ORIGINAL RESEARCH ARTICLE

Effects of Urban Wetland Patch Pattern on the Biodiversity of Aquatic Birds in Nairobi, Kenya

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ABSTRACT
Urban wetlands are ubiquitous landscape elements that affect the spatial pattern and functions of cities. Despite being rich and important habitats for a variety of birds, they are continually being isolated or lost. Isolation and loss negatively impact on the integrity of the urban landscape pattern and compromises on biophilic planning and development. Since urbanization is a continuous cultural process, it is important to investigate how its impacts, which are invariably in conflict with nature, would portend for aquatic bird communities in urban areas. This study sought to determine the variability and relationship between the structural patch pattern of palustrine wetlands in Nairobi and the species richness and abundance of aquatic birds in these wetlands. From a population of 300 wetlands, this study used heterogeneous sampling to identify and investigate 31 palustrine wetlands spread across the city of Nairobi. For each of these wetlands, a variety of landscape metrics were calculated and the species diversity of aquatic birds was quantified. Multiple regression analysis was performed in IBM SPSS Statistics 21 to determine the relationships between wetland patch pattern and wetland biodiversity. The study found that patch pattern significantly affects aquatic bird biodiversity, $R^2 = .516$, $F(7, 23) = 3.498$, $p < .05$. It was also found that the characteristics of the wetland neighbourhood significantly affected aquatic bird biodiversity, $R^2 = .301$, $F(3, 27) = 3.867$, $p < .05$. This study highlights the need to mainstream, plan, and design for the conservation and monitoring of spatial patterns and biodiversity of palustrine wetlands in urban landscapes. In doing so, biophilic cities are created, bio-systemic urban infrastructure is generated, human wellbeing is enhanced, and urban wetland ecosystem services are valued.

Keywords: Wetland configuration, Landscape metrics, Biodiversity structure, Aquatic birds, Biophilic planning

1.0 Introduction
Urban areas are highly associated with wetlands. Many cities developed because of, and around large natural marine, lacustrine, or riverine wetland systems. There are also smaller-size naturally occurring palustrine wetlands that many cities have preserved for their ecological value (Bridgewater, 2011). Further, wetlands have been constructed for various

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infrastructural purposes and have become part and parcel of the urban fabric (Hassall, 2014). The large wetlands upon which cities are built are usually domineering and rarely lost, perhaps only degraded. However, the relatively smaller palustrine wetlands have a high turnover, and are therefore at high risk of isolation and loss. The high turnover is invariably a function of competition for space by the various urban land uses which result in filling or draining of the wetlands. Others are accidental and ephemeral (Palta *et al*., 2017). These dynamics create a structural pattern in the urban landscape mosaic that may have effects on the biodiversity of urban palustrine wetlands.

Previous studies have demonstrated that small urban wetlands are important biodiversity areas (e.g. Hsu *et al*., 2011; Hassall, 2014; Hassall & Anderson, 2015; Mackintosh *et a*l., 2015; Wiegleb *et al*., 2017; Hill *et al*., 2017; Hale *et al*., 2019). Recently, wetland configuration, as measured using landscape metrics, has also been recognized as an important aspect of study in trying to understand effects of anthropogenic disturbance on wetland functions and reclamation design (Evans *et al*., 2017; Ridge *et al*., 2021). However, these studies are scanty, and there are hardly any studies that seek to understand how wetland configuration and composition in the landscape mosaic would affect the bird biodiversity of urban wetlands. Urban wetlands are known to be sensitive ecosystems that provide unmatched ecosystems services such as provision of food and water, recreation, and flood regulation. Since biodiversity is the foundation of all ecosystems services (MEA, 2005), wetland sustainability is dependent on the amount and structure of biodiversity within them. Bird communities in urban palustrine wetlands contribute immensely not only to the metapopulation bird dynamics, but also to the overall gamma diversity of the urban landscape.

With reference to the patch-corridor-matrix model (Forman, 1995; 2014), palustrine wetlands become discrete patches that over time, inadvertently, create patterns in the city landscape mosaic. They practically elucidate the urban ecological principle which states that urban form is a reflection of planned, incidental, and indirect effects of social, economic, cultural and environmental decisions (Pickett & Cadenasso, 2017). Overall, urban wetlands, be they natural or man-made, exist in varying sizes, shapes, edges, depths, contexts, building materials and management regime. Consequently, various levels of heterogeneity are created - at wetland patch level, at wetland types or class level, and over the entire landscape mosaic. With this variability comes challenge of determining the most appropriate patch pattern (for example the in terms of shape, size, and land uses within buffer zones) that would regenerate, protect or enhance bird biodiversity.

Spatial pattern is measured in terms of landscape composition and configuration (With, 2019). Landscape metrics are applied at patch level, class level, and at landscape level as a useful tool measure various aspects of landscape heterogeneity – spatial pattern (McGarigal *et a*l., 2012; With, 2019). These metrics include area metrics (e.g. patch size and patch density), edge metrics, shape metrics, core area metrics, nearest-neighbour metrics, diversity metrics, contagion metrics, and interspersion metrics. Evidence exist on how these metrics of spatial pattern affect urban ecosystem and landscape ecological processes and functions (Pauleit & Breuste, 2011; Pickett *et al*., 2016; Verhagen *et al*., 2016). Pellissier *et al*. (2012)

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more specifically found that birds are sensitive to landscape composition and configuration in cities. However, none of these studies have attempted to relate landscape pattern to urban palustrine wetlands and even to their biodiversity. This study seeks to address the question of how spatial pattern and distribution of wetland patches affects the biodiversity function of a city landscape.

Although most of the wetlands, if not all, are not planned, designed or constructed with biodiversity function in mind, they end up being important habitats for a variety of flora and fauna. They become fully established wetland ecosystems with functional biotic communities. At the landscape level, they are island-like habitat patches interspersed within a harsh urban matrix and serve as important ecological stepping stones (Hill *et al*., 2017) that help in landscape connectivity for plant and animal movement (Taylor *et al*., 1993; With, 2019). Consequently, the wetland patch dynamics affect the colonization and extinction of populations at the local and metapopulation scales (Swan *et al*., 2011; Johnson *et al*., 2013). An analysis of patch dynamics is therefore crucial for better understanding of the required conservation measures for populations in discrete patches such as wetlands located in unfavorable urban matrix.

According to the International Union for the Conservation of Nature *Red List*, 14% of all 11,158 assessed bird species are threatened with extinction (IUCN, 2021). In 2000, 1,183 species of birds were threatened with extinction compared to 1,481 in 2021 (IUCN, 2021). An increase of 298 bird species threatened with extinction in 20 years is indeed a worrying trend. There is a high risk of loss of biodiversity of aquatic birds in particular because wetland habitats are highly sensitive ecosystems that are also threatened by urbanization and agricultural expansion (Brondizio *et al*., 2019; IPBES, 2019).

For a long time, birds have been used as indicator species for ecosystem and environmental health (Browder *et a*l., 2002; Gregory & van Strien, 2010). Aquatic birds play a crucial role in wetland ecological function and ecosystem balance. These birds live in or near water for their breeding and feeding and are one group of animals that cities stand to lose if continued loss of wetlands is not halted. Smith & Chow-Fraser (2010) in a study of 20 coastal wetlands in Ontario, Canada, found that obligate marsh-nesting birds preferred rural to urban wetlands. This means that with increased urbanization, or encroachment to the rural fringe, such birds can become locally extinct; findings which perhaps are generalizable to other species of similar behavioral ecology. Not only is the loss of wetlands a big disadvantage to urban life, but the loss of biodiversity of aquatic birds results in degraded health of wetland ecosystems and therefore a compromise on their capacity to provide ecosystem services.

The biophilia hypothesis defends an anthropocentric environmentalism approach to nature conservation with much evidence (e.g. Kellert, 1995; Levy, 2003; Wilson, 2007). Specific to urban ecosystems, a number of studies provide evidence of the importance of nature to urban residents where they derive irreplaceable benefits from natural systems (Wu, 2008; Harrop, 2011; Grobbelaar, 2012; Pickett *et al*., 2016), and from urban wetlands in particular (Hettiarachchi *et al*., 2015; Ramsar Secretariat, 2020). Of particular concern are the poor

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urban residents, who are the majority in cities of developing countries, and they derive much benefits from urban wetlands (Palta *et al*., 2017). Since small size urban wetlands escape much of urban planning process, it is critical to provide scientific evidence of how their design, management and use can affect their biodiversity. This, it is hoped, would create awareness for their integration into urban planning. When the biodiversity of urban wetlands is affected, the overall integrity of these highly interconnected systems and their services are also affected.

Two closely related urban planning paradigms, biophilic cities and biophilic urbanism (Beatley, 2011; Beatley & Newman, 2013), are useful if applied to the conservation of natural ecosystems in urban areas. With biophilic cities and urbanism, urban elements and surfaces are considered platforms for greening towards increase in vegetation, natural systems and biodiversity (Newman, 2014). The paradigms stem from the concept of biophilia which recognizes human innate affinity to nature (Wilson, 1984; 2007). The idea has been successfully applied in Singapore where building walls and roofs are planted with plants resulting in 'the city in the garden' idea for better quality of urban life and high environmental aesthetics (Newman, 2014). From ecological planning perspective, high anthropogenic dominance and processes in cities need to be countered with biophilic urbanism. Palustrine urban wetlands are hotspots for nature and high biodiversity that can contribute immensely to biophilic urbanism and enhanced human wellbeing in cities.

This study examined the Nairobi city palustrine wetlands. The wetlands are ubiquitously distributed and face unique turnover challenges that are hardly addressed in planning and development processes. While some wetlands are lost through filling, draining, and eutrophication, others are designed and created as part of the urban infrastructure for sewage treatment, recreation, agriculture and infills of depressions, particularly abandoned quarries. Despite their abundance and continued construction on one hand, and their loss and isolation on the other, coupled with the biodiversity dynamics therein, palustrine wetlands remain unnoticed in the often simplistic urban planning and development processes. The objectives of this study were therefore to (1) determine the variability of the structural pattern of urban palustrine wetlands in Nairobi, (2) to identify species richness and relative abundances of aquatic birds in these wetlands, and (3) to determine the relationship between the wetland patch pattern and aquatic bird biodiversity. It is hoped that the knowledge generated from this study could contribute to the understanding of how urban wetland ecosystems could be structured to create biophilic cities, and in the development of city water infrastructure that are based on bioengineering patch patterns.

2.0 Material and Methods

2.1 Study area

Nairobi city is located at the central part of Kenya and it is the county's capital city. The city's population is approximately 4.4 Million and a population density of 6,200 people/ km2 (KNBS, 2019). The study area is defined by three major watersheds of Mbagathi River, Nairobi River, and Kamiti River; and is not by the city's administrative boundary. This choice of delimitation is in recognition that ecological processes and functions transcend

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administrative boundaries. Nonetheless, the sample of 31 wetlands are located within the administrative boundary of Nairobi City County except seven. The seven are located in Machakos, Kajiado and Kiambu counties.

The wetlands are distributed within a range of 1494m to 2000m elevation above sea level. The digital elevation model (DEM) shown in Figure 1 shows the distribution of the wetlands. Majority of the wetlands are located at the higher elevations of the city which may be attributed to historical damming of the rivers for agricultural purposes. In terms of the dominant vegetation cover, the high areas above 1670m are dominated by remnants of the tropical forest that existed before urbanization. The lower areas are characterized by tropical savannah vegetation dominated by grasses and scattered short acacia trees. Overall, there are five ecosystems that contextually may influence the distribution of aquatic birds: urban forest ecosystem, riverine ecosystems, urban ecosystem, and agricultural ecosystem and savannah grassland ecosystems.

2.2 Sampling design

The choice of sampling method varied with the two units of interest: the identification of the wetlands sample and transects for identifying the species of birds and their population counts.

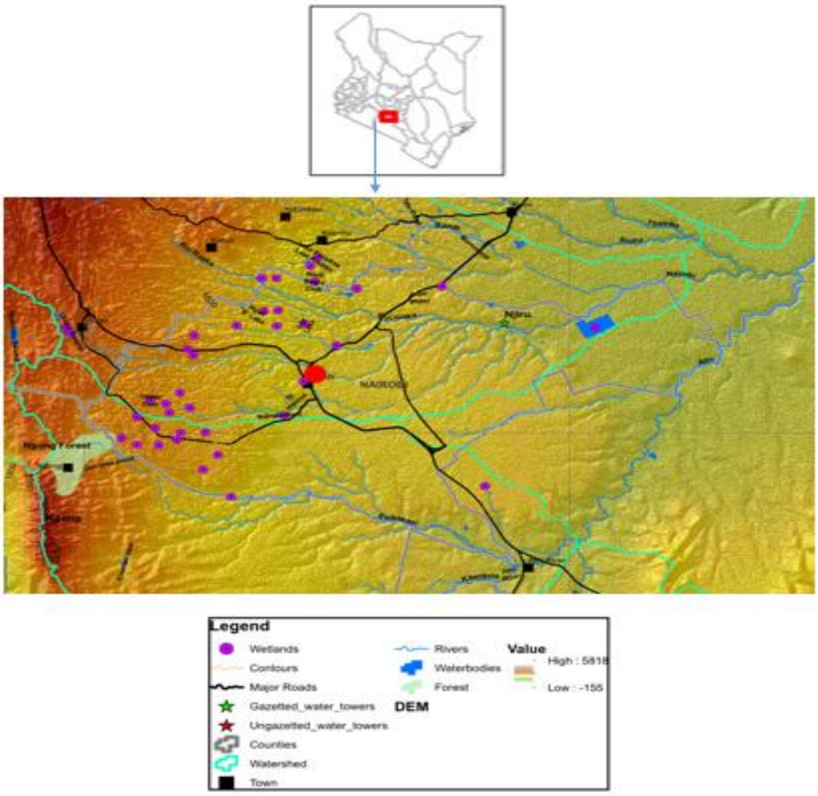

Figure 1 Study area and the distribution of the 31 wetlands

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2.2.1 Wetland cases

From satellite imagery and field surveys, the study found that there are 300 palustrine wetlands in Nairobi. A sample of 31 was drawn using the heterogeneity sampling method. This involved delineating the city into blocks or districts (Lynch, 1960; Jacobs, 1961) based on major roads (urban activity corridors) that are also act as ecological barriers and filters (Forman & Godron, 1986). This is to ensure that all areas of the city were represented. Secondly, from each city block, quota sampling was used to select wetlands so that wetlands from each of the following categories are represented: the various ways in which the wetland was created, the predominant land use of the wetland neighbourhood, and the various wetland uses (Figure 2).

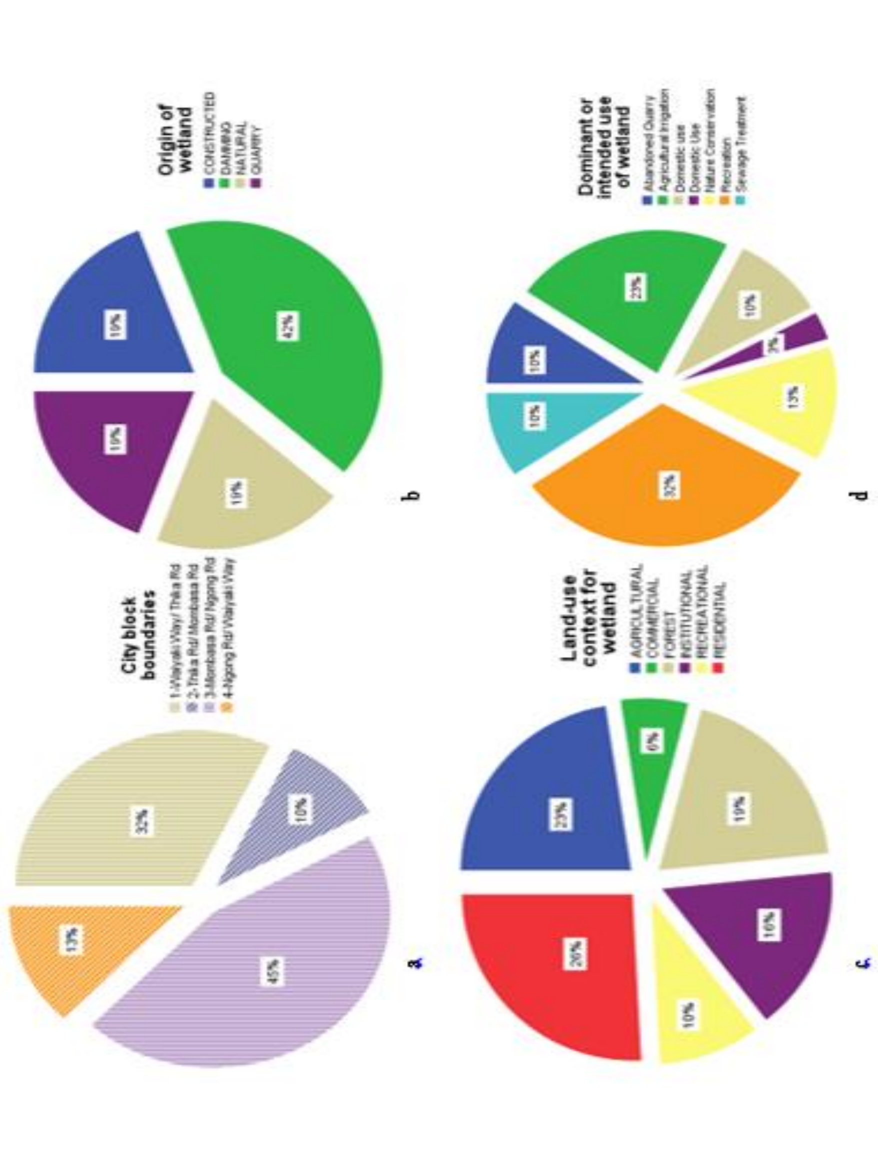

Figure 2 Pie charts showing the representation of variability of sample of 31 wetlands selection from (a) the city blocks as bounded by major urban activity corridors e.g., Waiyaki way and Thika road, (b) wetland origin e.g., whether constructed for recreational purposes or are naturally occurring, (c) predominant land use context of wetland e.g., agricultural or residential area, (d) predominant use of the wetland e.g., for sewage treatment or is an abandoned quarry.

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2.2.2 Birds population counts

Although all terrestrial and aquatic bird species were counted, of interest were aquatic bird species. Using the avian point count survey method (Gregory *et al*., 2004), total populations per bird species were enumerated per wetland during the months of August and September 2020. For each wetland, 3 observations points were identified. The choice of points depended on the wetland size, accessibility around the wetland edges, and boating accessibility into the inner core of the wetland. At each observation point, professional ornithologists counted birds for 20 minutes. With the use of an 8.16 x 40 DPS Olympus binoculars and the naked eye, birds were identified to the species level. Field observations were corroborated with field handbook *Birds of Kenya and Northern Tanzania*, (Zimmerman *et al*., 2018).

Figure 3 Bird counting at (A) Nyari residential estate recreational reservoir (B) Karen country club sewage treatment plant (C) Ngong forest nature conservation dam and (D) Lenana high school water reservoir.

2.2.3 Wetland patch pattern

Wetland characteristics were observed using satellite image for the year 2020, and ground truthing conducted in the months of August and September 2020. Aspects of patch pattern such as area, perimeter and edges were measured using Google Earth Pro version 7.1 which has an of accuracy ≤ 1.8m (Mohammed *et al.*, 2013) . This approach was found more reliable in identifying the land use properties of the surrounding landscape and wetlands at greater detail. In addition, this method allowed for differentiation, identification and estimation of proportions of area of open water versus area of hydrophytes and wetland altitude. All these constituted the heterogeneity properties that reflect the trend of wetland patch pattern.

The properties were categorized as per landscape metrics classification techniques by Mcgarigal *et.al* (2012) and With (2019). These techniques allow for the description of the characteristics of each pattern at the patch, class and landscape scales. At the patch scale,

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patch area (A), patch perimeter (P), patch shape (S), and patch core area (CA), perimeter of core area (PCA) and core area index (CAI) were used in addition to perimeter-area ratio (P/A) and the shape index (SI). Other patch level attributes unique to wetlands are the area (AOW) and perimeter (POW) of open water versus the area of hydrophytes (AHP). Area of open water index (OWI) was also calculated. A wetland patch core area excludes the outer edge effects where in this study, the edge width was a buffer of 6m. 6 m is the minimum length of riparian buffer zone as per environmental management and co-ordination (water quality) regulations, 2006 (NEMA, 2006). Therefore, the attributes of the edges that were measured included the perimeter (P6M) and area (A6M). At the class level, wetlands were categorized into different types including those located at different contextual city blocks, altitude, and wetland uses.

In addition to individual patch metrics, the variety of land uses within a 50m buffer zone were also identified. The 50m length is the distance provided under environmental management and co-ordination (water quality) regulations, 2006 (NEMA, 2006) as part of riparian zone for protection of wetlands. The buffer zone was calculated using the google earth buffering function. Polygons for each land use, as observed from satellite map, were drawn and the area and perimeter of each were calculated. On average, the land uses per wetland ranged from built-up residential, informal settlements, commercial and institutional areas. Non-built areas included agricultural, forest and bare land.

Figure 4 Satellite images of wetlands showing the polygons used to measure the patch metrics including land use areas within 50m buffer zone: (A) Kangemi agricultural dam, (B) Syokimau agricultural dam, (C) Nairobi sewage treatment plant, and (D) Githurai clayworks quarry wetland.

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2.3 Assessment of biodiversity

A number of essential biodiversity variables (EBV) have been suggested to help insulate against disjointed observation levels and changing approaches to indicator species in biodiversity research (Pereira *et al*., 2013). One of the EBVs adopted in this study is the counting of species populations. Species richness is the simplest and most useful concept used to assess biological diversity (Mittelbach & McGill, 2019). Similar to the heterogeneity levels of wetland pattern, biodiversity levels are measured and scaled in terms of counts or presence surveys for groups of birds per wetland and in the overall landscape.

Species richness and relative abundance was also assessed to determine how common or rare a species is in the population. To calculate relative abundance i.e. species dominance and eveness, Shannon Diversity Index was used (Shannon & Weaver, 1949):

$$\text{Shannon Diversity Index } H' = -\sum_{i=1}^{N} p_i \ln(p_i)$$

where N is total number of individuals in the community, p_i is the proportion of individuals found in species *i.* For the assessment of biodiversity across spatial scales in the landscape, the method proposed by Whittaker (1960) was adopted. It assesses biodiversity at various heterogeneity levels; at wetland patch scale (alpha (α) diversity), between wetland patches (beta (β) diversity), and at the entire landscape (*gamma (*ϒ) diversity). Beta diversity (β) = Gamma diversity (γ) / Alpha diversity (α). Or α*β = γ.

The effects of the wetland patch patterns on the species richness and abundance of aquatic birds were determined using regression models. The models would explain and predict the relationships first between the response variable, the number of species of birds per wetland, as predicted by variables such as wetland perimeter and area, area of open water surface and area of hydrophytes.

3.0 Results

3.1 Patch level metrics

Wetland patch characteristics varied significantly as indicated by the summary statistics of various configuration attributes shown in Table 1. There were wetlands with outlier values, mainly of the upper limit. For example, the Nairobi Sewage and Treatment Plant covers an area of 390.5 ha against an average of 3.0 ha. All outlier values were winzorised to within the 5th and 95th percentile to create more robust statistics (Blaine, 2018; Sullivan et al., 2021) for the purposes of analysis. For the sample of 31 wetlands, elevation (E) range was 506 m with a lower altitude of 1494 m and maximum altitude of 2000 m. The highest and lowest perimeter of wetland core area (P) was 9.6 km and 0.17 km respectively. The core area of wetlands ranged from 0.17 ha to 390.5 ha. The wetlands CAI measures the edge-to-interior ratio, and it ranged from 52% to 100%.

Patch shape complexity is measured by perimeter-to-area ratio (P/A) and patch shape index (SI) (With, 2019). The wetland sample exhibited varying shape complexity with P/A ranging from 1.21 and 9.87, and SI ranging from 1.00 and 1.93. Metrics that capture the attributes of

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the edges were also measured. Perimeter and area of the 6 m edge varied not only because of the size of the wetland but also because of presence of islands and convolutions or straightness of the edges. The edge perimeter ranged from 0.2 km to 9.6 km while the edge area ranged from 0.11 ha to 6.3 ha.

Perimeter and area of open water, in contrast with area grown with hydrophytes, was also calculated. The minimum perimeter of open water was 0.01 km and a maximum of 14.96 km, while the area of open water ranged from 0.01 ha to 362.01. The area grown with hydrophytes ranged from 0.11 ha to 34 ha at Ondiri swamp. Area of open water index was also calculated and it ranged from 0.00 to 2.36.

3.2 Neighborhood level metrics

Neighbourhood level metrics were largely about the variability of land uses as measured by the number of patches (NLUZ) for each category of land use within a 50 m buffer zone (Table 2). Within the buffer zone, area of built-up space (ABUZ); area of greenspace (AGRZ); ratio of greenspace area over total area of buffer zone GR/TAZ; and ratio of built-up area over total area of buffer zone (BU/TAZ) were calculated. Further, the outer perimeter of buffer zone (PZ); total area of wetland including buffer zone (AWZ); and area of buffer zone (AZ) were also calculated.

NLUZ ranged from one land use, commonly forest areas, to five land uses where urban activities are intense. Similarly, ABUZ was largely determined by the wetland context, whether in natural area such as a forest or in a mixed use neighbourhood; minimum built up area was zero and a maximum of 5.68 Ha at Nairobi dam, Kibera. GR/TAZ ranged from 62% to 100%. AZ ranged from 1.6 Ha to 21 Ha.

3.3 Biodiversity structure

The species richness (SR) was determined by the number of aquatic birds per each wetland, also as a measure of the alpha diversity at the wetland patch scale. Shanon diversity index (H′) was used to measure the aquatic bird abundance and evenness and it was found that this was positively correlated to SR. A total of 45 aquatic bird species (ABS) were found in the Nairobi wetlands. This number is also the value of gamma diversity for the wetland landscape of Nairobi. The total population of ABS was 2057. 42% of all these birds were found at the Nairobi water and sewage treatment plant (NWSTP).

The wetland with the highest SR for aquatic birds of 31 is the city’s sewage treatment plant (NWSTP), H′ = 2.48. NWSTP is also the largest wetland (390.5 ha) located in a sparsely built residential area and was also at the lowest altitude at 1494 m. The birds were found largely within the treatment cells. However, treated water that is released to Nairobi river flows through marshy area that too was habitat to high population of birds in the families of geese, storks and plovers. The 31 score of SR was an outlier because it is almost twice the second largest number of 17 which was found in the Mamba village recreational wetland.

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Table 1.0 Patch Metrics

	E (m)	P (km)	CA (ha)	A (ha)	P/A	SI	CAI (%)	P6M (km)	A6M (ha)	POW (km)	AOW (ha)	AHP (ha)	OWI
Mean	1770.484	.958	2.925	3.536	3.742	1.300	79	1.008	.660	.780	1.452	1.777	.627
Median	1803.000	.780	1.880	2.490	3.310	1.252	80	.760	.500	.610	.605	1.410	.656
Std. Deviation	112.369	.588	2.385	2.747	1.938	.245	.121	.648	.419	.630	1.651	1.446	.498
Range	506.0	2.03	7.33	8.72	8.66	.93	48	2.30	1.39	1.99	5.00	4.39	2.36
Minimum	1494.0	.17	.17	.28	1.21	1.00	52	.20	.11	.01	.01	.11	.00
Maximum	2000.0	2.20	7.50	9.00	9.87	1.93	100	2.50	1.50	2.00	5.00	4.50	2.36

Table 2.0 Neighbourhood Metrics

	P_Z (km)	AW_Z (ha)	A_Z (ha)	ABU_Z (ha)	AGR_Z (ha)	GR/TA_Z	BU/TA_Z	NLU_Z
Mean	1.229	8.488	4.993	.539	4.559	.906	.095	3.194
Median	1.010	6.990	4.320	.260	4.200	.930	.070	3.000
Std. Deviation	.573	5.333	2.025	.716	1.925	.1054	.105	1.515
Range	2.02	18.22	6.39	2.50	6.13	.38	.38	6.0
Minimum	.48	1.78	1.61	.00	1.37	.62	.00	1.0
Maximum	2.50	20.00	8.00	2.50	7.50	1.00	.38	7.0

Three wetlands had only 2 species types of aquatic birds, the lowest SR for the Nairobi wetlands. The 3 wetlands, one at the Hub, Karen, a busy commercial use area; one at Langata botanical gardens, a quiet recreation area; and the other at Ngong forest, a quiet interior of dense forest area, are also the smallest in size. Lowest value of H' = 0.43 was that of Uhuru park recreational reservoir. However, this value was skewed by a high population of 113 Marabou stork (Leptoptilos crumenifer). This creates unevenness in a wetland of only five ABS.

In terms of abundance and rarity, it was found that the little grebe (Tachybaptus ruficollis) with a population of 365 was the most abundant bird. 67% of the little grebe was found in the large lake-like open waters of the NWSTP contributing to the lowering of its H' =2.48 that would otherwise be high. The second and third most abundant bird species was the Sacred ibis (Threskiornis aethiopicus) and Egyptian goose (Alopochen aegyptiaca) with a population of 247 and 207 respectively. The rarest species with a population of one, in the whole city, was the Grey-headed kingfisher (Halcyon leucocephala), the Ruff (Calidris pugnax), the Water thick-knee (Burhinus vermiculatus), and the Osprey (Pandion haliaetus). The second rarest species with a population of two or three was the African black duck (Anas sparsa), the African snipe (Gallinago nigripennis), the Great white pelican (Pelecanus onocrotalus), and the purple swamphen (Porphyrio madagascariensis).

Globally, wetlands are being lost at a rate four times faster than that of forest loss (IPBES, 2019). In fact, it is argued that the world has lost 87% of its wetlands in the last 300 years

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(Convention on Wetlands, 2021). The ABS are generally regarded as threatened because of the continued loss of wetlands, particularly because of unfavorable land use activities and climate change (Convention on Wetlands, 2021). The International Union for the Conservation of Nature (IUCN) *Red List* classify the Grey crowned crane *(Balearica regulorum)* as an endangered species. These birds were found in only four of the wetlands under study with a population of 17, 71% at the NWSTP. Wetlands inhabited by this threatened species therefore become critical conservation units in urban planning and development. Although most of the ABS are classified as of 'least concern' in the IUCN Red list, there is real threat of local extinctions. Perhaps the current classification is arrived at because of inadequate information or weaknesses in the assessment criteria.

3.4 Relationship between wetland patch pattern and aquatic birds

3.4.1 Patch level pattern

To determine the effect of wetland patch pattern on the biodiversity of aquatic birds, multiple regression models were developed. Before regression was conducted, test for normality was run for the species richness response variable. The Shapiro-Wilk test, read together with normal Q-Q plot, indicated that the number of aquatic birds per wetland were normally distributed, W (16) = 0.960, p = .291.

To model the relationship between species richness and patch level properties of the wetlands, metrics of the core area (CA), perimeter of core area (PCA), area of 6m wide edge (A6M), shape index (SI), area of open water (AOW), perimeter of open water (POW) and open water index (OWI) were used. To avoid multicollinearity, wetland variables of total area (A), total perimeter (P), perimeter of wetland including the 6m wide edge (P_{6E}), perimeter-area ratio (P/A), core area index (CAI), and area of hydrophytes (AHP) although measured, were not included in the model. Nevertheless, scatter plots for the relationship between ABSR and CAI and SI were generated and they showed hump-shaped relationships commonly observed in biogeographic ecological studies (Guo & Berry, 1998; Fahrig *et al*., 2011; Sirami, 2016). See figure 5.

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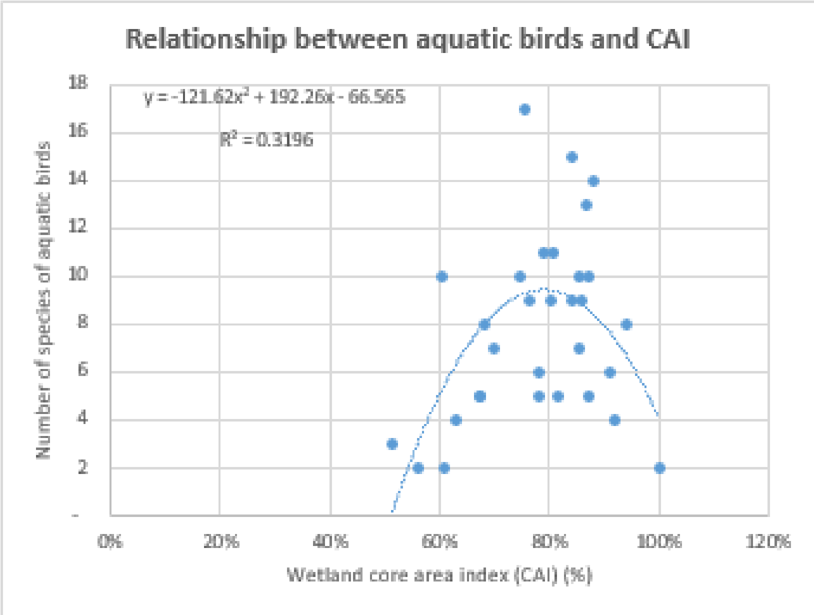
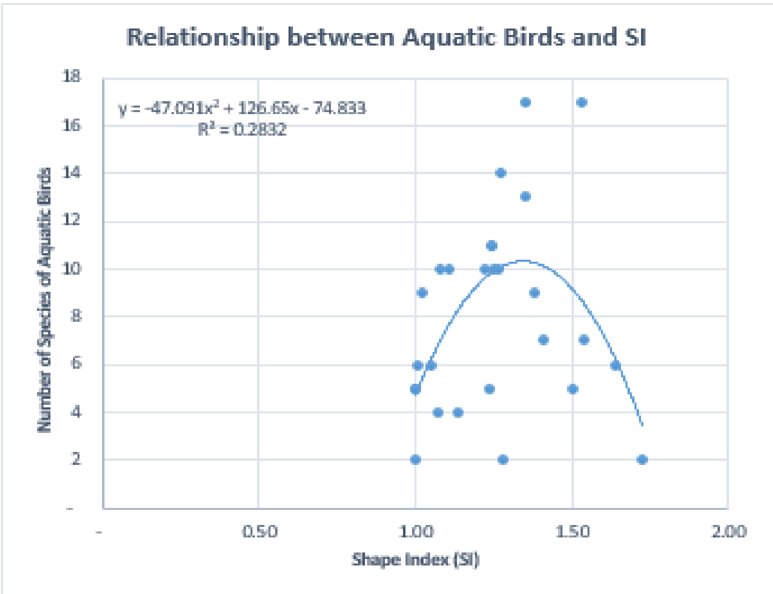


A



B

Figure 5 Scatter plots for relationships between ABSR and (A) wetlands core area index and (B) wetlands shape index

Table 3 summarizes the multiple regression results. The regression model with all the seven predictors produced $R^2 = .516$, $F(7, 23) = 3.498$, $p < .05$.

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ISSN 1561-7645 (online)
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Table 3 Summary of regression results for patch level properties

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.718[a]	.516	.368	3.3770

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	279.259	7	39.894	3.498	.011[b]
	Residual	262.290	23	11.404		
	Total	**541.548**	**30**			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	16.470	4.640		3.549	.002
	CA	-1.171	1.129	-.657	-1.037	.310
	PCA	11.997	5.307	1.663	2.261	.034
	A6M	-8.458	3.819	-.834	-2.215	.037
	SI	-9.738	4.445	-.562	-2.191	.039
	AOW	.728	.844	.283	.863	.397
	POW	2.884	1.856	.427	1.553	.134
	OWI	-1.874	1.734	-.220	-1.081	.291

As can be seen in Table 3, PCA, A6M, SI had significant positive regression weights, indicating wetland core area, area of buffer edge and the shape complexity explains and predicts variability in species richness for aquatic birds. However, when regressed individually against aquatic birds' richness, area of open water, perimeter of open water, and wetland core area understandably showed significant relationship at $p = .001$, $p = .018$, and $p = .032$ respectively. Wetland altitude (E) was found to be of little significance in determining the distribution of aquatic birds when regressed with other wetland patch level attributes.

Therefore, the prediction model for wetland patch level attributes is:

Aquatic bird biodiversity Y_1 = 16.470 - (1.17 x core area) + (11.997 x perimeter of core area) - (8.458 x area of 6m wide edge) - (9.738 x shape index) + (0.728 x area of open water) + (2.884 x perimeter of area of open water) - (1.874 x index of area of open water)

3.4.2 Neighbourhood level pattern

To model the relationship between ABSR and wetland neighbourhood level properties, the following attributes of a 50m wide buffer zone were used: number of land use patches (NLU_z),

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ISSN 1561-7645 (online)
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ratio of greenspace area over total area (GR/TA_Z), wetland altitude (E). To avoid multicollinearity, buffer zone attributes of total area (A_Z), area of wetland including buffer zone (AW_Z), total perimeter (P_Z), area of built-up space (ABU_Z); ratio of built-up area over total area of buffer zone (BU/TA_Z), although measured, were not included in the model.

The correlation between the attributes of the wetland neighbourhood and the ABSR was low. The maximum correlation was 0.337 for AW_Z and a minimum of 0.168 for NLU_z. There was a negative correlation of -0.193 between wetland ABSR and ABU_Z. This inidcates that the greater the level of disturbance caused by human activities, the lower the number of aquatic bird species inhabiting the wetlands. In the overal, these low correlation values may be attributed to the fact that as aquatic animals, the influnce of the surrounding neighbourhood is minimal. This is contrary to the earlier model explanation and prediction where the properties of the wetland patch itself greatly influenced ABSR.

Table 4 summarizes the multiple regression results. The regression model with three predictors produced $R^2 = .301$, $F(3, 27) = 3.867$, $p < .05$.

Table 4 Summary of regression results for neighborhood properties

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.548[a]	.301	.223	3.7456

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	162.759	3	54.253	3.867	.020[b]
	Residual	378.789	27	14.029		
	Total	541.548	30			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	10.911	14.299		.763	.452
	NLU_z	1.291	.580	.460	2.226	.035
	GR/TA_Z	18.921	8.345	.469	2.267	.032
	E	-.013	.006	-.355	-2.201	.036

Therefore, the prediction model for neighbourhood level attributes is:

Aquatic bird biodiversity $\mathbf{Y_2}$ **=** 10.911 + **(**1.291 x number of land uses) + **(**18.921 x ratio of greenspace area over total area - (0.013 x altitude)

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4.0 Discussion

This study found that the structural pattern of Nairobi palustrine wetlands is characterized by a variety of configurational and land use attributes. The configurational attributes were measured as patch level properties while land use attributes as neighbourhood level properties. Wetland size and configuration is a function of intended or accidental use and the process of creation or occurrence. For example, a wetland intended for sewage treatment would generally tend to be regular in shape and with straight edges resulting in a low shape index. Likewise, a left over quarry that filled up with water creating a wetland were found to be highly irregular in shape, with convoluted edges, resulting in a high shape index. Therefore, the city has a high diversity of palustrine wetlands that are relatively distributed. This diversity begets high heterogeneity levels that begets high biodiversity – the habitat heterogeneity hypothesis (Tews *et al*., 2004; With, 2019).

Landscape metrics relating to size, perimeter, shape and edges properties of patches have been useful in understanding landscape structure and heterogeneity (McGarigal *et al*., 2012; With, 2019). A fundamental assumption in landscape ecology is that structural patterns in landscape heterogeneity affect ecological responses (Riva & Nielsen, 2020). This study uniquely applied landscape metrics, with modifications, to understand the interface between wetland core area, area of open water, and width of wetland edge and aquatic bird biodiversity structure. Perimeter of open water area was particularly of importance in wetlands with islands and hydrophytes.

From the regression model of significance $p < 0.05$, it was empirically evident that up to 51% of variability in ABSR was attributed to patterns of wetland patch characteristics. To start with, patch size, is an important ecological factor that affects species richness. Large patches are generally known to contain high species diversity (Van Dorp & Opdam, 1987; Forman, 1995; Mittelbach & McGill, 2019), the well-known species-area relationship (SAR). The largest wetland in Nairobi, the city's sewage treatment plant at Ruai, was indeed found to host the highest number of aquatic birds at 31, ($H' = 2.48$), while the smallest one sampled, the Langata botanical gardens, had the lowest number of species at 2, ($H' = 0.64$). These findings empirically support SAR concept and therefore highlight the need for larger wetland patches at every opportunity for city planning, design and development.

On the other hand, there are small patch benefits that arguably are of more importance in urban areas. Tulloch *et al*. (2016) and Fahrig (2020) present evidence on why several small patches have a higher species richness that a few large patches. Likewise, the metapopulation theory provides concepts for which can be used to explain and predict the behavior of small size patch habitats that are distributed in an island-like manner - the Nairobi wetlands certainly follow this pattern. The dynamics of the number and distribution of habitats in an unfavorable urban matrix need to be understood from the premise of conservation of metapopulations and metacommunities - not single population or community. Although the debate about 'single large or several small' (SLOSS) continue (Fahrig, 2020), it is certain that the principles relating to small patch benefits contribute immensely to the protection and management of the invariably ubiquitous but shrinking urban palustrine wetland habitats and

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ISSN 1561-7645 (online)
https://dx.doi.org/10.4314/jagst.v21i1.8

their bird biodiversity.

Wetland patch shape complexity, measured in terms of shape index, contributed significantly to the variability in regression model, $p < 0.05$. Patch shape affects species richness in different habitats and contexts (Arellano-Rivas *et al*., 2018). Highly convoluted wetland shapes as measured by high shape index up to 1.93 for Paradise lost recreational dam, indicates the presence of lobes and coves that provide variability of the habitat, thus high species richness.

One significant observation in this study is that ABSR not only correlated positively (R = 0.56) and significantly with area of open water, $P = 0.001$, but also to the perimeter of open water $p = 0.018$. Although wetlands that were fully covered with hydrophytes still contained a number of aquatic bird species, it is important to highlight that the presence of open water contributed immensely to species richness and abundance. Therefore, in wetland planning, design, development and management, there is need to consistently provide for open water and avoid wetlands being fully covered with hydrophytes. In particular, for Nairobi, appropriate control measures are required to halt invasive species of reeds and rushes that menacingly covers wetlands, because of their high dispersal traits, choking other plants and animals.

The regression model to examine the relationship between ABSR and the characteristics of the neighbourhood context was also significant, $p < 0.05$. Whereas there was a positive correlation of 0.55, only 30% of the variability in ABSR could be explained by the neighbourhood characteristics. That notwithstanding, this study found that a high number of urban activities surrounding wetlands negatively affected the habitability by birds. On the other hand, greater proportion of open greenspace would increase habitability. Therefore, urban planning geared towards increasing biodiversity of aquatic birds would minimize urban activities around wetlands in order to reduce on disturbance to the wetland habitats.

Although an R^2 of 51% of wetland patch pattern was attributed to the variability of ABSR, the other 49% may be attributed to the fact that urban socio-ecological systems, unlike natural systems, are non-linear and idiosyncratic (Alberti, 2008; Riva & Nielsen, 2020). Success of sampling design in wetland studies has also been found to have challenges that affect results. Olsen et al. (2019) in a nation-wide study of US wetlands found that 65% of wetlands were sampleable, while 25% was estimated to be non-sampleable due to access denial, and 7% was physically inaccessible. Similar accessibility challenges were witnessed in this study.

Ecological planning is the application of ecological knowledge and concepts to integrate nature and natural processes in predominantly socio-economic urban systems (Ndubisi, 2014). Knowledge on biodiversity structure as influenced by urban patterns is therefore an important starting point. This study focused on urban palustrine wetlands which are key ecosystems with relatively high species richness. Proportionately, wetlands are the most biodiverse ecosystems hosting 40% of world’s species (Convention on Wetlands, 2021). It is therefore important that urban wetlands are planned for, designed, protected and managed

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in way that ensures continued biodiversity.

To achieve high and continued biodiversity of urban wetlands, this study has empirically demonstrated that collectively, wetland sizes, perimeters, areas of open water, edges and buffer zones, and neighbouring lands uses affect wetland biodiversity. Therefore, there is need for policy directions and wetland conservation frameworks that address this wetland attributes. In particular, the framework should provide the best factor or metric combinations that must be employed in determining wetland quantities, location, design, and planning, in order to increase and sustain biodiversity. Wetlands are fractal patches, reacting in similar ways to a disturbance or natural regime such as weather patterns, for example, flooding or dry climate. Therefore, the more they are assessed as metacommunity patches, the better for monitoring and management to avoid species local extinctions that lead to reduction of the overall landscape biodiversity.

The overriding objective for ensuring biodiverse wetlands is to increase access to nature for urban residence. According to the Convention on Biological Diversity (2021) the most important target of the post-2020 framework for cities is item number 12, where parties commit to “increase the area of, access to, and benefits from green and blue spaces, for human health and well-being in urban areas”. This important recognition at the UN level highlights the importance of assessing the interface between biodiversity and human well-being in urban areas. Human beings have an innate nature to associate closely with plants and animals, the biophilia hypothesis (Kellert, 1995; Wilson, 2007). This hypothesis has gained traction leading to development of related concepts of biophilic cities and biophilic design (Beatley, 2011; Beatley & Newman, 2013) which has been experimented successfully in Singapore (Newman, 2014). However, their application remains scanty and generalized. To have an impact, it behooves urban planners and urban policy makers to focus on specific natural ecosystems such as wetlands in order to understand individual contributions at the patch and landscape levels. For the Nairobi landscape, it is now quantitatively evident that wetlands are rich in aquatic bird biodiversity with a total population of 2057 aquatic birds, distributed in 46 species.

This study found that although wetlands are not designed or constructed for biotic communities, plants and animals would nevertheless inhabit them. This should not be the norm since most of biotic communities become endangered in ecological traps (Hale *et al*., 2019). At the wetland patch level, bioengineering patch patterns should be made a priority. Although urban wetland infrastructure and utilities are high engineering elements, it is important to incorporate biological processes that better sustain their functionality. For the various wetland needs and use, biosystems frameworks should be integrated to have scores that provide optimum factor combinations for bioengineering success.

Further, such frameworks should provide enhancement, regeneration and restoration measures for underperforming wetland types, whether existing or proposed. These may include adjustment of size, shape or the edges. Lastly, the framework should provide legal development control measures for creation of new wetlands or identification of critical

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ISSN 1561-7645 (online)
https://dx.doi.org/10.4314/jagst.v21i1.8

wetlands for conservation.

5.0 Conclusion

Empirical studies detailing relationship between wetland patch pattern and biodiversity of aquatic birds in an urban landscape contribute to a sound basis for ecological planning and result-oriented biodiversity conservation generally. From this study, it is evident that wetland size, perimeter, shape, edge affects the species richness and abundance of aquatic birds. Likewise, attributes of wetland neighbouhood such as the number of land uses and the proportion of greenspace also affect aquatic bird biodiversity. Efforts towards integration of biodiversity-oriented patch patterns will go a long way to mainstream and improve the quality and persistence of wetland ecosystems in cities. Being the first research on wetlands at the city-wide scale, this study can provide the baseline information for future monitoring and evaluation of wetland biodiversity trends in Nairobi and beyond.

The loss of wetland ecosystems not only denies urban areas the ecosystem services they would have benefitted from, but also lead to local extinction of species that could be pivotal for the biological preservation of such systems. That notwithstanding, one advantage of palustrine wetlands is their ubiquitous distribution, in addition to their constant creation, as part of the ever-expanding urban infrastructure. This, in principle, allows for continued persistence of aquatic biodiversity within the urban fabric. Practical implementation, thoughtful planning and development, drawing on the principles and concepts of the metapopulation theory can contribute to high success in the conservation efforts of biodiversity of urban wetlands.

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8.0 Appendixes

Appendix 1 Table of total population and number of species of aquatic birds in the 31 wetlands

	FAMILY	Common name	Karura forest Lily Pond 1	Karura forest butterfly marsh pond 2	UON-Kabete Campus marsh 3	Kangemi dam 4	Lake view estate dam 5	Rosslyn Red Hill roadside wetland 6	Nyari residential estate dam 7	Evergreen park & garden dam 8	Paradise lost recreational dam 9	Paradise gardens farm pond 10	Githurai clayworks quary pond 11	Nairobi water sewage treatment plant, Rua 12	Syokimau dam 13	Nairobi dam, Kibera 14	Ngong Race-course dam 15	Ngong forest quarry pond 16	South Bypass roadside dam 17	Southern Bypass-Karen interchange dam 18	Samburu Karen C,Hillcrest dam 19	Mamba village dam 20	CUEA quary pond 21	Karen Country club sewage treatment plant 22	Langata botanical gardens quarry pond 23	Karen Roses greenhouses pond 24	Multimedia University sewage plant 25	The Hub Karen pond 26	Ondiri swamp, Maguga 27	Gideon Dam, Ondiri 28	Lenana High School dam 29	Mountain view estate marsh 30	Uhuru park recreational pond 31	TOTAL POPULATION PER SPECIES
1	GREBES	Little Grebe	5	0	0	0	0	0	0	0	4	27	3	240	24	8	5	0	2	14	11	6	1	2	0	0	2	0	0	2	7	0	2	365
2	HAMERKOP & STORKS	Hamerkop	0	1	0	1	0	0	0	1	0	0	0	5	0	2	0	0	0	0	0	3	0	1	0	1	1	1	1	2	3	2	1	26
3		Marabou Stork	0	0	0	0	0	0	0	2	0	0	2	0	0	2	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	113	121
4		Yellow-billed Stork	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4
5	IBISES & SPOONBILLS	Sacred Ibis	0	0	2	4	3	4	11	24	0	0	14	130	5	6	0	0	0	0	3	11	2	0	1	0	7	0	5	3	11	1	0	247
6		Hadada Ibis	0	3	2	9	4	7	5	9	0	2	4	8	0	0	3	0	5	3	2	8	5	12	0	4	4	0	2	2	4	24	5	136
7		Glossy Ibis	0	0	0	0	0	0	0	0	0	0	0	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37
8	CRANES	Grey Crowned Crane	0	0	0	0	0	0	0	0	2	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	17
9	GALLINULES, COOTS, CRAKES	Black Crake	0	0	6	2	4	0	2	14	0	0	5	4	4	4	0	0	0	0	8	5	0	8	0	0	0	0	2	4	2	1	0	75
10		Common Moorhen	9	0	8	10	6	0	0	0	0	4	0	0	17	0	0	0	1	10	2	5	1	2	0	0	0	0	1	0	0	0	0	76
11		Purple Swamphen	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
12	CORMORANTS	Great Cormorant	0	0	0	2	3	0	0	0	4	0	0	0	15	0	0	0	0	0	4	1	0	0	0	0	0	0	0	0	9	0	0	38
13		Long-tailed (Reed) Cormorant	0	0	0	13	6	0	1	2	16	3	10	3	3	0	4	0	4	3	17	1	5	2	2	0	1	0	0	7	26	0	0	129
14	HERONS & EGRETS	Cattle Egret	0	3	0	0	0	0	0	0	15	0	2	68	7	0	0	0	0	0	0	1	5	0	0	0	0	5	0	1	10	1	0	118
15		Little Egret	0	0	0	0	0	0	0	0	0	0	0	16	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
16		Black-headed Heron	0	1	1	0	0	0	0	2	0	0	1	9	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	17
17		Common Squacco Heron	0	0	0	1	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
18		Great Egret	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
19		Grey Heron	0	1	1	0	0	2	0	0	0	0	5	4	0	0	0	1	0	0	2	0	0	0	0	0	1	0	0	0	1	0	0	18
20		Yellow-billed or Intermediate Egret	0	0	0	0	0	2	0	0	0	1	0	7	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	13
21	DARTER	African darter	0	0	0	0	0	0	1	0	0	0	0	0	5	0	0	0	0	0	4	2	1	0	0	0	0	0	0	0	4	0	0	17
22	DUCKS & GEESE	Yellow-billed Duck	9	0	0	0	3	3	0	0	0	22	0	0	4	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	51
23		White-faced Whistling Duck	0	0	0	0	0	0	0	0	0	1	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31
24		Egyptian Goose	0	5	0	0	4	0	2	5	4	0	13	136	0	0	14	0	0	0	5	3	3	2	0	7	2	0	0	0	2	0	0	207
25		Red-billed Teal	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
26		White-backed Duck	5	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
27	KINGFISHERS	Malachite Kingfisher	0	0	0	0	1	1	1	1	1	0	2	1	4	0	1	0	2	0	1	0	2	0	0	0	0	0	1	1	1	0	0	21
28		Pied Kingfisher	0	0	0	1	0	0	0	0	0	0	2	6	2	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	5	0	4	23
29		Grey-headed Kingfisher	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
30	PLOVERS	Giant Kingfisher	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
31		Black-crowned Night Heron	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	14	1	2	0	0	0	0	0	0	0	0	0	0	37
32	SANDIPIPPER	Ruff	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
33		Common Sandpiper	0	0	0	0	0	0	0	1	3	0	0	8	0	0	2	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	17
34		Marsh Sandpiper	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
35		Wood Sandpiper	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23
36	JACANAS	African Jacana	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
37	DUCKS	African Black Duck	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
38	PLOVER	Three-banded Plover	0	0	0	0	0	0	0	0	0	0	0	17	0	0	1	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	24
39		Spur-winged Plover (Lapwing)	0	0	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21
40		Blacksmith Plover (Lapwing)	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
41		Water Thick-knee	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
42		African Snipe	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
43	BIRDS OF PREY	Osprey	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
44		African Fish Eagle	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	7
45	PELICAN	Great White Pelican	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
46	STILTS & AVOCETS	Black-winged Stilt	0	0	0	0	2	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23
		TOTAL POPULATION	28	14	20	47	40	19	27	62	51	72	84	873	97	22	30	2	14	43	73	53	27	31	3	13	26	6	15	23	88	29	125	2057
		ALPHA DIVERSITY	4	6	6	10	10	5	9	11	9	11	14	30	13	5	7	2	5	6	11	17	10	9	2	4	9	2	8	9	15	5	5	

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Appendix 2 List of the 31 sample wetlands, city block context, surrounding land-use, how the wetland was created and current or intended use

	WETLAND	CITY_BLOCK	LAND_USE	ORIGIN	USE
1	Karura forest lily pond	1-Waiyaki Way/ Thika Rd	Forest	Quarry	Nature conservation
2	Karura forest butterfly marsh	1-Waiyaki Way/ Thika Rd	Forest	Natural	Nature conservation
3	UON Kabete campus marsh	1-Waiyaki Way/ Thika Rd	Agricultural	Natural	Agricultural irrigation
4	Kangemi dam	1-Waiyaki Way/ Thika Rd	Residential	Damming	Domestic use
5	Lakeview residential estate dam	1-Waiyaki Way/ Thika Rd	Residential	Damming	Recreation
6	Rosslyn Red Hill roadside marsh	1-Waiyaki Way/ Thika Rd	Residential	Natural	Agricultural irrigation
7	Nyari residential estate dam	1-Waiyaki Way/ Thika Rd	Residential	Damming	Recreation
8	Evergreen park & garden dam	1-Waiyaki Way/ Thika Rd	Agricultural	Damming	Recreation
9	Paradise lost recreational dam	1-Waiyaki Way/ Thika Rd	Agricultural	Damming	Recreation
10	Paradise gardens farm pond	1-Waiyaki Way/ Thika Rd	Agricultural	Quarry	Agricultural irrigation
11	Githurai clayworks quarry pond	2-Thika Rd/ Mombasa Rd	Residential	Quarry	Abandoned quarry
12	Nairobi water sewage treatment plant, Ruai	2-Thika Rd/ Mombasa Rd	Residential	Constructed	Sewage treatment
13	Syokimau dam	2-Thika Rd/ Mombasa Rd	Commercial	Damming	Domestic use
14	Nairobi dam, Kibera	3-Mombasa Rd/ Ngong Rd	Residential	Damming	Domestic use
15	Ngong race course dam	3-Mombasa Rd/ Ngong Rd	Forest	Damming	Recreation

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16	Ngong forest quarry pond	3-Mombasa Rd/ Ngong Rd	Forest	QUARRY	Abandoned quarry
17	Southern bypass roadside dam	3-Mombasa Rd/ Ngong Rd	Forest	DAMMING	Nature conservation
18	Southern bypass-Karen interchange dam	3-Mombasa Rd/ Ngong Rd	Forest	DAMMING	Nature conservation
19	Samburu Karen C, Hillcrest dam	3-Mombasa Rd/ Ngong Rd	Institutional	DAMMING	Recreation
20	Mamba Village dam	3-Mombasa Rd/ Ngong Rd	Institutional	DAMMING	Recreation
21	CUEA quarry pond	3-Mombasa Rd/ Ngong Rd	Institutional	QUARRY	Abandoned quarry
22	Karen country club sewage treatment plant	3-Mombasa Rd/ Ngong Rd	Recreational	CONSTRUCTED	Sewage treatment
23	Langata botanical gardens quarry pond	3-Mombasa Rd/ Ngong Rd	Recreational	QUARRY	Recreation
24	Karen roses greenhouses pond	3-Mombasa Rd/ Ngong Rd	Agricultural	CONSTRUCTED	Agricultural irrigation
25	Multimedia university sewage plant	3-Mombasa Rd/ Ngong Rd	Institutional	CONSTRUCTED	Sewage treatment
26	The Hub Karen pond	3-Mombasa Rd/ Ngong Rd	Commercial	CONSTRUCTED	Recreation
27	Ondiri swamp, Maguga	3-Mombasa Rd/ Ngong Rd	Agricultural	NATURAL	Agricultural irrigation
28	Ondiri swamp, Gedion dam	4-Ngong Rd/ Waiyaki Way	Agricultural	NATURAL	Agricultural irrigation
29	Lenana high school dam	4-Ngong Rd/ Waiyaki Way	Institutional	DAMMING	Agricultural irrigation
30	Mountain view estate marsh	4-Ngong Rd/ Waiyaki Way	Residential	NATURAL	Domestic use
31	Uhuru park recreational pond	4-Ngong Rd/ Waiyaki Way	Recreational	CONSTRUCTED	Recreation

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Appendix 3 List of alpha α diversity for birds in the 31 wetlands

	WETLAND	AQUATIC BIRDS	TERRESTRIAL BIRDS	ALL BIRDS
1	Karura forest lily pond	4	18	22
2	Karura forest butterfly marsh	6	14	20
3	UON Kabete campus marsh	6	21	27
4	Kangemi dam	10	17	27
5	Lakeview residential estate dam	10	15	25
6	Rosslyn Red Hill roadside marsh	5	12	17
7	Nyari residential estate dam	9	15	24
8	Evergreen park & garden dam	11	26	37
9	Paradise lost recreational dam	9	24	23
10	Paradise gardens farm pond	10	20	30
11	Githurai clayworks quarry pond	14	23	37
12	Nairobi water sewage treatment plant, Ruai	31	21	51
13	Syokimau dam	13	9	22
14	Nairobi dam, Kibera	5	18	23
15	Ngong race course dam	7	26	33
16	Ngong forest quarry pond	2	19	21
17	Southern bypass roadside dam	5	26	31
18	Southern bypass-Karen interchange dam	6	9	15
19	Samburu Karen C, Hillcrest dam	11	22	33
20	Mamba Village dam	17	30	47
21	CUEA quarry pond	10	21	31
22	Karen country club sewage treatment plant	10	28	38
23	Langata botanical gardens quarry pond	2	14	16
24	Karen roses greenhouses pond	4	14	18
25	Multimedia university sewage plant	9	24	33
26	The Hub Karen pond	2	24	26
27	Ondiri swamp, Maguga	8	20	28
28	Ondiri swamp, Gedion dam	7	19	26
29	Lenana high school dam	17	23	40
30	Mountain view estate marsh	5	23	28
31	Uhuru park recreational pond	5	16	21

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Appendix 4 List of the 31 wetlands and the values of landscape metrics and elevation

	WETLAND	E (m)	P_1 (km)	CA (ha)	P (km)	A (ha)	P/A	SI	CAI	A_E (ha)	P_W (km)	A_W (ha)	OWI
1	Karura forest lily pond	1685	0.55	1.18	0.62	1.87	3.32	1.14	0.63	0.70	0.37	0.46	0.39
2	Karura forest butterfly marsh	1715	0.70	2.70	0.72	2.96	2.44	1.05	0.91	0.26	0.01	0.01	0.01
3	UON Kabete campus marsh	1832	0.55	1.70	0.64	2.49	2.55	1.01	0.68	0.79	0.16	0.10	0.06
4	Kangemi dam	1852	1.02	3.85	1.06	4.49	2.36	1.25	0.86	0.64	0.87	3.29	0.85
5	Lakeview residential estate dam	1755	0.55	0.93	0.55	1.24	4.38	1.22	0.75	0.31	0.81	1.12	1.21
6	Rosslyn Red Hill roadside marsh	1723	0.68	2.88	0.72	3.30	2.16	1.00	0.87	0.42	0.02	0.01	0.01
7	Nyari residential estate dam	1718	1.17	4.07	1.20	4.73	2.54	1.38	0.86	0.66	1.23	4.06	1.00
8	Evergreen park & garden dam	1700	0.66	1.55	0.70	1.96	3.54	1.25	0.79	0.41	0.66	1.56	1.00
9	Paradise lost recreational dam	1676	2.20	7.02	2.23	8.36	2.66	1.93	0.84	1.33	1.86	6.28	0.89
10	Paradise gardens farm pond	1712	0.81	3.39	0.85	3.89	2.18	1.08	0.87	0.50	0.39	0.47	0.14
11	Githurai clayworks quarry pond	1539	1.39	6.87	1.43	7.81	1.82	1.27	0.88	0.94	1.80	3.55	0.52
12	Nairobi water sewage treatment plant	1494	9.59	384.17	9.64	390.5	2.46	1.22	0.98	6.31	14.96	362.0	0.94
13	Syokimau dam	1607	1.36	5.82	1.40	6.71	2.08	1.35	0.87	0.89	1.12	4.60	0.79
14	Nairobi dam, Kibera	1688	4.14	31.28	4.15	34.01	1.21	1.78	0.92	2.73	0.28	0.23	0.01
15	Ngong race course dam	1809	1.29	4.68	1.32	5.47	2.41	1.41	0.86	0.79	1.32	3.91	0.83
16	Ngong forest quarry pond	1831	1.08	2.55	1.10	2.55	4.32	1.73	1.00	3.21	4.71	0.07	0.03
17	Southern bypass roadside dam	1844	0.61	0.77	0.65	1.15	5.57	1.50	0.67	0.38	0.37	0.51	0.66
18	Southern bypass-Karen interchange dam	1835	1.14	2.49	1.17	3.19	3.66	1.64	0.78	0.70	1.40	0.62	0.25
19	Samburu Karen C, Hillcrest dam	1826	0.95	1.86	0.76	2.31	3.27	1.24	0.81	0.45	0.95	1.75	0.94
20	Mamba Village dam	1806	0.83	1.48	0.76	1.96	3.86	1.35	0.75	0.48	0.83	1.48	1.00
21	CUEA quarry pond	1798	0.24	0.24	0.28	0.39	6.99	1.10	0.61	0.16	0.21	0.18	0.73
22	Karen country club sewage plant	1856	0.74	1.88	0.78	2.34	3.31	1.27	0.80	0.46	0.04	0.01	0.01
23	Langata botanical gardens quarry pond	1803	0.17	0.17	0.20	0.28	7.13	1.00	0.61	0.11	0.27	0.41	2.36
24	Karen roses greenhouses pond	1873	0.40	0.62	0.47	1.21	3.88	1.07	0.52	0.59	0.27	0.41	0.65

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