



Nyandungu Urban Wetland Eco-Park, Rwanda



Biodiversity Baseline Survey

**Report by the UNESCO Category 2 Center of Excellence in Biodiversity and
Natural Resource Management (CoEB)
University of Rwanda**

October 2023

Executive Summary

The Nyandungu Urban Wetland Eco-Park represents a unique model of wetland restoration in an urban area with high human population density and nearby industrial zones. In order to document progress towards restoration of this wetland, which contributes to climate adaptation, biodiversity conservation and tourism opportunities, as well as other ecosystem services, a baseline assessment was conducted and indicator species identified to support monitoring and change detection. The baseline biodiversity survey for the restored Nyandungu Urban Wetland Eco-Park/Nyandungu Eco-Park in Rwanda took place 7-16 June 2023, in the transition period between the rainy and dry seasons. The purpose of the survey was to provide an assessment of biodiversity in the restored Eco-Park, which can be used for monitoring the state of the wetland complex over time. Seven taxon groups were sampled in a rapid assessment approach. These taxon groups were selected because they represent species that serve as indicators of ecosystem health and functioning and included amphibians, birds, aquatic macroinvertebrates, fish, butterflies, and mammals. Reptiles were also sampled but few were observed, and are not included in the proposed monitoring scheme, although the species observed are presented in this report. A water quality assessment was also conducted to contribute to the baseline information about the environmental status of the restored wetland.

Five sectors of the restored wetland complex were sampled during the survey. Sectors 3, 4 and 5 had the greatest species richness across all taxon groups, while 1 and 2 also had biodiversity observations. Most of the species documented across all taxon groups are indicative of disturbed wetland habitats and for birds, most reflect common birds in the country. A total of 83 bird species including one endangered species were observed. Non-native plant species were observed, including some invasive species.

The aquatic macroinvertebrates are especially good indicators of water quality. Most of the macroinvertebrate families found in the survey are generalists or pollution-tolerant groups, and their high dominance in the survey is likely associated with large amounts of organic wastes that accumulate in the wetland from the surrounding landscape. An important number of caddisfly individuals belonging to the family Hydropsychidae and Leptoceridae were recorded at one site in Sector 2 and at another site in Sector 4. They were found in less disturbed sites that are characterized by clean flowing water containing stony substrates and dense tree/vegetation cover. It is believed that these Trichoptera groups will continue to re-establish in several parts of the Nyandungu Urban Wetland Eco-Park if the wetland complex is well managed and protected from pollution. The future establishment of this group will serve as a good indication and monitoring tool of wetland recovery success. The amphibian assemblages found in the wetland complex reflect more disturbed wetlands. If the wetland complex continues to improve in health and integrity, continued monitoring over time of this taxon group should also serve as a good indicator of improved ecosystem health.

Water quality values were within the typical range, although fecal coliforms and *Escherichia coli* were detected. Pollution from garbage, including plastic waste, is a problem in the Eco-Park, as well as alien invasive species (plants mainly) and polluted water incoming from the surrounding areas. Management suggestions include improved signage that educates about the

importance of waste management, wetlands values, and about the various species that can be observed.

Biodiversity monitoring building on this baseline is suggested on an annual basis, and if possible capturing the seasonal variation in rainfall, including the key taxon groups included in this survey. It could be valuable to sample two different seasons, the wet and the dry season, to detect differences, but if only season can be sampled, this assessment provides a baseline for certain species that can serve as indicators of healthy, functioning ecosystems and ecological integrity. In addition to direct observations, camera traps and passive acoustic monitoring tools could be deployed. We identified several species that could serve as flagship species for the Eco-Park, including the endangered grey crowned crane (*Balearica regulorum*), the spotted-necked otter (*Hydrictis maculicollis*) listed as Near Threatened, and some charismatic butterfly species. Flagship species are attractive and charismatic species that are relatively easy to see and can be enjoyed by the general public; the ones identified in this survey are associated with wetland ecosystems.

A citizen science approach can be adopted, especially with park visitors, environmental clubs or school groups. There are several applications available for smart phones that enable georeferencing of observations. We also suggest some simple revenue generating projects that could help educate the public about biodiversity in the park.

Overall, the baseline survey suggests the park is in the early stages of restoration. Given the great interest in the park and its protection, there is good reason to assume the wetland complex will continue on a trajectory of restoration if the surrounding land use and land management are controlled, and there are several opportunities to promote biodiversity and engage citizens in its sustainable management.

Acronyms and Abbreviations

ARCOS: Albertine Rift Conservation Society
CAVM: College of Agriculture, Animal Sciences and Veterinary Medicine
CoEB: Center of Excellence in Biodiversity and Natural Resource Management
CST: College of Science and Technology
EDPRS: Economic Development and Poverty Reduction Strategy of Rwanda
IUCN: International Union for Conservation of Nature
pH: Hydrogen Potential
RBIS: Rwanda Biodiversity Information System
REMA: Rwanda Environment Management Authority
UR: University of Rwanda
°C: Degree Celcius
EIA: Environmental Impact Assessment
MEA: Multilateral Environmental Agreement
NUWEP: Nyandungu Urban Wetland Ecotourism Project
ILAM: Integrated Landscape Assessment and Monitoring

Table of contents

Executive Summary	ii
Acronyms and Abbreviations	iv
Table of contents	v
List of Figures	vii
List of tables.....	viii
1. Introduction.....	1
1.1. Goal.....	2
1.2. Specific objectives	2
2. Literature Review.....	2
2.1. Nyandungu Urban Wetland Eco-Park conservation and management	2
2.2. Previous Biodiversity surveys.....	3
3. The Baseline Biodiversity Assessment.....	3
3.1. Amphibians and reptiles.....	3
3.1.1. Introduction.....	3
3.1.2. Methods.....	4
3.1.3. Species identification	4
3.1.4. Amphibian and Reptile Findings	6
3.1.5. Discussion	12
3.2. Birds.....	14
3.2.1. Introduction.....	14
3.2.2. Methods.....	15
3.2.3. Birds of Nyandungu Urban Wetland Eco-Park.....	16
3.2.4. Discussion	19
3.3. Plants.....	20
3.3.1. Introduction.....	20
3.3.2. Methods.....	20
3.3.3. Findings.....	20
3.3.4. Comparison with previous survey.....	28
3.3.5. Discussion	28
3.4. Fish.....	28
3.4.1. Introduction.....	28
3.4.2. Methods.....	29
3.4.3. Results.....	30
3.4.4. Discussion	34
3.5. Aquatic invertebrates	34
3.5.1. Introduction.....	34
3.5.2. Methods.....	35
3.5.6. Discussion.....	39
3.6. Butterflies.....	40
3.6.1. Introduction.....	40
3.6.2. Methods.....	40
3.6.3. Data analysis	41
3.6.4. Findings.....	42
3.6.5. Discussion	44
3.7. Mammals.....	46
3.7.4. Introduction.....	46
3.7.5. Methods.....	47
3.7.6. Findings.....	48
3.7.7. Discussion	50
3.8. Water Quality Assessment.....	51
3.8.1 Physical and Chemical characteristics of water in the Ponds	51

3.9 Conclusion and recommendations	53
3.9.1 Conclusions.....	53
3.9.2 The Biodiversity Monitoring Framework	59
3.9.3 Recommendations.....	61
References.....	67
Appendix 1. Data on Biodiversity surveys done in Nyandungu Urban Wetland Eco-park.....	73
Appendix 2. List of taxon teams from the CoEB what conducted the surveys.....	77
Appendix 3. Check list of birds observed during 2023 biodiversity survey (LC: Least Concern; EN: Endangered).....	78
Appendix 4. Water Quality Assessment Data from June 2023 for the Nyandungu Urban Wetland Eco-Park, Rwanda.....	80

List of Figures

Figure 1. Sampling sites and number of individuals of amphibian taxon found at Nyundungu Urban Wetland Eco-Park, Rwanda	5
Figure 2. Photos of the various locations where amphibians were sampled at Nyandungu Urban Wetland Eco-Park, Rwanda	6
Figure 3. Amphibian species richness and diversity of the Nyandungu Urban Wetland Eco-Park, Rwanda	8
Figure 4. Photos of reptile species observed in Nyandungu Urban Wetland Eco-Park, Rwanda.....	10
Figure 5. Photos of amphibian species observed in Nyandungu Urban Wetland Eco-Park, Rwanda. Photo credit: Mapendo Mindje	12
Figure 6. Bird sampling localities in the Nyandungu Wetland Eco-Park, Rwanda	15
Figure 7. Photos of some of the bird species observed in the Nyandungu Wetland Eco-Park, Rwanda. Photo credit: Jean de Dieu Nsenganeza	18
Figure 8. Disturbances and threats observed during the survey in Nyandungu Wetland Eco-Park, Rwanda	19
Figure 9. Photos of some plant species observed in the Nyandungu Urban Wetland Eco-Park, Rwanda	21
Figure 10. Fish sampling localities from the Nyandungu Urban Wetland Eco-Park, Rwanda.....	30
Figure 11. <i>Clarias liocephalus</i> Boulenger, 1898	31
Figure 12. <i>Poecilia reticulata</i> Peters, 1859.....	32
Figure 13. <i>Pseudocrenilabrus multicolor</i> (Scholler, 1903).	33
Figure 14. <i>Haplochromis</i> spp 1 (left) and <i>Haplochromis</i> spp 2 (right) are an undescribed <i>Haplochromis</i> species at the time of this report.	33
Figure 15. <i>Acapoeta tanganicae</i> (Boulenger, 1900).....	33
Figure 16. <i>Enteromius Pellegrini</i>	34
Figure 17. Macro-invertebrates sampling localities from the Nyandungu Urban Wetland Eco-Park, Rwanda.	36
Figure 18. Water quality parameters associated with aquatic invertebrates sampling in Nyandungu Urban Wetland Eco-Park, Rwanda.	39
Figure 19. Butterfly sampling localities in the Nyandungu Urban Wetland Eco-Park, Rwanda.....	41
Figure 20. Butterfly trapping techniques. Use of fruit-baited trap (left) and butterfly net (right) for butterfly sampling.	41
Figure 21. Butterfly species sample (n=56) and their proportions in their respective families in Nyandungu Urban Wetland Eco-Park, Rwanda.....	43
Figure 22. Photos of some butterflies collected at Nyandungu Urban Wetland Eco-Park, Rwanda	44
Figure 23. Locations of mammal sampling and observations in Nyandungu Urban Wetland Eco-Park, Rwanda.	48
Figure 24. Small mammals recorded from the Nyandungu Urban Wetland Eco-Park.....	50
Figure 25. Signs observed during the survey of mammal presence in the Nyandungu Urban Wetland Eco-Park, Rwanda (Carnivore scats that may be serval or side-striped jackal (left), and skin and fur remains of rodents eaten by a carnivores (right)).....	50
Figure 26. The processes involved in biodiversity monitoring and the role of the indicator species and common co-variates associated with the species monitoring. The baseline biodiversity assessment will establish the foundation for the systematic biodiversity monitoring. From Siddig et al. (2015)...	58

List of tables

Table 1. Amphibian habitat description by sector in Nyandungu Urban Wetland Eco-Park, Rwanda ..	5
Table 2. Amphibian and reptile species of the Nyandungu Urban Wetland Eco-Park, Rwanda.....	7
Table 3. Diversity of amphibians per sector in Nyandungu Urban wetland eco-park	8
Table 4. Amphibian species assessments in previous years compared to the 2023 survey	9
Table 5. Beta diversity of amphibians among sectors of Nyandungu Urban Wetland Eco-Park, Rwanda	9
Table 6. Birds surveyed across Nyandungu Urban Wetland Eco-Park, Rwanda by Sectors.....	16
Table 7. Native plant species observed per sector in Nyandungu Urban Wetland Eco-Park, Rwanda. Species names in bold are those recommended to plant in the Eco-Park when more planting is scheduled.....	22
Table 8. Non-native plant species observed per sector in Nyandungu Urban Wetland Eco-Park, Rwanda. Species suspected to be invasive are marked with an ‘x’.	25
Table 9. Fish species and their abundance (N) at the five sampled sectors from Nyandungu Urban Wetland Eco-Park, Rwanda. LC: Least Concern, The sign + indicates the presence and - indicates absence of the fish species in the sampling location.....	30
Table 10. Shannon-Weiner diversity index (H) and taxon occurrence of macroinvertebrates at different streams and rivers in Nyandungu Urban Wetland Eco-Park, Rwanda.....	37
Table 11. Butterfly species recorded in Nyandungu Urban Wetland Eco-Park, Rwanda.....	42
Table 12. Details of sampling design for the survey of mammals at Nyandungu Urban Wetland Eco-Park, Rwanda in June 2023.....	47
Table 13. Mammals recorded at Nyandungu Urban Wetland Eco-Park, Rwanda based on direct and indirect observations.	49
Table 14. Mammals possibly extant at Nyandungu Urban Wetland Eco-Park, Rwanda based on indirect observations, anecdotal observations from interviews, and uncertain identifications.	49
Table 15. Proposed indicator species and their attributes to monitor change and restoration success in Nyandungu Urban Wetland Eco-Park, Rwanda.....	55
Table 16. Potential species for phytoremediation in the Nyandungu Urban Wetland Eco-Park, Rwanda	62

1. Introduction

The Nyandungu wetland, ~121.8 hectares, is shared by the administrative sectors of Nyarugunga (Kicukiro District), Ndera and Kimironko (Gasabo District) in Kigali city. It is located north of the Kigali International Airport and bordered to the south by the Kigali-Kayanza Road (RN3) and the road to Ndera to the east, while Kigali's industrial zone abuts Nyandungu to the north. Nyandungu wetland is drained by two streams: Mwanana and Kabagenda which both flow into the Mulindi stream, a tributary of the Nyabarongo River. In 2018, the Nyandungu wetland was transferred to Rwanda Environment Management Authority (REMA) for management under the Ministry of Environment. Subsequently, REMA initiated a process to rehabilitate the wetland, which represents an incredible ecological restoration story that mirrors Rwanda's country-level commitment to conservation, restoration, and climate adaptation. This area had been severely affected by anthropogenic activities including agriculture for subsistence and cattle grazing in the past, which are the major drivers of biodiversity loss and /or decline. The restored area of the Nyandungu wetland complex is 121.7 hectares. The site was transformed into an Eco-Park meant to promote biodiversity and give visitors an opportunity to connect with nature. An overview of the process of transforming this wetland can be found in the Feasibility Study (REMA 2022). The wetland has become an important destination for residents seeking outdoor activities like walking, biking, running and bird watching, as well as a tourism attraction. The wetland has important habitats for wildlife, native trees, and streams and ponds. The Eco-Park contributes to the improvement of human livelihoods through the provision of various ecosystem services including flood control, and green jobs to surrounding communities.

However, there is currently very little information available on the biodiversity of the Nyandungu Urban Wetland Eco-Park (NUWEP). Based on a survey conducted in 2017 by ARCOS, 96 plant species were recorded. In addition, several species have been introduced including medicinal, cultural, and ornamental plants since the restoration project started. Regarding fauna, only birds have been inventoried, and 100 bird species have been recorded so far. Little has been systematically documented about mammals, reptiles, amphibians, fish, insects, and macro-invertebrates, many of which are good indicators of ecosystem health. Though some data do exist, they cannot be relied on for monitoring the wetland restoration and ecosystem services provisioning due to the lack of baseline information embedded into a solid monitoring system. It is in this regard that the Center of Excellence in Biodiversity and Natural Resource Management (CoEB) at University of Rwanda assembled taxon expertise to conduct biodiversity baseline surveys in NUWEP upon the request of REMA to provide information for a baseline that will support long term monitoring of the restored wetland.

The Nyandungu Urban Wetland Eco-Park is located at an elevation of 1397m and lies near the Nyabarongo River that belongs to Akagera River system and catchment. The wetland is divided into five sectors. In each sector ponds were created that currently harbor fish species and other organisms, and serve as wetland habitats. Sectors 3 to 5 are fenced and reserved for touristic activities, and sectors 1 and 2 are not fenced and are open for some amount of access for fodder collection by local citizens. All the sectors contain a variety of waterbodies in the form of ponds or drainage streams. Sector 1 is located upstream and contains multiple ponds established to contain an amount of sewage evacuated from the surrounding neighborhood.

1.1. Goal

The goal of this study was to contribute to the sustainable management of the Nyandungu Urban Wetland Eco-Park by establishing a baseline for biodiversity at the site. This biodiversity information can be used for future monitoring of the restored wetland complex.

1.2. Specific objectives

- 1) Develop an assessment of the biodiversity of the Nyandungu Urban Wetland Eco-Park including species checklists and information about the threats to the ecosystem health.
- 2) Provide guidance on development of citizen science monitoring of the biodiversity of the Nyandungu Urban Wetland Eco-Park.
- 3) Suggest a monitoring framework for the Eco-Park based on the baseline biodiversity assessment, using biological indicators of the health and ecosystem integrity of the wetland complex.
- 4) Propose approaches for sustainable biodiversity conservation in the Eco-Park.

2. Literature Review

2.1. Nyandungu Urban Wetland Eco-Park conservation and management

Wetlands in Kigali, Rwanda have been threatened by human activities including conversion to agriculture, human settlements, pollution, and commercial and industrial activities that have decreased the flood and pollution abatement capacity of wetlands and compromised their ecological functions. The implementation of urban plans promises to help them recover. During storms, urban wetlands absorb excess rainfall, which reduces flooding in cities and prevents disasters and their subsequent costs. The abundant vegetation in urban wetlands acts as a filter for domestic and industrial waste and this contributes to improving water quality.

In 2012, REMA identified the need to establish an urban wetland recreation and eco-tourism park (REMA, 2012). This was important as there was no park in Kigali, and green spaces are known to be important for human wellbeing and environmental sustainability. The Nyandungu Urban Wetland Eco-Park of Kigali City, Rwanda was completed in 2022 and is open for visitors. It was created under the NUWEP with the goal to restore the Nyandungu degraded area including the biodiversity by introducing native tree species, and restore terrestrial and aquatic habitats (REMA 2022). The area of restoration was 121.7 hectares. The restoration approach used in the Nyandungu wetland is meant to showcase design and management techniques and green technologies that can be used in Rwanda's secondary cities as a model for other wetlands. This new Eco-Park project responds to the Green Economy in the EDPRS II and one of the aspirations of the Vision 2050 of developing green cities. Ecosystem rehabilitation through urban wetland rehabilitation also contributes toward global mitigation of climate change and promote carbon sequestration. NUWEP includes ornamental ponds, gallery forests, medicinal plant garden, paved walkways and cycle lanes, restaurant, information center, and recreational space. It is meant to attract both foreign and local visitors in the City of Kigali.

2.2. Previous Biodiversity surveys

The Rwanda Biodiversity Information system, a national repository for biodiversity information and open access web-based portal (<https://rbis.ur.ac.rw/>) mobilized data records of biodiversity in the Nyandungu Urban wetland Eco-Park. The RBIS indicates that in 2019, seven amphibian species were reported to be present in the wetland from a biodiversity assessment in the City of Kigali; in 2021, the Albertine Rift Conservation Society (ARCOS) through the Integrated Landscape Assessment and Monitoring (ILAM) project, conducted a wetland biodiversity survey where findings showed six species of amphibians present in the wetland; 12 water bird species were reported by the UR-CoEB in 2021 and 15 species of water birds in 2022, two species of insects (odonates) in 2016, and 132 plant species reported in 2021 by Gasabo 3d Design Ltd, Astrik International through the Nyandungu Eco-Park Project compendium (RBIS, 2023) (Appendix 1). Further, 97 plant species were reported in 2017 by the Gasabo 3D project (Gasabo 3D 2017) which were complemented by the report from Mvukiyumwami (2019) showing 373 plant species. For bird species, 100 bird species were recorded in the feasibility study (REMA 2022). These species lists do not represent a comprehensive survey for the Nyandungu Urban Wetland Eco-Park, and indicators species were not highlighted.

3. The Baseline Biodiversity Assessment

To determine if the ecosystem has been restored, and to monitor the health and functioning of the ecosystem, baseline data are needed which will serve as a foundation for regular systematic monitoring of the Nyandungu Urban Wetland Eco-Park. In this baseline assessment, conducted from 7-16 June 2023, seven taxon groups were sampled in a rapid assessment approach. These taxon groups were selected because they represent species that serve as indicators of ecosystem health and functioning, and the CoEB has expertise in the taxon groups (sampling and taxonomy). The teams that sampled in each taxon group are shown in Appendix 2.

3.1. Amphibians and reptiles

3.1.1. Introduction

Amphibians are a comparatively well studied group in Rwanda and have been attributed more attention due to their ecological played roles of excellent biological indicators. Amphibians in Rwandan consist mainly of a large group of frogs and toads under the order Anura (Dehling, 2012; Fischer et al., 2011; Mindje et al., 2020; Roelke & Smith, 2010; Sinsch et al., 2012; Tumushimire et al., 2020). In Rwanda, 62 species of amphibians have been identified, where 58 are fully described and four species remain known at the genus level. Among the fully described species, 53 are frogs, four are toads and one is a Caecilian (Dehling & Sinsch, 2023). Among the families, Hyperoliidae is the largest group with 17 species, and the smallest families include Herpelidae, Microhylidae and Dicoglossidae with one species known for each. Among these species two are known to be endemic to Rwanda: *Hyperolius jackie* (Jackie's Reed Frog/African glass frog) and *Boulengerula fischeri* (Fischer's Caecilian) (RBIS, 2023). Most species are least concern under the IUCN Global Red List Status except two that are Vulnerable

(*Leptopelis karissimbensis* and *Boulengerula fischeri*), two Nearly Threatened (*Phrynobatrachus acutirostris* and *Cardioglossa cyaneospila*), one reported extinct (*Callixalus pictus*) in Rwanda but Vulnerable under the IUCN Red List, two Data Deficient (*Phrynobatrachus kakamikro* and *Hyperolius jackie*) and two not evaluated (*Africalus phantasma* and *Sclerophrys berghei*) (Dehling & Sinsch, 2023).

Amphibians are known to be excellent biological indicators because of their sensitivity to changes in the quality of freshwater ecosystems (Mindje et al., 2020). With the current rate of human use of wetlands in Rwanda, amphibians are threatened by loss of their natural habitats. Amphibian communities in altered habitats generally lose the range-restricted specialist species and predominantly contain wide-spread habitat generalists, leading to community homogeneity at the landscape scale (Dehling & Dehling, 2023). Hence, surveying amphibians in the NUWEP is important to generally understand not only their distribution but also their ecological roles in ecosystems and particularly, the provision of information important to guide policy and decisions on the management and conservation of NUWEP.

3.1.2. Methods

Sampling in NUWEP was done in each of five sectors that comprise the site. In each sector, five sampling units were chosen based on their differences in vegetation and water availability (Table 1; Figure 1). The survey was carried out both days and nights from 7 to 16 June, 2023. Amphibians were surveyed using a visual encounter survey complemented by night acoustic sampling. The visual encounter survey (Crump & Scott, 1994; Roelke and Smith, 2010) was done following existing trails complemented by an active search (Burger et al. 2006) on each side of the trail such as in leaf litter, meadows, channels, ponds, creeks and in Papyrus swamps considered as major sampling units in each of the five sectors (Figure 2). Night assessments were carried out starting shortly after sunset, i.e. from 18h00 to 20h00 in the night. For acoustic sampling, frog calls were recorded using a recording device (iPhone XS Max) (Mindje et al., 2020) to aid identification by acoustic structure (Dehling & Sinsch, 2023). During data collection, to complement the herpetofauna, reptiles were assessed during the day using active searching in likely habitats and opportunistic encounter survey following trails.

3.1.3. Species identification

For amphibians, call recordings were used to develop acoustic structures used in case of identifying calling species. This was complemented by morphological corroborations (Dehling & Sinsch, 2023). Species that were not fully identified in the field were collected, photographed and specimens kept in 70% ethanol for further identification. Field identification was based on morphological characteristics (e.g., skin color patterns, body morphology/toe webbing/toe length, snout). For reptiles, species encountered were photographed and identified with collaboration of reptile experts in Rwanda and Field Guide to East African Reptiles (Spawls et al., 2006).

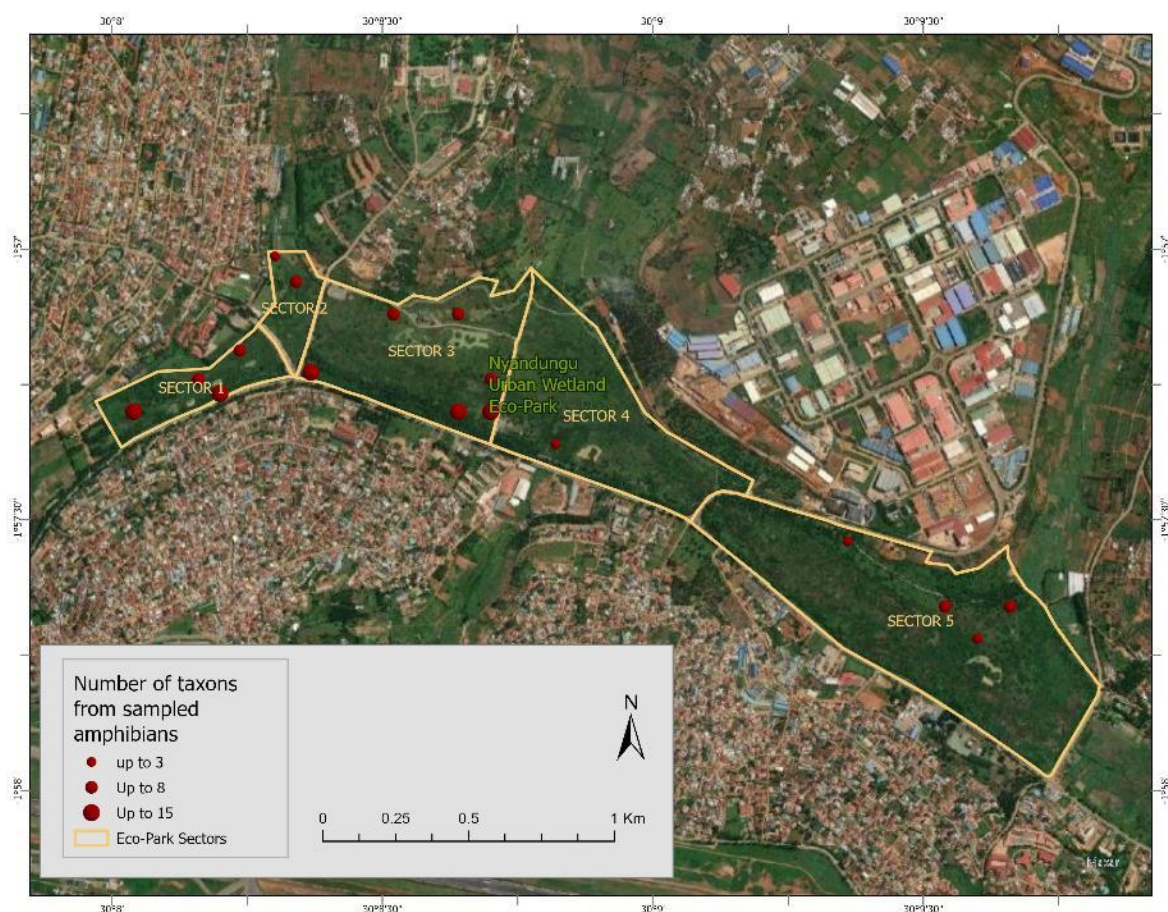


Figure 1. Sampling sites and number of individuals of amphibian taxon found at Nyundungu Urban Wetland Eco-Park, Rwanda

Table 1. Amphibian habitat description by sector in Nyundungu Urban Wetland Eco-Park, Rwanda

Sector	Habitat description	Degree of disturbance	Threats
1	Area dominated by ponds, creek, flooded and unflooded grasses, water canal, Cyperus vegetation	70%	Plastic pollution
2	Water creek, Cyperus vegetation (dominant), flooded grasses	70%	Plastic pollution
3	Cyperus (dominant), small water pools, ponds, flooded and unflooded grasses	70%	Invasive species (<i>Paspalum sp</i>)
4	One Pond, Cyperus vegetation (dominant), tree shrubs	40%	Invasive species (<i>Paspalum sp</i>)
5	Small water pools, flooded and unflooded grasses, a pond	60%	Plastic pollution



Water holes and ponds



Cyperus vegetation and flooded meadows



Creek and flooded meadows

Figure 2. Photos of the various locations where amphibians were sampled at Nyandungu Urban Wetland Eco-Park, Rwanda

3.1.4. Amphibian and Reptile Findings

During the 2023 amphibian and reptile surveys, a total of 11 species of amphibians and two reptile species were recorded (Table 2).

Table 2. Amphibian and reptile species of the Nyandungu Urban Wetland Eco-Park, Rwanda

Species	Common names	IUCN- Global	IUCN – National
Amphibians			
Order: Anura			
Hyperoliidae			
<i>Afraxalus quadrivittatus</i> - Werner, 1908	Four-lined Spiny Reed Frog	LC	LC
<i>Hyperolius kivuensis</i> Ahl, 1931	Kivu Reed Frog	LC	LC
<i>Hyperolius viridiflavus</i> (Duméril & Bibron, 1841)	Common reed frog	LC	LC
Pyxicephalidae			
<i>Amietia nutti</i> (Boulenger, 1896)	Nutt's River Frog	LC	LC
Bufonidae			
<i>Sclerophrys gutturalis</i> (Power, 1927)	African Common Toad	LC	LC
Phrynobatrachidae			
<i>Phrynobatrachus kakamikro</i> Schick, Zimkus, Channing, Köhler & Lötters, 2010	Kakamega Puddle Frog	DD	LC
<i>Phrynobatrachus natalensis</i> (Smith, 1849)	Dwarf puddle frog	LC	LC
Ptychandenidae			
<i>Ptychadena anchietae</i> (Bocage, 1868)	Anchieta's Plain Frog	LC	LC
<i>Ptychadena nilotica</i> (Seetzen, 1855)	Nile Grass Frog	LC	LC
Pipidae			
<i>Xenopus victorianus</i> Ahl, 1924	Lake Victoria Clawed Frog	LC	LC
<i>Xenopus muelleri</i> (Peters, 1844)	Muller's Clawed Frog	LC	LC
Reptiles			
Chamaeleonidae			
<i>Trioceros ellioti</i> (Günther, 1895)	Montane Side-striped Chameleon	LC	-
Scincidae			
<i>Trachylepis striata</i> (Peters, 1844)	African Striped Mabuya	LC	-

DD: Data deficient LC: Least Concern

Alpha diversity (α) among sampled sites

The α -diversity, represented by the Shannon Weiner index (Barnes et al. 1998) was computed based on species abundance data estimates using EstimateS 9.1 version- of the software package (Colwell, 2009). The Shannon Weiner Index represented the α -diversity.

$$H = -\sum_{j=1}^s p_i \ln p_i$$

Where, **H** is the Shannon Index, **p** is the proportion (**n/N**) of individuals of one particular species found (**n**) divided by the total number of individuals found (**N**), **ln** is the natural log, **Σ** is the sum of the calculations, and **s** is the number of species.

Results indicate that Sector 4 had the lowest diversity index and Sector 3 had the highest (Table 3). Sectors 1, 2 and 5 were fairly similar, and sector 1 had the highest richness value (Figure 3).

Table 3. Diversity of amphibians per sector in Nyandungu Urban wetland eco-park

Species	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Eco-park
<i>Afrivalus quadrivittatus</i>	+	-	-	-	-	+
<i>Amietia nutti</i>	+	+	+	+	+	+
<i>Hyperolius kivuensis</i>	+	+	+	+	-	+
<i>Hyperolius viridiflavus</i>	+	+	+	+	+	+
<i>Phrynobatrachus kakamikro</i>	+	+	-	-	-	+
<i>Phrynobatrachus natalensis</i>	-	+	-	-	-	+
<i>Ptychadena anchietae</i>	-	-	+	-	-	+
<i>Ptychadena nilotica</i>	+	+	+	-	+	+
<i>Sclerophrys gutturalis</i>	+	-	-	-	-	+
<i>Xenopus cf. victorianus</i>	+	+	+	+	+	+
<i>Xenopus cf. muelleri</i>	-	-	+	-	+	+
Species richness	8	7	7	4	5	11
Shannon Weiner Index	1.54	1.50	1.67	1.27	1.43	1.81

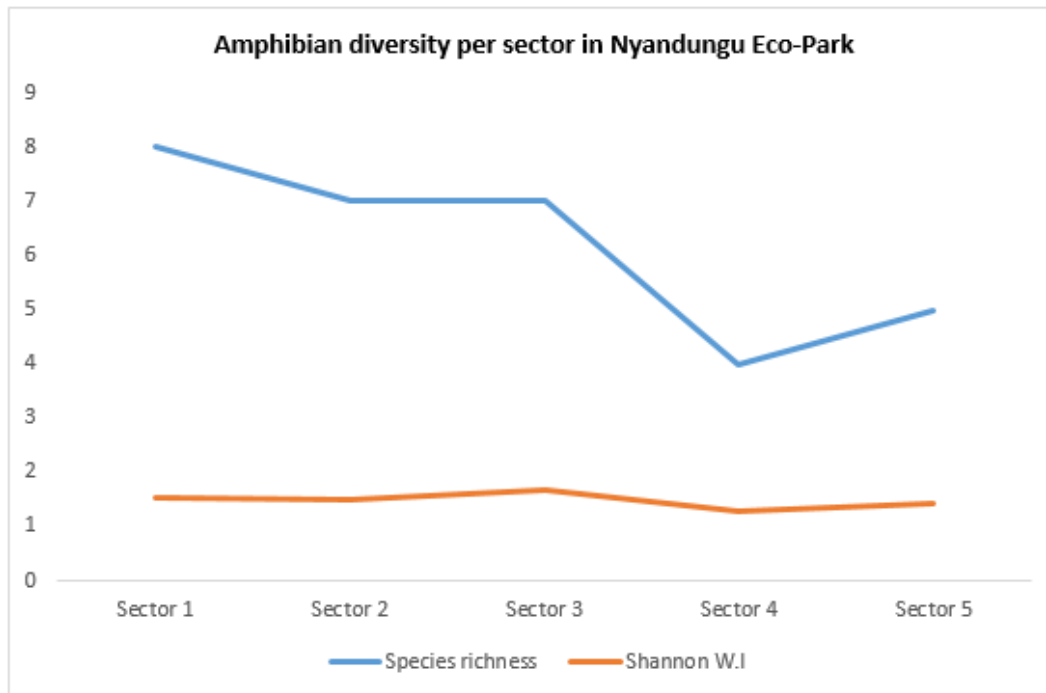


Figure 3. Amphibian species richness and diversity of the Nyandungu Urban Wetland Eco-Park, Rwanda

Table 4 shows a comparison of species presence/absence across three years where data are available, indicating an increase in species richness in 2023. The increase does not necessarily reflect changes in vegetation structure or restoration efforts; it could be due to sampling period and sampling effort. Over the three years of surveys shown in Table 4, the sampling effort was

different making comparative analysis of amphibian species changes over the three years difficult. Systematic sampling done over consistent periods and areas will yield comparative findings.

Table 4. Amphibian species assessments in previous years compared to the 2023 survey

Species	May 2019	July 2021	June 2023
<i>Africalus quadrivittatus</i>	-	+	+
<i>Amietia nutti</i>	+	-	+
<i>Hyperolius kivuensis</i>	+	+	+
<i>Hyperolius viridiflavus</i>	+	+	+
<i>Kassina senegalensis</i>	+	-	-
<i>Phrynobatrachus kakamikro</i>	+	+	+
<i>Phrynobatrachus natalensis</i>	-	+	+
<i>Ptychadena anchietae</i>	-	-	+
<i>Ptychadena nilotica</i>	+	+	+
<i>Sclerophrys gutturalis</i>	+	-	+
<i>Xenopus cfr. victorianus</i>	-	-	+
<i>Xenopus cf. muelleri</i>	-	-	+
Species richness	7	6	11

Beta diversity (β) among the sampled sectors

β -diversity was computed based on both Sorenson index (SI) for species similarity among the sampled sites and Bray Curtis index for species dissimilarity.

(1) Sorenson index $SJ = c / (a + b + c)$

Where:

SJ is the similarity index, c is the number of shared species between the two sites and a and b are the number of species unique to each site

(2) Bray Curtis index $BC_{ij} = 1 - \frac{2C_{ij}}{S_i + S_j}$

Where: i & j are the two sites, S_i is the total number of specimens counted on site i , S_j is the total number of specimens counted on site j , C_{ij} is the sum of only the lesser counts for each species found in both sites.

Results indicate high species similarity between Sectors 3 and 4 ($SI=0.80$), and high dissimilarity between Sectors 2 and 4 ($BCI= 0.188$) (Table 5).

Table 5. Beta diversity of amphibians among sectors of Nyandungu Urban Wetland Eco-Park, Rwanda

Sectors	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5
Sector 1	-	0.714	0.714	0.666	0.615
Sector 2	0.295	-	0.666	0.60	0.545
Sector 3	0.629	0.240	-	0.80	0.727
Sector 4	0.50	0.188	0.62	-	0.666
Sector 5	0.290	0.368	0.4	0.327	-

Bolded numbers: Sorenson index- Similarity index; un-bolded number: Bray Curtis index- Dissimilarity Index.

Figures 4 and 5 show photos of some of the reptiles and amphibians observed in the NUWEP during this baseline survey.



Trioceros ellioti- the montane side-striped chameleon (upper and lower images). Photo credit: Mapendo Mindje



African striped skink (*Trachylepis striata*). Photo Credit: Rachel Uwigenye.

Figure 4. Photos of reptile species observed in Nyandungu Urban Wetland Eco-Park, Rwanda.



Afrixalus quadrivittatus Four-lined Spiny Reed Frog



Amietia nutti Nutt's River Frog



Hyperolius kivuensis Kivu Reed Frog



Hyperolius viridiflavus Common reed frog



Phrynobatrachus kakamikro Kakamega Puddle Frog



Phrynobatrachus natalensis Dwarf puddle frog



Ptychadena anchietae Plain Grass Frog



Ptychadena nilotica Nile Grass Frog



Sclerophrys gutturalis African common toad



Xenopus cfr. Victorianus L Victoria clawed frog



Xenopus cf. muelleri Muller's clawed frog (left and right images)

Figure 5. Photos of amphibian species observed in Nyandungu Urban Wetland Eco-Park, Rwanda. Photo credit: Mapendo Mindje

3.1.5. Discussion

The Nyandungu Urban Wetland Eco-Park survey resulted in eleven amphibian species distributed across the five sectors of the wetland. Previous surveys showed that the wetland

consisted of species known to inhabit altered wetlands which have not changed during the current 2023 survey. The literature by Tumushimire et al. (2019) has shown that altered wetlands in Rwanda share common species that are generalist and able to tolerate heavy ecosystem disturbance. The species recorded in 2019, 2020 and 2023 in Nyandungu Urban Wetland Eco-Park are more of generalist species and hence, can be used to explain the current status of the wetland. Amphibians are known to be good excellent indicators of wetland quality and habitat structure (Cortés-Gómez et al., 2013). The response to habitat change has been observed through changes in alpha diversity which is also measured in terms of species richness and corresponding abundance data (Mindje et al., 2020). Changes in habitats in terms of alteration caused by anthropogenic activities or ecological changes following management efforts during restoration of an ecosystem are reflected in amphibian species presence and abundance (Jongsma et al., 2014; Mindje et al., 2020).

In Rwanda, 62 species have been so far determined and 14-17 among them are known to dominate wetlands whose natural structure has been destroyed by anthropogenic activities (Tumushimire et al., 2020). The Nyandungu Urban Wetland Eco-Park has been rehabilitated following the Government of Rwanda's decision since 2017 to restore this wetland. The current status of the wetland shows high heterogeneity of habitats such as ponds, creeks, flooded and unflooded grassy areas and many others. There was no single habitat specific species observed during this survey. According to the findings from Mindje et al. (2020), the presence of *Hyperolius lateralis* and *Hyperolius cinnamomeoventris* indicate wetlands of relatively natural or intact status. Other species such as *Ptychadena nilotica*, *P. anchietae*, *Sclerophrys gutturalis*, *Hyperolius kivuensis*, *Phrynobatrachus kakamikro*, and *P. natalensis* among others indicate a disturbed wetland state. This was the case of the Nyandungu Urban Wetland Eco-Park where these species were observed distributed across its spatial scale. As a response, amphibians that merely tolerate disturbances have been observed in these habitats which indicates the current status of the wetland as a secondary wetland which does not yet have full recovery of natural composition of amphibian community from previous disturbances.

This report presents a checklist of amphibian species in the Nyandungu Urban Wetland Eco-Park and the differences in diversity among the sectors comprising the wetland complex. Based on the findings, species diversity was seen to be high at Sector 3 followed by the first and second Sectors and lower at Sector 4 followed by the fifth Sector. Findings from Jongsma et al. (2014) demonstrate that amphibian species are very sensitive and vulnerable to little changes in the structure of an ecosystem where little changes in vegetation can affect entire amphibian community assemblages and diversity, hence, their potential to indicate ecosystem health (Saber et al., 2017). For the case of the Nyandungu Urban Wetland Eco-Park, the structure of the habitats with high species diversity have been seen to be more heterogeneous than those with low species diversity, hence more species coexistence among the habitats. Habitat heterogeneity is an important factor influencing alpha diversity among the wetland's sectors, and it is known that disturbance can lead to homogeneity of habitats (Roxburgh et al., 2011). Similar findings were reported by Mindje et al. (2020) in a study of the Mugesera wetland in Rwanda, where habitats that were more heterogeneous had a high species diversity than those with low heterogeneity. This study presents for the first time an overall alpha diversity of

Nyandungu Urban Wetland Eco-Park which would be the basis of information important for the monitoring of the health and restoration effectiveness of the wetland.

Beta diversity explains how species differ or are shared between sectors where findings have shown a high Sorenson similarity index measured between Sector 3 and 4 but also with sector 1 and 2. However, high dissimilarity was observed between Sectors 2 and 4 but also with sector 5. Species similarity or dissimilarity is associated with habitat structure and also ability of a particular species to adapt to particular habitats (Jongsma et al., 2014). In Nyandungu Urban Wetland Eco-Park, sectors with high similarity of species also were seen to share more or less similar habitat structure. This also applied to the sectors with high Bray–Curtis dissimilarity index where differences in habitat structure also influenced differences in shared species. Similarity or dissimilarity of amphibians among sectors of the Nyandungu Urban Wetland Eco-Park is a good indication of the need for general management and conservation of the wetland since all the species shared between sectors or observed in the entire wetland are due to previous degradation and alteration of the natural wetland structure and currently, none of the sectors show full recovery of primary structure that will support unique or habitat-specific species such as species restricted to natural vegetation. This survey was not able to determine species diversity of reptiles due to few observations of species and individuals during the survey period.

Nyandungu Urban Wetland Eco-Park as a wetland under rehabilitation presents an amphibian community assemblage that represents an ecosystem that is disturbed. The absence of species that are specific to natural vegetation in this wetland and indicators of intact healthy wetlands is not surprising since there has not been much time since the wetland has been subjected to restoration activities. The data from this amphibian survey serve as a baseline to monitor changes in the wetlands and its restoration trajectory. Conservation management will be a good practice to assure the wetland recovers fully. Management practices should include the removal of non-native vegetation in the wetland, and removal of other threats such as invasive species to allow regeneration and natural recovery. Section 3.2.4 below presents some of the threats observed in the wetland complex during the survey. There is a need for continuous assessment to monitor changes over time and measure the restoration success of the wetland through assessing and comparing the alpha diversity of species indicators of change.

3.2. Birds

3.2.1. Introduction

Birds are important for different ecosystem services such as regulating through pollination, pest control, and useful indicators for monitoring environmental change (Whelan et al., 2008) such as their ability to track inter-annual variations in food availability related to short-term fluctuations in precipitation (Angelier et al., 2011). Rwanda consists of a comparatively well-known bird community with about 703 bird species including 23 species of global conservation concern, and many endemic and restricted-range species. Rwanda plays a key role in bird and wetlands conservation and promotes tourism through bird watching. The distributions of birds are known to be influenced by several factors including habitat structure and availability of food and nest sites (Fox et al., 2005). Documenting bird distribution and ecology is important to provide information on restoration effectiveness and key to the need of conservation efforts.

To date, there has been little systematic information available on avian diversity for the Nyandungu Urban Wetland Eco-Park. The survey conducted in this project serves as a baseline of information evaluate restoration impacts on wetlands and ecosystems in general.

3.2.2. Methods

Bird assessment in Nyandungu Urban Wetland Eco-Park included a stationary point-count sampling method to record avian occurrence and abundance (Volpato et al., 2009). The stationary point-count method maximizes species detectability and minimizes habitat destruction and intrusion (Fuller & Langslow, 1984). This method has been widely applied in surveys in Rwanda and a range of studies in other tropical ecosystems (Rurangwa et al., 2021). In this survey, the point-count technique used a circular point (station) with 50 m radius to conduct audio-visual detection of birds from the center point.

The points were established along pre-determined habitat types across the sectors in the park, and a distance of 100 m was maintained between the points to avoid double counting (Figure 6). To increase the chances of detecting cryptic and nocturnal species, acoustic recording was used (Hobson et al., 2008) with opportunistic acoustic sampling using a mobile phone application. A minimum of ten point counts were conducted per day from 6h30 to 11h30 to cover a large area of the wetland, with a duration of 15 minutes per point. All birds observed were identified and the main activity and habitat type in which they were observed was noted.

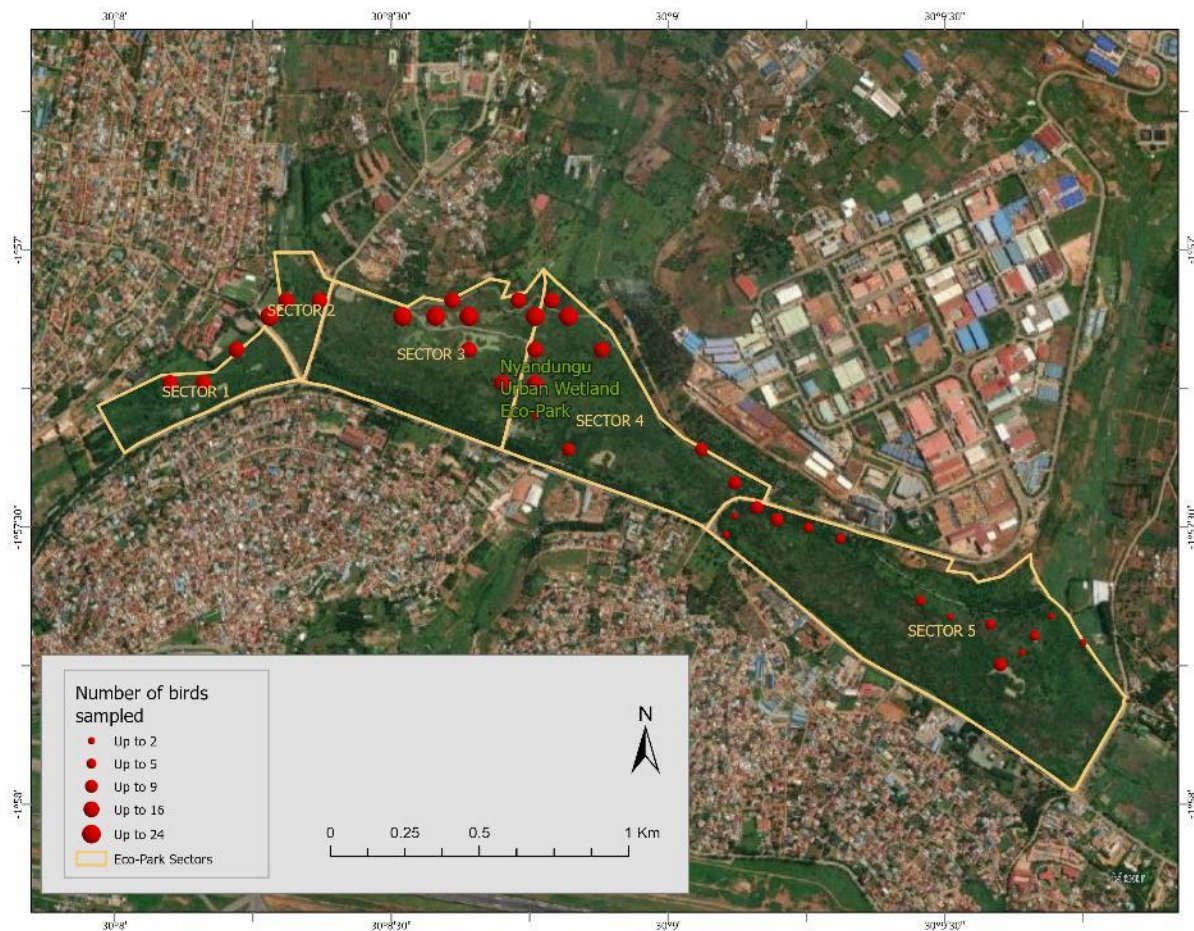


Figure 6. Bird sampling localities in the Nyandungu Wetland Eco-Park, Rwanda

3.2.3. Birds of Nyandungu Urban Wetland Eco-Park

During the bird survey, a total of 83 species of birds belonging to 37 families were recorded (Table 6), and among them eight species were waterbirds, and only one, the Grey crowned crane (*Balearica regulorum*) is endangered according to the IUCN Red List (Appendix 3).

Table 6. Birds surveyed across Nyandungu Urban Wetland Eco-Park, Rwanda by Sectors

Common names	Scientific name	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5
Lesser Swamp Warbler	<i>Acrocephalus gracilirostris</i>	-	+	-	-	-
Black Crake	<i>Amaurornis flavirostra</i>	+	+	+	-	-
Gross beak weaver	<i>Amblyospiza albifrons</i>	+		+	-	-
Yellow billed duck	<i>Anas undulata</i>	-	-	-	-	+
African openbill	<i>Anastomus lamelligenus</i>	-	+	+	+	-
Grassland Pipit	<i>Anthus cinnamomeus</i>	-	-	+	-	-
Grey heron	<i>Ardea cinerea</i>	-	-	+	+	-
Black headed Heron	<i>Ardea melanocephala</i>	+	-	+	-	-
Grey crowed Crane	<i>Balearica regulorum</i>	-	-	+	-	-
Chin spot Batis	<i>Batis molitor</i>	-	-	-	-	+
Hadada Ibis	<i>Bostrychia hagedash</i>	+	+	+	-	+
Gray-backed Camaroptera	<i>Camaroptera brevicaudata</i>	-	-	+	-	-
Square-tailed nightjar	<i>Caprimulgus fossii</i>	-	-	+	-	-
Blue- headed Coucal	<i>Centropus monachus</i>	-	-	+	-	-
White-browed coucal	<i>Centropus superciliosus</i>	-	+	-	-	+
White-browed Scrubrobin	<i>Cercotrichas leucophrys</i>	-	-	+	-	+
Pied Kingfisher	<i>Ceryle rudis</i>	+	-	+	-	+
Scarlet-Chested Sunbird	<i>Chalcomitra senegalensis</i>	-	+	-	+	-
Red-Chested sunbird	<i>Cinnyris erythrocerus</i>	-	-	+	+	+
Mariko Sunbird	<i>Cinnyris mariquensis</i>	-	-	+	-	-
Variable sunbird	<i>Cinnyris venustus</i>	-	-	-	+	+
Singing Cisticola	<i>Cisticola cantans</i>	+	+	-	+	-
Chub's Cisticola	<i>Cisticola chubbi</i>	+	-	+	+	+
Winding Cisticola	<i>Cisticola marginatus</i>	-	+	-	-	+
Speckled mousebird	<i>Colius striatus</i>	+	-	+	+	+
Pied Crow	<i>Corvus albus</i>	-	+	+	-	-
Bare-faced Go-away-bird	<i>Corythaixoides personatus</i>	-	-	+	-	+
Malachite Kingfisher	<i>Corythornis cristatus</i>	+	+	+	+	+
White-browed Robin Chat	<i>Cossypha heuglini</i>	+	-	-	+	+
Thick billed seadeater	<i>Crithagra burtoni</i>	-	-	+	-	+
Western Citril	<i>Crithagra citrinelloides</i>	-	+	+	+	+
Blue- headed Sunbird	<i>Cyanomitra alinae</i>	-	+	-	-	+
Cardinal woodpecker	<i>Dendropicos fuscescens</i>	-	-	-	-	+
Fork-tailed Drongo	<i>Dicrurus adsimilis</i>	-	-	+	-	-
Little Egret	<i>Egretta garzetta</i>	-	-	+	-	-
Common waxbill	<i>Estrilda astrild</i>	-	-	+	+	-
Fan-tailed Widowbird	<i>Euplectes axillaris</i>	+	-	+	+	-
Southern-Red Bishop	<i>Euplectes orix</i>	-	-	-	+	-
Common Morheen	<i>Gallinula chloropus</i>	+	-	-	-	-

Woodland Kingfisher	<i>Halcyon senegalensis</i>	-	-	-	-	+
Wire-tailed Swallow	<i>Hirundo smithii</i>	-	+	-	+	+
African pygmy kingfisher	<i>Ispidina picta</i>	-	-	-	+	-
African firefinch	<i>Lagonosticta rubricata</i>	-	-	-	+	-
Red-billed firefinch	<i>Lagonosticta senegala</i>	+	-	-	+	-
Ruppell's long tailed Starling	<i>Lamprolornis purpuroptera</i>	-	-	-	+	+
Black headed gonolek	<i>Laniarius erythrogaster</i>	-	-	-	-	+
Tropical Boubou	<i>Laniarius major</i>	-	-	-	-	+
Gray backed Fiscal	<i>Lanius tephronotus</i>	+	+	+	+	+
Black and White Mannikin	<i>Lonchura bicolor</i>	+	+	+	-	+
Bronze Mannikin	<i>Lonchura cucullata</i>	+	+	+	-	+
Long-crested Eagle	<i>Lophaetus occipitalis</i>	-	+	+	-	+
Yellow throated longclaw	<i>Macronyx croceus</i>	-	-	-	-	+
Little Bee Eater	<i>Merops pusillus</i>	-	-	+	-	-
Long-tailed Cormorant	<i>Microcarbon Africanus</i>	-	-	+	+	-
Yellow billed Kite	<i>Milvus aegyptius</i>	+	-	+	-	+
Black kite	<i>Milvus migrans</i>	-	+	+	-	-
Cape wagtail	<i>Motacilla capensis</i>	-	-	+	-	-
Swamp flycatcher	<i>Muscicapa aquatica</i>	+	-	+	+	-
Bronze Sunbird	<i>Nectarinia kilimensis</i>	-	-	-	+	-
White- collared oliveback	<i>Nesocharis ansorgei</i>	-	-	+	+	+
Northern gray headed sparrow	<i>Passer griseus</i>	+	+	+	+	+
Brown throated wattle eye	<i>Platysteira cyanea</i>	-	-	-	-	+
Spur-winged Goose	<i>Plectropterus gambensis</i>	-	-	+	-	-
Baglafecht Weaver	<i>Ploceus baglafecht</i>	-	+	+	+	-
Village Weaver	<i>Ploceus cucullatus</i>	+	+	+	+	+
Spectacled Weaver	<i>Ploceus ocularis</i>	-	-	+	+	+
Slender billed Weaver	<i>Ploceus pelzelni</i>	-	-	+	+	-
Holub's golden-Weaver	<i>Ploceus xanthops</i>	-	-	+	+	-
Tawny franked Prinia	<i>Prinia subflava</i>	-	-	-	+	-
Dark-capped bulbul	<i>Pycnonotus tricolor</i>	+	+	+	+	+
Green winged Pytilia	<i>Pytilia melba</i>	-	-	+	+	-
Red-chested Flufftail	<i>Sarothrura rufa</i>	-	-	+	-	-
African stone Chat	<i>Saxicola torquatus</i>	-	-	+	+	-
Hamerkop	<i>Scopus umbretta</i>	+	-	+	+	-
Yellow fronted canary	<i>Serinus mozambicus</i>	-	-	+	+	+
Streaky Seadeater	<i>Serinus striolatus</i>	+	-	-	+	+
Ring-necked Dove	<i>Streptopelia capicola</i>	+	+	+	+	+
Red-eyed Dove	<i>Streptopelia semitorquata</i>	+	+	-	+	+
African paradise flycatcher	<i>Terpsiphone viridis</i>	+	+	+	+	+
Arrow marked Babbler	<i>Turdoides jardineii</i>	-	+	+	-	-
Black lored Babbler	<i>Turdoides sharpei</i>	-	+	+	-	-
Olive Thrush	<i>Turdus olivaceus</i>	+	+	+	-	+
Red-cheeked cordonbleu	<i>Uraeginthus bengalus</i>	+	-	-	+	-
Species richness		28	28	55	41	41
Shannon Weiner Index		2.84	3	3	3.31	3.28

The results indicate that Sectors 4 and 5 have higher species diversity compared to the other sectors, while sector one had the least species diversity. Figure 7 shows photos of some of the bird species observed during the survey.



Balearica regulorum- Grey crowned crane



Ardea melanocephala- Black-headed heron



Lanius excubitoroides- Grey-backed fiscal



Plectropterus gambensis- Spur-winged goose



Anastomus lamelligerus- African openbill



Saxicola torquatus- African stonechat



Centropus monachus- Blue-headed Coucal



Lophaetus occipitalis-Long-crested Eagle

Figure 7. Photos of some of the bird species observed in the Nyandungu Wetland Eco-Park, Rwanda. Photo credit: Jean de Dieu Nsenganeza

Threats encountered during the bird survey

During the bird survey, disturbances and potential threats to the biodiversity were noted (Figure 8). These include the presence of plastic waste and other garbage, and inflow of polluted water.



Dumping of plastic waste



Industrial waste from special economic zone



Harvest of natural vegetation

Figure 8. Disturbances and threats observed during the survey in Nyandungu Wetland Eco-Park, Rwanda

3.2.4. Discussion

Distribution and abundance of bird species in NUWEP is influenced by different factors; all sectors are different in size and vegetation cover which have significant impacts on distribution and abundance of bird species because they influence food availability and habitat heterogeneity (Paracuellos & Tellería, 2004). In addition, some sectors were observed to have high disturbance and improper waste management which may have negative impacts on bird species presence. Sector 1 and two have small size, high disturbance and plastic waste in the ponds which may play a role in the lower species diversity observed there compared to the other sectors. Sectors 4 and 5 had higher species diversity compared to other sectors mainly due to the larger sizes of these sectors, habitat heterogeneity and less disturbance which influences food availability for different bird species. Among the 83 identified bird species belonging to 37 families, there were eight waterbird species and one endangered species (*Balearica regulorum*).

Despite the protection of Nyandungu Urban Wetland Eco-Park, some anthropologic activities are causing disturbances to bird habitat, including grass harvesting, improper waste management, industrial wastes and water pollution. People should be educated about biodiversity and conservation to raise their awareness about how they can behave while in the Eco-Park to reduce their impact on the habitats. Law enforcement is highly recommended for sustainable protection and monitoring of the wetland ecosystems to better protect the birds and their habitats.

3.3. Plants

3.3.1. Introduction

Nyandungu Urban Wetland Eco-Park is characterized by natural and anthropic vegetation (Gakuba, 2012). The natural vegetation is mainly growing in the wetlands whereas the anthropic vegetation occurs in the upland areas and is heavily influenced by humans. The anthropic vegetation includes the planted trees such as *Croton megalocarpus*, *Ficus benjamina*, *F. thoningii*, *F. ovata*, *F. sur*, *F. vallis-choudae*, *Syzygium guineense*, *S. parvifolium*, *Markhamia lutea*, *Hallea stipulosa*, and *Olea europaea* as well as the bamboo zone of *Bambusa vulgaris*, *Sinarundinaria alpine*, *Bambusa textilis* and *Bambusa tulda*. The predominant species of the wetland areas is *Cyperus papyrus*, *C. latifolius*, *Ludwigia octovalvis*, *Typha latifolia* and *Phragmites mauritianus* in the permanent flooded area. The remaining space is savannah grassland with a variety of plant species that grow seasonally like *Acacia polyacantha*, *Digitaria* sp., and *Mimosa pigra*. Some species such as *Casuarina equisetifolia*, *Vernonia amygdalina*, *Solanum aculeastrum* and *Acanthus pubescens* are found abundantly on the park edge. Many plants in the wetland are wetland indicators, meaning they are common to or restricted to wetlands (Butterwick & Kirchner, 2012), and in the Eco-Park they are represented by *Cyperus papyrus*, *Nymphaea nouchali*, *Ludwigia octovalvis*, and *Phragmites australis*. Other plants such as *Vacheria polyacantha*, *Carissa edulis*, *Combretum molle*, *Euphorbia candelabrum*, and *Erythrina abyssinica* are indicators of uplands or savanna.

3.3.2. Methods

Plant sampling in NUWEP was done in the five sectors of the wetland complex. In each sector five sampling transects were used (US Forest Service, 2003). The plant survey was conducted between 7 and 16 June 2023, and in Sectors 1 and 2 without paved walkway, trails used by the visitors were used for the data collection; for the rest of the sectors (3, 4, and 5) there were paved walkways that the plant team used. Along the trails or walkways, the team recorded the plant species encountered. The Plants of the World online database was used to identify species distribution (native or non-native) as well as providing a guide to up to date nomenclature.

3.3.3. Findings

A total of 258 taxa of plants were observed from 73 families (Rwanda Biodiversity Specimen Data Portal. 2023), with 37 plant species (47 specimens) being collected, dried, and deposited into the National Herbarium of Rwanda (Thomas et al., 2023). There were 154 native plants (Table 7) and 104 non-native plants observed (Table 8). Photos of some of the plants

observed in the survey can be seen in Figure 9. Online species survey checklists are available at <https://bit.ly/3tGMP8e> and the vouchered herbarium specimens at <https://bit.ly/3ScFAph>.



Carissa edulis



Erythrina abyssinica



Nymphaea nouchali



Mimosa pudica



Papyrus sp



Jasminum meyeri-johannis

Figure 9. Photos of some plant species observed in the Nyandungu Urban Wetland Eco-Park, Rwanda

Sectors 4 and 5 had the highest species richness, and the other sectors were not much lower, with similarities of species across the sectors. This is in part because of the plantings that have

been done and the past history of disturbance at the site. Sector 4 had the highest number of non-native plant species.

Table 7. Native plant species observed per sector in Nyandungu Urban Wetland Eco-Park, Rwanda. Species names in bold are those recommended to plant in the Eco-Park when more planting is scheduled.

Family	Scientific Name†	IUCN RL	Sectors					Tot
			1	2	3	4	5	
Acanthaceae	<i>Acanthus polystachyus</i>	NE	1	1	0	0	0	2
Acanthaceae	<i>Brillantaisia cicatricosa</i> *	NE	1	1	1	1	0	4
Acanthaceae	<i>Hygrophila auriculata</i>	LC	1	0	0	0	0	1
Acanthaceae	<i>Hypoestes triflora</i> *	NE	0	0	0	1	0	1
Amaranthaceae	<i>Achyranthes aspera</i>	NE	0	0	0	1	0	1
Amaranthaceae	<i>Psilotrichum patulum</i>	NE	0	0	0	1	1	2
Anacardiaceae	<i>Rhus longipes</i>	LC	0	0	1	0	1	2
Anacardiaceae	<i>Searsia pyroides</i> var. <i>pyroides</i>	NE	0	0	1	0	1	2
Apiaceae	<i>Hydrocotyle mannii</i>	LC	1	1	0	1	1	4
Apiaceae	<i>Hydrocotyle sibthorpioides</i>	LC	1	1	0	0	0	2
Apocynaceae	<i>Carissa spinarum</i>	LC	0	0	1	1	1	3
Apocynaceae	<i>Cynanchum insipidum</i>	NE	0	0	0	1	1	2
Araliaceae	<i>Polyscias fulva</i> *	LC	0	0	0	0	1	1
Arecaceae	<i>Phoenix reclinata</i> *	LC	1	0	0	1	0	2
Asparagaceae	<i>Asparagus africanus</i>	NE	0	1	1	0	0	2
Asparagaceae	<i>Dracaena fragrans</i>	LC	1	1	1	1	1	5
Asparagaceae	<i>Dracaena steudneri</i> *	LC	1	1	1	1	1	5
Aspleniaceae	<i>Asplenium</i> sp.	NE	1	1	1	1	1	5
Asteraceae	<i>Acmella caulirhiza</i>	LC	0	0	0	0	1	1
Asteraceae	<i>Bothriocline longipes</i>	NE	0	0	0	1	0	1
Asteraceae	<i>Crassocephalum montuosum</i>	NE	1	1	1	1	1	5
Asteraceae	<i>Crassocephalum paludum</i>	NE	0	1	0	1	0	2
Asteraceae	<i>Crassocephalum rubens</i>	NE	1	1	0	0	0	2
Asteraceae	<i>Crassocephalum vitellinum</i>	NE	1	0	0	0	0	1
Asteraceae	<i>Guizotia scabra</i> *	NE	0	1	0	1	1	3
Asteraceae	<i>Gymnanthemum amygdalinum</i> *	NE	1	0	1	1	1	4
Asteraceae	<i>Gymnanthemum auriculiferum</i>	LC	1	0	1	0	1	3
Asteraceae	<i>Gymnanthemum urticifolium</i>	NE	0	1	1	0	1	3
Asteraceae	<i>Hoffmannanthus abbotianus</i>	NE	1	0	1	0	1	3
Asteraceae	<i>Lactuca</i> sp.	NE	0	0	0	1	1	2
Asteraceae	<i>Laggera alata</i> *	NE	0	0	1	0	0	1
Asteraceae	<i>Laggera elatior</i>	NE	1	0	1	0	0	2
Asteraceae	<i>Melanthera scandens</i>	NE	1	0	0	0	0	1
Asteraceae	<i>Microglossa densiflora</i>	NE	0	0	0	0	1	1
Asteraceae	<i>Solanecio mannii</i> *	LC	0	0	1	0	0	1
Asteraceae	<i>Sphaeranthus suaveolens</i>	LC	0	1	1	1	1	4
Bignoniaceae	<i>Kigelia africana</i> *	LC	0	0	1	0	0	1
Bignoniaceae	<i>Markhamia lutea</i> *	LC	1	1	1	1	1	5
Cannabaceae	<i>Celtis africana</i> *	NE	1	1	1	1	1	5
Cannabaceae	<i>Trema orientale</i>	LC	0	0	0	1	0	1

Capparaceae	<i>Capparis erythrocarpos</i> *	NE	0	0	1	1	1	3
Capparaceae	<i>Capparis tomentosa</i>	NE	0	0	1	1	1	3
Colchicaceae	<i>Gloriosa superba</i>	LC	1	0	0	0	0	1
Combretaceae	<i>Combretum molle</i>	LC	0	0	0	0	1	1
Commelinaceae	<i>Commelina africana</i>	LC	1	1	1	1	1	5
Commelinaceae	<i>Commelina diffusa</i>	LC	1	1	1	1	1	5
Convolvulaceae	<i>Astripomoea malvacea</i>	NE	0	0	1	0	0	1
Convolvulaceae	<i>Ipomoea cairica</i>	LC	0	0	0	1	0	1
Convolvulaceae	<i>Ipomoea tenuirostris</i>	NE	1	1	1	1	1	5
Convolvulaceae	<i>Ipomoea wightii</i>	LC	1	1	0	0	1	3
Crassulaceae	<i>Kalanchoe crenata</i>	NE	1	1	1	1	1	5
Cucurbitaceae	<i>Cucumis aculeatus</i>	NE	0	1	1	0	0	2
Cucurbitaceae	<i>Momordica foetida</i>	NE	0	0	0	1	1	2
Cyperaceae	<i>Cyperus papyrus</i> *	LC	1	1	1	1	1	5
Euphorbiaceae	<i>Croton macrostachyus</i> *	LC	0	0	0	1	1	2
Euphorbiaceae	<i>Croton megalocarpus</i> *	LC	1	1	1	1	1	5
Euphorbiaceae	<i>Euphorbia umbellata</i> *	NE	0	0	1	0	1	2
Euphorbiaceae	<i>Erythrococca fischeri</i>	NE	0	0	0	1	1	2
Euphorbiaceae	<i>Macaranga kilimandscharica</i> *	NE	1	1	0	1	1	4
Euphorbiaceae	<i>Neoboutonia macrocalyx</i> *	LC	1	1	1	1	1	5
Fabaceae	<i>Albizia adianthifolia</i> *	LC	0	1	0	1	0	2
Fabaceae	<i>Albizia amara</i>	LC	0	0	1	0	0	1
Fabaceae	<i>Albizia gummifera</i> *	LC	0	0	1	1	1	3
Fabaceae	<i>Albizia versicolor</i> *	LC	1	1	0	1	0	3
Fabaceae	<i>Crotalaria dewildemania</i>	NE	0	0	1	0	0	1
Fabaceae	<i>Crotalaria recta</i>	NE	0	0	1	1	0	2
Fabaceae	<i>Eriosema scioanum</i>	LC	1	1	1	1	1	5
Fabaceae	<i>Erythrina abyssinica</i> *	LC	1	1	1	1	1	5
Fabaceae	<i>Hylodesmum repandum</i>	NE	0	0	1	1	1	3
Fabaceae	<i>Indigofera arrecta</i>	LC	1	1	1	1	1	5
Fabaceae	<i>Indigofera atriceps</i>	NE	0	0	1	0	0	1
Fabaceae	<i>Kotschya africana</i>	LC	1	1	0	0	0	2
Fabaceae	<i>Lablab purpureus</i>	NE	1	1	1	1	1	5
Fabaceae	<i>Newtonia buchananii</i>	LC	0	0	0	1	0	1
Fabaceae	<i>Pterolobium stellatum</i>	LC	0	0	0	1	1	2
Fabaceae	<i>Pseudarthria hookeri</i>	NE	0	0	1	1	1	3
Fabaceae	<i>Senegalia polyacantha</i>	NE	1	1	1	1	1	5
Fabaceae	<i>Senna didymobotrya</i>	LC	0	0	1	1	0	2
Fabaceae	<i>Tephrosia vogelii</i> *	LC	0	0	1	0	0	1
Fabaceae	<i>Vigna schimperii</i>	LC	1	1	0	0	1	3
Gentianaceae	<i>Anthocleista grandiflora</i> *	NE	1	0	1	1	1	4
Gentianaceae	<i>Anthocleista schweinfurthii</i>	LC	0	0	0	1	1	2
Hypericaceae	<i>Harungana madagascariensis</i> *	LC	0	0	0	1	0	1
Lamiaceae	<i>Clerodendrum bukobense</i>	VU	0	0	0	1	1	2
Lamiaceae	<i>Clerodendrum johnstonii</i>	LC	0	0	0	1	0	1
Lamiaceae	<i>Leonotis ocymifolia</i>	NE	1	1	1	1	1	5
Lamiaceae	<i>Ocimum gratissimum</i> *	NE	0	0	0	1	0	1
Lamiaceae	<i>Coleus barbatus</i> *	LC	1	1	1	1	1	5

Malvaceae	<i>Dombeya rotundifolia</i>	LC	1	1	1	1	1	5
Malvaceae	<i>Dombeya torrida</i> *	NE	0	0	0	1	1	2
Malvaceae	<i>Grewia similis</i>	NE	1	1	1	1	1	5
Malvaceae	<i>Hibiscus diversifolius</i> *	NE	0	0	0	1	0	1
Malvaceae	<i>Hibiscus fuscus</i> *	LC	0	0	0	1	0	1
Malvaceae	<i>Hibiscus reekmansii</i>	LC	0	0	0	1	0	1
Malvaceae	<i>Pavonia burchellii</i>	NE	1	1	1	1	1	5
Malvaceae	<i>Pavonia urens</i> *	NE	1	1	1	1	1	5
Malvaceae	<i>Pterygota mildbraedii</i> *	NE	0	0	0	0	1	1
Malvaceae	<i>Triumfetta rhomboidea</i>	NE	0	0	1	0	0	1
Malvaceae	<i>Sida rhombifolia</i>	NE	0	1	0	0	0	1
Malvaceae	<i>Triumfetta cordifolia</i>	NE	0	1	1	0	0	2
Meliaceae	<i>Carapa grandiflora</i>	LC	1	1	1	1	1	5
Meliaceae	<i>Entandrophragma excelsum</i> *	LC	1	1	1	1	1	5
Menispermaceae	<i>Hyalosepalum caffrum</i>	NE	1	1	1	1	1	5
Monimiaceae	<i>Xymalos monospora</i> *	LC	0	1	1	0	1	3
Moraceae	<i>Ficus asperifolia</i>	LC	0	0	0	1	0	1
Moraceae	<i>Ficus laurifolia</i>	NE	1	1	1	1	1	5
Moraceae	<i>Ficus sur</i> *	LC	1	1	1	1	1	5
Moraceae	<i>Ficus thonningii</i> *	LC	1	1	1	1	1	5
Moraceae	<i>Ficus vallis-choudae</i> *	NE	1	1	1	1	1	5
Moraceae	<i>Trilepisium madagascariense</i> *	NE	1	0	0	1	1	3
Myrsinaceae	<i>Maesa lanceolata</i> *	LC	1	1	1	1	1	5
Myrtaceae	<i>Syzygium cordatum</i>	LC	0	0	1	1	1	3
Myrtaceae	<i>Syzygium guineense</i> *	LC	1	0	1	1	0	3
Myrtaceae	<i>Syzygium parvifolium</i> *	NE	1	0	1	1	0	3
Nymphaeaceae	<i>Nymphaea nouchali</i>	LC	0	0	0	0	1	1
Oleaceae	<i>Jasminum schimperi</i>	NE	0	0	0	1	0	1
Oleaceae	<i>Olea europaea</i> *	DD	0	0	0	1	0	1
Orobanchaceae	<i>Cycnium tubulosum</i>	LC	0	0	0	0	1	1
Oxalidaceae	<i>Biophytum helenae</i>	NE	1	1	0	0	0	2
Peraceae	<i>Clutia abyssinica</i> *	LC	0	0	0	0	1	1
Phyllanthaceae	<i>Bridelia micrantha</i> *	LC	1	1	1	1	1	5
Phyllanthaceae	<i>Flueggea virosa</i> *	LC	1	1	1	1	1	5
Phyllanthaceae	<i>Phyllanthus fischeri</i>	NE	1	1	1	1	1	5
Phytolaccaceae	<i>Phytolacca dodecandra</i> *	NE	1	1	1	1	1	5
Plantaginaceae	<i>Plantago palmata</i> *	NE	1	1	1	1	1	5
Poaceae	<i>Cenchrus purpureus</i>	NE	0	1	0	0	0	1
Poaceae	<i>Eragrostis cylindriflora</i>	NE	1	0	0	0	0	1
Poaceae	<i>Oldeania alpina</i>	NE	0	1	0	0	0	1
Polygonaceae	<i>Oxygonum sinuatum</i>	NE	1	1	1	1	1	5
Polygonaceae	<i>Rumex nepalensis</i> var. <i>nepalensis</i>	NE	1	1	1	1	1	5
Polygonaceae	<i>Rumex usambarensis</i>	NE	0	0	0	0	1	1
Rhamnaceae	<i>Maesopsis eminii</i> *	LC	1	1	1	1	1	5
Rhamnaceae	<i>Ziziphus mucronata</i> *	LC	1	1	0	0	1	3
Rosaceae	<i>Hagenia abyssinica</i> *	LC	1	1	1	1	1	5
Rosaceae	<i>Prunus africana</i>	VU	1	1	1	1	1	5
Rubiaceae	<i>Mitragyna rubrostipulata</i> *	NE	0	0	1	0	0	1

Rubiaceae	<i>Keetia gueinzii</i>	LC	0	0	1	1	0	2
Rubiaceae	<i>Rubia cordifolia</i>	NE	0	0	0	1	0	1
Rubiaceae	<i>Tarenna pavettoides</i>	LC	1	1	1	1	1	5
Rutaceae	<i>Zanthoxylum chalybeum</i> *	LC	1	1	0	0	1	3
Rutaceae	<i>Harrisonia abyssinica</i>	LC	0	0	0	1	1	2
Sapindaceae	<i>Allophylus pseudopaniculatus</i>	NE	0	0	1	1	1	3
Sapindaceae	<i>Blighia unijugata</i> *	LC	1	1	1	1	1	5
Sapindaceae	<i>Cardiospermum halicacabum</i> *	LC	0	0	0	1	0	1
Sapindaceae	<i>Dodonaea viscosa subsp. angustifolia</i>	NE	1	0	0	1	1	3
Sapindaceae	<i>Paullinia pinnata</i>	NE	1	1	1	1	1	5
Sapotaceae	<i>Chrysophyllum gorungosanum</i>	NE	1	0	0	1	1	3
Solanaceae	<i>Solanum aculeastrum</i> *	LC	1	1	1	1	1	5
Urticaceae	<i>Urtica massaica</i>	NE	1	0	1	0	0	2
Urticaceae	<i>Scepcarpus hypselodendron</i> *	NE	0	0	0	0	1	1
Verbenaceae	<i>Lantana viburnoides</i>	NE	1	1	1	1	1	5
Vitaceae	<i>Cissus quadrangularis</i>	NE	0	0	0	1	0	1
Vitaceae	<i>Rhoicissus tridentata</i> *	LC	1	1	0	0	0	2
Zingiberaceae	<i>Aframomum angustifolium</i>	LC	0	0	0	1	0	1
Species occurrences			78	73	86	104	96	437

† species nomenclature follows APG IV (2016) and the Plants of the World database as authoritative resources.

* denotes species identified from previous survey.

IUCN status: Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), Not Evaluated (NE). Categories are used to classify species based on their conservation status, with "Extinct" being the most critical category, and "Least Concern" indicating a lower level of threat. "Data Deficient" is used when there is insufficient information to assess a species, and "Not Evaluated" is applied to species that have not yet been assessed using the IUCN Red List criteria.

Table 8. Non-native plant species observed per sector in Nyandungu Urban Wetland Eco-Park, Rwanda. Species suspected to be invasive are marked with an 'x'.

Family	Scientific Name	Red List	Invasive	Sectors					Tot
				1	2	3	4	5	
Acanthaceae	<i>Asystasia gangetica</i>	NE	x	1	1	1	1	1	5
Acanthaceae	<i>Barleria submolis</i>	NE		0	0	1	1	1	3
Acanthaceae	<i>Haplanthus laxiflorus</i> var. <i>laxiflorus</i>	NE		0	0	0	0	1	1
Acanthaceae	<i>Meiosperma bracteatum</i>	NE		0	0	0	0	1	1
Acanthaceae	<i>Thunbergia paulitschkeana</i>	NE		0	0	0	1	0	1
Amaranthaceae	<i>Chenopodium berlandieri</i> var. <i>boscianum</i>	NE		0	0	0	1	0	1
Amaryllidaceae	<i>Crinum</i> × <i>augustum</i>	NE		0	0	0	0	1	1
Anacardiaceae	<i>Mangifera indica</i>	DD		1	1	1	1	1	5
Anacardiaceae	<i>Searsia natalensis</i>	LC		0	0	1	1	0	2
Apocynaceae	<i>Gomphocarpus fruticosus</i> *	NE		0	0	0	1	0	1
Aponogetonaceae	<i>Aponogeton subconjugatus</i>	LC		0	0	1	0	0	1
Araceae	<i>Colocasia esculenta</i> *	LC		1	1	1	1	1	5

Araceae	<i>Xanthosoma sagittifolium</i>	NE		0	0	0	1	1	2
Araucariaceae	<i>Araucaria angustifolia</i>	CR		1	0	0	1	0	2
Arecaceae	<i>Elaeis guineensis</i> *	LC	x	1	0	0	1	1	3
Arecaceae	<i>Latania lontaroides</i>	EN		0	0	0	1	0	1
Asparagaceae	<i>Agave sisalana</i>	NE	x	0	0	1	1	0	2
Asphodelaceae	<i>Aloe lateritia</i> *	LC		0	0	0	1	0	1
Asteraceae	<i>Ageratum conyzoides</i>	LC	x	1	1	1	1	1	5
Asteraceae	<i>Bidens pilosa</i>	NE	x	1	1	1	1	1	5
Asteraceae	<i>Crassocephalum picridifolium</i>	LC		1	1	0	0	0	2
Asteraceae	<i>Galinsoga parviflora</i>	NE		0	0	0	1	0	1
Asteraceae	<i>Sonchus asper</i>	NE	x	1	1	1	1	1	5
Asteraceae	<i>Tagetes minuta</i>	NE	x	1	1	1	1	1	5
Asteraceae	<i>Tithonia diversifolia</i>	NE	x	0	0	0	1	0	1
Asteraceae	<i>Tridax procumbens</i>	NE	x	1	1	1	1	1	5
Bignoniaceae	<i>Jacaranda mimosifolia</i>	VU	x	0	0	0	0	1	1
Bignoniaceae	<i>Spathodea campanulata</i> * ⁺	LC		0	1	0	0	0	1
Bignoniaceae	<i>Tecoma stans</i>	LC	x	0	0	1	1	1	3
Cannaceae	<i>Canna indica</i>	NE	x	1	1	0	1	0	3
Caricaceae	<i>Carica papaya</i>	DD		1	1	0	0	0	2
Casuarinaceae	<i>Casuarina equisetifolia</i>	LC	x	1	1	1	1	1	5
Celastraceae	<i>Gymnosporia heterophylla</i>	LC		0	1	1	1	1	4
Combretaceae	<i>Terminalia mantaly</i>	LC		1	0	1	1	1	4
Convolvulaceae	<i>Ipomoea littoralis</i>	LC		1	1	0	0	0	2
Convolvulaceae	<i>Dichondra repens</i>	NE		0	0	1	1	0	2
Convolvulaceae	<i>Ipomoea purpurea</i>	NE	x	0	0	1	0	0	1
Convolvulaceae	<i>Ipomoea spathulata</i>	NE		1	1	1	1	1	5
Crassulaceae	<i>Kalanchoe pinnata</i>	NE	x	1	1	1	1	1	5
Cucurbitaceae	<i>Cucurbita maxima</i>	NE		0	1	0	0	0	1
Cucurbitaceae	<i>Luffa aegyptiaca</i>	NE	x	1	1	1	1	1	5
Cucurbitaceae	<i>Momordica friesiorum</i>	NE	x	1	0	1	1	1	4
Euphorbiaceae	<i>Ricinus communis</i> ⁺	NE	x	1	1	1	1	1	5
Euphorbiaceae	<i>Euphorbia murielii</i> *	LC		0	1	1	1	0	3
Euphorbiaceae	<i>Euphorbia hirta</i> *	NE	x	0	0	1	0	0	1
Euphorbiaceae	<i>Euphorbia prostrata</i>	CR	x	1	1	1	1	1	5
Euphorbiaceae	<i>Euphorbia tirucalli</i> *	LC		1	1	1	1	1	5
Fabaceae	<i>Albizia forbesii</i> *	LC		0	0	1	1	1	3
Fabaceae	<i>Chamaecrista rotundifolia</i>	NE		0	0	0	0	1	1
Fabaceae	<i>Desmodium uncinatum</i>	NE	x	1	1	0	0	0	2
Fabaceae	<i>Indigofera homblei</i>	LC		1	1	1	1	1	5
Fabaceae	<i>Indigofera spinosa</i>	NE		0	0	0	1	0	1
Fabaceae	<i>Lysiloma latisiliquum</i>	NE		0	0	1	0	0	1

Fabaceae	<i>Macroptilium atropurpureum</i>	NE		1	1	1	1	1	5
Fabaceae	<i>Millettia laurentii</i>	EN		0	0	0	1	1	2
Fabaceae	<i>Mimosa pudica</i>	NE	x	1	0	0	0	0	1
Fabaceae	<i>Senna racemosa</i> var. <i>racemosa</i>	NE		0	0	0	1	0	1
Fabaceae	<i>Senna occidentalis</i> *	LC		0	0	1	1	1	3
Fabaceae	<i>Senna spectabilis</i>	LC		1	1	0	0	0	2
Lamiaceae	<i>Coleus defoliatus</i>	LC		0	0	0	0	1	1
Lamiaceae	<i>Tetradenia riparia</i> *	LC		1	1	1	1	1	5
Lauraceae	<i>Cinnamomum camphora</i>	LC		1	1	1	1	1	5
Lauraceae	<i>Persea americana</i>	LC		1	1	0	0	0	2
Malvaceae	<i>Hibiscus acetosella</i>	NE		1	1	1	1	1	5
Malvaceae	<i>Hibiscus flavifolius</i>	NE		0	0	1	1	0	2
Malvaceae	<i>Waltheria indica</i>	LC	x	1	1	0	0	1	3
Moraceae	<i>Artocarpus heterophyllus</i>	NE		0	0	1	0	0	1
Moraceae	<i>Ficus benjamina</i>	LC		0	0	1	0	0	1
Moraceae	<i>Morus alba</i>	LC		1	0	0	0	1	2
Musaceae	<i>Musa</i> sp.	NA		1	1	0	1	0	3
Myrtaceae	<i>Psidium guajava</i>	LC		1	1	1	0	1	4
Nyctaginaceae	<i>Bougainvillea spectabilis</i> *	NE		1	0	0	0	1	2
Oleaceae	<i>Jasminum meyeri-johannis</i>	NE		1	1	1	1	1	5
Onagraceae	<i>Ludwigia octovalvis</i>	LC		1	0	0	1	1	3
Passifloraceae	<i>Passiflora edulis</i>	NE		1	1	1	1	1	5
Pedaliaceae	<i>Sesamum calycinum</i>	NE		1	0	1	0	0	2
Poaceae	<i>Bambusa textilis</i> *	NE		0	0	1	1	0	2
Poaceae	<i>Bambusa tuldoidea</i>	NE		0	0	1	1	0	2
Poaceae	<i>Bambusa balcooa</i>	NE		1	1	1	1	1	5
Poaceae	<i>Paspalum notatum</i>	NE	x	1	1	1	1	1	5
Poaceae	<i>Phragmites australis</i>	LC		1	1	1	1	1	5
Poaceae	<i>Saccharum officinarum</i>	NE		1	1	1	1	0	4
Podocarpaceae	<i>Afrocarpus falcatus</i>	LC		1	1	0	0	0	2
Podocarpaceae	<i>Podocarpus latifolius</i>	LC		0	0	1	0	0	1
Polygonaceae	<i>Persicaria pulchra</i>	LC		1	1	1	1	1	5
Polygonaceae	<i>Persicaria amphibia</i>	LC		0	1	0	0	0	1
Proteaceae	<i>Grevillea robusta</i>	LC		1	1	1	1	1	5
Ranunculaceae	<i>Ranunculus hyperboreus</i>	LC		1	1	0	1	1	4
Rhamnaceae	<i>Hovenia dulcis</i>	LC		1	0	0	1	1	3
Rubiaceae	<i>Coffea arabica</i>	EN		1	1	0	0	0	2
Rubiaceae	<i>Mitragyna stipulosa</i>	NT		1	1	1	1	1	5
Rosaceae	<i>Prunus salasii</i>	EN		0	0	0	1	0	1
Sapindaceae	<i>Sapindus saponaria</i>	LC		0	0	0	1	0	1

Solanaceae	<i>Brugmansia suaveolens</i>	EW		0	0	1	0	0	1
Solanaceae	<i>Nicandra physalodes</i>	LC		1	1	1	1	1	5
Solanaceae	<i>Nicotiana tabacum</i>	NE		1	1	1	1	1	5
Solanaceae	<i>Solanum mauense</i>	LC		0	0	0	1	0	1
Solanaceae	<i>Solanum mauritianum</i>	NE		1	1	0	0	0	2
Solanaceae	<i>Solanum nigrum</i>	NE	x	0	0	0	0	1	1
Solanaceae	<i>Solanum nigriviolaceum</i>	LC		1	1	1	1	1	5
Verbenaceae	<i>Lantana camara</i>	NE		1	1	1	1	1	5
Verbenaceae	<i>Lantana trifolia</i>	NE		1	1	1	1	1	5
Tropaeolaceae	<i>Tropaeolum majus</i>	NE		1	0	0	0	0	1
Vitaceae	<i>Cyphostemma maranguense</i>	NE		1	0	0	0	1	2
	<i>Species occurrences</i>			60	53	58	69	58	298

† species nomenclature follows APG IV (2016) and the Plants of the World database as authoritative resources.

* denotes species identified from previous survey.

+ denotes most likely non-native but original native range is uncertain based on existing evidence; currently naturalized in Rwanda
IUCN status: Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), Not Evaluated (NE). Categories are used to classify species based on their conservation status, with "Extinct" being the most critical category, and "Least Concern" indicating a lower level of threat. "Data Deficient" is used when there is insufficient information to assess a species, and "Not Evaluated" is applied to species that have not yet been assessed using the IUCN Red List criteria.

3.3.4. Comparison with previous survey

Results from the plant survey in 2023 show an increase in species richness (260 species recorded in total and 210 native species) from the 2021 survey which recorded 132 plant species. This increase may reflect the restoration efforts which included planting of many different species in the NUWEP and protection of the wetland from human impacts. There may also be a difference in sampling effort which could cause differences. See Appendix 1 for previous plant survey data.

3.3.5. Discussion

The plants identified during this survey include a number of native plant species, but there also many non-native and invasive species present in the wetland complex. It will be useful to have a plan to remove the non-native species targeting those indicated in Table 7. We also suggest promote planting of native species within the NUWEP, to provide varied habitats for wildlife and to promote ecosystem services from the complex. In addition, native fruit producing species should be prioritized to attract birds and other wildlife, and also flowering species that attract pollinators should also be prioritized. The species recommended for planting are indicated in Table 7 in bold and represent fruit producing tree and shrub or understory species, as well as flowering species.

3.4. Fish

3.4.1. Introduction

Rwanda's fish species have been documented in a series of publications (De Vos et al. 1990, De Vos & Thys van den Audenaerde 1990a, b, De Vos 1993, Snoeks 1994, and Snoeks et al. 1997), and there are now 82 fish species documented from 12 families (De Vos et al. 2001). With at least 37 species, the Cichlids are the biggest family of fish in Rwanda. The Cyprinidae,

Mormyridae, and Mochokidae are second, third, and fourth with 24, 6, and 4 species each in their respective families. Only one or two species are present for the other eight families. At least 12 species have been introduced as a consequence of human activity. Presumably, Rwandan ichthyofauna belongs to two ichthyogeographic sub-units, the Congo and Akagera basins (De Vos et al. 2001). The literature shows that the fish endemism in Rwanda is relatively low. Endemism has been documented with 15 Lake Kivu *Haplochromis* species (Snoeks, 1997; Verheyen et al., 2004; Olapade et al., 2010).

A phylogenetical analysis has shown the crucial role of Lake Kivu haplochromines in the evolution of all Haplochromines in Eastern African (Verheyen et al., 2004). However, the Lake Kivu *Haplochromis gracilior*, an endemic Lake Kivu species was found to be phylogenetically distinct from the superclade haplochromines but appears to be its recent sister species (Verheyen et al., 2004). The conservation measures for these species are still precarious like so many other fish species that are currently assessed as threatened. Two fish species are assessed critically endangered and concrete actions for their habitat restoration are of great preoccupation: *Labeo victorianus* and *Chiloglanis ruziziensis*.

Recently, ARCOS (2021) conducted a fish taxonomic survey in Rwandan streams, rivers, of nine wetlands. The survey reported 26 fish species classified into nine families (Protopteridae, Cyprinidae, Cichlidae, Claridae, Poeciliidae, Schilbeidae, Mochokidae, Bagridae and Mormyridae). Three abundant species were African catfish (*Clarias gariepinus*), Nile tilapia (*Oreochromis niloticus*), and African lungfish (*Protopterus aethiopicus*). These were also recorded previously in Murugo wetland (Bizimana, 2021). The *Tilapia rendalli* recorded in the same report (ARCOS, 2021) is currently named *Coptodon rendalli* (Boulenger, 1897). *Protopterus aethiopicus* is a fish species that was introduced in Lake Muhazi in 1988 (Mukankomeje et al., 1996; Micha & Gashagaza, 2002) to increase the fish production of this lake by complementing its fish biodiversity. Currently, this *Protopterus aethiopicus* invaded the whole Akagera River System and wetlands associated with this river system. A recent fish survey after the flooding period that lasted two weeks in June 2023 in this Akagera River System showed that the abundance of both fish predators *Protopterus aethiopicus* and *Clarias gariepinus* is likely the cause for the absence of small fish species like Haplochromis, specifically at the Masangano and Lower Akagera River (Munyandamutsa, unpublished data). Regarding the conservation status of *Labeo victorianus* which was mentioned found in this survey, is a critically endangered fish species and merits conservation management focus in the whole region of the Akagera River System.

The Nyandungu Urban Wetland Eco-Park is a wetland complex that harbors a variety of fish species and given the restoration context of this site, it is important to document the species assemblage. The ichthyofauna can serve as an indicator of water quality and ecosystem health. The current survey provides a species check list for the Nyandungu Urban Wetland Eco-Park.

3.4.2. Methods

Fishing equipment including scoop nets and fish-traps were used to sample fish (Lekshmi et al., 2023) in the ponds created in the five sectors of the wetland (Figure 10). Caught fish were

preserved in 100% ethanol and transported to the Ichthyology laboratory of University of Rwanda, Nyagatare campus for further identification. The imaging took place in the same laboratory. A 35 mm Nikon D7200 camera was used to image each fish species caught for further shape analysis (Dürrani et al., 2023). Several sources for fish identification were used (De Vos et al. 1990, De Vos & Thys van den Audenaerde 1990a, 1990b, De Vos 1993, Snoeks 1994, and Snoeks et al. 1997).

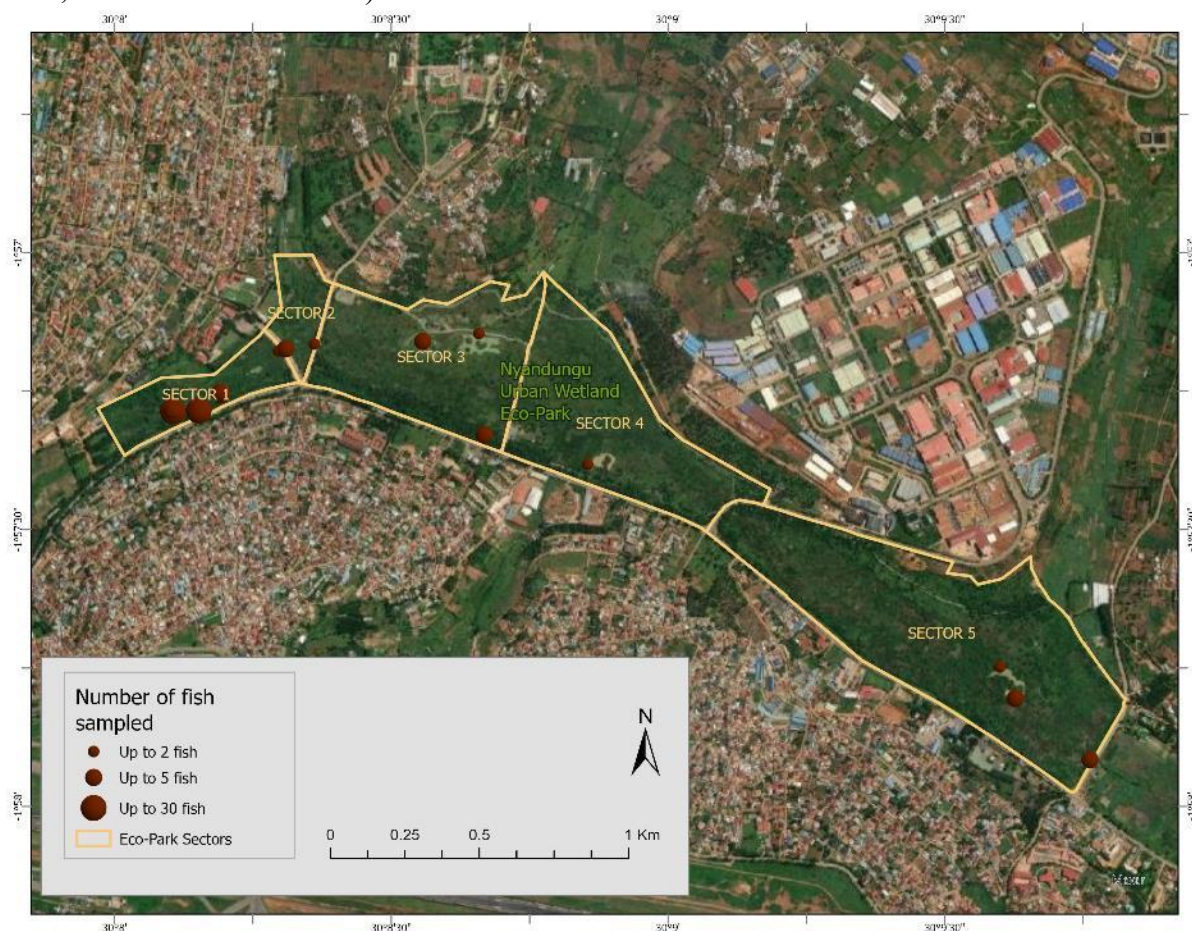


Figure 10. Fish sampling localities from the Nyandungu Urban Wetland Eco-Park, Rwanda

3.4.3. Results

Seven species of fish were found during this survey (Table 9). Two *Haplochromis* fish species were identified to the genus level. Five fish identified at species level are of Least Concern in the IUCN Red List. Sector 1 of the Eco-Park had the highest species richness, and Sector 2 had the lowest. Representative specimens

Table 9. Fish species and their abundance (N) at the five sampled sectors from Nyandungu Urban Wetland Eco-Park, Rwanda. LC: Least Concern, The sign + indicates the presence and - indicates absence of the fish species in the sampling location.

Species name	IUCN	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Eco-Park
Claridae <i>Clarias liocephalus</i> Boulenger, 1898	LC	+ (13)	-	-	-	+ (4)	+ (17)

Poeciliidae <i>Poecilias reticulata</i> Peters, 1859 (introduced)	LC – non-native	+ (8)	+ (65)	+ (27)	+ (53)	+ (33)	+ (186)
Cichlidae <i>Pseudocrenilabrus multicolor</i> (Scholler, 1903)	LC	-	-	-	+ (1)	-	+ (1)
<i>Haplochromis</i> spp1		+ (98)	+ (25)	+ (8)	+ (31)	+ (67)	+ (229)
<i>Haplochromis</i> spp 2		+ (1)	-	+ (4)	+ (1)	-	+ (6)
Cyprinidae <i>Acapoeta tanganyicae</i> (after Moore, 1903)	LC	+ (1)	-	-	-	-	+ (1)
<i>Enteromius pellegrini</i> (Poll, 1939)	LC	+ (1)	-	-	-	+ (8)	+ (9)
Species richness	LC	6	2	3	4	4	7
Shannon Weiner Index	LC	0.71	0.59	0.81	0.77	0.97	0.99
Fish abundance (N)		122	90	39	86	112	449

Below are photos and details of some of the fish species detected in this survey (Figures 10-15).

***Clarias liocephalus* Boulenger, 1898** (Figure 11). This species feeds on fish, plants and insects, and its preferred habitat includes rivers, streams, lakes and ponds. This species is a catfish in the Siluriformes (catfishes), Clariidae family which are airbreathing catfishes. The genus *Clarias* (from the Greek *chlaros* which means lively) refers to its ability to live for a long time out of water. Its known distribution is Lake Victoria, Edward, George, small lakes of Uganda, Lake Kivu, smaller lakes of Rwanda, Lake Tanganyika, in Malawi, Kagera, Malagarazi and Ruzizi Rivers. Also in Lake Rukwa, the Luapula and Lualaba River drainages (Congo River basin) and in Cunene, Okavango, upper Zambezi, and Kafue river systems. This species is facultative air-breathing, and is considered epibenthic, known to occur in marginal water-lily and papyrus swamps as well as in weed beds; abundant in high mountain streams and torrents on the bottom among stones; not found in any situation lower than about 915 m above sea level nor in water of a higher temperature than 18 °C. In the Rukwa and Malawi drainage they are sometimes found in very cold upland streams. These fishes are omnivores, feeding on insect larvae and sometimes on small fish.



Figure 11. *Clarias liocephalus* Boulenger, 1898

***Poecilia reticulata* Peters, 1859** (Figure 12). This is an introduced species of Cyprinodontiformes (rivulines, killifishes and live bearers) in Poeciliidae (Poeciliids). Its native range is South America, in Venezuela, Barbados, Trinidad, northern Brazil and the Guyanas. It has been widely introduced and established elsewhere, mainly for mosquito control, but has had limited to non-existing effects on mosquitoes, and negative to neutral effects on native fishes. In Africa there are populations reported from the coastal reaches of Natal rivers from Durban southwards, as well as in the Kuruman Eye and Lake Otjikoto in Namibia. This fish species was recorded in different wetlands of Rwanda, connected to Akagera River System and could be used as an indicator of water pollution (Gomes-Silva et al., 2020). Several countries report adverse ecological impact after introduction and generally it is considered a pest species. It is found in freshwater and brackish water, and is considered benthopelagic. It is usually found in water of pH range of 7.0 - 8.0. Its average total length is reported to be 2.8 cm. This species usually inhabits warm springs and effluents, weedy ditches and canals. It can be found in highly turbid water in ponds, canals and ditches at low elevations to pristine mountain streams at high elevations. It has a wide salinity tolerance range but requires fairly warm temperatures (23-24 °C) and quiet vegetated water for survival. It feeds on zooplankton, small insects and detritus. It is one of the most popular aquarium fishes and is used in genetics research.



Figure 12. *Poecilia reticulata* Peters, 1859

***Pseudocrenilabrus multicolor* (Scholler, 1903)** (Figure 13). This is a cichlid with a distribution in Africa in the Nile River system, Lake Albert, Semliki River, Lakes Victoria and Kyoga, Malawa and Aswa Rivers, Lake George, Lake Nabugabo, Lakes Kachira, Kijanebalola and Nakavali which lie between Lakes Edward and Victoria; and rivers and lakes of Uganda including the Albert Lake drainage. Previously, two subspecies were recognized: *Pseudocrenilabrus multicolor victoriae* and *Pseudocrenilabrus multicolor multicolor*. It generally inhabits streams and ponds and feeds on worms, crustaceans, insects, algae, vegetable fragments and small fish. Its pH range is 6.8 - 7.2.



Figure 13. *Pseudocrenilabrus multicolor* (Scholler, 1903).

Haplochromis species. Two distinct Haplochromis fish species were collected in Nyandungu Eco-Park (Figure 14). Most of the qualitative observations, such as shape, number of teeth, inner tooth rows, and gill rakers do not fall in the range of known species in the current Rwandan Haplochromines assemblages. This is true also for their pharyngeal bones and dentition. A further deep analysis of these species is needed.



Figure 14. *Haplochromis* spp 1 (left) and *Haplochromis* spp 2 (right) are an undescribed *Haplochromis* species at the time of this report.

***Acapoeta tanganyicae* (Boulenger, 1900)** (Figure 15). This is a species of carp in the Cypriniformes. It is considered benthopelagic, and is distributed in Africa in Lake Tanganyika, including inflowing streams, and Lake Rukwa catchment. Maximum totallength has been documented at 61.0 cm and weight of 2.3 kg. Its habitat is inshore rocky areas of Lake Tanganyika, and rapid sections of rivers. It is one of the most common species in rivers. It feeds on plants and animals adhering to parts of rooted aquatic plants and other open surfaces and also detritus coating rocks in an aquatic environment.



Figure 15. *Acapoeta tanganyicae* (Boulenger, 1900)

Enteromius pellegrini (Poll, 1939) (Figure 16). This is a freshwater, benthopelagic and tropical species distributed in the drainage basins of Lakes Kivu, Edward and Tanganyika, both in tributaries and in lakes, and in Democratic Republic of the Congo at Pinga (Lualaba, upper Congo River basin) and Ituri drainage (middle Congo River basin) based on misidentified *E. trinitatus*. Its maximum length is 11.7 cm SL male/unsexed.



Figure 16. *Enteromius Pellegrini*

3.4.4. Discussion

Seven fish species were recorded in the NUWEP, including three non-native species. This is a relatively poor ichthyofauna assemblage, possibly due to the position of the catchment and the history of past disturbances, as well as ongoing disturbances. Size and structure of the watershed are considered the most important factors influencing fish abundance and diversity (Jenkins and Jupiter, 2011). *Poecilia reticulata* is a well-known invasive species that has a detrimental impact on native fish, particularly native cyprinodonts (Global Invasive Species Data-base, 2018). Cichlids have been found to be tolerant to pollution (Hugueny et al., 1996) and *Haplochromis* species may be considered moderately tolerant to habitat disturbance and pollution (Raburu and Masese 2012), while *Poecilia reticulata* in the wetland indicates high organic pollution and anthropogenic activities disturbing the watershed (Copeland et al., 2016). The two undescribed *Haplochromis* species are under investigation and when identified to species level will contribute to understanding the ecosystem health of the wetland complex.

Good quality habitat for fish can generally be defined by no human activity within 50m of the riparian zone and no point sources of pollution. Tolerant species will be those that occur along a wide range of sites that have signs of heavy degradation, high levels of sedimentation and turbidity and extensively damaged habitat; sensitive species will not be found at these sites. This information can be applied to fish assemblages as indicators of wetland and freshwater ecosystem health.

3.5. Aquatic invertebrates

3.5.1. Introduction

Benthic macroinvertebrates comprise a group of aquatic animals that are understudied in Rwanda despite their widely recognized role in ecosystem functions as well as in environmental monitoring and assessments. A few macroinvertebrate studies conducted in

Rwanda provided crucial insights into the role of macroinvertebrates to indicate the impacts of human activities on water quality and ecosystem health (Wronski et al., 2015; Dusabe et al., 2020; Uyizweye et al. 2021). Elsewhere, plenty of papers have been published on the role of macroinvertebrates in water quality and ecological assessments. However, this survey is not about water quality or ecological aspects of wetlands. Instead, our aim is to document and describe some of the species that comprise the biological communities in the wetland complex, which will be important information for monitoring the changes over time in this system, and the effectiveness of the restoration activities. This survey is also about building up knowledge of key macroinvertebrate taxa that would help understand ecological patterns and trends and help follow up conservation and management actions of the Nyandungu Urban Wetland Eco-Park.

Benthic macroinvertebrates form a large group of aquatic animals that lack backbone and spend at least part of their life cycle in the aquatic environments. They are large enough to be seen with the naked eye and include various groups of worms, molluscs, crustaceans, mites, and above all insects. They include species that have a very important ecological roles in freshwater and terrestrial habitats near water. The ecological impact of macroinvertebrates is mainly due to their role in the processing of organic matter and their value as food for fish and other aquatic biota, as well as birds and other terrestrial biota. They are thus not only essential for aquatic trophic chains but also key elements of aquatic and terrestrial tradeoffs. Additionally, because many species are highly sensitive to perturbations, they are valued in ecological assessments as excellent indicators of water quality and ecosystem integrity.

Prior knowledge and species documentation of benthic macroinvertebrates in the Nyandungu Urban Wetland Eco-Park is very low and is only based on a survey conducted in 2017 by ARCOS. During this survey only the odonates (dragonflies and damselflies) were targeted for sampling which was based on adult stages observed along the riverbanks. Nothing has been documented on other macroinvertebrate taxa which represents an important knowledge gap especially for monitoring water quality, ecosystem health and restoration success. This survey was therefore conducted not only to establish a taxonomic baseline but also to build up an understanding of potential ecological and restoration impacts that macroinvertebrates have for the sake of future monitoring and conservation of the Eco-Park.

3.5.2. Methods

Sampling sites were randomly established in all five sectors following the presence of waterbodies and accessibility (Figure 17). A total of 24 sites were sampled. The water-dwelling macroinvertebrate stages were sampled using a 500µm mesh-size kick-net. The sampling efforts was 20-30 min, trying to survey all habitats in the waterbodies, including sediment, rocks, plants debris, aquatic macrophytes (water lily) and marginal emergent vegetation. Additionally, two Malaise traps were mounted for a few days at selected streams to collect adult specimens.

The collected samples were immediately stored in about 80% alcohol (ethanol) and attributed a detailed label for each site. The whole set of labelled material was transferred to the laboratory for identification. Water parameters including pH, dissolved oxygen, electrical conductivity,

temperature, turbidity and total suspended solids (TSS) were measured at each sampling site using a Multiparameter device - HANNA HI9829. Geographic coordinates were taken using a GPS device.

Taxonomic diversity

Invertebrates are a difficult group for taxonomy because they are very diverse, and many species are not identified, especially in Africa. Identification to family or genus where possible is the most common approach; it has been shown that family classification is sufficient to detect impacts from point sources of pollution and other impacts in freshwater and marine systems (Wright et al. 1995, Vanderklift, Ward & Jacoby, 1996). Thus, family or genus characteristics (rather than species level characteristics) are typically used to identify indicator species categories. In this survey, the invertebrates were identified to family, and then when possible genus and species were also identified, but as identification keys for most species are lacking for Rwanda and the region, it was not always possible to get to species level. However, the

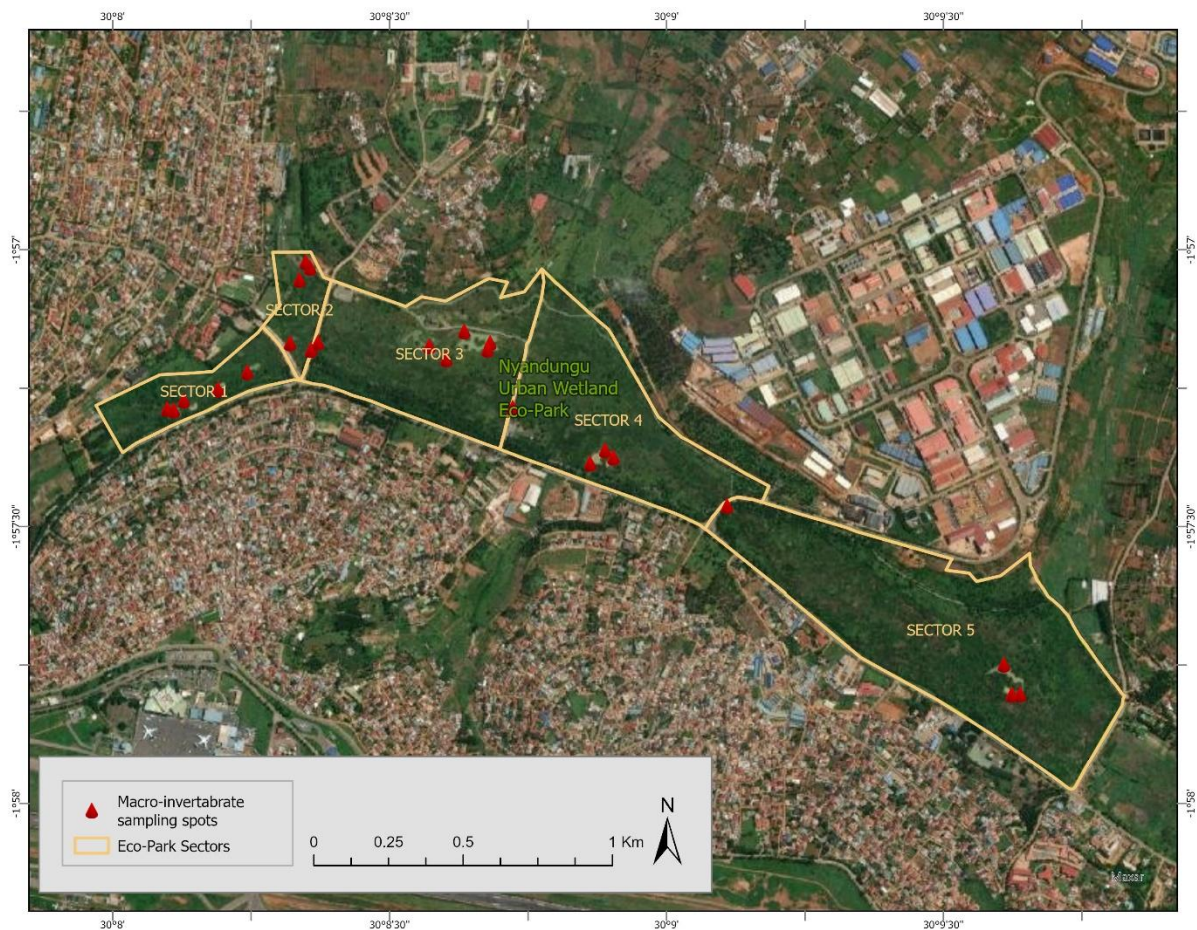


Figure 17. Macro-invertebrates sampling localities from the Nyandungu Urban Wetland Eco-Park, Rwanda.

families identified are usually associated with habitat quality and this level can be used as indicator groups. The species diversity of the macroinvertebrates was estimated using Shannon Weiner Index that was computed using EstimateS910 software. Shannon wiener Index is calculated as follows.

$$H = -\sum_{j=1}^s p_i \ln p_i$$

Where:

H is the Shannon Index, **p** is the proportion (**n/N**) of individuals of one particular species found (**n**) divided by the total number of individuals found (**N**) and **s** is the number of species.

3.5.3. Findings

A total of 29 macroinvertebrate families including 20 insects, three molluscs, two annelids, two crustaceans and one arachnid. Among the insects, 20 genera were identified and seven genera were not identified. The four mollusc families were identified to include four genera. While the two crustacean families were identified to contain two genera, annelids and arachnids were not identified to genus level. The survey found three species not previously recorded in Rwanda. These were identified to the genus level and include *Buenoa*, *Appasus*, and *Phyllomacromia*. These genera are from three different families.

Coenagrionidae and Chironomidae were the most frequently found families across the sampling sites followed by the family Caenidae. While it appears there is no pronounced habitat preference for the two Coenagrionidae and Chironomidae, the family Caenidae was frequently encountered at sites of running water. The representatives of the families Hydropsychidae and Leptoceridae were collected in Sector 2 and Sector 4 and were restricted at sites of running clean water containing dense tree or vegetation cover where substrates consist of stones and/or emergent vegetation. Molluscs were mainly collected in ponds and stagnant waters.

There was not a large difference in species diversity among the freshwater macroinvertebrates sampled across sectors in this survey (Table 10). According to the Shannon Wiener diversity index, the highest taxonomic diversity was recorded in Sector 1 ($H'=2.47$) followed by Sector 5 ($H'=2.33$). Sectors 2 and 3 displayed low taxonomic diversity.

Table 10. Shannon-Weiner diversity index (H) and taxon occurrence of macroinvertebrates at different streams and rivers in Nyandungu Urban Wetland Eco-Park, Rwanda

Order	Family	Genus	Sector				
			1	2	3	4	5
Architaenioglossa	Ampullariidae	<i>Pila</i>	+	-	-	+	-
	Hydrophilidae	<i>Hydrophilus</i>	+	-	-	-	-
Coleoptera	Noteridae		-	-	+	+	-
	Dytiscidae	<i>Hydaticus</i>	-	-	+	-	+
Decapoda	Cambaridae	<i>Procambarus</i>	-	+	+	+	+
Diptera	Chironomidae		+	+	+	+	+
	Tipulidae	<i>Tipula</i>	-	+	-	+	+
	Simuliidae	<i>Simulium</i>	-	+	-	+	-
Ephemeroptera	Leptophlebiidae		+	-	-	+	+
	Baetidae	<i>Baetis</i>	+	+	-	-	-

	Caenidae	<i>Caenis</i>	+	+	-	+	+
	Tricorythidae	<i>Tricorythus</i>	-	+	-	-	-
Hemiptera	Notonectidae	<i>Buenoa</i> *	+	+	-	+	+
	Notonectidae	<i>Enithares</i>	+	+	-	-	-
	Belostomatidae	<i>Appasus</i> *	+	-	+	+	+
	Corixidae	<i>Sigara</i>	+	-	-	+	+
	Nepidae	<i>Ranatra</i>	-	+	+	+	+
Hygrophila	Physidae		+	+	-	+	-
	Planorbidae	<i>Biomphalaria</i>	+	+	+	-	-
Isopoda	Philosciidae		+	-	-	-	-
Lumbriculida	Lumbriculidae		+	+	-	+	+
Neotaenioglossa	Thiaridae	<i>Melanoides</i>	+	+	+	+	+
Odonata	Macromiidae	<i>Phyllomacromia</i> *	+	+	-	-	-
	Libellulidae	<i>Crocothemis</i>	+	+	-	-	-
	Libellulidae	<i>Trithemis</i>	-	-	+	+	+
	Coenagrionidae	<i>Ischnura</i>	+	+	+	+	+
	Coenagrionidae	<i>Ceragrion</i>	+	+	+	+	+
	Lestidae	<i>Lestes</i>	-	+	-	-	-
Rhynchobdellida	Glossiphoniidae		+	+	-	-	-
Trichoptera	Hydropsychidae	<i>Cheumatopsyche</i>	-	+	-	+	+
	Hydropsychidae	<i>Hydropsyche</i>	-	+	-	+	+
	Leptoceridae	<i>Triaenodes</i>	-	+	-	+	-
Trombidiformes	Hydrachnidae	<i>Hydracarina</i>	-	-	+	-	-
Shannon Weiner diversity index (H)			2.47	2.06	2.17	2.28	2.33

* Possible new species records for Rwanda

Water parameters

The measurements of water quality parameters at each macroinvertebrate sampling site indicate that there is not a significant difference in water quality between sectors (Figure 18). The highest mean temperature was recorded in Sector 3 (24.9°C) while the lowest temperature was seen in sector 2 (21.9°C). The pH was nearly neutral across all the sectors with a mean pH ranging between 7.0 (Sector 1) and 8.0 (Sector 3). While the dissolved oxygen did not vary significantly across sites, the mean turbidity at macroinvertebrate sampling sites was high in Sector 5 (61.6 FNU) high compared to the rest of sectors. This difference may be due to land use activities or pollution sources around the perimeter of Sector 5, but specific causes of the higher turbidity were not assessed in this survey.

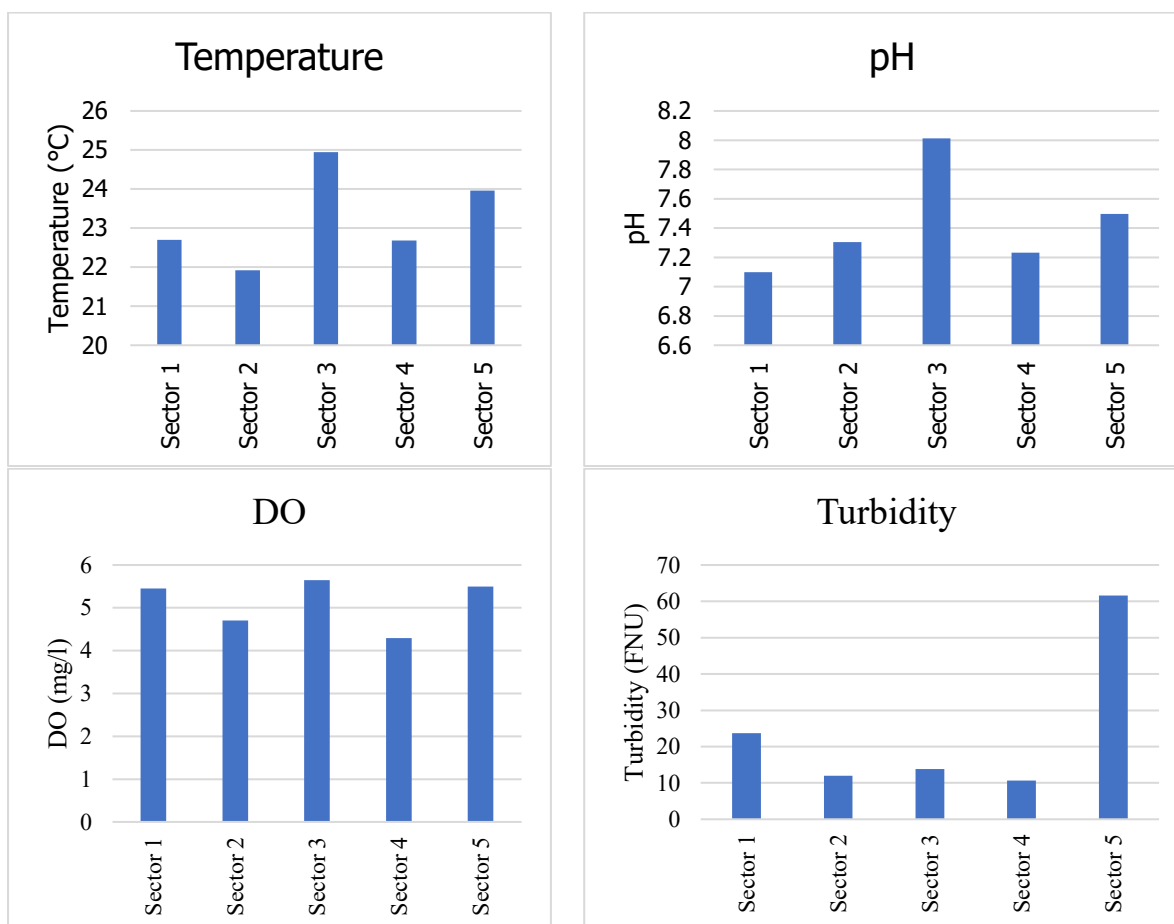


Figure 18. Water quality parameters associated with aquatic invertebrates sampling in Nyandungu Urban Wetland Eco-Park, Rwanda.

3.5.6. Discussion

We found that the macroinvertebrate families with the highest abundance and frequency across the Nyandungu Urban Wetland Eco-Park are Canidae, Chironomidae, Coenagrionidae, Physidae, Libellulidae and Belostomatidae. Most of these families are generalists or pollution-tolerant groups, and their high dominance might be associated with large amounts of organic waste that accumulate in the wetland from the surrounding neighborhood. Inversely, macroinvertebrates were less abundant in our sampling sites in Sector 3 probably because sampling was only restricted to a couple of ponds surrounded by dry grassland, while the wet sector is hard to access or sample.

An important number of caddisfly individuals belonging to the family Hydropsychidae and Leptoceridae were recorded at one site in Sector 2 and at another site in Sector 4. They were found in less disturbed sites that are characterized by clean and flowing waters containing stony substrates and dense tree/vegetation cover. It is believed that these Trichoptera groups will continue to reestablish in several parts of the Nyandungu Urban Wetland Eco-Park, especially the protected part, and their future extended establishment will serve as a good indication and monitoring tool of wetland recovery success. Although, caddisfly larvae of the family Hydropsychidae and Leptoceridae are known to occur in many types of running waters and sometimes lakes, different studies have shown that representatives of these families can occur

in restricted parts of waterbody system depending on biotic and abiotic factors, which can be used for making water typologies and water quality assessments (Higler & Tolkamp, 1982).

The measured water parameters (pH, temperature, dissolved oxygen and turbidity) show little variations across sampling sites and or between types of waterbodies except for Sector 5 which had higher turbidity. Therefore, the difference in distribution recorded for certain macroinvertebrate taxa can be mainly attributed to the types and density of vegetation cover.

3.6. Butterflies

3.6.1. Introduction

Butterflies are the most documented subject among insects worldwide (Bonebrake et al., 2010). However, although some information on butterflies is available within some neighboring countries of Rwanda (Carder & Tindimubona, 2002; Ducarme, 2018; Kielland, 1990; Mtui, Congdon, Bampton, Kalenga, & Leonard, 2019), little is known about butterflies of Rwanda (Uwizelimana, 2022; Uwizelimana, Nsabimana, & Wagner, 2021). These butterflies are of important use for environmental change studies (Kremen, 1992; Maleque, Maeto, & Ishii, 2009) and they have been used as good models to monitor ecosystem restoration after anthropogenic disturbances (Oloya et al., 2021).

From the literature, it is evident that no systematic study has been conducted in the wetland to document how its biodiversity is bouncing back, including the butterflies, and this is why the butterfly survey was conducted to provide baseline data for future use in monitoring the Nyandungu Urban Wetland Eco-Park health. Knowledge of butterfly species inhabiting Nyandungu Urban Wetland Eco-Park will serve as a starting point to monitor the effect of the restoration process on the biodiversity of the wetland. This information will help the management of the wetland to establish good sound policies related to both tourism activities and biodiversity conservation of the wetland.

3.6.2. Methods

Butterflies in the Nyandungu Urban Wetland Eco-park were sampled using line transects, fruit-baited traps, and opportunistic sampling methods (Molleman et al., 2006; Uwizelimana, 2022). As a site under restoration process, butterfly sampling was conducted with minimal disturbances to the surrounding habitats. Sampling sites within the wetland were selected based on the existing five sectors (Figure 19).

Depending on the weather on the day, sampling was conducted in the morning after sunrise until evening at sunset. The existing tourist trails within each sector were walked on sunny days and all butterfly individuals encountered along the trail within 5m width were collected using a hand butterfly net (Figure 20). Being poikilothermic animals (Martins & Collins, 2016), the use of tourist trails was the most effective to sample butterflies as most butterflies use them to warm up in the sunshine. In addition to butterfly net use, fermented banana traps (Figure 20) were also used to collect fruit-feeding species (Molleman et al., 2006). Opportunistic sampling was also performed around ponds where some butterflies came for drinking or mud puddling.

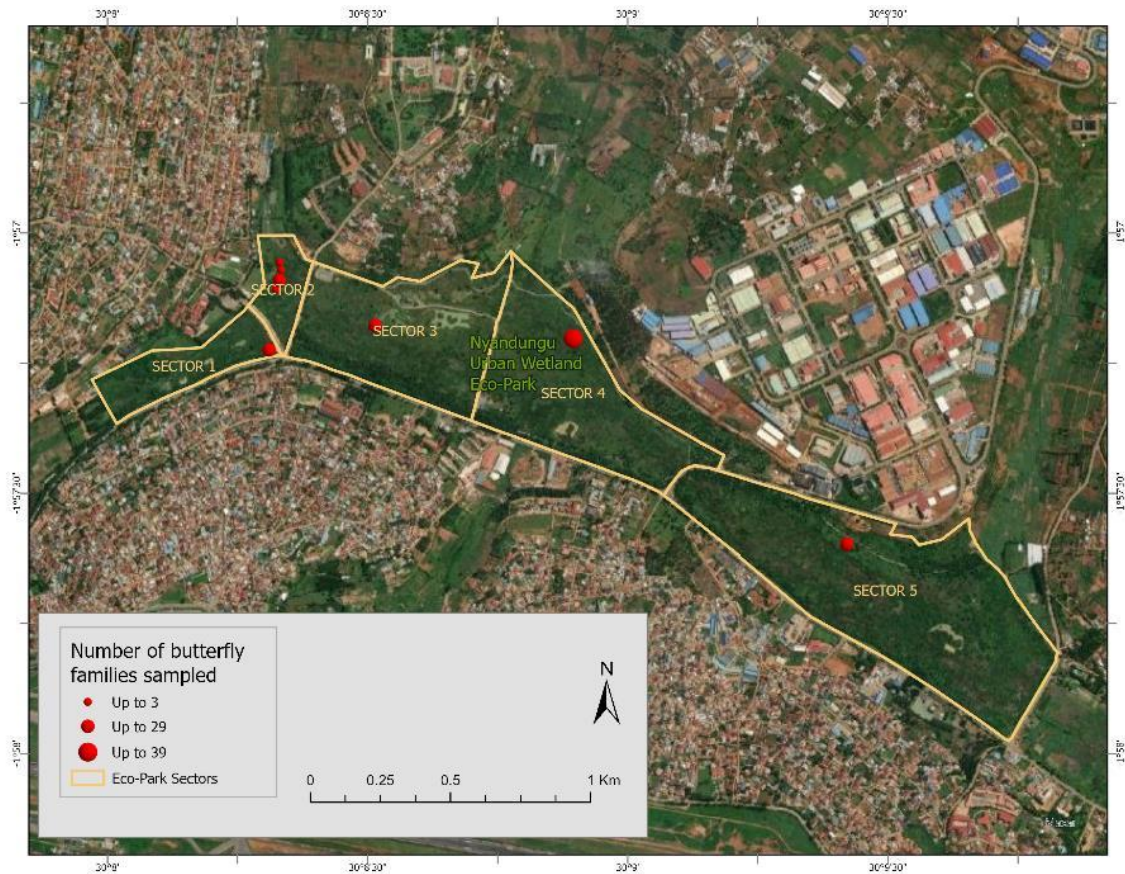


Figure 19. Butterfly sampling localities in the Nyandungu Urban Wetland Eco-Park, Rwanda

3.6.3. Data analysis

All collected butterfly individuals were identified using available literature on African butterflies (Larsen, 1991, 2005; Martins & Collins, 2016; Williams, 2021) and a preliminary species checklist was provided for the NUWEP (Table 11). A proportion of each recorded butterfly family was tabulated and species richness and a diversity index calculated using Biodiversity Professional software version 2 (McAlece, et al. 1997).



Figure 20. Butterfly trapping techniques. Use of fruit-baited trap (left) and butterfly net (right) for butterfly sampling.

3.6.4. Findings

A total of 56 butterfly species were recorded in the NUWEP from four butterfly families; the Nymphalids group is dominant (Figure 21). Among the sampled sectors, Sector 4 was the most species rich and diversified while Sector 5 was the least diversified (Table 11).

Table 11. Butterfly species recorded in Nyandungu Urban Wetland Eco-Park, Rwanda

Family/ species	Sectors within Nyandungu Urban Wetland Eco-Park				
	1	2	3	4	5
Hesperiidae					
<i>Borbo detecta</i>	1				
<i>Eretis lugens</i>	1	2	2	2	1
<i>Gegenes niso</i>			1		
<i>Metisella orientalis</i>	1	1	1	2	1
<i>Pardaleodes incerta</i>			1	1	
<i>Pelopidas thrax</i>	1				
Lycaenidae					
<i>Azanus natalensis</i>				3	
<i>Cacyreus lingens</i>	1	1	1	1	
<i>Cupidopsis sp</i>	1				
<i>Euchrysops malathana</i>			1		
<i>Harpenderyus sp</i>				1	
<i>Lampides boeticus</i>	1				
<i>Leptotes sp</i>		1	1	1	
<i>Spalgis lemolea</i>		1		1	
<i>Zizeeria knysna</i>			1		2
Nymphalidae					
<i>Acraea encedana</i>	4	4		1	
<i>Acraea acerata</i>	2		1	1	
<i>Acraea cabira</i>				2	
<i>Acraea encedon</i>	1				
<i>Aterica galene</i>				1	
<i>Bicyclus jefferyi</i>				1	2
<i>Bicyclus safitza</i>	2				
<i>Bicyclus vulgaris</i>	2		1	1	2
<i>Charaxes achaemenes</i>		1			
<i>Colotis euippe</i>					3
<i>Danaus chrysippus</i>	2	1			
<i>Eurytela dryope</i>	1				
<i>Junonia aenone</i>			1	2	1
<i>Junonia sophia</i>	3			2	
<i>Junonia terea</i>	1	1	1	2	2
<i>Melanitis leda</i>	1		2		1
<i>Neptis serena</i>	3	2		2	
<i>Phalanta sp</i>				1	

<i>Pseudacraea lucretia</i>		1				
<i>Tirumala petiverana</i>				1		
<i>Ypthima albida</i>	2	1	1	1	3	
<i>Ypthima asterope</i>	2	2		1	5	
<i>Amauris tartarea</i>			1			
Papilionidae						
<i>Papilio dardanus</i>			1			
<i>Papilio demodocus</i>			1			
Pieridae						
<i>Belenois aurota</i>				1		
<i>Belenois crawshayi</i>			3	1	1	
<i>Belenois creona</i>			1	3	2	
<i>Belenois zochalia</i>			2	2	4	
<i>Catopsilia florella</i>		2				
<i>Colotis euippe</i>	1	1	4	5		
<i>Eronia cleodora</i>			2		2	
<i>Eurema regularis</i>				2		
<i>Eurema brigitta</i>		3	1	1		
<i>Eurema desjardinsi</i>	1		1	1	4	
<i>Eurema hapale</i>	1	1		1		
<i>Eurema hecabe</i>		1		1		
<i>Leptosia alcesta</i>			2	2	4	
<i>Leptosia nupta</i>		5	1	2	3	
<i>Mylothris rubricosta</i>	2	1		2	4	
<i>Colotis elgonensis</i>	2					
Species richness		24	21	26	35	19
Shannon diversity index		1.35	1.27	1.38	1.49	1.23

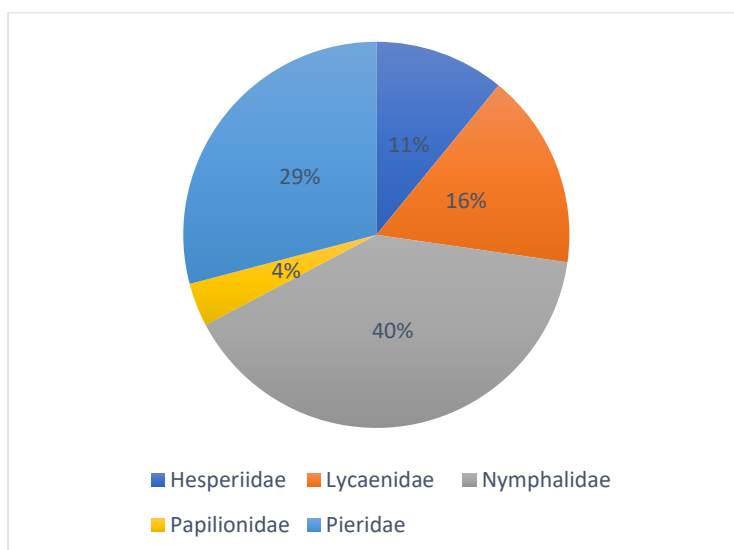


Figure 21. Butterfly species sample (n=56) and their proportions in their respective families in Nyandungu Urban Wetland Eco-Park, Rwanda.

Below are some images of some of the species collected during the butterfly surveys.



Amauris tartarea



Tirumala petiverana



Aterica galena



Pseudacraea lucretia



Melanitis leda



Junonia aenone

Figure 22. Photos of some butterflies collected at Nyandungu Urban Wetland Eco-Park, Rwanda

3.6.5. Discussion

This baseline butterfly survey in NUWEP recorded a dominance of Nymphalids among other butterfly groups. Although they differ in sampled habitat types, this Nymphalids dominance is similar to recent butterfly inventories conducted within Rwandan ecosystems (Uwizelimana, 2022; Uwizelimana et al., 2021) and in neighbouring countries like Tanzania (Mtui et al., 2019) and the eastern part of Democratic Republic of Congo (Ducarme, 2018).

The dominance of Nymphalids in Nyandungu may be explained by their wide range of feeding habits including nectar, fruits, and carrion. However, the study recorded only one species of Charaxes group (*Charaxes achaemenes*), which is the main fruit-feeder butterfly group. A low number of fruit feeders should partly be due to the fact that the site is under restoration process and fruit trees are still not available yet for fruit feeder butterfly species. We hope future monitoring would record more fruit feeders when the planted trees will have reached maturity.

Sector 4 within NUWEP had both a high number of butterfly species and species diversity. This is probably due to the vegetation type within the sector which offers more food either at the caterpillar or adult stage. This baseline survey is of good use to tourists who will be interested in butterflies within the wetland. However, because butterflies have a large dispersal ability, they can fly and use the whole wetland and only a study on host plants would explain why they are more frequent in one sector and not in another one.

The butterfly survey in NUWEP was conducted within a short time, and we think a more extended sampling period could document more species. It would also be important to establish the butterfly exhibit house in Nyandungu as an income tourist activity but also as means of restoring its butterfly biodiversity. Butterflies are good indicators of ecosystems health (Nyafwono et al., 2014; Oloya et al., 2021) and future monitoring would show whether the ongoing restoration process allows the wetland to bounce back its biodiversity and consequently its ecological functions and services.

Butterflies as a group of species are considered important indicators because they react to any change in the environment and serve as a warning that something strange is happening within their environment (Kremen, 1992; Maleque et al., 2009). Butterflies rely on the vegetation type of the habitat mostly at their larva stage (larva host plants) but also at their adult stage where they feed either on flowers, pollen (Beck & Fiedler, 2009) or rotting fruits (Molleman et al., 2005).

Thus, a diversity of butterflies in a given habitat is an indicator that the ecosystem is healthier. Hence, for NUWEP, butterflies would serve as a group of indicator species to monitor the ecological integrity of the wetland. For example, the paucity of *Charaxes* spp in this survey that are fruit feeders at the adult stages is an indication that the ecosystem is unbalanced in terms of butterfly diversity. Thus if future monitoring documents a diversity of the *Charaxes* within the wetland it will be an indication that the restoration will have achieved the ecological integrity for butterflies and possibly for other species because also butterflies can be used to predict the diversity of other species within the area (Ricketts, Daily, & Ehrlich, 2002).

Because the indigenous tree species are still small and only recently planted, and it will take time to mature, regular monitoring of butterflies in the site could be scheduled at the flowering and fructification stages of the planted trees to assess the recovery of the Nyandungu wetland ecosystem. In this line, a butterfly exhibit house could be established in the Nyandungu wetland where some species could be used to generate income on one side and other butterfly species would be released to serve as pollinators of the planted tree species. Thus, the butterfly exhibition house would contribute at the same time to the rapid restoration of the site and the sustainability of the butterfly exhibition tourism activities through income generation.

3.7. Mammals

3.7.4. Introduction

Many wetlands around the world are considered as places of exceptionally rich biodiversity including mammals (May, 2001) and some African wetlands are recognized among the most productive ecosystems in the world (Kabii, 1996). While wetlands play essential roles for both humans and nature, including flood and erosion control, water purification, recreation and nature appreciation, and conservation (Alexander & McInnes, 2012), human activities carried out in wetland ecosystems reduce their capacity to produce such important ecosystem services, affecting a variety of species with both aquatic and terrestrial preferences (Tang, 2021). Other most recognized threats to African wetlands include industrial effluents and agricultural pesticides, siltation from upland sources, and introduction of alien species that cause dominance of one species and loss of endemic species (Kabii, 1996).

Few studies have examined the linkages between mammals and wetlands unlike terrestrial ecosystems. Sometimes, the vegetation of wetlands and high production levels are often associated with more diversity of mammals, especially small mammals, than surrounding lands or dry upland habitats (Hails, 1997; Bowland & Perrin, 1993). The foraging habits of mammals include herbivorous, omnivorous and carnivorous diets (May, 2001). Pendleton (1984) found that modification of wetlands and the resulting level of moisture determine the population diversity and abundance of small mammals. Decomposing plant parts of wetlands serve as food resources for large predatory reptiles, birds and some mammals (Hails, 1997). The main threats facing the mammals in freshwater ecosystems include habitat loss, habitat modification, degradation as a result of pollution and dumping, and some other direct and specific menaces such as hunting and trapping (Kabii, 1996; Veron et al., 2008). For example, African freshwater otters are threatened by the different human activities that change the structure and function of wetlands; in addition to trapping and hunting, they suffer the effects of pollution (Veron et al., 2008).

Monitoring ecological integrity requires that there are efforts to investigate and determine key indicator species of a given ecosystem but no single species could reflect adaptation to a whole ecosystem; therefore, it is better to select more than one mammal species to monitor ecological integrity when using mammals (Carignan & Villard, 2002). A study conducted in Akanyaru wetland in Rwanda recognizes mammals as integral component of its biodiversity, with at least five species of mammals known in the wetland, all of which live inside the wetlands, including the sitatunga, otters, monkeys, hares, and hippopotamus (Nsabagasani et al., 2008). Since the mammals are regarded as the mainstay of the tourism industry all across Africa, the mammals found in wetlands should be focused for the conservation of their biodiversity (Kabii, 1996). The mammalian group has a large number of species that live in both terrestrial and aquatic habitats, giving them a good chance of survival even under harsh conditions due to their capacity to move when adverse conditions arise. Aquatic or semi-aquatic carnivores (e.g., otter and marsh mongoose) and rodents (e.g., cane rat) are dependent on fishes, freshwater invertebrates, or wetland vegetation.

One study that addressed the diversity of mammals in the wetlands of Rwanda explored the ones located in four wetland complexes in Rwanda, namely Kamiranzovu, Rugezi, Rweru-Mugesera, and Akagera (Fischer, 2011). The current baseline study at NUWEP will provide helpful information on the status of mammals diversity which should be used in long-term in monitoring and management of the Nyandungu habitat. The main purpose of this mammal survey was to establish a baseline set of species checklists and their status for long-term ecological monitoring that can assist in sustainable management and eco-tourism development.

3.7.5. Methods

The NUWEP was surveyed according to the different habitat types found in each sector (Figure 23, Table 12). Different sampling methods were applied according to their suitability to sample different mammal groups. They included direct observations, survey of signs, live trapping, night survey, and opportunistic interviews. In most cases, one indirect method such as interview information on mammal sighting or presence of signs helped us set sampling sites while targeting direct records, such as direct captures of small mammals or observations (sighting) of mammals across NUWEP. We had a total of 40 Sherman traps that we set at different locations to live-trap small mammals (rodents and shrews).

Using direct observations, we walked along reconnaissance trails and set some strategic observation spots for opportunistic observation of animals closely or at large distances using binoculars. Binoculars were used for searching mammals in inaccessible places in marshland where the eye view can reach. Wetland reconnaissance paths were utilized for direct observation of active animals. The reconnaissance trails in wetland were used for assessing mammals signs such as scats.

We also live-trapped small mammals using Sherman folding traps in aluminum. We used all accessible sectors of wetland along various habitat types such as ponds, trees and shrubs, herbs, and grassy vegetation to set baited Sharman traps with mixtures of peanut butter and white oats for capturing small mammals (rodents, and shrews). Night survey was used once using torches.

Table 12. Details of sampling design for the survey of mammals at Nyandungu Urban Wetland Eco-Park, Rwanda in June 2023

Sampling period	Sector number	Trapline number	Survey methods applied
7 June	1, 2, 3	N/A	Signs and reconnaissance trail survey
8 June	4, 5	1	Trapping and reconnaissance trail survey
9 June	4, 5	N/A	Night survey
9 – 11 June	3, 4	1, 2	Trap surveys (live trapping) and sign surveys
11 June	1, 2	1	Reconnaissance trail survey
11 – 15 June	5	3, 4, 5	Trap surveys (live trapping) and sign surveys
13 – 15 June	4	6	Trap surveys (live trapping) and sign surveys
13 – 15 June	3	7	Trap surveys (live trapping) and sign surveys

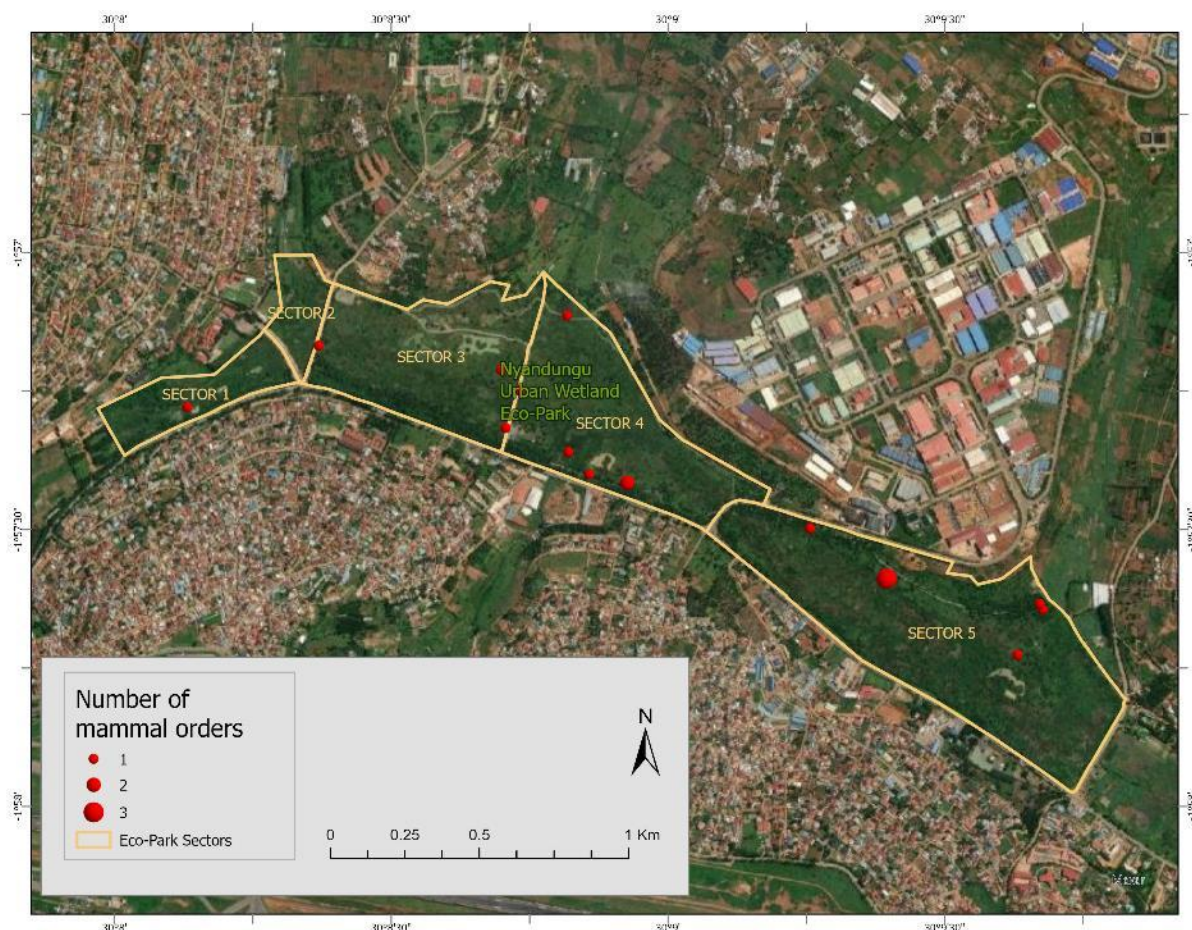


Figure 23. Locations of mammal sampling and observations in Nyandungu Urban Wetland Eco-Park, Rwanda.

Opportunistic interviews were a complementary approach to document the mammals at different sites. Through purposeful group discussions with Nyandungu workers, we obtained their perceptions and experiences with the mammal species known from the wetlands. The data we collected included the location with geographic coordinates, type and status of habitat, and body measurements for captured animals to facilitate identification.

Species identifications

The species were identified based on the morphological observations and measurements, with support of the field guide book entitled “The Kingdon Field Guide to African Mammals” (Kingdon, 2015). We also had species identification experience from previously conducted field surveys in Rwanda.

3.7.6. Findings

A total of 15 species were noted or documented in various ways during the survey. Eight species of mammals were observed at Nyandungu Eco-Park (Table 13). Seven other mammal species are tentatively believed to be present at the Eco-Park based on indirect observations, anecdotal accounts from interviews, and direct observations for which we were unable to confirm the species identification (Table 14). Photos of some of the species and sign observed at the NUWEP can be seen in Figures 24 and 25.

Table 13. Mammals recorded at Nyandungu Urban Wetland Eco-Park, Rwanda based on direct and indirect observations.

SN	Species scientific name	Species common name	Group (order)	Number of records	Sector number	Record means	IUCN status
1	<i>Oenomys hypoxanthus</i>	Rufous-nosed rat	Rodentia	1	3	Sherman traps; observation	LC
2	<i>Lemniscomys striatus</i>	Grass striped mouse or zebra mouse	Rodentia	1	5	Sherman traps	LC
3	<i>Otomys sp.</i>	Vlei rat	Rodentia	2	5	Sherman traps	LC*
4	<i>Crociodura sp. 1</i>	White-toothed shrew	Soricomorpha	1	3	Sherman traps	
5	<i>Crociodura sp. 2</i>	White-toothed shrew	Soricomorpha	1	4	Sherman traps	
6	<i>Thryonomys sp.</i>	Cane rat	Rodentia	1 10+	3, 5 3, 4, 5	Record of skins Grass feeding signs	LC**
7	<i>Atilax paludinosus</i>	Marsh mongoose	Carnivora	4	3, 5	Sighting	LC
8	<i>Hydrictis maculicollis</i>	Spotted-necked otter	Carnivora	4	3	Sighting	NT

* The three species of *Otomys* known in Rwanda are all classified by IUCN Red List as LC

** The two species of *Thryonomys* known in Rwanda are classified by IUCN Red List as LC

Table 14. Mammals possibly extant at Nyandungu Urban Wetland Eco-Park, Rwanda based on indirect observations, anecdotal observations from interviews, and uncertain identifications.

	Species scientific name	Species common name	Group (order)	Number of records	Sector number	Record means	IUCN status
1	<i>Aonyx congicus</i>	Congo clawless otter	Carnivora	1		Sighting without sure confirmation	NT
2	<i>Leptailurus serval</i>	Serval cat	Carnivora	2	1, 5	Based on scats	LC
3	<i>Canis adustus</i>	Jackal	Carnivora	2	1, 5	Based on scats	LC
4	<i>Genetta sp.</i>	Genet	Carnivora			Interviews	LC
5	<i>Sylvicapra grimmia</i>	Bush duiker	Artiodactyla			Interviews	LC
6	<i>Cephalophus nigrifrons</i>	Black-fronted duiker	Artiodactyla			Interviews	LC
7	-----	Unidentified bat	Chiroptera	1	4	Sighting from night survey	



Vlei rat *Otomys sp.*



Rusty-nosed rat *Oenomys hypoxanthus*



Grass striped mouse *Lemniscomys striatus*



Shrew *Crociodura sp.*

Figure 24. Small mammals recorded from the Nyandungu Urban Wetland Eco-Park



Figure 25. Signs observed during the survey of mammal presence in the Nyandungu Urban Wetland Eco-Park, Rwanda (Carnivore scats that may be serval or side-striped jackal (left), and skin and fur remains of rodents eaten by a carnivores (right)).

3.7.7. Discussion

In this survey, there was only one mammal species classified as Near Threatened found among the species observed, the spotted-necked otter (*Hydrictis maculicollis*). The presence of this species suggests the wetlands are in good condition, as otters can be somewhat sensitive to

water and habitat quality. It is yet to be known if the Congo clawless otter exists at the site. Clear measures should be established to protect the otter from cumulative pollution that affects it exposing it to more endangerment. Otters are animals that require wetland habitat to live, for example and wetlands provide a zone of refuge for many large mammals during periods of droughts (Keddy et al., 2009).

Some of most recognized threats to African wetlands include industrial effluents and agricultural pesticides, siltation from upland sources, and introduction of alien species (these cause dominance of one species and loss of endemic species) (Kabii, 1996). Wetlands in Kigali have been more affected than elsewhere due to the pressure for development and the different impacts associated with urbanization. Overexploitation of wetlands in Kigali is associated with levels of poverty of people living around the wetland who rely on resources from the wetlands, but also from more affluent populations who create a lot of waste and pollution in their daily activities that flow into the wetlands.

We can suggest some critical wetland species of which scientific information is scarce to be used as indicator species, the carnivores that depend on water: the spotted-necked otter, Congo clawless otter and marsh mongoose. The measures that restore or protect whole wetland ecosystems need to be enhanced under the wildlife regulatory framework of the Rwandan government. We recommend: to continue monitoring mammals around the wetland since the sampling results showed that more species of small mammals (rodents and shrews) were being captured until the last day, to verify the situation of those mammals that remained in doubt to establish with confidence if they are there or not, and to involve staff and even visitors in observing and monitoring mammals through capacity trainings.

3.8. Water Quality Assessment

Water Quality Assessment was conducted in fifteen sampling points located in five sectors and water samples were collected in each pond at the middle of the pond in order to get a representative sample for the whole pond. During the water quality assessment some in situ parameters were measured directly on the site using a field meter. The field measurement was focused on water temperature, pH, E conductivity, Total Dissolved Solids and Dissolved Oxygen. At each sampling point we collected two samples, one for microbiology analysis in sterilized bottles and another for physical chemical analysis in plastic bottles. Water samples were brought to the Chemistry laboratory at Nyarugenge campus, College of Science and Technology, University of Rwanda, for further analysis.

Analyses conducted in the Chemistry lab included: Total Hardness, Calcium, Magnesium, Potassium, Sodium, Ammonia Nitrogen, Nitrite Nitrogen, Nitrate Nitrogen, Phosphate, Total Nitrogen, Total Phosphorus, Chloride, Sulfate, Iron. Manganese, Total Suspended Solids, Chemical Oxygen Demand, Biochemical Oxygen Demand, Fecal Coliforms and *Escherichia coli*.

3.8.1 Physical and Chemical characteristics of water in the Ponds

Temperature & pH

The Temperature in water body affects the speed of chemical reactions, aquatic plant photosynthesis, rate of metabolism for animals and other organisms, as well as influences how

pollutants, parasites, and other pathogens interact with aquatic residents. Temperature is important in aquatic system because it can cause mortality and influence solubility of dissolved oxygen and other chemicals substances (GEMS 2007). Water temperature measured on the field varied between 19.8 – 24.0° C which is normal ambient temperature for the living aquatic organisms. The lower temperature was measured at down the bridge while the higher temperature was measured at Sector 1 pond.

The pH of aquatic ecosystem is important because it is linked to biological productivity. The pH values between 6.5 and 8.5 usually indicate good water quality and this range is typical of most major drainage basins of the world (GEMS 2007). The pH varied between 5.93 – 7.98, which values compare to the standards for aquatic life to be in healthy condition (6.5 – 8.5) and are in the acceptable range. The lowest value of pH was measured at the sector 1 pond 1 while the highest pH was measured at the sector 3 pond 2 Muhazi.

Turbidity & Total Suspended Solids

Turbidity refers to water clarity, and greater the amount of suspended solids in the water the higher the measured turbidity. The major source of turbidity and suspended solids in the open water is natural and anthropogenic (human) activities in the watershed and excess of soil erosion from agriculture, construction, urban runoff, and industrial effluents. The water turbidity sampled in this study showed a low level; the values measured varied between 0.08 – 5.8 NTU. The lower value was measured at Sector 1 on pond 5 while the higher value was measured at the same sector on the pond.

The values of Suspended Solids were high compared to the turbidity. The higher value was measured at the sector 1 pond 1 while the lower value was measured at the sector 1 at the exit to the sector 2 at the bridge to Kimironko.

Conductivity & Total Dissolved Solids

Electric conductivity is a measure of the property that is proportional to the concentration of ions in solution. Conductivity is often used as a salinity measurement and is considerably higher in saline systems than in non-saline systems. The total dissolved solids is an indication of dissolved salts in the water body. The major cations responsible for the dissolved solids are Calcium, Magnesium, Potassium and Sodium. The major ions responsible are carbonate, bicarbonates, sulfates and chloride.

The conductivity measured varied between 202 – 620 $\mu\text{S}/\text{cm}$, the lower value was measured at sector 3 pond 1 Bamboos, the higher value was measured at sector 5 pond 1. The dissolved solids measured varied between 96.6 – 306 mg/l, the lower and higher values of Dissolved Solids were measured at the same point as per conductivity.

Dissolved Solids, Chemical Oxygen Demand, Biochemical Oxygen Demand

The oxygen that is dissolved in water is the most important in aquatic systems. It is often used as an indicator of water quality such high concentration of oxygen (above 5 mg/l) indicate a good water quality and less organic matter present in the water body.

Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) are two common measures of water quality that reflect the degree of organic matter pollution of a water body. At all water sampling where we collected water in the ponds, the results showed a low concentration of COD and BOD which varied between (7.59 – 59.9 mg/l) and (2.02 – 22.16 mg/l) respectively and high concentration of dissolved oxygen.

Hardness, Calcium and Magnesium

Water hardness was analyzed and its responsible minerals (Ca & Mg) which is expressed as calcium carbonate. In the ponds water hardness was between (117 – 186 mg/l). Calcium varied between 16.9 – 65.8 mg/l CaCO₃, and Magnesium varied between 0.3 – 1.7 mg/l CaCO₃. Following the results of hardness obtained we can conclude that water in the ponds at Nyandungu can be classified as moderately hard (120 – 180 mg/l CaCO₃).

Nutrients

Nutrients are elements essential to life. In aquatic systems, nitrogen and phosphorus are the two nutrients that most commonly limit maximum biomass of algae and aquatic plants (primary producers). Nitrogen and Phosphorus are considered to be primary drivers of eutrophication of aquatic productivity. Eutrophic is considered as a result of human activities through factors such as runoff from agricultural lands and the discharge of municipal waste into rivers and lakes (GEMS 2006). Nutrient load measured in the ponds were found to be poor in Nitrogen and Phosphorus, which varied as following: total Nitrogen or TN (1.6 – 9.1 mg/l) while total Phosphorus of TP varied between (0.61 – 1.25 mg/l). Considering these finding we can say that water in the ponds has low concentration of nutrients but if the ponds are receiving runoff and municipal discharge in the long term they can become eutrophic ponds.

Iron and Manganese (Fe, Mn)

The Fe & Mn measured was found to be high at almost sampling points. The Fe concentration varied from 0.31 – 2.28 mg/l Fe while Mn varied from 0.330 - 0.963 mg/l Mn. These concentrations are higher than the recommended value 0.3 mg/l Fe and 0.1 mg/l Mn. These two microelements have a higher concentration in all water ponds where water samples have been collected. Common sources of iron and manganese in groundwater are often naturally occurring from the natural weathering of minerals and rocks that have iron and manganese in them. Industrial effluent, acid-mine drainage, sewage and landfill leachate may also contribute iron and manganese to local groundwater and can leach into wetlands.

Bacteria (Fecal coliforms and *Escherichia coli*)

Surface and groundwater water can be easily infected by bacteria, measured as Total coliforms or Fecal coliforms. Coliform Bacteria usually increases when populations are living upstream and their effluent drains into the downstream wetlands, and this can be seasonal. Bacteria can increase in surface water due to runoff from municipal wastewater from untreated influent especially with heavy rainfall, and in dry season the number of bacteria may decrease. Total and Fecal coliforms are measured as indicators of pathogenic bacteria. Fecal coliforms measured in all water ponds showed a contamination at 1.4×10^4 Cfu/100ml which was the highest measure, while *Escherichia coli* showed 2.25×10^2 Cfu/100ml. Normally these should be not detectable in healthy aquatic ecosystems.

Data from the water quality assessment can be found in Appendix 4.

3.9 Conclusion and recommendations

3.9.1 Conclusions

The Nyandungu Urban Wetland Eco-Park baseline biodiversity survey results suggest that the restoration activities have created habitat that serves as a foundation for further restoration and

development of ecosystem functioning over time. Sectors 3, 1, 4 and 5 had the highest observations across all taxon groups, while 2 was also high for amphibians. Most of the species observed during the baseline survey (amphibians, freshwater macroinvertebrates, insects, birds and fish) are representative of disturbed or newly recovering wetlands.

This baseline survey occurred in June 2023, the transition period between the wet season and the dry seasons. Biodiversity surveys should ideally be conducted in the wet and the dry season to capture the variability in species presence related to rainfall, temperature and humidity changes. However, data from this transition period provides enough information for a baseline or benchmark against which to monitor the progress of restoration and change over time.

A key component to be considered in developing a monitoring system is ecological integrity (Innis et al., 2000). Indicators of integrity will include species which can be indicators of ecosystem health and function over time. Figure 26 shows the process of ecological monitoring and how indicators species fit into this process, including the covariates that help understand the presence or absence of specific indicator species. Monitoring ecological integrity requires that there are efforts to investigate and determine key indicator species of a given ecosystem; such indicators may include keystone, umbrella and flagship species, as well as species subject to factors of dispersal or migration, area constraints, etc. (Carignan & Villard, 2002). For the NUWEP, monitoring should focus on the freshwater aquatic ecosystem health and integrity, and the upland sites with native vegetation. The goal should be a Park with healthy functioning ecosystems, indicated by presence of native species representative and characteristic of the location. This goal will also serve to support climate adaptation and tourism objectives for the Park. Natural regeneration should be promoted through the types of plantings that create habitats and attract species such as seed dispersers to promote regeneration of the site.

We have identified species that can serve as indicators for a monitoring framework for the NUWEP (Table 15) based on on the baseline results. Some of these species are tolerant of pollution and other forms of disturbance, and when found in the ecosystem, indicate problems with the quality and functioning of the ecosystem. We also identified species that are intolerant of disturbance, or sensitive to habitat conditions and changes, and will only be found in healthy, functioning ecosystems.

Notably, the endangered grey crowned crane (*Balearica regulorum*) which is an endangered species, and the spotted-necked otter (*Hydriectis maculicollis*) listed as Near Threatened, were observed in the Eco-Park during the biodiversity survey. These species could be considered **flagship species** for the Eco-Park as they are larger charismatic species that are relatively easy to see and enjoyed by the general public, and are associated with healthy wetland ecosystems. Certain butterfly species could also serve as flagship species, as well as dragonfly species which are indicators of ecosystem integrity (Uyizeye et al. 2021). Both butterflies and odonates are charismatic and relatively easy to see and report by citizens.

Table 15. Proposed indicator species and their attributes to monitor change and restoration success in Nyandungu Urban Wetland Eco-Park, Rwanda

Taxon	Species	Attributes
Amphibians		
Species of disturbed wetlands		
	<i>Africalus quadrivittatus</i>	Occurs widely in moist and dry savannah, and degraded former forest and wetlands.
	<i>Amietia nutti</i>	Occurs in both undisturbed forest habitat and disturbed landscapes with slow-moving streams, including agricultural water channels and ponds.
	<i>Kassina senegalensis</i>	Occupies a wide range of habitats including humid and dry savannas, shrubland, forest edge, degraded forest, the lower levels of montane grassland, and a variety of anthropogenic habitats.
	<i>Hyperolius kivuensis</i>	Occurs in moist savannah, tropical deciduous forest, heavily degraded former forest (farm bush) and wetlands, and in banana plantations (living in the leaf axils). It has been found breeding in large ponds and swamps.
	<i>Hyperolius viridiflavus</i>	Associated with emergent vegetation at margins of swamps, rivers and lakes in all types of savannah, grassland, forest edge and bush land, and human-modified habitats, including cultivated land, urban areas and gardens. It spreads rapidly into recently created waterbodies and breeds in a wide variety of aquatic habitats.
	<i>Phrynobatrachus kakamiko</i>	Occurs in small seasonal ponds in anthropogenic grassland dominated by human activities.
	<i>Phrynobatrachus natalensis</i>	Occurs in herbaceous vegetation along the margins of shallow marshes, lakes, rivers, streams and pools, both permanent and temporary. It is also found in agricultural land, and even at clearings deep within forest.
	<i>Ptychadena nilotica</i>	Occurs in agricultural areas, rice fields, disturbed areas with tall herbaceous vegetation and marshy areas, and is often found near large lakes, rivers and other wetland habitats (including irrigation canals).
	<i>Ptychadena anchietae</i>	Inhabits woodland, savannah, grassland, and agricultural areas and forest clearings, usually (but not always) in close proximity to permanent water. It breeds in shallow temporary ponds.
	<i>Ptychadena porosissima</i>	An adaptable species that can survive in altered habitats.
	<i>Sclerophrys gutturalis</i>	A very adaptable species occurring in a wide variety of savannahs, grassland, thickets, and agricultural land. It is able to breed in permanent and semi-permanent standing water. It breeds frequently in garden pools.
	<i>Xenopus victorinus</i>	A water-dependent species occurring in a very wide range of habitats, including heavily modified anthropogenic habitats including pools, ponds and stagnant water bodies in mud holes.
	<i>Xenopus muelleri</i>	A water-dependent species, using both temporary and permanent ponds, and also streams and rivers in the dry season. It is found in agricultural and other altered habitats.
Species of undisturbed wetlands or those that are tolerant of slight disturbance		
	<i>Hyperolius lateralis</i>	Indicates restoration success. It breeds in a variety of habitats, including papyrus and reed vegetation along savannah streams, swamps covered with grass, swamps in farm bush and dense swamp forests.
	<i>Hyperolius cinnamomeoventris</i>	Indicates restoration success. It breeds in both temporary and permanent water, including swamps, swamp forest, lakes, pools and

	seasonally flooded grassland. Its breeding sites generally have abundant grassy vegetation.
<i>Hyperolius rwandae</i>	The species has been collected from ponds and swamps in farmland and open natural wetlands.
Aquatic invertebrates	
Species of disturbed wetlands	
<i>Procambarus</i>	This is the swamp crayfish, an alien invasive species. It is an indicator of disturbed wetland habitats. It has been used to indicate microplastic pollution (Pastorino et al. 2023) and heavy metals bioavailability (Alcorlo et al. 2006).
Species of undisturbed wetlands or those that are tolerant of slight disturbance	
<i>Hydropsychidae</i>	This family is part of the Order <i>Trichoptera</i> which are known to be good indicators of water quality and freshwater ecosystems. The Orders Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly) together are referred to as the EPT and are macro-invertebrates usually found in streams with good water quality and are sensitive to water pollution such as excessive sediment inputs (Pollard and Yuan 2010). Thus EPT presence and abundance indicates how healthy a stream is. The presence of <i>Hydropsychidae</i> is a commonly used ecological indicator for monitoring aquatic ecosystems (Higler & Tolkamp 1983; Ratia et al. 2012).
Fish	
Species of disturbed wetlands	
<i>Clarias liocephalus</i>	Usually indicates disturbed aquatic ecosystems. <i>Clarias liocephalus</i> usually indicates the continuing decline of the quality of habitat/wetland due to industrial and agricultural effluents pollution. Mostly the family of Claridae fishes were found to be tolerant to the environmental pollution (Raburu et al., 2010).
<i>Poecilia reticulata</i>	An introduced species that indicates disturbed wetlands and polluted freshwater ecosystems. This species has been widely introduced intentionally into many parts of the world as a vector control for mosquito-borne disease, and unintentionally through aquarium release (Deacon et al. 2011). It continues to negatively impact native fauna throughout its introduced range. <i>P. reticulata</i> persists in highly degraded habitats, displays generalist characteristics, adapts to a broad range of abiotic parameters, and exhibits reproductive ecology that favours rapid colonization.
<i>Haplochromis spp.</i>	The genus <i>Haplochromis</i> is generally an indicator of organic pollution in aquatic ecosystem and high water turbidity. This genus was found to be moderately sensitive to environmental pollution (Raburu et al., 2010).
Species of undisturbed wetlands or those that are tolerant of slight disturbance	
<i>Cyprinidae</i>	Species in this family may be sensitive to habitat quality and may serve as good indicators of ecosystem health and if found in a survey could indicate ecosystem integrity, especially the endemic cyprinid.
Birds	
Species of undisturbed wetlands or those that are tolerant of slight disturbance	
<i>Ceryle rudis</i> , <i>Corythornis cristatus</i> , <i>Halcyon senegalensis</i>	These genera of kingfishers feed on fish and aquatic macroinvertebrates and their presence in ecosystems indicates that prey are available may suggest that waterbodies have good health
<i>Plectropterus gambensis</i>	The goose occurs where there is clean water; they rely on water and wetlands for nesting and foraging sites

<i>Phalacrocorax africanus</i>	Cormorants nest in colonies often in trees and shrubs near waterbodies; the presence of breeding colonies indicates good health of local habitat
<i>Corythaixoides personatus</i>	Sensitive to environmental change, require specific vegetation for feeding and nesting
<i>Balearica regulorum</i>	Their survival depends on wetlands, grassland and savannah, their presence indicates health and stability of an ecosystem
<i>Centropus monachus</i>	Occur in dense and well vegetated wetlands and grasslands for feeding and nesting, and can indicate ecosystem health
Mammals	
Species of undisturbed wetlands or those that are tolerant of slight disturbance	
<i>Hydricitis maculicollis</i>	Occur in habitats with healthy freshwater ecosystems and access to riparian zones; good indicators of habitat quality
<i>Aonyx congicus</i>	Occur in habitats with healthy freshwater ecosystems and access to riparian zones; good indicators of habitat quality
<i>Atilax paludinosus</i>	Occur in habitats with healthy freshwater ecosystems and access to riparian zones; good indicators of habitat quality
Butterflies	
Species of undisturbed wetlands or those that are tolerant of slight disturbance	
<i>Charaxes</i>	The presence of species from this group of butterflies indicates ecological integrity and the diversity of butterfly species in general in the landscape provides an indication of healthy or restored ecosystems

Although more research is needed, there is enough knowledge of aquatic macroinvertebrate taxonomy and environmental sensitivity in Rwanda to enable this group to be an ideal indicator for monitoring the freshwater ecosystems of the NUWEP. The current baseline is a good starting point from which to benchmark restoration progress over time using existing knowledge of this taxonomic group. Similarly, the amphibians are well documented in Rwanda, especially in terms of disturbance tolerant and sensitive species, and this group makes an ideal group for monitoring. Both amphibians and aquatic macroinvertebrates sampling techniques can be readily taught to the general public including school children, and these groups could make ideal taxon groups for a citizen science monitoring program.

Birds also make an ideal group for monitoring because they can be easy to see and hear, and there is ample information about species presence, distribution, and habitat characteristics to use this group as an indicator group for the Eco-Park. Many citizens enjoy watching birds and this could be readily adapted to a citizen science monitoring program. The eBird app (<https://ebird.org/home>) could be an ideal platform to promote bird watching and informal monitoring of the Eco-Park. The Center of Excellence in Biodiversity and Natural Resource Management at University of Rwanda has a project to record all birdsounds in the country (Planet Birdsong <https://www.planetbirdsong.org/>), and the recordings are uploaded into the Rwanda Biodiversity Information System (<https://rbis.ur.ac.rw/>) where they are freely accessible and can support acoustic bird monitoring.

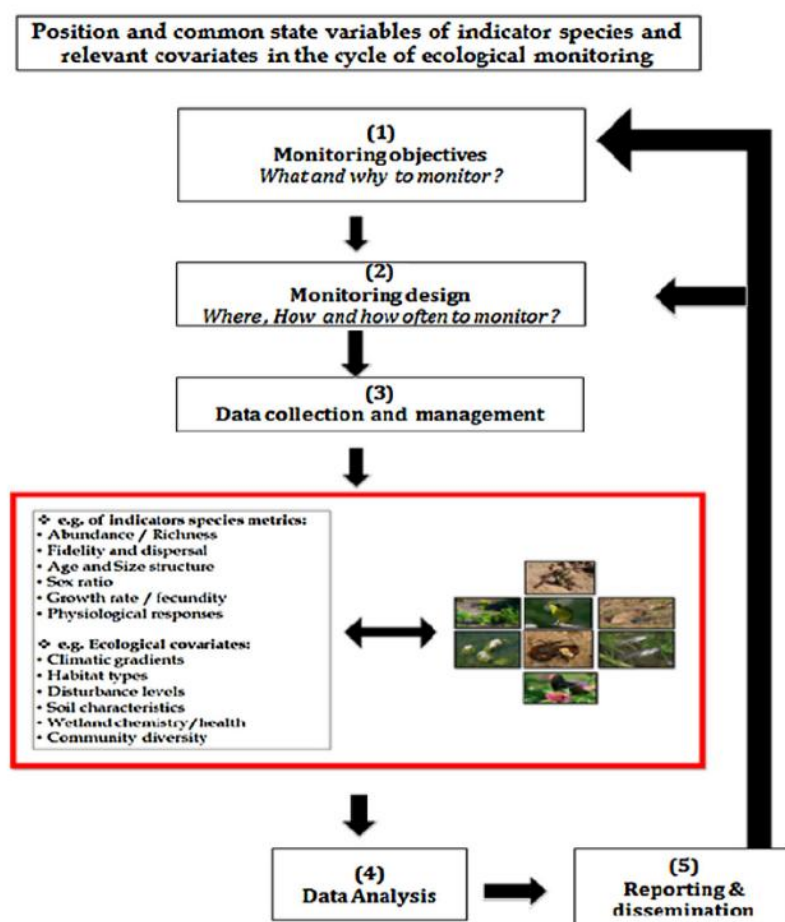


Figure 26. The processes involved in biodiversity monitoring and the role of the indicator species and common co-variates associated with the species monitoring. The baseline biodiversity assessment will establish the foundation for the systematic biodiversity monitoring. From Siddig et al. (2015).

There are certain bird species characteristic of wetlands which can serve as good indicators of the health and integrity of the Eco-Park ecosystem. Furthermore, as the plantings (trees and shrubs) mature, we may expect them to attract more bird species of different guilds, especially fruit eaters and seed dispersers. We would also expect more diversity and attraction of endemic bird species to the Eco-Park as the vegetation matures and natural regeneration of native species continues.

In the mammal group, as mentioned above, otters including the spotted-necked otter and African clawed otter (*Aonyx congicus*) serve as good indicators of the wetland health, as well as the Marsh mongoos (*Atilax paludinosus*) which is listed as Least Concern. Butterflies are a charismatic species and relatively easily sampled with citizens, and this baseline assessment provides a good starting point to track changes in the ecosystem over time. We may expect more of the fruit-feeding butterflies (Charaxes group) as the planted trees and shrubs mature and produce flowers and fruit. The fish species observed in this study represent a baseline to support monitoring of the aquatic ecosystem. For all groups, a larger budget will allow more

days to establish a baseline that captures more of the potential species present in all taxon groups, but the checklists presented here represent a sound baseline for monitoring plans.

Monitoring can include annual surveys similar to the surveys done across the taxon groups in this study, and if done annually at the same time each year, can provide a database for relative comparisons over time. If funds are available, an additional sample period within the year in a different season would also be valuable, but an one annual survey done consistently based on this baseline can provide solid information about the ecological integrity and state of the restoration at the Nyandungu Urban Wetland Eco-Park.

Monitoring could also be expanded to include camera traps set at strategic locations to capture terrestrial and arboreal wildlife species. Passive acoustic monitoring could also be used to monitor species presence over time, with machine learning applications to detect specific species of interest for the monitoring protocol.

Our methodology in this project has been to focus on Rwandan biodiversity science capacity building. This project had a home-grown approach: the CoEB has been developing taxon expertise among its early career researchers, especially in biologically important groups that serve as indicators of ecosystem health and change. There are taxon experts in all the key groups able to sample and identify the species. We had junior researchers join the teams with emphasis on selection of young women as well as men, to build research capacity in this area.

Below is the presentation of the monitoring framework based on the results of the baseline survey.

3.9.2 The Biodiversity Monitoring Framework

The framework presents the purpose of the monitoring (why), the indicators (what will be monitored), and details of how (what values or metrics will be generated such as species presence or richness). The methods described above in this baseline survey report should be used to maintain standards and allow comparisons over time with the baseline data in this report. The descriptions within each taxon group in this report as well especially the information presented in Table 15 provide details for each taxon group.

National Outcome for the Biodiversity Monitoring: Restored wetland with ecological integrity and attractiveness to tourists.

Objectives:

- 1) Maintain ecosystem processes
- 2) Reduce presence of alien invasive species
- 3) Reduce environmental pollutants
- 4) Prevent species declines
- 5) Attract biodiversity (migratory species, aquatic species)
- 6) Maintain a beautiful and enjoyable space for visitors and tourists

Targets:

- Native species dominate
- Improved water quality and pollution management
- Improved ecosystem composition with diverse habitats represented
- Biodiversity well represented across the different ecosystems; functional trait diversity present (species representing different function groups such as pollinators, nutrient cycling, detritivores, frugivores, seed dispersers, etc.)
- Sustainably managed visitor/tourist space

Indicators	To Monitor	Metrics	Expected changes	Monitoring Frequency	Notes
Reduced alien invasive species	Vegetation surveys	Presence and density along line transects; both native and alien invasives	Reduction in presence & dominance	Annual	School groups can be engaged to assist and learn about invasive species
Improved water quality	Physico-chemical sampling: water temperature, pH, E conductivity, Total Dissolved Solids and Dissolved Oxygen, Bacteria	Standard measures (see Section 3.8 in this report)	Reduction in bacteria load, suspended solids, and reduction in Fe & Mn; other parameters should maintain	Annual	Integrate with a citizen science monitoring program
Improved Wetland Quality//Native species dominate	- Family <i>Hydropsychidae</i> and other members of EPT - Amphibians from the <i>Hyperolius</i> genus - Fish - Vegetation - Butterflies - Migratory bird species (See table 15 for specific indicator species)	Presence & relative abundance within assemblages, non-native species presence; indicator species; threatened and endangered species presence Species diversity indices	Increase in presence & abundance of indicator families, genera and species (from Table 15) Especially caddisflies in family Hydropsychidae and Leptoceridae should increase as the site quality is improved over time since restoration started; Trichoptera groups should reestablish in parts of the Nyandungu Urban Wetland Eco-Park. Continued or increased presence of	Annual; if funds allow twice/year once in dry and once in wet season	Good indicators of water quality and freshwater ecosystems: Orders Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly) together are referred to as the EPT and are macro-invertebrates usually found in streams with good water quality and are sensitive to water pollution such as excessive sediment inputs

			spotted-necked otter (<i>Hydricictis maculicollis</i>)		
Improved Uplands & forest quality/Native species dominate	Birds, vegetation, mammals, butterflies (See table 15 for specific indicator species) Flowering & fruiting of trees and shrubs	Presence & relative abundance of indicator species (birds, vegetation, mammals) Species diversity indices Presence/absence of flowers & fruits	Maintained or increased presence of native trees, especially fruiting and flowering species. Charaxes group of butterflies (fruit-feeding butterflies) should increase as restoration proceeds.	Annual Flowering & fruiting on a monthly basis	Refer to Table 15; Compare with baseline data Flowering & fruiting could be done by park guides or guards with simple data sheet
Sustainable use/sustainable tourism	Native species documented in baseline survey from these taxon groups in vicinity of visitor facilities: birds, amphibians, plants, mammals (see species lists) – especially in Sector 3 Presence of solid waste (plastics) Visitor/tourist feedback	Change in presence & relative abundance (compare with baseline) including flagship species; signs of disturbance on and off trails Survey comments from visitors/tourists	Presence of most of the same species as found in baseline, or increases Reduction in solid waste (especially plastics)	Bi-annual	Possibility for new species arrivals indicating improvement and protection of the sites especially tourism sites

We emphasize the application of the RBIS to the monitoring work. The information system, developed by the CoEB with support from the JRS Biodiversity Foundation, holds more than 141,000 species records and growing regularly as new data are procured, and includes modules for the taxon groups used in this project. The RBIS was developed in collaboration with REMA and Ministry of Environment to contribute to conservation and land use planning, EIA reporting, MEA reporting, and effective conservation of biodiversity. The RBIS <https://rbis.ur.ac.rw/> is used to store and visualize data collected in this project, and will support monitoring and production of data products related to biodiversity and the different habitats and ecosystems (e.g., wetlands, ponds, upland forested areas, grassland areas) that compose the NUWEP. The data are readily accessible in RBIS in a standardized data format.

3.9.3 Recommendations

This biodiversity baseline survey report should be circulated to all park staff to inform and engage with biodiversity and support the monitoring. Ideally it should be translated into Kinyarwanda for all including maintenance staff. It should be made available for a small fee

to visitors of the park to help promote interest in and education about biodiversity and ecosystem health. A short synthesis fact sheet could also be developed from this report to share with the public and park staff. Below are specific recommendations for the park management.

Removal of alien invasive species

Management of the Eco-Park should include removal of invasive plant species (see plant list in this report). Signage should be placed around the park pathways to educate visitors about the hazards of alien invasive plants and visitors can help in spotting newly established invasive plants and reporting to the Park management.

Water Pollution

Incoming polluted water is also a problem for the NUWEP, and a study should be conducted to test the water entering the wetland complex from the surrounding land use types and industries. Regular water quality monitoring as described in the biodiversity monitoring framework is recommended. The industrial zone stakeholders should be engaged in discussion about water treatment techniques, and constructed wetland filtration area could be established in between the industrial zone and the NUWEP boundary to filter inflowing water. Finally, the quality of the water exiting the Eco-Park should be sampled to compare with inflowing water to assess if the NUWEP is cleaning water and retaining pollutants, as one of its main ecological services. This information can be used to develop evidence-based policies and strategies to guide the management of the Eco-Park and adjacent industrial and urban zones.

Phytoremediation, the use of plants to reduce the concentration of toxic contaminants in the environment, can be used to manage the heavy metals and some other toxins in the water or soil of the Eco-Park. Below is a table showing some suggested plant species identified as effective at phytoremediation.

Table 16. Potential species for phytoremediation in the Nyandungu Urban Wetland Eco-Park, Rwanda

Plant species	Purpose	Source
<i>Lemna minor</i>	TDS = 68% (28%), turbidity = 97% (61%), COD = 92% (45%), BOD5 = 92% (41%), 400 cfu/100 ml faecal coliforms measured at the end of experiment Heavy metal removal	Schnabel et al. 2022 Birame 2012
<i>Ipomoea aquatica</i>	Removal efficiencies of TSS and COD were 85.6 and 44.8%, respectively	Schnabel et al. 2022
<i>Spirodela polyrhiza</i>	heavy metals Pb, Cr and Cd from surface water	Schnabel et al. 2022
<i>Brachiaria mutica</i>	Removal efficiency for faecal coliforms >64%	Schnabel et al. 2022
<i>Cyperus papyrus</i>	Reduction efficiency for faecal coliforms of 98%	Schnabel et al. 2022
<i>Thalia geniculata</i>	BOD removal efficiency = 96%, COD removal performance = 69%	Schnabel et al. 2022
<i>Azolla pinnata</i>	Preliminary treatment of paint wastewater	Echiegu et al. 2021
<i>Helianthus annuus</i>	Industrial discharge; uptake of As	Odoh et al. 2019
<i>Sporobolus pyramidalis</i>	Roots accumulate high concentration of Pb (757.78 $\mu\text{g g}^{-1}$)	Kahangwa et al. 2021
<i>Blepharis maderaspatensis</i>	Absorbs Pb, Cd, Cu, Mn and Ni	Kahangwa et al. 2021

Additional Visitor Opportunities

We offer several suggestions to enhance visitor opportunities and strengthen connections to nature. The creation of a butterfly house where visitors can enter and observe butterflies and learn about them would be a valuable asset for the NUWEP, and could generate revenue for local communities who could be providing butterfly stock (Gordon and Ayiamba, 2003). This could also generate interest in biodiversity and promote citizen science monitoring of butterflies in the NUWEP.

Other revenue generating activities that could promote biodiversity observation, monitoring and awareness raising include production of T-shirts, hats and water bottles as souvenirs for purchase, with images of the animals and plants that can be seen in the Eco-Park. These could include species that are relevant biological indicators in the Eco-Park. Revenue generated from these activities could help support the annual biodiversity monitoring.

Among the *Haplochromis* fish species inhabiting the Nyandungu Urban Wetland Eco-Park, the presence of colorful fish haplochromis could be explored for tourism like the ones of Lake Malawi called Mbuna Cichlid, and if raised in aquarium, even exported for income country generation (Choi et al., 2023). A space for tanks or aquariums where visitors can more closely observe the aquatic diversity (e.g., frogs, fish, turtles) and hands-on activities like microscopes to observe the rich diversity in the water, could also be an option for education and awareness-raising and simple enjoyment of nature.

Box 1. Specific suggestions to enhance visitor experience

- Keep a blackboard inside entrance which changes each day, showing what was seen that day, any new sightings, etc., updated by park staff
- Hats, coffee mugs, water bottles, T shirts with images of the biodiversity of Nyandungu
- Signage along trails of species to look out for while walking and to advise visitors to take care where known populations of threatened and endangered populations exist
- Sell printed checklists
- Rental of binoculars
- Clipboards and checklists for any visitor to borrow while in the Park
- Use an app for people to record what they see while in the park (could be an iNaturalist ‘project’)
- Employ professional interns as ‘docents’ to guide people or stand along trails and point out what can be seen
- Butterfly enclosure
- Install tanks in a visitors’ gallery for easy, close observations of aquatic invertebrates
- Establish a butterfly house to rear butterflies and provide visitor educational experience

Citizen Science

Monitoring can be done regularly using citizen groups (visitors to the park, school groups, environmental clubs) or staff in the Eco-Park. For example, an application for a smart phone can be created to report georeference species observations, or the eBird app or the iNaturalist app (<https://www.inaturalist.org/>) can be used on personal smartphones. Signage around the Eco-Park paths can help visitors begin to learn and identify species useful for monitoring. A very simple strategy could be to place a blackboard near the park entrance to allow visitors and park staff to record daily observations of wildlife, which can begin to attract attention and excitement about the species present in the Eco-Park. Citizen science is considered an approach that invites volunteers (individuals who may or may not have any formal training as scientists) to collect data that can be used in organized scientific projects (Bonney et al. 2015), such as biodiversity monitoring.

Volunteer participation in biodiversity and ecological studies has become a mainstay in projects aimed at biodiversity conservation (Dickinson et al. 2010). Citizen science projects have been shown to produce reliable data that can be used in monitoring projects, and using a citizen science approach can also help participants gain scientific knowledge, increase public awareness of biodiversity, and can contribute positively to social well-being by giving people a voice in local environmental decision making (Bonney et al. 2015). Using citizen science in biodiversity monitoring will present a win-win situation for monitoring and restoration effectiveness, and helping people get closer to nature and gain deeper experiences of the Nyandungu Urban Wetland Eco-Park which could go beyond their visit to the Park.

Box 2. Establishing a citizen science monitoring program

- 1) Train a team of park staff to manage the citizen science program
- 2) Identify monitoring targets; suggestions include birds, butterflies, mammals, frogs, migratory species, invasive species
- 3) Develop simple sampling protocol for each taxon group to be included in the monitoring program
- 4) Determine how the data will be used: by park management, by citizen groups, etc.
- 5) Gather needed equipment: binoculars, clipboards, identification keys (or use an app developed for the monitoring program)
- 6) Identify frequency of the citizen monitoring – monthly could be a good start to get people engaged
- 7) Develop a fact sheet about the monitoring program: why, what, how and when
- 8) Target citizens to get involved and develop a registration program
- 9) Create a data management protocol for the data and the analyses of the data
- 10) Establish a regular synthesis and reporting schedule and provide the citizens with reports of the data they participated in collecting
- 11) Solicit pre- and post- feedback from participants in the program
- 12) Build in periodic evaluation sessions with the management team to assess how the program is running and what issues or problems need to be addressed

Management of the visitor and tourist sites

Sectors 3 and 4 are the main areas accessed for tourism, as well as section 5. We recommend that any new populations of threatened and endangered species found in these sites be mapped, marked and checked regularly by park staff. The maps and species lists developed in this report indicate populations of threatened and endangered species in sectors 3 and 4 that should also be tracked to ensure that visitors and tourists are not damaging them. Signage may be needed to ensure that visitors stay on trails and avoid disturbing populations of plants or wildlife. Any plans for expansion of the infrastructure should consult the maps to avoid areas where populations of threatened and endangered species are located. Tourist trails should be carefully designed to avoid erosion, and in some cases, temporary floating trails may be used to enable access and avoid damage to vulnerable areas. We also recommend establishing research access trails into inaccessible sites to support research activities in sectors 1 and 2.

References

- Alcorlo P., Otero M., Crehuet M., Baltanás A., Montes, C. (2006). The use of the red swamp crayfish (*Procambarus clarkii*, Girard) as indicator of the bioavailability of heavy metals in environmental monitoring in the River Guadiamar, SW, Spain. *Science of the Total Environment*, 366(1):380-390. doi: 10.1016/j.scitotenv.2006.02.023
- Alexander, S., & McInnes, R. (2012). The benefits of wetland restoration (Issue 4, p. 20). Ramsar Convention Secretariat. <https://doi.org/10.13140/RG.2.1.3024.1124>
- Angelier, F., Tonra, C. M., Holberton, R. L., & Marra, P. P. (2011). Short-term changes in body condition in relation to habitat and rainfall abundance in American redstarts *Setophaga ruticilla* during the non-breeding season. *Journal of Avian Biology*, 42(4), 335–341. <https://doi.org/10.1111/j.1600-048X.2011.05369.x>
- Barnes, B.V., D.R. Zak, S.R. Denton and S.H. Spurr, 1998. *Forest Ecology*. 4th Edn., John Wiley and Sons Inc., ISBN: 13: 978-0471308225, pp: 773.
- Beck, J., & Fiedler, K. (2009). Adult life spans of butterflies (Lepidoptera: Papilionoidea + Hesperioidea): BROADSCALE CONTINGENCIES WITH ADULT AND LARVAL TRAITS IN MULTI-SPECIES COMPARISONS. *Biological Journal of the Linnean Society*, 96, 166–184. <https://doi.org/10.1111/j.1095-8312.2008.01102.x>
- Birame, C.S. (2012). Development of a Low-Cost Alternative for Metal Removal from Textile Wastewater. PhD dissertation, Wageningen University and Research, The Netherlands. <https://www-webofscience-com.antioch.idm.oclc.org/wos/alldb/full-record/PQDT:85685088>
- Bonebrake, T. C., Ponisio, L. C., Boggs, C. L. & Ehrlich, P. R. (2010). More than just indicators: A review of tropical butterfly ecology and conservation. *Biological Conservation*, 143(8), 1831–1841. <https://doi.org/10.1016/j.biocon.2010.04.044>
- Bonney, R., T.B. Phillips, H.L. Ballard, and J.W. Enck (2015) Can citizen science enhance public understanding of science? *Public Understanding of Science* 1-15. DOI: 10.1177/0963662515607406
- Bowland, J. M., & Perrin, M. R. (1993). Wetlands as reservoirs of small-mammal populations in the Natal Drakensberg. *S. Afr. J. Wildl. Res.*, 23(2), 39–43.
- Burger, M., Rauwels, O. S. G., Branch, W. R., Tobi, E., & Yoga, J. (2006). An assessment of the amphibian fauna of the Gamba Complex of Protected Areas, Gabon. *Bulletin of the Biological Society of Washington*, 12, 297-307
- Butterwick, M. L., & Kirchner, W. N. (2012). Indicator Rating Definitions Cold Regions Research. July.
- Carder, N., & Tindimubona, L. (2002). Butterflies of Uganda: A field guide to butterflies and silk moths from the collection of the Uganda society. Uganda society.
- Carignan, V., & Villard, M.-A. (2002). Selecting indicator species to monitor ecological integrity: a review. *Environmental Monitoring and Assessment*, 78, 45–61. <https://doi.org/10.1023/A>
- Colwell, R. K. 2009. EstimateS: Statistical estimation of species richness and shared species from samples. Version 8.2. User's Guide and application published at: <http://purl.oclc.org/estimates>.
- Copeland, L.K., Boseto, D.T. and Jenkins, A.P., 2016. Freshwater ichthyofauna of the Pacific-Asia biodiversity transect (PABITRA) gateway in Viti Levu, Fiji. *Pacific Conservation Biology*, 22(3), pp.236-241.
- Cortés-Gómez, A. M., Castro-Herrera, F., & Urbina-Cardona, J. N. (2013). Small changes in vegetation structure create great changes in amphibian ensembles in the Colombian Pacific rainforest. *Tropical Conservation Science*, 6(6), 749-769.
- Crump, M., & Scott, N. (1994). Visual encounter surveys. In W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, & M. S. Foster (Eds.), *Measuring and monitoring biological diversity: Standard methods for Amphibian*.
- De Vos, L. & D. Thys van den Audenaerde (1990a). Description de *Barbus claudinae* sp.n. (Cyprinidae) avec synopsis des grandes espèces de *Barbus* du Rwanda. *Cybiu* 14(1): 3-25.

- De Vos, L. & D. Thys van den Audenaerde (1990b). Petits Barbus (Pisces, Cyprinidae) du Rwanda. *Revue d'Hydrobiologie Tropicale* 23(2): 141-159
- De Vos, L. (1993). Le genre *Chiloglanis* (Siluriformes, Mochokidae) dans le bassin de la Ruzizi: description de deux nouvelles espèces. *Journal of African Zoology* 107: 153-168.
- De Vos, L. (1995). A systematic revision of the African Schilbeidae (Teleostei, Siluriformes). With an annotated bibliography. *Annales du Musée royal de l'Afrique Centrale, Sciences Zoologiques* 271: 1-450.
- De Vos, L. (2002). Projet DAB-RWA/022 (Développement Agricole du Bugesera, Rwanda): Rapport de mission de diagnostic rapide du volet « Pêche », RWA/922-DAB Bugesera II, Agence luxembourgeoise pour la Coopération au Développement.
- De Vos, L., J. Snoeks & D. Thys van den Audenaerde (1990). The effects of *Tilapia* introductions in Lake Luhondo, Rwanda. *Environmental Biology of Fishes* 27: 303-308.
- Dehling J. M. & Sinsch U. (2023): Amphibians of Rwanda: Diversity, community features, and conservation status. – *Diversity* 15: 512. <https://doi.org/10.3390/d15040512>.
- Dickinson, J.L., B. Zuckerberg and D.N. Bontar (2010) Citizen Science as an Ecological Research Tool: Challenges and Benefits. *Annual Review of Ecology, Evolution, and Systematics* 4: 149-172. <https://www.jstor.org/stable/27896218>
- Ducarme, R. (2018). The butterflies (Lepidoptera: Papilionoidea) of the north-eastern Democratic Republic of Congo. *Metamorphosis*, 29, 23–37.
- Dusabe, M. C., Wronski, T., Gomes-Silva, G., Plath, M., Albrecht, C. & Apio, A. (2019). Biological water quality assessment in the degraded Mutara rangelands, northeastern Rwanda. *Environ Monit Assess*, 191: 139. <https://doi.org/10.1007/s10661-019-7226-5>
- Echiegu, E.A., C.O. Ezimah, M.E. Okechukwu, & O.A. Nwoke. (2021). Phytoremediation of emulsion paint wastewater using *Azolla Pinnata*, *Eichhornia Crassipes* and *Lemna Minor*. *Nigerian Journal of Technology* 40(3): [10.4314/njt.v40i3.21](https://doi.org/10.4314/njt.v40i3.21)
- Fischer, E. (2011). Biodiversity inventory for key wetlands in Rwanda, Final report.
- Fischer, E., Dumbo, B., Dehling, M., Lebel, J.-P., & Killmann, D. (2011). Biodiversity Inventory for Key Wetlands in Rwanda.
- Fox, A. D., Madsen, J., Boyd, H., Kuijken, E., Norriss, D. W., Tombre, I. M., & Stroud, D. A. (2005). Effects of agricultural change on abundance, fitness components and distribution of two arctic-nesting goose populations. *Global Change Biology*, 11(6), 881–893. <https://doi.org/10.1111/j.1365-2486.2005.00941.x>
- Fuller, R. J., & Langslow, D. R. (1984). Estimating numbers of birds by point counts: How long should counts last? *Bird Study*, 31(3), 195–202. <https://doi.org/10.1080/00063658409476841>
- Gasabo 3D (2017). NUWEP Feasibility Study. Final Report Volume 1: Developing an Improved Design Plan of the Park and Construction Supervision of Nyandungu Urban Wetland Eco-Tourism Park. Kigali: Gasabo 3D.
- Gakuba, A. (2012). Rwanda Environment Management Authority Study for Establishing Urban Wetland Recreation and Eco-tourism Park in Nyandungu Valley, Kigali City (Rwanda) Study for Establishing Urban Wetland Recreation and Eco-tourism Park in Nyandungu Valley, Kigali City
- Genner, M.J., G.F. Turner, A. Smith, S. Mzighani and B.P. Ngatunga, 2015. Presence of *Acapoeta tanganicae* (Actinopterygii: Cypriniformes: Cyprinidae) within the Lake Rukwa catchment supports historic riverine connectivity with Lake Tanganyika. *Acta Ichthyol. Piscat.* 45(1):109-112.
- Gordon, I. and Ayiemba, W. 2003. Harnessing Butterfly Biodiversity for Improving Livelihoods and Forest Conservation: The Kipepeo Project. *Journal of Environment and Development* 12(1):82-98.
- Hails, A. J. (1997). Wetlands, Biodiversity and the Ramsar Convention: the role of the Convention on Wetlands in the Conservation and Wise Use of Biodiversity. Ramsar Convention Bureau, Ministry of Environment and Forest, India.

- Higler I. W. G. And Tolkamp H. H. (1983). Hydropsychidae as Bio-indicators. *Environmental Monitoring and Assessment* 3: 331-341. 0167-6369/83/0034-0331\$01.65.
- Hobson, K. A., Rempel, R. S., Greenwood, H., Turnbull, B., Wilgenburg, L. Van, & Van, S. L. (2008). of Birds Using Electronic From Recordings : Potential Omnidirectional Microphone System. *Society*, 30(3), 709–720.
- Hugueny B, Camara S, Samoura B, Magassouba M. 1996. Applying an index of biotic integrity on fish assemblages in a West African river. *Hydrobiologia* 331: 71–78.
- Innis, S. A., Naiman, R. J., & Elliott, S. R. (2000). Indicators and assessment methods for measuring the ecological integrity of semi-aquatic terrestrial environments. *Hydrobiologia*, 422–423, 111–131. https://doi.org/10.1007/978-94-011-4164-2_9
- Johnson, J. M.-F. and Morgan, J. 2010. Sampling Protocols. Chapter 2. Plant Sampling Guidelines. IN Sampling Protocols. R.F. Follett, editor. p. 2-1 to 2-10. Available at: www.ars.usda.gov/research/GRACEnet
- Jenkins, A.P. and Jupiter, S.D., 2011. Spatial and seasonal patterns in freshwater ichthyofaunal communities of a tropical high island in Fiji. *Environmental Biology of Fishes*, 91, pp.261-274.
- Jongsma, G. F., Hedley, R. W., Durães, R., & Karubian, J. (2014). Amphibian diversity and species composition in relation to habitat type and alteration in the Mache–Chindul Reserve, Northwest Ecuador. *Herpetologica*, 70(1), 34-46.
- Kabii, T. (1996). An Overview of African Wetlands. Ramsar Bureau, Switzerland.
- Kahangwa, C.A., C.L. Nahonyo, G. Sangu, E.K. Nassary. (2021). Assessing phytoremediation potentials of selected plant species in restoration of environments contaminated by heavy metals in gold mining areas of Tanzania. *Heliyon* 7(9): e07979.
- Keddy, P. A., Fraser, L. H., Solomeshch, A. I., Junk, W. J., Campbell, D. R., Arroyo, M. T. K., & Alho, C. J. R. (2009). Wet and Wonderful: The World's Largest Wetlands Are Conservation Priorities. *BioScience*, 59(1), 39–51. <https://doi.org/10.1525/bio.2009.59.1.8>
- Kielland, J. (1990). Butterflies of Tanzania. Hill House publishers, London.
- Kingdon, J. (2015). The Kingdom field guide to African Mammals (N. Redman (ed.); 2nd ed.).
- Kremen, C. (1992). Assessing the indicator properties of species assemblages for natural areas monitoring. *Ecological Applications*, 2(2), 203–217. Retrieved from <http://www.jstor.org/stable/1941776>
- Larsen, T. B. (1991). The butterflies of Kenya and their natural history. New York: Oxford University Press Inc.
- Larsen, T. B. (2005). Butterflies of West Africa Plate volume. Stenstrup: Apollo Books.
- Lyons, T.J. 2021. *Poecilia reticulata*. The IUCN Red List of Threatened Species 2021.
- Maleque, A. M., Maeto, K., & Ishii, H. T. (2009). Arthropods as bioindicators of sustainable forest management, with a focus on plantation forests. *Applied Entomology and Zoology*, 44(1), 1–11. <https://doi.org/10.1303/aez.2009.1>
- Martins, D. J., & Collins, S. (2016). Pocket Guide Butterflies of East Africa. Struk Nature.
- May, H. L. (2001). Wetland mammals (Issue 21, pp. 1–20). Wildlife Habitat Management Institute.
- McAleece, N., Gage, J. D., Lamshead, J., & Patterson, G. L. J. (1997). Biodiversity Professional. The Natural History Museum & The Scottish Association for Marine Science, London.
- Mindje, M., Tumushimire, L., & Sinsch, U. (2020). Diversity assessment of anurans in the Mugesera wetland (eastern Rwanda): impact of habitat disturbance and partial recovery. *Salamandra*, 56(1), 27-38.
- Molleman, F., Kop, A., Brakefield, P. M., DeVries, P. J., & Zwaan, B. J. (2006). Vertical and temporal patterns of biodiversity of fruit-feeding butterflies in a tropical forest in Uganda. *Biodiversity and Conservation*, 15, 107–121. <https://doi.org/10.1007/s10531-004-3955-y>

- Molleman, F., van Alphen, M. E., Brakefield, P. M., & Zwaan, B. J. (2005). Preferences and Food Quality of Fruit-Feeding Butterflies in Kibale Forest, Uganda. *Biotropica* 37(4), 657–663.
- Mtui, D., Congdon, C., Bampton, I., Kalenga, P., & Leonard, H. (2019). Altitudinal Distribution and Monthly Occurrence of Butterflies in the Kihansi Gorge Forest, Tanzania, with a Checklist of Species. *Tanzania Journal of Science*, 45(4), 543–558.
- Mvukiyumwami, J. (2019). Inventory of plants in Nyandungu Urban Wetland Eco-tourism Park in January 2019. Afrilandscapes, unpublished internal report.
- Nsabagasani, C., Nsengimana, S., & Hakizimana, E. (2008). Biodiversity survey in Akanyaru wetlands, unprotected important bird areas in Rwanda (p. 32).
- Ntakimazi, G. 2006. *Acapoeta tanganicae*. The IUCN Red List of Threatened Species 2006: e.T61308A12459046.
- Nyafwono, M., Valtonen, A., Nyeko, P., & Roininen, H. (2014). Fruit-feeding butterfly communities as indicators of forest restoration in an Afro-tropical rainforest. *Biological Conservation*, 174, 75–83. <https://doi.org/10.1016/j.biocon.2014.03.022>
- Odoh, C.K., N. Zabbey, S. Kabari, & C.N. Eze. (2019). Status, progress and challenges of phytoremediation - An African scenario *Journal of Environment Management* 237: 365-378.
- Olapade, O.J. and Omitoyin, B.O. (2010). Fish species composition in Lake Kivu, Rwanda, East Africa. 25th Annual Conference of the Fisheries Society of Nigeria (FISON) <http://hdl.handle.net/1834/38185>
- Oloya, J., Malinga, G. M., Nyafwono, M., Akite, P., Nakadai, R., Holm, S., & Valtonen, A. (2021). Recovery of fruit-feeding butterfly communities in Budongo Forest Reserve after anthropogenic disturbance. *Forest Ecology and Management*, 491, 119087. <https://doi.org/10.1016/j.foreco.2021.119087>.
- Paracuellos, M., & Tellería, J. L. (2004). Factors affecting the distribution of a waterbird community: The role of habitat configuration and bird abundance. *Waterbirds*, 27(4), 446–453. [https://doi.org/10.1675/1524-4695\(2004\)027\[0446:FATDOA\]2.0.CO;2](https://doi.org/10.1675/1524-4695(2004)027[0446:FATDOA]2.0.CO;2)
- Pastorino, P., Anselmi S., Zanolli A., Esposito G., Bondavalli F., Dondo A., Pucci A., Pizzul E., Faggio C., Barceló D., Renzi M. & Prearo M. (2023). The invasive red swamp crayfish (*Procambarus clarkii*) as a bioindicator of microplastic pollution: Insights from Lake Candia (northwestern Italy). *Ecological indicators*, 150:1-8.
- Patterson, G. & Makin, J., 1998. The state of biodiversity in Lake Tanganyika – A literature review. Natural Resources Institute, Chatham, UK.
- Pendleton, G. W. (1984). Small Mammals in Prairie Wetlands: Habitat Use and the Effects of Wetland Modifications. South Dakota State University.
- Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet; <http://www.plantsoftheworldonline.org/> Retrieved 25.10/2023.
- Raburu, P. O., & Masese, F. O. (2012). Development of a fish-based index of biotic integrity (FIBI) for monitoring riverine ecosystems in the Lake Victoria drainage Basin, Kenya. *River Research and Applications*, 28(1), 23-38.
- Ratia H, Vuori K.-M., Oikari A. (2012). Caddis larvae (Trichoptera, Hydropsychidae) indicate delaying recovery of a watercourse polluted by pulp and paper industry. *Ecological indicators* 15(1): 217-226 <https://doi.org/10.1016/j.ecolind.2011.09.015>
- RBIS. 2023. Biodiversity Information System. (Rwanda Biodiversity Information System (RBIS)) Retrieved 19/June/2023, from Biodiversity Information System: <https://rbis.ur.ac.rw>
- REMA. 2012. Study for Establishing Urban Wetland Recreation and Eco-tourism Park in Nyandungu Valley, Kigali City (Rwanda) Downloaded at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjNkKbknpQAAxXMxgIHHbnWC2gQFnoECA0QAQ&url=https%3A%2F%2Frema.gov.rw%2Ffileadmin%2Ftemplates%2FDocuments%2Frema_doc%2Fpublications%2FPlanning%2520docs%2FNyandungu%2520wetland%2520plan_2012.pdf&usg=AOvVaw00gx7pOUWmqouHdcF2dzJ&opi=89978449

- REMA, 2022. Updated Feasibility Study for Establishing Nyandungu Urban Wetland Eco-Tourism Park in Nyandungu Valley Kigali City, Rwanda.
- Ricketts, T. H., Daily, G. C., & Ehrlich, P. R. (2002). Does butterfly diversity predict moth diversity? Testing a popular indicator taxon at local scales. *Biological Conservation* 103, 361–370. [https://doi.org/10.1016/S0006-3207\(01\)00147-1](https://doi.org/10.1016/S0006-3207(01)00147-1)
- Rodriguez, C.M., 1997. Phylogenetic analysis of the tribe Poeciliini (Cyprinodontiformes: Poeciliidae). *Copeia* 1997(4):663-679.
- Roelke, C. E., & Smith, E. N. (2010). Herpetofauna, Parc National des Volcans, North Province, Republic of Rwanda. *Check List*, 6(4), 525-531.
- Roxburgh, S. H., Shea, K., & Wilson, J. B. (2011). The Intermediate Disturbance Hypothesis: Patch Dynamics and Mechanisms of Species Coexistence. *Ecology*, 85(2), 359–371.
- Rurangwa, M. L., Aguirre-Gutiérrez, J., Matthews, T. J., Niyigaba, P., Wayman, J. P., Tobias, J. A., & Whittaker, R. J. (2021). Effects of land-use change on avian taxonomic, functional and phylogenetic diversity in a tropical montane rainforest. *Diversity and Distributions*, 27(9), 1732–1746. <https://doi.org/10.1111/ddi.13364>
- Rwanda Biodiversity Specimen Data Portal. 2023. Nyandungu Urban Wetland Eco-Park, Rwanda Plant Checklist. Facilitated by the CoEB, University of Rwanda. Published on the Internet. <https://bit.ly/3ScFAph>. Retrieved 25/10/2023.
- Saber, S., Tito, W., & Said, R. (2017). Amphibians as Bioindicators of the Health of Some Wetlands in Ethiopia. *The Egyptian Journal of Hospital Medicine*, 66, 66–73. <https://doi.org/10.12816/0034635>
- Sinsch, U., Lümkmann, K., Rosar, K., Schwarz, C., & Dehling, M. (2012). Acoustic niche partitioning in an anuran community inhabiting an Afromontane wetland (Butare, Rwanda). *African Zoology*, 47(1), 60-73.
- Schnabel, B., S. Wright, R. Miller, L.D. Bryant, T.R. Kjeldsen, R. Maconachie, S.P. Gbanie, K.S. Bangura, & A.J. Kamara. (2022). Urban surface water quality and the potential of phytoremediation to improve water quality in peri-urban and urban areas in sub-Saharan Africa – a review. *Water Supply* 22 (11): 8372–8404. doi: <https://doi.org/10.2166/ws.2022.352>
- Siddig, Ahmed A.H., A.M. Ellison, A. Ochs, C. Villar-Leeman, and M.K. Lau (2016) How Do Ecologists Select and Use Indicator Species to Monitor Ecological Change? Insights from 14 Years of Publication in Ecological Indicators. *Ecological Indicators* 60(January): 223–230. doi:10.1016/j.ecolind.2015.06.036.
- Skelton, P.H., 1991. Pseudocrenilabrus. p. 394-398. In J. Daget, J.-P. Gosse, G.G. Teugels and D.F.E. Thys van den Audenaerde (eds.) Check-list of the freshwater fishes of Africa (CLOFFA). ISNB, Brussels; MRAC, Tervuren; and ORSTOM, Paris. Vol. 4.
- Spawls, S., Howell, K., & Drewes, R. (2006). *A Pocket Guide to Reptiles and Amphibians of East Africa*.
- Tang, X. (2021). The protection planning of small and micro habitats in urban fringe areas: Enlightenment from the management of high natural value farmland in the EU to the maintenance of biodiversity in urban areas in China. *City Diversity*, 2(1), 18. <https://doi.org/10.54517/cd.v2i1.1935>
- Teugels, G.G., 1986. A systematic revision of the African species of the genus *Clarias* (Pisces; Clariidae). *Ann. Mus. R. Afr. Centr., Sci. Zool.*, 247:199 p.
- The Angiosperm Phylogeny Group. 2016. An update of the Angiosperm Phylogeny Group classification of the orders and families of flowering plants: APG IV. *Botanical Journal of the Linnean Society* 181: 1-20. doi:10.1111/boj.1238
- Thomas, M.B., B.A. Kaplin, V. Minani, and R. Umazekabiri. 2023. Albertine Rift Herbaria Network Data Portal. Downloaded at: <https://bit.ly/3tGMp8e>. Retrieved 25/10/2023.
- Tumushimire, L., Mindje, M., Sinsch, U., & Dehling, J. M. (2020). Anuran diversity of cultivated wetlands in Rwanda: Melting pot of generalists. *Salamandra*, 56(2), 99-112.
- US Environmental Protection Agency. (1994). Standard Operating Procedures: Terrestrial Plant Community Sampling. 1–11. <https://clu-in.org/download/ert/2037-R00.pdf>

- US Forest Service. (2003). Ecological Monitoring Tools and Methods. Multiparty Monitoring and Assessment Guidelines for Community-Based Forest Restoration in Southwestern Ponderosa Pine Forests, 45–55. <http://www.fs.fed.us/r3/spf/cfrp/monitoring/>
- Uyizeye, E., Clausnitzer, V., Kipping, J., Dijkstra, K.D.B., Willey, L., and Kaplin, B.A. 2021. Developing an odonate-based index for prioritizing conservation sites and monitoring restoration of freshwater ecosystems in Rwanda. *Ecological Indicators* 125: 107586, <https://doi.org/10.1016/j.ecolind.2021.107586/>
- Uwizelimana, J. D. D. (2022). The butterflies of Nyungwe National Park , Rwanda (Lepidoptera : Rhopalocera , Papilionoidea). *Entomologische Zeitschrift*, 132(2), 67–79.
- Uwizelimana, J. D. D., Nsabimana, D., and Wagner, T. (2021). A preliminary butterfly checklist (Lepidoptera : Papilionoidea) for Cyamudongo tropical forest fragment, Rwanda. *Metamorphosis*, 32, 93–103. <https://doi.org/https://dx.doi.org/10.4314/met.v32i1.15>
- Vanderklift, M.A., Ward, T.J. and Jacoby. C.A. (1996). Effect of reducing taxonomic resolution on ordinations to detect pollution induced gradients in microbenthic. *Freshwater Biology*, 49:474-489.
- Verheyen, E., Salzburger, W., Snoeks, J. and Meyer, A., 2004. Response to comment on" Origin of the superflock of cichlid fishes from Lake Victoria, East Africa". *Science*, 304(5673), pp. 963-963.
- Veron, G., Patterson, B. D., & Reeves, R. (2008). Global diversity of mammals (Mammalia) in freshwater. *Hydrobiologia*, 595(December), 607–617. <https://doi.org/10.1007/978-1-4020-8259-7>
- Volpato, G. H., Lopes, E. V., Mendonça, L. B., Boçon, R., Bisheimer, M. V., Serafini, P. P., & dos Anjos, L. (2009). The use of the point count method for bird survey in the Atlantic forest. *Zoologia*, 26(1), 74–78. <https://doi.org/10.1590/S1984-46702009000100012>
- Whelan, C. J., Wenny, D. G., & Marquis, R. J. (2008). Ecosystem services provided by birds. *Annals of the New York Academy of Sciences*, 1134, 25–60. <https://doi.org/10.1196/annals.1439.003>
- Williams, M. C. (2021). Butterflies and Skippers of the Afrotropical Region. Retrieved from <https://www.mtmetamorphosis.org.za/?p=articles&s=atb>
- Wright, I.A., Chessman, B.C., Fairweather, P.G. and Benson, L.J. (1995). Measuring the impact of sewage effluent on the macroinvertebrate community of an upland stream: The effect of different levels of taxonomic resolution and quantification. *Australian Journal of Ecology*, 20: 142–149.
- Wronski, T., Dusabe M. C., Apio, A., Hausdorf, B. & Albrecht, C. (2015). Biological assessment of water quality and biodiversity in Rwandan rivers draining into Lake Kivu. *Aquatic ecology*, 49:309–320. DOI 10.1007/s10452-015-9525-4

Appendix 1. Data on Biodiversity surveys done in Nyandungu Urban Wetland Eco-park.

Taxa	Species	Sampling period	Reference
Amphibians	<i>Afrixalus quadrivittatus</i>	May 2021	ILAM by ARCOS
	<i>Hyperolius kivuensis</i>		
	<i>Hyperolius viridiflavus</i>		
	<i>Phrynobatrachus kakamikro</i>		
	<i>Phrynobatrachus natalensis</i>		
	<i>Ptychadena nilotica</i>		
	<i>Amietia nutti</i>	July 2019	REMA
	<i>Hyperolius kivuensis</i>		
	<i>Hyperolius viridiflavus</i>		
	<i>Kassina senegalensis</i>		
	<i>Phrynobatrachus kakamikro</i>		
	<i>Ptychadena nilotica</i>		
	<i>Sclerophrys gutturalis</i>		
Birds	<i>Alcedo cristata</i>	June 2021	UR-CoEB
	<i>Amaurornis flavirostra</i>		
	<i>Ardea melanocephala</i>		
	<i>Bostrychia hagedash</i>		
	<i>Gallinula chloropus</i>		
	<i>Lophaetus occipitalis</i>		
	<i>Microcarbo africanus</i>		
	<i>Muscicapa aquatica</i>		
	<i>Scopus umbretta</i>		
	<i>Tachybaptus ruficollis</i>		
	<i>Threskiornis aethiopicus</i>		
	<i>Vanellus senegallus</i>		
	<i>Actophilornis africanus</i>	February 2022	UR-CoEB
	<i>Alcedo cristata</i>		
	<i>Amaurornis flavirostra</i>		
	<i>Anastomus lamelligerus</i>		
	<i>Ardea cinerea</i>		
	<i>Ardea melanocephala</i>		
	<i>Bostrychia hagedash</i>		
	<i>Bubulcus ibis</i>		
	<i>Ceryle rudis</i>		
	<i>Halcyon senegalensis</i>		
	<i>Microcarbo africanus</i>		
	<i>Platalea alba</i>		
	<i>Plectropterus gambensis</i>		
	<i>Scopus umbretta</i>		
	<i>Threskiornis aethiopicus</i>		
Odonates	<i>Pantala flavescens</i>	January 2016	Clausnitzer et al., 2016
	<i>Tholymis tillarga</i>		
Plants	<i>Acanthus pubescens</i>	January 2021	REMA
	<i>Acocanthera schimperi</i>		
	<i>Albizia adiantifolia</i>		
	<i>Albizia forbesii</i>		
	<i>Albizia gummifera</i>		

Albizia versicolor
Aloe lateritia
Anthocleista grandiflora
Bamboussa vulgaris
Bambusa multiplex
Bambusa textilis
Bersama abyssinica
Blighia unijugata
Bougainvillea spectabilis
Bridelia micrantha
Brillantaisia cicatricosa
Capparis erythrocarpos
Carapa procera
Cardiospermum
halicacabum
Carissa spinarum
Celtis africana
Centella asiatica
Clerodendrum myricoides
Clerodendrum rotundifolium
Clutia abyssinica
Coleus barbatus
Colocasia esculenta
Combretum collinum
Combretum molle
Croton macrostachyus
Croton megalocarpus
Cyperus latifolius
Cyperus papyrus
Dodonaea viscosa
Dombeya torrida
Dombeya torrida torrida
Dovyalis caffra
Dracaena afromontana
Dracaena steudneri
Elaeis guineensis
Entada abyssinica
Entandrophragma excelsum
Erythrina abyssinica
Euphorbia candelabrum
Euphorbia hirta
Euphorbia tirucalli
Euphorbia umbellata
Ficus asperifolia
Ficus ingens
Ficus lutea
Ficus ovata
Ficus sur
Ficus sycomorus
Ficus thonningii
Ficus vallis-choudae
Flueggea virosa

Gambeya gorungosana
Gomphocarpus fruticosus
Guizotia scabra
Gymnanthemum
amygdalinum
Hagenia abyssinica
Harungana
madagascariensis
Harungana montana
Hibiscus diversifolius
Hibiscus fuscus
Hibiscus rosa-sinensis
Hymenodictyon floribundum
Hypoestes triflora
Juncus effusus
Kalanchoe deficiens
Kigelia Africana
Laggera alata
Ludwigia abyssinica
Macaranga kilimandscharica
Macaranga schweinfurthii
Maesa lanceolata
Maesopsis eminii
Markhamia lutea
Milletia dura
Mitragyna rubrostipulata
Mycroglora pyrifolia
Myrianthus holstii
Neoboutonia macrocalyx
Ocimum gratissimum
Olea europaea
Pavonia urens
Persicaria attenuata pulchra
Phoenix reclinata
Phragmites mauritianus
Phytolacca dodecandra
Plantago palmata
Podocarpus falcatus
Podocarpus latifolius
Polygonum salicifolium
Polyscias fulva
Pterygota mildbraedii
Pygeum africanum
Ranunculus multifidus
Rhoicissus tridentata
Rosa canina
Rumex bequaertii
Scepcarpus hypselodendron
Schrebera alata
Searsia pyroides
Senegalia montigena
Senegalia polyacantha

Senna didymobotrya
Senna occidentalis
Senna septemtrionalis
Solanecio mannii
Solanum aculeastrum
Spathodea campanulata
Spermacoce verticillata
Strombosia scheffleri
Symphonia globulifera
Syzygium guineense
Syzygium parvifolium
Syzygium rowlandii
Tabernaemontana stapfiana
Tephrosia vogelii
Tetradenia riparia
Trema orientalis
Trilepisium madagascariense
Typha capensis
Typha domingensis
Typha latifolia
Vachellia abyssinica
Vachellia sieberiana
Xymalos monospora
Zanthoxylum asiaticum
Zanthoxylum chalybaeum
Ziziphus mucronata

Source: RBIS data (2016, 2021 and 2022).

Appendix 2. List of taxon teams from the CoEB what conducted the surveys.

Taxa	Names	Affiliations	Contacts
Amphibians and Reptiles	Mapendo Mindje	University of Rwanda- CoEB & CAVM	majulesdor@gmail.com
	Umulisa Christella	University of Rwanda- CoEB	umulisachristella1@gmail.com
Birds	Nsenganeza Jean de Dieu	University of Rwanda- CoEB	jnsenganeza@gmail.com
	Dufatanye Fabrice	University of Rwanda- CoEB	dufabrice21@gmail.com
Butterflies	Dr. Jean de Dieu Uwizelimana	University of Rwanda- CoEB & CST	juwizelimana@gmail.com
	Thacien Hagenimana	University of Rwanda- CoEB	hagenathacien4@gmail.com
Mammals	Methode Majyambere	University of Rwanda- CoEB & CST	methodemajyambere@gmail.com
	Alexis Nsabimana	University of Rwanda- CoEB	nsabimanalexis023@gmail.com
Fish	Dr. Philippe Munyandamutsa	University of Rwanda- CoEB & CAVM	philippe.sanzira@hotmail.com
	Jeannette Uwitonze	University of Rwanda- CoEB	ujeannette27@gmail.com
Aquatic macro-invertebrates	Leonce Ngirinshuti	University of Rwanda- CoEB & CAVM	lngirinshuti@gmail.com
	Edmond Twagirayezu	University of Rwanda- CoEB	edmondtwagirayezu1997@gmail.com
Plants	Bonny Dumbo	University of Rwanda- CoEB	bonny.dumbo@gmail.com
	Pascal Sibomana	University of Rwanda- CoEB	sibomanapascal20@gmail.com
	Dr. Michael Thomas	University of Rwanda- CoEB	michaelbthomas@gmail.com
Spatial Analyst	Dr. Apollinaire William	University of Rwanda- CoEB	williappollo2005@gmail.com
Water quality	Mardochee Birori	University of Rwanda- CST	mbirori64@gmail.com
PI	Prof Beth Kaplin	University of Rwanda- CoEB	b.kaplin@ur.ac.rw

Appendix 3. Check list of birds observed during 2023 biodiversity survey (LC: Least Concern; EN: Endangered)

Vernacular name	Scientific name	Family	IUCN Status
African firefinch	<i>Lagonosticta rubricata</i>	Estrildidae	LC
African openbill	<i>Anastomus lamelligenus</i>	Ciconiidae	LC
African paradise flycatcher	<i>Terpsiphone viridis</i>	Monarchidae	LC
African pygmy kingfisher	<i>Ispidina picta</i>	Alcedinidae	LC
African stone Chat	<i>Saxicola torquatus</i>	Muscicapidae	LC
Arrow marked Babbler	<i>Turdoides jardineii</i>	Leiothrichidae	LC
Baglafecht Weaver	<i>Ploceus baglafecht</i>	Ploceidae	LC
Bare-faced Go-away-bird	<i>Corythaixoides personatus</i>	Musophagidae	LC
Black Crake	<i>Amaurornis flavirostra</i>	Rallidae	LC
Black headed gonolek	<i>Laniarius erythrogaster</i>	Malaconotidae	LC
Black headed Heron	<i>Ardea melanocephala</i>	Ardeidae	LC
Black kite	<i>Milvus migrans</i>	Accipitridae	LC
Blue- headed Coucal	<i>Centropus monachus</i>	Cuculidae	LC
Blue- headed Sunbird	<i>Cyanomitra alinae</i>	Nectariniidae	LC
Brown throated wattle eye	<i>Platysteira cyanea</i>	Platysteiridae	LC
Cape wagtail	<i>Motacilla capensis</i>	Motacillidae	LC
Cardinal woodpecker	<i>Dendropicos fuscescens</i>	Picidae	LC
Chub's Cisticola	<i>Cisticola chubbi</i>	Cisticolidae	LC
Dark-capped Bulbul	<i>Pycnonotus tricolor</i>	Pycnonotidae	LC
Fork-tailed Drongo	<i>Dicrurus adsimilis</i>	Dicruridae	LC
Gray backed Fiscal	<i>Lanius tephronotus</i>	Laniidae	LC
Grey crowed Crane	<i>Balearica regulorum</i>	Gruidae	EN
Hadada Ibis	<i>Bostrychia hagedash</i>	Threskiornithidae	LC
Hamerkop	<i>Scopus umbretta</i>	Scopidae	LC
Lesser Swamp Warbler	<i>Acrocephalus gracilirostris</i>	Acrocephalidae	LC
Little Bee Eater	<i>Merops pusillus</i>	Meropidae	LC
Long-tailed Cormorant	<i>Microcarbon Africanus</i>	Phalacrocoracidae	LC
Northern gray headed sparrow	<i>Passer griseus</i>	Passeridae	LC

Olive Thrush	<i>Turdus olivaceus</i>	Turdidae	LC
Pied Crow	<i>Corvus albus</i>	Corvidae	LC
Red-eyed Dove	<i>Streptopelia semitorquata</i>	Columbidae	LC
Ruppell's long tailed Starling	<i>Lamprotornis purpuroptera</i>	Sturnidae	LC
Speckled mousebird	<i>Colius striatus</i>	Coliidae	LC
Spur-winged Goose	<i>Plectropterus gambensis</i>	Anatidae	LC
Square-tailed nightjar	<i>Caprimulgus fossii</i>	Caprimulgidae	LC
Streaky Seadeater	<i>Serinus striolatus</i>	Fringillidae	LC
Wire-tailed Swallow	<i>Hirundo smithii</i>	Hirundinidae	LC
Total	83	37	

Appendix 4. Water Quality Assessment Data from June 2023 for the Nyandungu Urban Wetland Eco-Park, Rwanda

		Sector 1 pond 1	Sector 1 pond 2	Sector 1 pond 3	Sector 1 pond 4	Sector 1 pond 5	Sector 1, exit at the bridge to Kimironko	Sector 2 down the bridge	Sector 2 exit at the bridge to Masoro	Sector 3 pond 2 Muhazi	Sector 3 pond 3 Kivu	Sector 3 pond 1 at Bambou	Sector 4 pond 1 Ruhondo	Sector 5 at the bridge	Sector 5 pond 1	Sector 5 pond 2 Ihema
Parameters measured	Unit															
Water Temperature	o C	24	23.6	24	22.6	21.7	21.8	21.1	21.1	22.1	23	22.3	22.4	19.8	23.7	23.8
pH		5.93	6.19	6.24	6.95	7.83	6.93	6.23	7.43	7.98	7.4	7.25	8.5	7.84	7.65	7.06
Turbidity	NTU	5.8	1.8	1.8	0.8	0.08	0.8	2.6	2.5	3.5	1.7	4	1.8	2.5	2.6	1.7
E. Conductivity	uS/cm	435	425	420	503	490	490	481	314	370	324	202.1	533	440	620	612
Total Dissolved Solids	mg/l	211.8	209.9	205.1	254	252	252	250	162.1	182.1	157.4	96.6	270	216.9	305	303
Dissolved Oxygen	mg/l	7.72	5.64	7.72	4.43	7.84	2.52	3.3	6.01	6.36	7.9	5.14	4.25	5.14	6.34	6.43
Total Hardness	mg/l	146.18	141.08	129.64	181.5	186.52	183.44	186.6	119.96	145.58	117.66	47.58	198.98	157.98	166.72	166.22
Calcium	mg/l	40.96	40.59	51.38	63.25	56.87	65.79	64.44	46.38	47.77	41.19	16.91	62.6	52.63	58.02	54.9
Magnesium	mg/l	10.70	9.60	0.30	5.70	10.80	4.60	6.20	1.00	6.40	3.60	1.30	10.30	6.40	5.30	7.10
Potassium	mg/l	6.15	3.93	3.19	6.15	6.52	6.15	6.52	3.56	6.15	5.04	1.33	5.78	3.93	11.7	12.07
Sodium	mg/l	26.79	38.37	41.53	33.11	38.89	39.42	38.89	16.26	42.58	43.11	35.21	59.42	54.68	75.74	72.58
Ammonia Nitrogen	mg/l	0.05	0.01	0.01	0.01	0.02	0.04	0.02	0.15	0.03	0.04	0.1	0.03	0.01	0.01	0.04
Nitrite Nitrogen	mg/l	0.202	0.361	0.501	0.049	0.011	0.011	0.017	0.025	0.013	0.009	0.285	0.39	0.141	0.068	0.029
Nitrate Nitrogen	mg/l	10	6.8	7.7	5.4	4.3	2.5	2.9	3.2	1.4	1.8	8.6	2.9	1.1	1.7	1.1
Phosphate	mg/l	0.25	0.28	0.33	0.4	0.28	0.2	0.63	0.67	0.69	0.2	0.43	0.33	0.23	0.12	0.16
Total Nitrogen	mg/l	7.0	5.6	6.6	5.9	4.6	2.9	3.8	3.8	1.6	2.3	9.1	3.5	2.0	2.0	2.7
Total Phosphorus	mg/l	0.78	0.61	0.98	0.43	0.82	0.86	1.16	0.87	0.92	0.85	0.87	1.25	0.88	0.95	0.29
Chloride	mg/l	99.64	86.69	93.49	116.22	112.92	115.66	113.41	76.88	78.72	73.38	42.52	134.51	108.02	194.91	184.28
Sulfate	mg/l	35	42	29	38	39	36	35	15	11	8	12	23	20	2	2
Iron (mg/l)	mg/l	0.75	1.2	0.95	0.61	0.53	0.41	1.91	0.45	0.31	0.23	0.08	0.92	0.77	2.28	1.36
Manganese (mg/l)	mg/l	0.668	0.584	0.561	0.825	0.362	0.330	0.800	0.338	0.345	0.144	0.047	1.455	0.745	0.963	0.519
Total Suspended Solids	mg/l	28	10	13	11	10	1	25	8	14	11	1	23	25	8	14
Chemical Oxygen Demand	mg/l	22.6	7.59	46.1	56.7	59.9	49.9	25.8	27.7	53.8	50.6	38.7	36	25.8	27.7	53.8
Biochemical Oxygen Demand	mg/l	7.59	2.02	34.2	17.08	22.16	16.12	14.56	13.36	10.44	14.44	23.64	13.12	14.56	13.36	20.44
Fecal Coliforms	Cfu/100ml	1.4×10^4	2.1×10^1	$< 1 \times 10^0$	2.3×10^1	2.25×10^2	3.4×10^3	3.4×10^2	5.23×10^3	3.16×10^3	$< 1 \times 10^0$	$< 1 \times 10^0$	1.12×10^2	3.2×10^2	$< 1 \times 10^0$	$< 1 \times 10^0$
Escherichia coli	Cfu/100ml	2.25×10^2	2.1×10^0	$< 1 \times 10^0$	2.3×10^0	$< 1 \times 10^0$	2.14×10^2	$< 1 \times 10^0$	4.1×10^2	1.2×10^2	$< 1 \times 10^0$	$< 1 \times 10^0$	$< 1 \times 10^0$	$< 1 \times 10^0$	$< 1 \times 10^0$	$< 1 \times 10^0$