, 2005). The geographical coordinates of the swamp are approximately 32˚14' - 32˚27' E and 00˚02' - 00˚12' N. A map of the study area is shown in Figure 1.

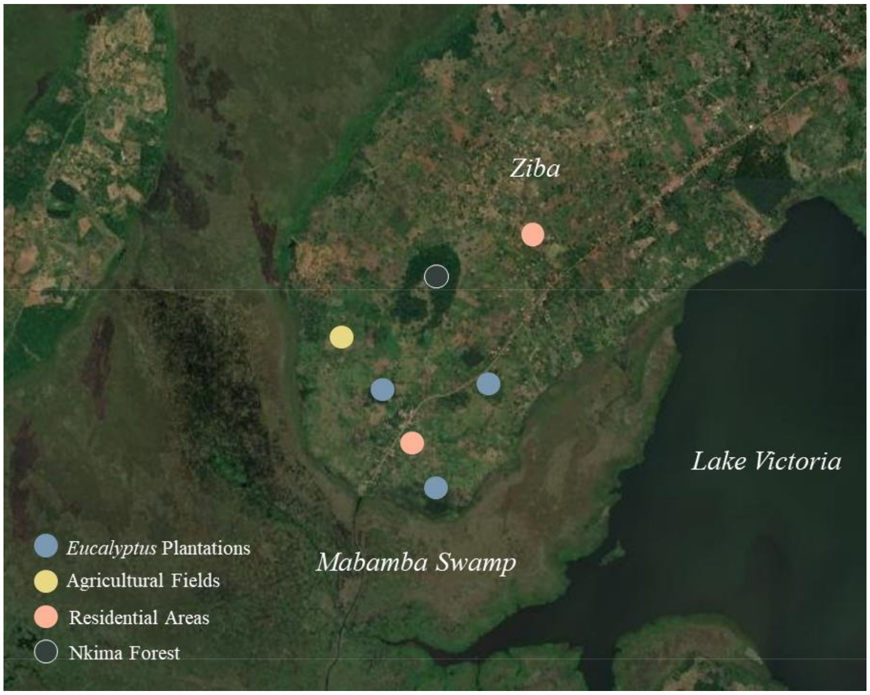

Figure 1 Map of the study area, Mabamba Swamp, with individual study sites indicated

3.2 Study Sites: Wetland-Adjacent Land Use

Eucalyptus Timber Plantations

There are six different landings for entry into Mabamba Swamp; one is located just southeast of the town of Ziba at the northeastern corner of the swamp and is a popular tourist destination for Shoebill trekking.

There are many *Eucalyptus* plantations scattered near this landing and in the village of Ziba. One of the largest plantations is located just south of the landing, along a trail that hugs the wetland edge. The trail is a small barrier between standing water and plantation: the two areas are separated by about 20 meters. Other plantations are located to the north of landing; all *Eucalyptus* stands are monocultural enterprises with limited to no understory growth. The geographic coordinates of two wetland-edge eucalyptus plantations are approximately 32˚35' E, 00˚07' N and 32˚35' E, 00˚08' N

Agricultural Fields

To the north of this landing, another trail winds through agricultural fields and smallholder farms, where maize, papayas, watermelons, tomatoes, beans, among other crops, grow. Crop fields are owned by separate families and mostly contain a single crop within each plot of land. The trail hugs the edge of the wetland, staying within approximately 200m of standing water. Located close to one of the *Eucalyptus* plantations, the geographic coordinates of the agricultural fields are approximately 32˚35' E, 00˚08' N.

Nkima Forest

Nkima forest is located about 2 km from the edge of the swamp and a 20-minute walk from the main landing. The semi-evergreen Guineo-Congolian forest rests on a 30-acre patch of land on Nansubuga Hill, preserved from deforestation by the construction of an eco-lodge. Though most of the larger trees were logged in the late nineteenth century, the forest is now a mature secondary forest. The geographic coordinates of Nkima Forest are approximately: 32˚35' E, 00˚12' N.

Residential Areas

The landing at Mabamba can be accessed by a single main road, which connects the town of Ziba to Kasanje Road, eventually leading to Buwaya Landing and Entebbe. The village of Ziba is located within a network of paths and homes directly off the main road. The outer edge of the residential area is located approximately 500m north of Nkima Forest. The geographic coordinates for the village of Ziba are approximately 32˚37' E, 00˚10' N. Photos of all four study sites are shown in Figure 1

Figure 2 Photos of four land use areas around Mabamba Swamp. From top left: Eucalyptus plantation, the agricultural field, residential area, and Nkima Forest

3.3 Methods & Study Design

This observational study investigated the relationship between anthropogenic disturbance and avian species richness and abundance. 25-minute point counts were conducted between 7:00 am and 10:00 am and assessed four different land-use areas: *Eucalyptus* plantations, wetland-edge agricultural fields, residential areas, and Nkima Forest. To avoid temporal bias, point counts within a single land-use type alternated between early-morning and late-morning data collection. Point counts conducted within a single day were separated by at least one kilometer, assessed by a GPS locator. Bird species within a 50-meter radius of the observer were recorded, along with behaviors and number of individuals if possible. To avoid bias due to differences in visibility between habitats, birds were recorded if they were seen or heard.

3.4 Data Collection Instruments

For data collection, the following materials were used: A Guide to the Birds of East Africa by Terry Stevenson, a pair of binoculars, and a notebook and pen. A mobile recorder was also used to identify unfamiliar bird calls. A guide trained in bird identification was essential for accurate data collection.

3.7 Study Design

This study used a mixed-methods approach by combining a correlational study with qualitative independent variables. The study investigated potential correlations between land use and avian diversity, with a categorical dependent variable (i.e., land use). The dependent variable represents a gradient of anthropogenic disturbance, with residential areas exhibiting the greatest disturbance and secondary forests exhibiting the least disturbance.*3.6 Data Analysis*

Alpha diversity was calculated as the total number of species observed per point count, and avian abundance was calculated as the total number of birds observed per point count.

Species evenness between land-use types was calculated as Shannon's diversity index (H) divided by the natural logarithm of species richness (ln(S)). (H) can be calculated using the following equation, where p_1 is equal to the proportion (n/N) of individuals of one species found (n) divided by the total number of individuals found (N).

$$(H) = -\sum_{i=1}^{s} p_i \ln p_i$$

Species richness, abundance, and evenness values were averaged over 10 point counts for each land type. Because data were normally distributed, means were then compared using a one-way ANOVA and Tukey's Test for Honest Significant Difference (HSD).

4.0 Results

4.1 Effect of Land Use on Avian Richness

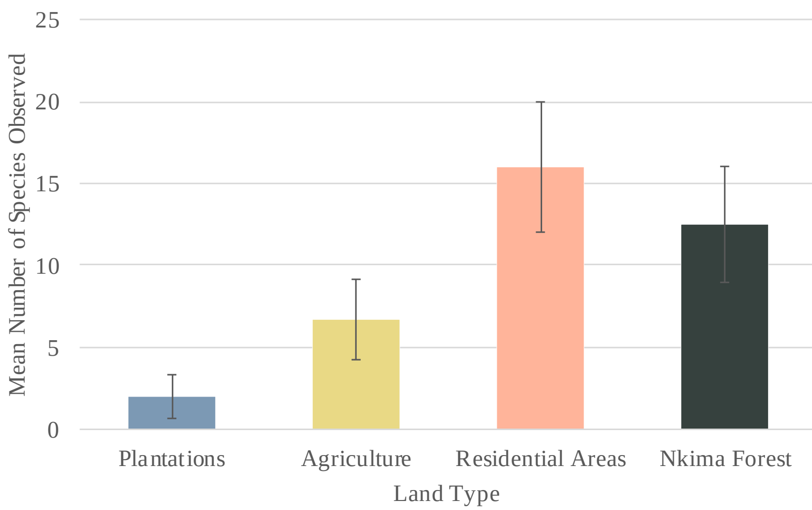

Figure 3 Effect of wetland-adjacent land use on avian species richness in areas surrounding Mabamba Swamp. Means represent the average species richness over 10 point counts in November and December of 2021. Differences between all means are significant except between residential areas and Nkima Forest (*p=0.06)*.

A one-way ANOVA was performed to assess the impact of land use on species richness. The ANOVA revealed a statistically significant difference in avian richness between at least two groups ($F\ (3, 36) = 42.580$, $p<0.01$).

Tukey's HSD test for multiple comparisons found that richness was significantly different between Eucalyptus plantations and agricultural areas (p=0.006), Eucalyptus plantations and residential areas *(p=0.001*), Eucalyptus plantations and secondary forest (p=0.001), agricultural areas and residential areas (p=0.001), and agricultural areas and secondary forest (p=0.001). There was no statistically significant difference between residential areas and secondary forests (p=0.06).

4.2 Effect of Land Use on Species Evenness

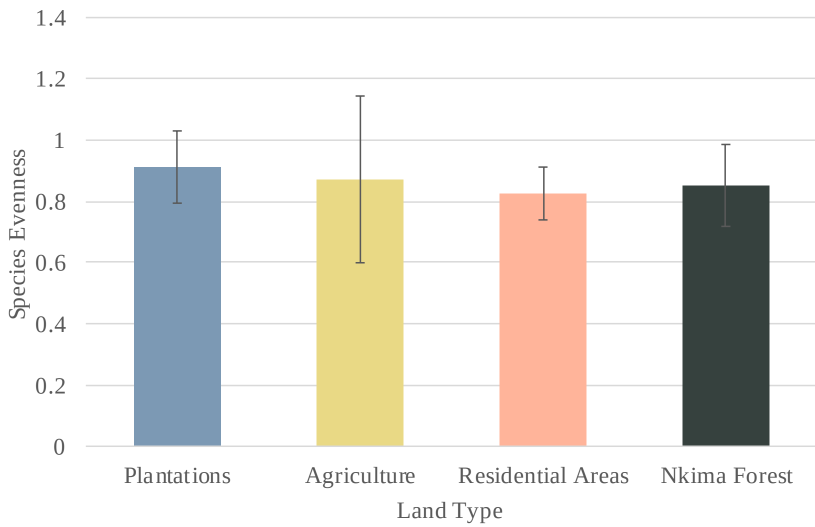

Figure 4 Effect of wetland-adjacent land use on avian species evenness in areas surrounding Mabamba Swamp. Differences between all means are insignificant ($F3,34$) =0.367, $p=0.777$).

Using a one-way ANOVA, the relationship was between land use and species evenness was found to be insignificant for all groups ($F(3, 34)=0.367$, $p=0.777$).

4.3 Effect of Land Use on Avian Abundance

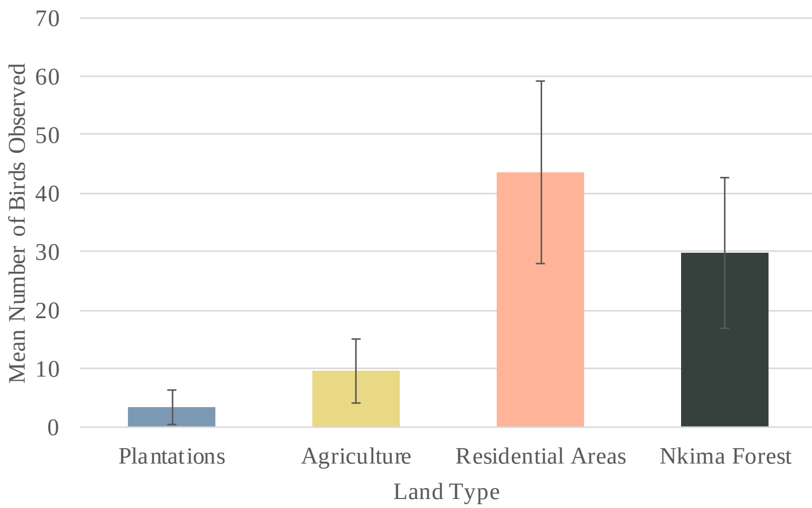

Figure 5 Effect of wetland-adjacent land use on avian species abundance in areas surrounding Mabamba Swamp. Means represent the average species abundance over 10 point counts in November and December of 2021. Differences between all means are significant except between agricultural areas and Eucalyptus plantations (0.692) and between residential areas and Nkima Forest (*P=0.133*).

Another one-way ANOVA was performed to assess the impact of land use on avian abundance. The ANOVA revealed a statistically significant difference in avian abundance between at least two groups ($F(3, 36) = 24.003$, $p<0.01$).

Tukey's HSD Test for multiple comparisons found that abundance was significantly different between agricultural areas and residential areas (*p=0.001*), agricultural areas and secondary forest (*p=0.002*), Eucalyptus plantations and residential areas (*p=0.001*), and Eucalyptus plantations and secondary forest (*p=0.001*). There was no statistically significant difference between agricultural areas and Eucalyptus plantations (*p=0.692*) or residential areas and secondary forest (*p=0.133*).

4.4 Unique Species Per Land Type

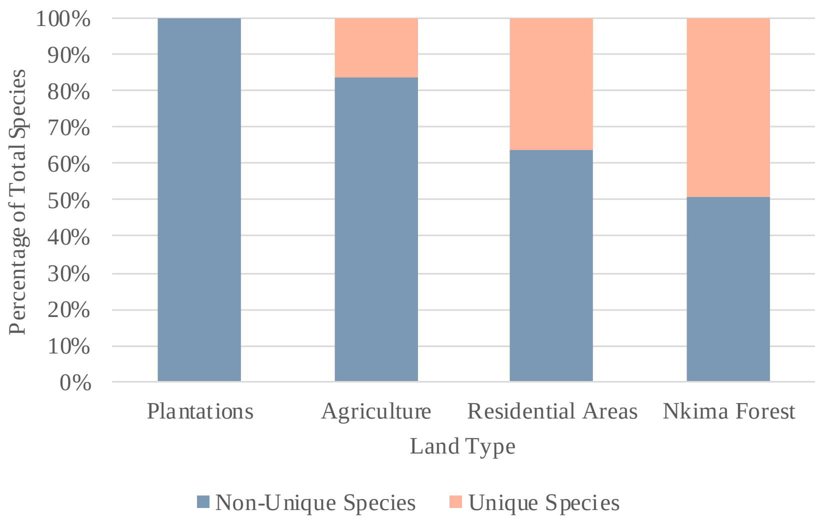

Figure 6 Number of unique avian species found in four land use areas surrounding Mabamba Swamp, Uganda. "Unique species" are defined as species found exclusively in one land use type. Total species for each land type represent the sum of recorded species over 10 point counts.

The number of species found in a single land-use area was calculated for each land type. Eucalyptus plantations contained no unique species, agricultural fields contained 9 (16.07% of total species found in agricultural areas), residential areas contained 27 (36% of total species found in residential areas), and Nkima Forest contained 38 (49.35% of total species found in Nkima Forest).

5.0 Discussion

5.1 Relationship Between Species Richness, Evenness, Avian Abundance

This study documented the relationship between wetland-adjacent land use and avian diversity and abundance in areas surrounding Mabamba Swamp, Uganda. Findings indicate that residential areas and secondary forests exhibit the greatest avian species richness and abundance, while secondary forest harbors the greatest number of specialist species.

Land-use influenced avian richness and abundance in a similar manner; the means for all land use types were significantly different except for those between Nkima Forest and residential areas. For abundance, the means between plantations and agricultural fields were also significant, though farm fields exhibited consistently higher abundance values than *Eucalyptus* plantations. The similarity in these relationships can be attributed to two species in particular: the bronze mannikin (*Spermestes cucullate*) and the weaverbird (*g. Ploceus*), both of which are gregarious habitat generalists often found in flocks of dozens to hundreds (Calf et al., 2002; Khan et al., 2019). Because these species were found in all habitats, the relationship between land use and abundance was an amplified form of the relationship between land use and richness; in this study, therefore, richness and abundance can be used similarly as indicators of avian well-being.

The insignificance of species evenness may be attributed to the fact that aside from a few gregarious species, most birds in all habitats were sighted either alone or in pairs.

5.2 Effects of Monoculture Agriculture on Avian Diversity

Limited avian richness in eucalyptus plantations supports the hypothesis that monoculture plantations reduce faunal biodiversity. Previous studies have found that monoculture timber plantations—from pine and eucalyptus to needlewood—negatively impact bird assemblages (Volpato et al., 2010; Mendonca-Lima, 2012). This relationship may be driven by habitat homogenization, which limits the presence of rare and specialist species. Additionally, the relationship may be due to resource scarcity, as plantations offer limited substrates for nesting and foraging (Jacobski et al. 2016). Behavioral observations from this study support the theory of resource scarcity: only three of 18 species found in the *Eucalyptus* stands were actively using resources provided by the plantations: a black-headed paradise-flycatcher (*Terpsiphone rufiventer*) perched on a branch, a gray-headed camaroptera (*Camaroptera brevicaudata*) foraged in small shrub within the plantation, and six cattle egrets (*Bubulcus ibis*) fed alongside grazing cattle. The 16 other species associated with *Eucalyptus* stands were seen flying through timber rows or perched in vegetation directly adjacent to the plantation.

Eucalyptus trees have also been shown to deplete the soil of nutrients and moisture reserves (Terarai et al., 2013) and inhibit the growth of an understory through the release of allelopathic chemicals (Khan et al., 2009). Limited understory growth and flowering plant cover inhibits insect populations, subsequently excluding a variety of avian feeding guilds from plantations: namely frugivores, nectarivores, and insectivores (Mulwa et al., 2021). The effects of homogenization and allelopathy have led some to describe plantations of exotic monocultures as "biological deserts" (Liu et al., 2018)

Monoculture agricultural fields also lead to landscape homogenization, but the effects on avian diversity appear to be less dramatic. Though there was no significant difference between plantation and crop field avian abundance, agriculture fields had a significantly greater mean avian richness. Additionally, nine out of 56 species found in agricultural fields (16.07% of total species) were found exclusively in that land type. Many of these unique species are known to favor open grasslands, such as the whinchat (*Saxicola rubetra*) and the white-browed scrub-robin (*Cercotrichas leucophrys*). These findings indicate that agricultural fields provide limited resources for avian survival, though some species can capitalize on available insects and farm-adjacent scrub. While long-term intensive agriculture has been shown to diminish avian diversity (Hendershot et al., 2020), farm fields play an important role in habitat for some specialist, often granivorous, species (Munoz-Saez et al., 2017).

5.3 High Avian Diversity in Residential Areas

High avian diversity in residential areas may be explained through the positive effects of habitat complexity on wildlife communities. Residential areas in Ziba are characterized by a high degree of spatial complexity: houses are surrounded by small-scale agricultural plots, patches of indigenous trees, open areas for cooking and washing, and patches of pasture for grazing cattle. Avian diversity has been shown to increase in structurally complex areas compared to homogenous ones due to the increased variety of microhabitats and corresponding ecological niches (Khanaposhtani et al., 2012; Mitchell et al., 2006).

While avian richness remained high in residential areas, anthropogenic development alters the composition of avian communities. Notably, residential areas were associated with a greater number of a habitat generalist, disturbance-dependent species, and synanthropic species, such as the pied crow (*Corvus albus*) and mourning collared dove (*Streptopelia decipiens*). The exclusion of specialist species from developed areas is well-documented (Silva et al., 2016).

Urbanization has also been shown to influence the structure of avian feeding guilds, with urbanization and anthropogenic development favoring granivores and omnivores. Insectivores, frugivores, and nectarivores are less resilient to changes in vegetation structure and depend on less disturbed habitats for sufficient forage (Sliva et al, 2016). While this study did not find significant differences in feeding guild composition, Nkima Forest was home to a greater number of fruit-eating species. Additionally, behavioral observations suggest the forested area may provide a more suitable habitat for insectivorous species: during the yearly emergence of long-horned grasshoppers (*Luganda* “nsenene”) in late November, dozens of white-throated bee-eaters (*Merops albicollis*), village weavers (*Ploceus cucullatus*), and other insectivorous species were found foraging at the forest edge. Though the grasshopper emergence extended into residential areas, the same feeding phenomenon was not observed in these areas.

5.4 Nestedness

Species assemblages in eucalyptus plantations and Nkima forest exhibited a high degree of nestedness: the 18 species found within Mabamba's timber plantations were a subset of Nkima's avian community. Additionally, 38 out of 77 (49.35%) of the species found in Nkima forest were not found in other land types, the highest percentage of all land use areas. These findings indicate that Nkima is a refuge for forest-specialist species, which is supported by the presence of the white-spotted flufftail (*Sarothrura pulchra*), western nicator (*Nicator chloris*), and black-and-white-casqued hornbill (*Bycanistes* subcylindricus), all of which are dependent on dense forest habitats.

The importance of forest fragments as a refuge for habitat specialists is well-documented (Mulwa et al., 2021; Kline et al., 2020; Kapos et al., 2003). Increased forest cover in fragmented patches is associated with a significant increase in forest-specialist avian species and a significant decrease in generalist species (Morante-Filho et al., 2015). Additionally, the nested structure of *Eucalyptus* stands and Nkima Forest indicates that wetland-adjacent silviculture acts as a wildlife filter, habitable only to a select group of highly adaptable forest species.

5.5 Conclusions

This study is the first to investigate the impact of wetland-adjacent land use in the areas surrounding Mabamba Swamp, Uganda. Findings indicate that land use does have a significant effect on avian richness and abundance, with residential areas and Nkima Forest exhibiting the greatest avian diversity and *Eucalyptus* plantations and agricultural areas exhibiting the lowest. Additionally, Nkima Forest was found to harbor the greatest number of specialist species.

These results are likely due to the positive impact of spatial complexity and resource availability on avian survival. In the village of Ziba, residential areas have a high degree of habitat heterogeneity: homes are surrounded by open pasture, small-scale farms, patches of indigenous trees, and open areas for washing and cooking. Spatial complexity in these areas and Nkima Forest allows for a variety of vegetation cover, microhabitats, and ecological niches. The anthropogenic disturbance does, however, shift the composition of avian communities, as altered habitats are associated with a greater number of habitat generalists and synanthropic species. The landscape homogenization associated with monoculture agriculture inhibits avian biodiversity, but farm fields offer resources for a select group of specialist species. These findings have the potential to inform the protection and regulation of resource use in wetland-adjacent communities, in East Africa and on a global scale.

In addition to broadening the spatial and temporal scope of this study, future research should investigate the role of sand mining on avian communities, explore the use of wetland habitat by terrestrial species, and measure the effect of land use on avian feeding guild composition. Additionally, a study investigating the knowledge and lifestyle of wetland-adjacent residents is necessary to most effectively promote conservation programs in the area.

5.6 Limitations

This study suffered from many limitations common to avian surveys: difficulty in measuring an accurate radius from a designated point, trouble in identifying fast-moving or well-hidden species, and a bias towards recording known birds rather than unfamiliar species. Additionally, land-use types were characterized by varying levels of visibility, from high visibility in agricultural fields to low visibility in forested areas. To minimize the effects of these differences, birds were recorded that were both seen and heard, but data may still have been affected. Data collection was also limited to designated trails through the forest and on the outskirts of agricultural fields. Village centers and areas with high human traffic were avoided to avoid discomfort and suspicion from community members.

5.7 Recommendations

5.7.1 Incorporate Mixed-Species Agriculture

An increase in mixed-crop agriculture would positively impact wetland-edge biodiversity. Interspersing *Eucalyptus* stands with other species would allow for the benefits of monoculture plantations—a fast-growing source of timber and improved treatment of wastewater—while sustaining local biodiversity (Liu et al., 2018). Despite *Eucalyptus'* aggressive growth and allelopathic properties, recent studies have uncovered the potential for mixed-species systems. The key is to incorporate a nitrogen-fixing species with readily decomposable leaf litter and high rates of nutrient cycling, as *Eucalyptus* has been shown to benefit from fixed nitrogen in as early as the first or second year of plantation establishment (Forrester et al., 2006). Successful mixed-species plantations benefit from high soil fertility and increased productivity and carbon sequestration (Forrester et al., 2006; Pretzsch & Schutze, 2015).

Intercropping in wetland-edge subsistence farms would also benefit local biodiversity. Unlike the residential areas in the village of Ziba, most agricultural plots at the wetland's edge employ monocropping. Heterogeneity associated with increased crop promotes avian diversity while protecting farmers from the unpredictable impacts of climate change (Mthembu, N., & Zwane, E., 2017; Ndang'ang'a et al., 2013).

Planting native trees within agricultural plots will also increase the structural complexity of an area and enhance farmland habitat for local wildlife. Creating multi-functional agricultural lands through tree-planting has been shown to positively impact ecosystem services by influencing water regulation, nutrient cycling, and food production (Kuyah et al., 2016). There are potential trade-offs, however, in interspersing agricultural land with native trees: though the effect is largely positive, some farmers in Sub-Saharan Africa have reported a decline in crop yield and the modification of microclimate (Kuyah et al., 2016).

5.7.2 Protect Nkima Forest

Nkima Forest is currently protected by the recent development of Nkima Forest Lodge, a tourist attraction that depends on the in-tact forest for revenue. Though only a small remainder of the forest that once thrived in the catchment, it is essential that this 30-acre fragment remains protected. Based on this study, Nkima contributes more to local avian diversity than any other land-use type. This is not an isolated phenomenon—many others have found forest fragments to be biodiversity hotspots in a degraded landscape (Mulwa et al., 2021; Kline et al., 2020; Kapos et al., 2003).

5.7.3 Improve Communication Between Communities and Local Governments

Improved communication between the Wakiso Local Government and the village of Ziba is essential for the long-term protection of Mabamba's biodiversity. In 2014, the Mabamba Bay Wetland Eco-Tourism Association released a community action for the protection of the swamp (MBWETA, 2014). The report included actionable steps to promote wetland preservation over four years, including foresting the Mabamba catchment, controlling illegal fishing, regulating resource harvesting, and controlling sand mining (MBWETA, 2014). Three years after the proposed conclusion to the project, many of the goals have not been seen to completion, and Mabamba still suffers from alarming degradation. Additionally, the plan did not include specific steps for regulating wetland-adjacent agricultural use—an essential component in protecting the area's biodiversity.

The action plan should be revitalized, with the following actions given particular attention: the implementation of educational programs in wetland-adjacent villages, the creation and enforcement of bylaws on sustainable resource use, and the regulation of agriculture.

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Appendix A

Ethical Considerations

This study involved observing bird species from a distance; no mist-netting or trapping was used and thus no animals were harmed. The leaders of local communities were informed before collecting data in residential areas, and photos were only taken if individuals gave informed verbal consent.

Appendix B

The following timeline is a brief schedule of the ten days of data collection:

November 16th: Arrive in Mabamba Swamp, Uganda

November 17th: Meet with local community leaders to achieve informed consent of the project

November 18th: Conduct point counts in plantations and agricultural fields

November 19th: Conduct point counts in residential areas and Nkima Forest

November 22nd: Conduct point counts in agricultural fields and residential areas

November 23rd: Conduct point counts in Nkima forest and plantations

November 24th: Conduct point counts in plantations and agricultural fields

November 25th: Conduct point counts in residential areas and Nkima Forest

November 26th: Conduct point counts in agricultural fields and residential areas

November 29th: Conduct point counts in Nkima Forest and plantations

November 30th: Conduct point counts in plantations and agricultural fields

December 1st: Conduct point counts in residential areas and Nkima Forest

December 2nd-4th: Begin analysis of data

December 5th: Return to Entebbe

Appendix C

The following budget was used during the ISP period:

	Amount	Number	Total
Food			
Breakfast	5000	20	100000
Dinner	10000	20	200000
Water	2000	20	40000
Guiding			
Bird guiding	50000	10	500000
Advisor	200000	1	200000
Acommodation			
Airtel	50000	1	50000
Zion Camp	40000	20	800000
Transportation			
Boda	2000	20	40000
Ferry	3000	6	18000
		Total Used	1948000
		Budget Remaining	52000

Appendix D

source	sum of squares SS	degrees of freedom ν	mean square MS	F statistic	p-value
treatment	1,151.8000	3	383.9333	42.5804	6.2640e-12
error	324.6000	36	9.0167		
total	1,476.4000	39			

treatments pair	Tukey HSD Q statistic	Tukey HSD *p*-value	Tukey HSD inferfence
A vs B	4.9497	0.0066096	** $p<0.01$
A vs C	14.7437	0.0010053	** $p<0.01$
A vs D	11.0577	0.0010053	** $p<0.01$
B vs C	9.7940	0.0010053	** $p<0.01$
B vs D	6.1081	0.0010053	** $p<0.01$
C vs D	3.6859	0.0609244	insignificant

Appendix D: Statistical output for a one-way ANOVA and Tukey's HSD Test on the impact of land use on avian species richness.

Commented [F2]: For consistence use either p<0.01 or p=0.01 format throughout,

Appendix E

source	sum of squares SS	degrees of freedom νν	mean square MS	F statistic	p-value
treatment	10,264.8000	3	3,421.6000	30.4986	5.4436e-10
error	4,038.8000	36	112.1889		
total	14,303.6000	39			

treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inferfence
A vs B	1.8510	0.5571349	insignificant
A vs C	12.0019	0.0010053	** p<0.01
A vs D	7.8819	0.0010053	** p<0.01
B vs C	10.1509	0.0010053	** p<0.01
B vs D	6.0308	0.0010053	** p<0.01
C vs D	4.1201	0.0297714	* p<0.05

Appendix E: Statistical output for a one-way ANOVA and Tukey's HSD Test on the impact of land use on avian abundance.

Appendix F

source	sum of squares SS	degrees of freedom ν	mean square MS	*F* statistic	p-value
treatment	0.0327	3	0.0109	0.3671	0.7772
error	0.9788	33	0.0297		
total	1.0115	36			

treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inferfence
A vs B	0.6714	0.8999947	insignificant
A vs C	0.3625	0.8999947	insignificant
A vs D	0.8460	0.8999947	insignificant
B vs C	1.0004	0.8894861	insignificant
B vs D	1.4391	0.7183768	insignificant
C vs D	0.4834	0.8999947	insignificant

Appendix E: Statistical output for a one-way ANOVA and Tukey's HSD Test on the impact of land use on avian species evenness.