Reducing vulnerability to climate change through enhanced community based biodiversity conservation in the Eastern Province of Rwanda

Biodiversity Baseline Inventory and Mapping of seven intervention sites in the Eastern Province of Rwanda

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Executive Summary

The Eastern Province of Rwanda is an important region of the country for agriculture and tourism. However, it has been experiencing significant land use/land cover changes which may be reducing its resilience, compounded with the effects of climate change, particularly reduced rainfall. This region of Rwanda has unique ecosystems and biodiversity but there have been few systematic studies, and there is little information available about the biodiversity and threat status in this region. The Government of Rwanda through its commitments to sustainable development, climate adaptation and biodiversity conservation, has enabled the Ministry of Environment, the Rwanda Forestry Authority (RFA), the Belgian Development Agency Enabel, and the International Union for the Conservation of Nature (IUCN) to collaborate to establish and implement a project entitled *Reducing vulnerability to climate change through enhanced community based biodiversity conservation in the Eastern Province of Rwanda*. The project is commonly referred to as COMBIO.

COMBIO is an important investment because despite the country's conservation efforts, the ecosystems hosting biodiversity and agricultural lands are experiencing threats from climate change including floods, droughts and landslides mainly as a consequence of reduced resilience, high pressure and unsustainable use of natural resources. Human activity has also been changing the natural ecosystems through agricultural and industrial development, and human settlement, over-exploitation of certain species and the introduction of alien invasive species. Therefore, human and climate change impacts on ecosystems have resulted in habitat loss and degradation, the loss of some species and ecological processes, pollution of the soil, water and atmosphere. This leads to the degradation of natural ecosystems and thereby reducing their capacity to provide ecosystem services, and increasing the vulnerability of local communities to the effects of climate change.

To address climate change impacts on ecosystems and build adaptative capacity, restoration interventions of degraded lands and vulnerable ecosystems are being implemented in the Eastern Province under the COMBIO project. The restoration activities will assist the recovery of degraded ecosystems to sustain biodiversity and re-establish ecological functions. Vulnerability to climate change is exacerbated by stressors such as loss of biodiversity, damage to ecosystem services, and land degradation. Adaptation will be increasingly important to enhance protection and management of protective and productive ecosystems. Adaptation to climate change will have positive impacts on biodiversity by maintaining and restoring natural ecosystems, protecting and enhancing ecosystem services, actively preventing and controlling invasive alien species, managing habitats for threatened and endangered species, and developing agroforestry systems. Reduction of other pressures on biodiversity arising from deforestation, habitat conversion, overexploitation of forests and other natural ecosystems, pollution, and alien species invasions will also contribute also to climate change adaptation measures.

The COMBIO project has a goal to enhance biodiversity in production forests and agroecological lands. The purpose of this study was to complete a biodiversity baseline assessment of a representative set of intervention sites that will be rehabilitated or restored under the COMBIO project. There are seven intervention sites that are targeted for interventions: Production forests, sylvopastoral lands, Community biodiversity sanctuaries, river buffers, dam buffers, lake buffers and road buffers. This study sampled multiple sites in each of these seven intervention types. Six taxon groups were selected for focus of the biodiversity assessment including plants, herpetofauna (amphibians and reptiles), flying insects, terrestrial arthropods, birds, and mammals. These taxon groups were selected because they include species that are good indicators of ecosystem integrity, or conversely, are indicators of disturbance (e.g., invasive species or tolerant species). They therefore can be used in a monitoring framework. Furthermore, we chose these taxon groups because the Center of Excellence in Biodiversity and Natural Resource Management (CoEB) has researchers with expertise in the sampling and taxonomy (species identifications) of these selected groups. Threats and human activity in the forests were also surveyed. The survey was conducted between September and December 2023.

Overall, the larger sites (community biodiversity sanctuaries and production forests) as well as some of the buffer areas, still have significant elements of biodiversity, including valuable native plant species, migratory birds, endangered bird species, communities of native pollinators and pest predators. The amphibian baseline is also a valuable indicator of healthy ecosystems. Nine species

of mammals were found from five orders and seven families in dam buffer, lake buffer, road buffer, community biodiversity sanctuaries, and sylvopastoral land, but the sanctuaries contained the majority of the mammals. While recorded mammals are common in natural and semi-natural ecosystems in Rwanda, the sylvopastoral land had a unique record of the savannah hare *Lepus victoriae*. Serval cat *Leptailurus serval* also observed during the baseline surveys, and savannah hare are considered indicator species of healthy habitats that can be used in future monitoring, while most of other species indicate habitats with various levels of disturbance.

The main threats and human activities observed in the seven intervention sites are, in their order of frequencies occurrence, plastic material, waste dumping, agriculture, human excreta, groundcover clearing, charcoal making, burning, livestock grazing, hardware material, mining, poaching, tree cutting, and water pollution. The five last threats listed here are of least concern as their frequencies in overall records and in individual sites are small. The most common threat is the plastic material and is followed by waste damping mostly composed og plastic materials. Livestock grazing, agriculture, and groundcover clearing are destructive for ecological processes, while waste dumping, plastic material, charcoal making, and human excreta contribute to pollution of the environment and disease risk.

The assessment of pollinators in the sites provides valuable evidence for an ecosystem service often overlooked in agricultural landscapes. Although analysis of the pollination network structure indicates that invasive plant species often dominate the pollinator network, the pollinators are valuable assets to the surrounding landscape. They may harbor in the remnant forests and provide pollination services in the surrounding agricultural lands. They may also be important for honey production in the region where native trees are available for the honey bees that use nearby native trees or remnant forests. Furthermore, other flying insects and terrestrial arthropods found in the sites may provide services such as insect pest control and support to soil fertility through decomposition and soil aeration activities.

The summary of the biodiversity surveys are presented in a table format at the end of the report for easy interpretation. The biodiversity scores for each site can be used as the baseline for monitoring and recommendations are made for targets and frequency of monitoring based on the results of this baseline. The summary tables can guide site management and help track restoration or rehabilitation effectiveness using the biological indicators. For future monitoring, a subset of the indicators could be selected to monitor progress in rehabilitation (e.g., presence of invasive species, hectares cleared of invasive species, density of native tree seedlings and saplings characteristic of the Eastern Province forests, frequency of forest interior specialists or disturbance-intolerant species such as certain amphibians, birds or mammals).

As recommendations, better monitoring and patrolling of these intervention areas is needed. The buffer zones (lakes, dams and rivers) have potential to harbor biodiversity and support ecosystem-based adaptation, and the sanctuaries and production forests could also become more important as hosts for biodiversity that supports natures benefits to people. Invasive plant species should be removed. Programs to sensitize the local communities, and activities with local schools and cooperatives could help draw attention to the value of these areas, the policies that protect them, and the need for their protection. Limited and controlled community access to non-timber forest products could be made available if careful community-led controls are developed, for example honey collection along buffer areas or medicinal plant collection within the sanctuaries. Alternatives for waste dumping and tree cutting urgently need to be found. A program for local guards or forest champions from the local communities could help the situation.

The work in this report represents an important step in the development and conservation of the Eastern Province. The information contained in these pages provides information not only to guide restoration, but also to contribute to development of natural capital accounts, payments for ecosystem services, and possibly ecotourism and community-based projects that help value and protect the working landscapes of the Eastern Province.

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Introduction

The Government of Rwanda is committed to promoting sustainable development through conserving biodiversity and natural resources, the Rwanda Forestry Authority (RFA), the Belgian Development Agency Enabel, the International Union for the Conservation of Nature (IUCN), and the Ministry of Environment are collaborating to establish and implement a project entitled Reducing vulnerability to climate change through enhanced community based biodiversity conservation in the Eastern Province of Rwanda. The project is commonly referred to as COMBIO. The project involves many partners and stakeholders.

The Center of Excellence in Biodiversity Conservation and Natural Resource Management is tasked with working on biodiversity monitoring by providing past information regarding biodiversity and the current biodiversity status and threats across COMBIO's intervention sites. These intervention sites include natural remnant forests, roads, rivers, lakes, sylvopastoral lands, dams, and sanctuaries that are being created by the COMBIO project.

In this report, we present the results of the biodiversity baseline survey for the seven intervention sites of the Eastern Province. This includes a desk review of state of information about the regions environment and socio-economic context. In addition to the desk review, surveys in each of seven sites were conducted to document flora and fauna (birds, flying insects, terrestrial arthropods, birds, mammals) and threatened, endangered and endemic species were identified. Threats were also documented in each forest. Biological indicator species are identified and presented and the sites were scored in terms of biodiversity value. This information is a tool to support restoration and monitoring. The sites were mapped. The annex includes species checklists and photos.

Background

Rwanda's landscapes have undergone tremendous changes over the previous six centuries. These changes have included removal of native vegetation, forest cover loss, fragmentation and isolation of remnant forests, and disruptions to ecosystems services. Historically, according to the Spatial Biodiversity Assessment Report (Figure 1; SANBI, CoEB, & REMA, 2022) for Rwanda, in the pre-industrial period before large-scale human modification of landscapes, the eastern part of Rwanda consisted of 18 ecosystem types: Acacia Gallery Forest, Afromontane Rain Forest, Eastern evergreen Plateau Grassland Savanna, Evergreen Riverine Tropical Savanna, Evergreen Semi-evergreen Bushland and Thicket, Evergreen Semi-evergreen Plateau, Evergreen Semi-evergreen Riverine Sub-humid Highland Savanna, Evergreen Semi-evergreen Sub-humid Savanna, Evergreen Tropical Savanna, Humid Savanna Wetland, Lake ecosystems, Miscanthus and Cyperus Wetland, Mixed Vegetation Wetland, Semi-evergreen Forest Wetland, Sub-humid Wooded savanna, Transitional Plateau Rain Forest, Transitional Tropical Savanna, and Wooded savanna distributed into seven biomes: Akagera Sub-humid Savanna, Montane Woodland, Plateau grassland savanna, Tropical Savanna, Highland Plateau, Wetland, Lakes.

Analysis indicates that after the pre-industrial period of the 1700's, human encroachment has had a significantly impact on ecosystems, causing some ecosystems to be considered Vulnerable, Endangered, and Critically Endangered based on the International Union for Conservation of Nature (IUCN) threatened ecosystem assessment criteria. The ecosystems of the Eastern Part of Rwanda are among the most vulnerable ecosystems based on the Spatial Biodiversity Assessment (SANBI, CoEB, & REMA, 2022).

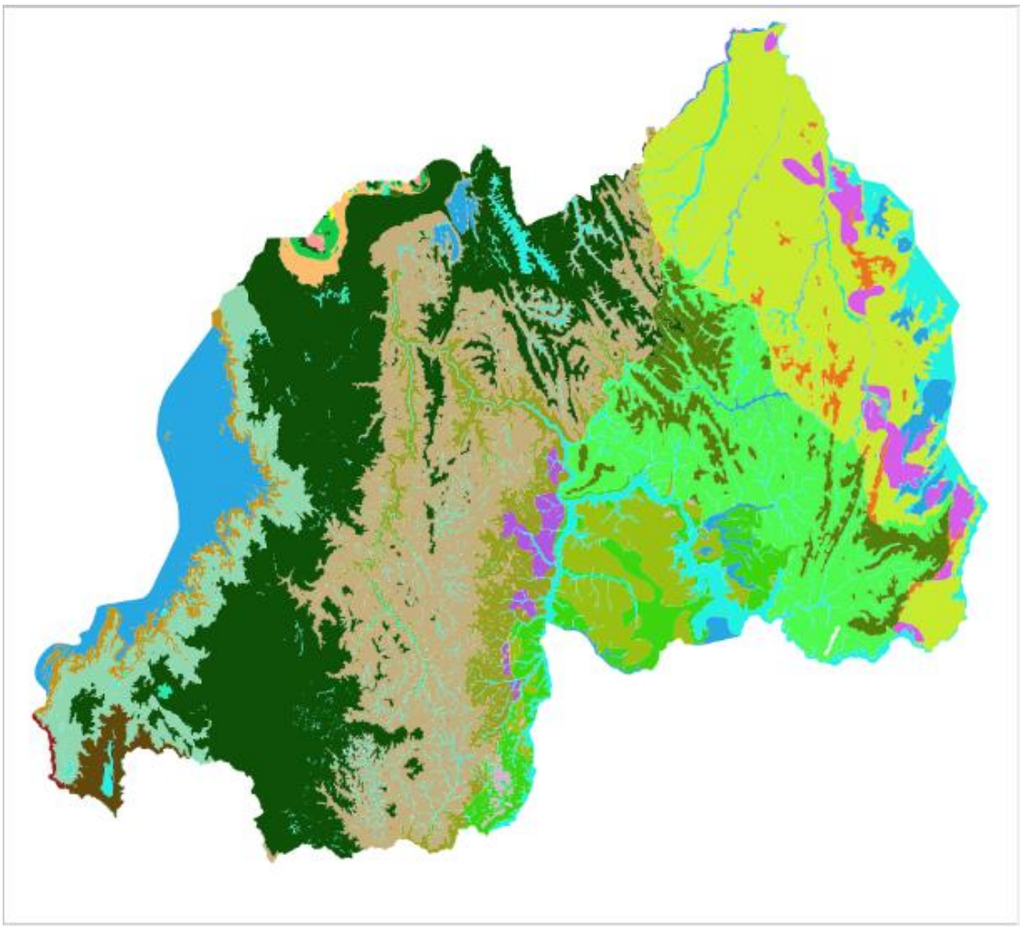

Figure 1. Map of the ecosystem types of Rwanda showing terrestrial and freshwater ecosystems. The legend for the map is shown below. Source: (SANBI, CoEB, & REMA, 2022).

Agriculture is the major land use in Rwanda, and accounts for more than 50% of the employment in the country (Moise, 2023). Rwanda has embarked on a process of agricultural modernization, transforming the small-scale family farming units (with an average plot size of 0.75 hectare) to focus on production for household consumption and local market exchange (Davide et al., 2016), involving a crop intensification program (Kim et al., 2022). In addition to increasing agricultural output, this process has also contributed to the transformation of Rwanda's natural vegetation cover and ecosystems.

The Eastern Province has a population density of 433 people/km2 as of 2022 (NISR 2022). The employment-to-population ratio is highest among residents of Kigali city, at 55.4%, followed closely by Eastern Province with a ratio of 48.4% (NISR, 2023). The employment landscape in eastern province has undergone significant changes since the 2000 Enquête Intégrale sur les Conditions de Vie des ménages, or Integrated Household Living Conditions Survey, referred to as EICV1, with an increase of nearly a quarter in the number of employed individuals. Eastern Province stands out with the highest growth rate at 36%, with a surge in employment opportunities. Interestingly, all rural provinces have witnessed a robust increase in non-farm jobs, exceeding 100%. Despite this substantial growth, the impact on overall job expansion in rural provinces remains relatively modest. This is primarily because non-agricultural employment constitutes a minor proportion of the total jobs in these regions (NISR, 2015). Most of the youth reside in the Eastern Province (942,370) in comparison with other provinces of Rwanda (NISR, 2023).

Eastern Province has a total population of 144,000 in EICV3, with 3,216,000 in the urban area and 3,360,000 in the rural area. In EICV2, Eastern Province's total population is 99,000, with 1,356,000 in the urban area and 1,455,000 in the rural area. In EICV5 from 2017, among the 3.3 million households, 69% are engaged in agriculture. The Eastern Province has the highest number of agricultural households (886,000 private households), followed by the Southern, Western, and Northern Provinces, and Kigali City (NISR, 2022).

The Eastern province has seven districts: Nyagatare, Kayonza, Gatsibo, Rwamagana, Bugesera, Kirehe, and Ngoma. Together, they represent 26.9% of the total population of Rwanda. The population of the Eastern Province is predominantly female, with 1,828,751 women accounting

for 51.3% of the total population. Nyagatare was the most densely inhabited district with 653,861 residents as of 2022. Most Eastern Province residents are engaged in farming activities. Out of the 886,132 households in the Eastern province, 638,806 are classified as agricultural households (NISR, 2023).

The distribution of private households by the main source of energy for cooking in Eastern Province reveals diverse energy consumption patterns across different districts. Province-wide, the predominant source of cooking energy is firewood, accounting for 83.8% of households, followed by charcoal at 10%. Gas represents a smaller proportion at 3.2%, while other sources and households that do not cook contribute 1.5% and 1.6%, respectively. By district, Rwamagana households show a reliance on firewood (73.7%) and charcoal (22%) for cooking, whereas Nyagatare and Gatsibo districts exhibit higher usage of firewood, at 83.6% and 89.7%, respectively (NISR, 2023). Kayonza district also has high firewood use (87%) as the primary cooking energy source. Kirehe district stands out with a considerable proportion of households utilizing gas (11.1%) for cooking, in addition to firewood (83.8%). Ngoma district has the highest dependency on firewood (93.1%) for cooking purposes. Bugesera district includes the three sources, firewood (77.4%), charcoal (16.7%), and gas (3.9%) for cooking needs (NISR, 2023). These findings underscore the importance of understanding regional energy consumption dynamics to inform targeted energy policies and initiatives aimed at promoting sustainable energy practices and mitigating environmental impacts associated with traditional cooking fuels like firewood and charcoal (NISR, 2023).

Changes in climate and fluctuations in weather conditions have a significant impact on agricultural productivity in different locations in Rwanda including the eastern province region (Mikova, 2015). One of the solutions that can contribute to building resilience to climate change, supporting food security and increasing farmer income is the establishment of dams (IFAD, 2019; JICA, 2020). In Rwanda there are many dams with different uses. Some of them are used for livestock, hydropower, irrigation, human consumption or aquaculture. The dams established in the Eastern province of Rwanda are valley dams built for livestock watering and irrigation. In total, 77 valley dams have been established in the eastern part of Rwanda: 42 dams were introduced in Nyagatare district, 12 valley dams were introduced in Gatsibo, and 23 dams were introduced in Kayonza (RWB, 2021).

In addition to valley dams that are meant to support the local communities in the Eastern Province, water ponds have also been introduced for small scale irrigation. Among those established water ponds, 69 water ponds are located in Gatsibo district, 183 water ponds in Bugesera, 40 water ponds are in Kayonza, 14 water ponds are in Kirehe district, 15 water ponds in Ngoma and, 33 were introduced in Rwamagana (RWB, 2023). However, although these water ponds and valley dams are crucial to local communities, some of them are not operating due to lack of regular maintenance and poor management, lack of buffer zones, invasion of papyrus and water hyacinth, overtopping, destruction caused by cattle, and lack of clarity about the boundaries or extent of the valley dams (RWB, 2021, 2023).

Of the 77 dams introduced in the Eastern part of Rwanda, Bugugu and Cyimpima dams were introduced in Rwamagana district and they serve as irrigation dams (Ines, 2020; JICA, 2020). Bugugu dam was constructed at Gatoki River and its purpose is for irrigation. Rugende dam is also located in Rwamagana district, and the main agricultural crops grown in the farmlands in proximity to the Rugende dam are rice, vegetables and fodder crops for livestock (Assiel et al., 2022). In addition, water from Rugende dam is used by local communities in their home activities. Another dam located in Rwamagana is Nyirabidibiri located in Nzige sector. Crops grown near the dam are maize and soya.

The water system of Rwanda is made up of rivers, lakes, and the wetlands. An assessment of Rwanda's wetlands carried out in 2008 revealed that there are 101 lakes with a total area of 149487 ha; and 863 rivers (including 747 big rivers and 116 small rivers) with the length of 6462 kilometers (REMA, 2008). The principal rivers of Eastern Province are Akagera, Akanyaru, Kagitumba, Muvumba, Nyabarongo (Table 1).

Table 1. Major lakes of Eastern Province, Rwanda

Lakes of Eastern Province	**Lakes**
Lake of Rwamagana	Muhazi
Lakes of Bugesera	Rweru Cyohoha South Cyohoha North Kidogo Gashanga Kilimbi Gaharwa
Lakes of Gisaka	Mugesera Birira Sake
Lakes of Nasho Basin	Mpanga Cyambwe Nasho
Lakes of Akagera National Park	Ihema Kivumba Hago Mihindi Rwanyakizinga

There are four level 1 catchments in the Eastern Province (Figure 2):

1. Akagera Lower: This is the largest catchment in Rwanda and covers a significant portion of the Eastern Province. The Akagera River is the longest river in Rwanda and forms part of the country's eastern border with Tanzania.
2. Nyabarongo Lower (NNYL): The Nyabarongo River is one of the major tributaries of the Akagera River. Its basin covers a considerable area in the Eastern Province, contributing to the overall water resources of the region.
3. Muvumba (NMUV): The Muvumba River is another important river in the Eastern Province. Its basin encompasses parts of the province and supports agricultural activities and water supply for communities in the area.
4. Akagera Upper (NAKU): This basin is smaller compared to the others but still plays a significant role in the water resources of the Eastern Province. The Nyabugogo River flows through parts of the province, contributing to local water supply and irrigation.

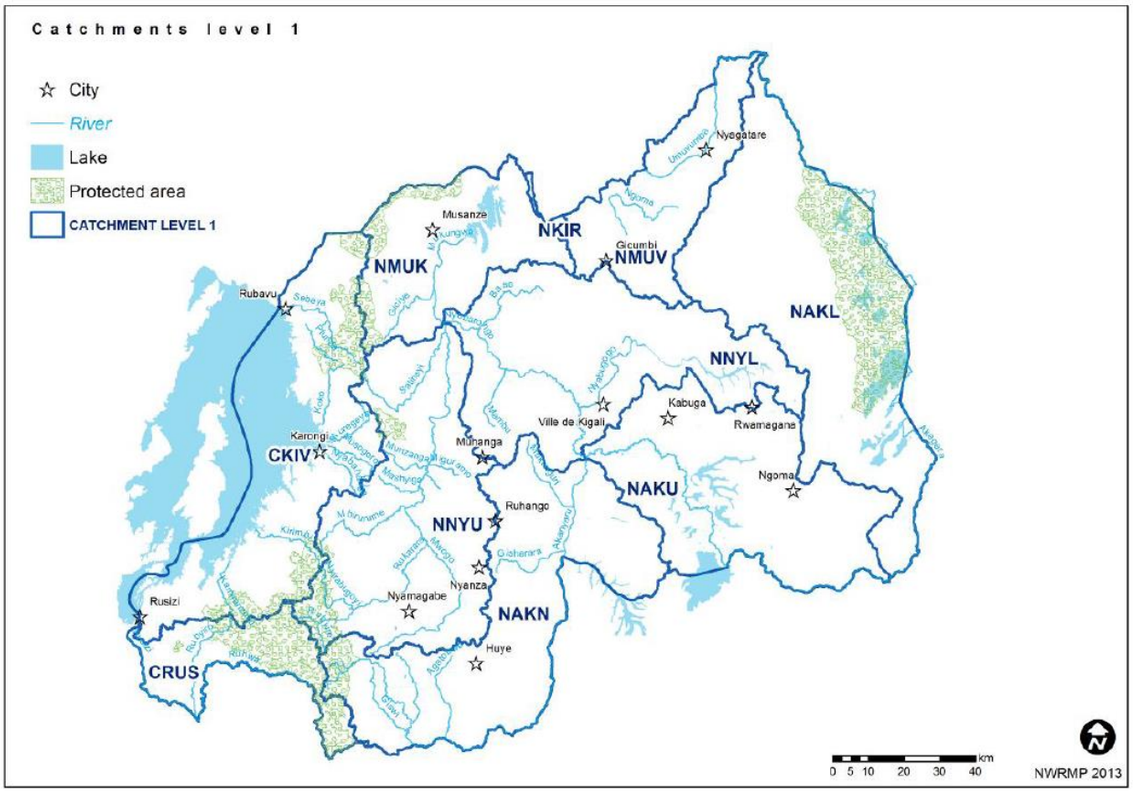

Figure 2. Level 1 catchments of Rwanda, Source: Rwanda National Water Resources Master Plan https://www.rwb.rw/index.php?eID=dumpFile&t=f&f=87854&token=32ae0db2c8c592bff470d0fa558c16d7d4c35df2

Numerous studies and reports have explored the variety of rivers and lakes, with a notable focus on selected intervention sites for specific contexts. Most studies show poor water quality due to agricultural runoff (pesticides and chemical fertilizers) and poor land use practices. For example, a comprehensive study was undertaken at the Muvumba River to assess the potential impacts of agricultural activities on water quality within the Nyagatare district (Bayingana et al., 2021). This investigation scrutinized the extent of water contamination and explored the nexus between agricultural practices and water quality parameters. Through a series of interviews and laboratory analyses of water samples collected monthly from March 2019 to March 2020, relevant data were systematically compiled. The study findings underscored that various agricultural practices, including crop cultivation, inadequate anti-erosion measures, the absence of wetland buffer zones, and the indiscriminate use of chemical pesticides and fertilizers significantly contribute to water pollution along the Muvumba River. Consequently, the study advocates for the urgent implementation of strategic interventions such as vegetation cover establishment, erosion prevention strategies, buffer zone protection, enhanced water management protocols, and farmer education about ecosystem functions and services. These proactive measures are deemed imperative to mitigate the detrimental impacts of agricultural activities on water quality and foster sustainable environmental stewardship (Bayingana et al., 2021).

A study assessed water quality in Mutara grasslands using a biotic index. Poor water quality was found across Muvumba and Karangazi Rivers. The study advocated for continuous monitoring and training local students for future public health surveys (Dusabe et al., 2019). Results from laboratory testing and interviews revealed that agricultural practices, such as crop varieties, lack of anti-erosions protection, lack of wetland buffers, and usage of chemical pesticides and fertilizers, greatly contribute to contamination of water quality. In order to prevent erosion, the study suggests planting vegetation covers, implementing buffer zones, causing water management bodies, and educating farmers about the roles that ecosystems play (Dusabe et al., 2019).

A cross-sectional study conducted along Muvumba River found that over 95% of small-scale rice growers did not comply with minimum standards for safe pesticide use, and 80% stored pesticides without personal protection measures. The study also found that 90% of respondents experienced adverse health effects after using pesticides, including intense headaches, dizziness, stomach cramps, skin pain, itching, and respiratory distress. The study also revealed that animals in and around the rice scheme had abnormalities or signs consistent with pesticide exposure in the six

months preceding the study, which may be linked to pesticide-contaminated water (Ndayambaje et al., 2019).

The Akagera Transboundary River's pollution levels were assessed including Muvumba River, based on data collected at the Rwanda Water Resources Board sampling station, which collects various parameters such as NH4-N, NO3-N, PO4-P, TDS, conductivity, pH, temperature, and turbidity. Landuse and land form characteristics were studied using satellite imagery and ground truthing. Results showed that bare soils were the most important factor affecting water quality in the river, with changes in NH3-N, NO3-N, and PO4-P values (Wali, 2011).

At Lake Muhazi a study was conducted to evaluate nutrient levels in the lake and the rivers that feed into it (Usanzineza et al., 2011). At four sampling stations, samples were taken at depths of 0.5, 2, 5, and 1 meter from the lake's surface and bottom, respectively. The findings showed that the Lake has high nutrient levels (total nitrogen was 0.85±0.22 mg/L, total phosphorus was 0.29 ±0.15 mg/L, chlorophyll-a was 18.1±10.5 g/L, and Secchi disc was 0.76±0.07 m) and is becoming eutrophic. The authors suggested developing acceptable discharge regulations for all operations along the lakeshore and implementing suitable watershed management measures to lower nutrient inputs into the lake (Usanzineza et al., 2011).

There are few studies of the upland savanna woodland and forest areas of the Eastern Province outside the wetlands and Akagera National Park. A study of forest cover and plant diversity in Rwanda's Muvumba wetland and neighboring savannah woodlands found 49 plant species, with monodominant stands of Vachellia kirkii (Mugunga et al., 2021). The amount of V.kirkii cover decreased by almost 70% in ten years, underscoring the urgent need for sustainable development strategies to preserve V. kirkii forests and biodiversity (Mugunga et al., 2021). Along the Muvumba River, another study examined land-snail fauna in gallery forest sites in northeastern Rwanda, collecting 12,419 individuals from 34 species (Umuntunundi et al., 2017). Despite human impact, no introduced species were recorded. Snail assemblage composition was influenced by elevation, leaf litter depth, and dead wood. High snail abundances in gallery forests may be due to higher soil calcium content from flooding.

Collectively, these studies and reports describe a landscape of the Eastern Province that is heavily transformed by human activities, and possesses ecosystems unique to drier, woodland savanna ecosystem types. This project set out to produce a baseline assessment of the biodiversity in seven selected intervention sites in the Eastern Province (Table 1) to enable follow up monitoring of the restoration activities planned for these sites.

Methods

The intervention sites sampled are shown in Table 2 below. Transects were placed parallel across each intervention site at 100m distance apart (e.g., sancta, production forests) but in narrow intervention areas of only a few meters width only one transect per site was placed. Sampling took place along these plots using the specific methods for each taxon group, described below.

Table 2. The seven types of intervention sites sampled in the Eastern Province in the biodiversity baseline survey, and their names.

	Site categories	**Numbers**	**Intervention sites**
1	Production Forests	4	Nyakariro 3, Bibare, Gatunga, Kamugozi
2	Sylvopastoral lands	4	Cyenjojo, Gahabwa, Rwintashya, Kibirizi
3	Dam buffer	4	Bugugu dam, Kampima Dam, Rugende Dam, Nyirabidibiri Dam
4	Lake buffer	2	Muhazi Lake, Cyambwe Lake

5	Community Biodiversity Sanctuaries – plantation forests that have been cut and are being re-planted with indigenous trees (formerly planted with non-native timber spp)	7	Nyamata CBS Karushuga CBS Rusumo CBS Muhazi CBS Zaza CBS Ryarubamba CBS Gahini CBS
6	River buffer	2	Warufu and Nyirasuru river buffer
7	Road buffer	12	Gare-Kariyeri Road, Bugesera Road, Ruhuha-Nyamata Road, Rwamagana Road 1, Rwamagana Road 2, Rwamagana Road 3, Kirehe1, Gacundezi Road Kirehe-Mushikiri, Gatore Mutenderi Road Murama-Remera Road

Plants

Plants were surveyed in the seven intervention sites. The purpose of the plant sampling was to obtain a baseline of indicators for seven intervention sites, including plant diversity, density and size class distributions, which provide indications of biodiversity and can contribute to monitoring carbon storage capacity, and enable monitoring of change over time. Circular plots with a 10-meter diameter (0.01 hectares) were placed along each transect at 50m intervals within the intervention sites, including the production forests, sylvopastoral lands, river buffers, selected sancta (Bugesera Sanctum, Jambo, Karushuga, and Kigarama Sanctum), lake buffers, and two dam buffers Rugende and Nyirabidibiri. This comprehensive coverage ensures a holistic assessment of vegetation across the diverse ecosystems. Circular plots were chosen due to their ease of establishment, minimal edge effects, and comparable sampling efficiency to square or rectangular plots (Packalen et al. 2023). Herbaceous vegetation cover was sampled using four-meter square plots in specific areas such as road buffers, certain dam buffers like Kampima, Bugugu Dam Buffer, and Lake Muhazi, and sanctums such as Buhonde, Ngoma, Ryarubamba, Karambi, and Murambi Sanctum.

The plant survey team-initiated sampling from predefined starting points at each intervention site along each transect, with each point georeferenced for accurate documentation and future resampling. Direction of travel was recorded to facilitate consistent sampling across visits. Key attributes such as tree density, woody plant species richness, and life forms were recorded within each plot. Data collection included identifying trees with a diameter at breast height (DBH) greater than 5cm and recording DBH. Additionally, shrubs, small trees, grass tussocks, and lianas were counted or estimated. We compiled information about wood density for our species list from the Global Wood Database (Chave et al., 2009; Zanne et al., 2009) using the BIOMASS package in R, which contains published wood densities (mass per unit volume) of adult trees. For our dataset, mean wood density was obtained at the lowest specific taxonomic level possible (family = 55, genus = 49, species = 39) because wood density tends to show a phylogenetic signal (Momo et al., 2020). We used the vegan () package in R to calculate species richness and shannon diversity of plants at each site (Oksanen et al., 2022). We used the rarity package in R to caclulate an average rarity index of the plants found at each site (Leroy et al. 2012).

Plants were directly identified in the field and when not possible, specimens were collected, dried and brought to the National Herbarium of Rwanda for further identification. Information about endemic species, their habitats, IUCN status, national statu, and geographical distributions were noted for each species identified. Analyses of the plant data were conducted in R software (R Core Team, 2019). Species richness, evenness, Shannon diversity and evenness indices were calculated.

Herpetofauna

Amphibians and reptiles were surveyed using opportunistic visual encounter surveys (VES) during the day in the seven intervention sites that included sanctuaries, Production Forests, sylvopastoral lands, dam buffers, lake buffers, river buffers, and dam buffers. This survey was not conducted

during the night time and all observed amphibians were recorded before sunset (18:00). Each surveyed site was searched along existing footpaths and trails with special attention paid to known amphibian and reptile biotopes, at least once per day. Each search period lasted 40 min to 3 hours, depending on the size of the fragment and the same total search time was invested during the day. During direct observation, the location of each animal detected was noted (GPS coordinates and distance from road), habitat type and water type if present (permanent running water, temporary running water, permanent pond or temporary pond and swamps); if the animal was >10 m from one of these aquatic habitats, its position was noted as far from water. The search for species was exhaustive to ensure that all species present in each forest were detected and the accumulation curve was against the time plateau.

Field identification was based on morphological characteristics (e.g., skin color patterns, body morphology/toe webbing/toe length, snout). For amphibians, species identification was done in the field using morphological corroborations (Dehling & Sinsch, 2023) and detected anuran calls were recorded to develop acoustic structures used in case of identifying calling species. For reptiles, species encountered were photographed and identified with collaboration of reptile experts in Rwanda and reference to the Field Guide to East African Reptiles (Drewes et al. 2002). Animals that could not be identified in the field were collected and preserved in 70% alcohol for later laboratory identification. The specimens were kept at the Natural History Collections of the Center of Excellence in Biodiversity and Natural Resource Management at University of Rwanda. Endemics were identified if detected, along with IUCN Red List status for each species observed, as well as indication of their status as indicator species. Checklists and distribution maps of the recorded species were produced for each sampled forest. Data analysis was done using the Paleontological Statistics software package, PAST Version 4.3 (Hammer et al. 2001) using data organized from excel sheets to develop graphs of species richness, accumulation curves and diversity measurements.

Flying insects

Butterflies and pollinators were collected along the transect lines using the appropriate methods for each taxon. The sampling technique followed the Pollard transect methodology, which is used to detect long-term changes in butterfly populations (Taron & Leslie, 2015; Kral et al., 2018a). During the field data collection, the established transects were followed as a walking path; the size of the area to be sampled around the transects or path can vary depending on the habitat types. Along each transect, we opportunistically recorded, captured, and identified all butterflies seen either flying, feeding on flowers, resting, or mud puddling along the transect depending on the types of the intervention site (Uwizelimana et al., 2021). We used aerial insect nets to capture butterflies, and the capture and release method was applied to the butterflies that were able to be identified from the field. Some of the butterflies that were not able to be identified in the field needed to be sampled for laboratory identification. For sampling, we captured one individual and kept them in entomological envelopes, which were then transferred to the laboratory for further identification. For the pollinators, observations of pollinating insects including butterflies, wild bees, honeybees, wasps, and flies were recorded while walking along the transects. The same procedure of capturing specimens, keeping the specimens in the entomological envelopes and transfer of the specimens to the laboratory for further identification and confirmation were applied to the pollinators that were not able to be identified in the field. As usual, the insect is considered as a pollinator when it visits a flower and makes contact with the female sexual part of the flower at least in one second (Fantinato, 2019). All flower-visiting insects were recorded and identified to the lowest taxonomic level possible (family, genus, or species). The host plants of these flower-visiting insects were also identified to the lowest taxonomic level possible (family, genus, or species).

We identified butterflies and pollinating insects using multiple field guides, including: Insects of Kakamega Forest, Insects of East Africa (Martins, 2015), Butterflies of East Africa (Martins & Collins, 2016), The Butterflies of Kenya: And Their Natural History (Larsen B., 1992), and Afrotropical resources of the butterflies. The distribution of the pollinating insects and butterflies were mapped using the Global Position System (GPS). The species diversity index (Shannon index) for each sampling point was calculated based on butterfly distribution. The butterflies distributed in the 50 meters interval were grouped and assigned to single geographic location. The data were analyzed using RStudio (R Core Team, 2023).

Terrestrial Arthropods

Terrestrial arthropods were sampled using line transect methods (Naranjo, 2008) in the seven intervention sites. Along each transect, sampling points were demarcated every 250m. The geographic coordinates at each sampling station were recorded by using the Global Positioning System (GPS) for the purpose of making species distribution maps. At each sampling point, two sampling methodologies were used to ensure the capture of the diversity of the terrestrial arthropods present. The first method is a hand collection method to collect insects from the ground (McCravy, 2018). For hand collecting insects, we demarcated a 1m2 plot on the ground, removed the surface debris, and then searched for terrestrial arthropods by using manual aspirators and forceps, once arthropod is captured it is being kept in the concentrated ethanol (96%) for preservation.

The second method used was sweep-netting to collect insects from the air (Spafford & Lortie, 2013), because some terrestrial arthropods can fly or jump, and may move from the ground to the vegetation cover. We used nets to sweep across the vegetation around the sampling point for five minutes, transferring the captured insects from the net to the curved tubes which were fifty milliliters and five centimeters in diameter. Once captured, regardless of method, specimens were transferred to plastic tubes containing concentrated alcohol of 96% for preservation. We archived one-thousand and fifteen arthropod samples in the laboratory at the Center of Excellence in Biodiversity and Natural Resource Management Collections Management Unit at the University of Rwanda for identification. We conducted the identification of species in the laboratory using identification keys (Holstein, 2015; Picker et al. 2019) and comparison to the reference species insect collections found at the Centre of Excellence in Biodiversity and Natural Resource Management. Data were analyzed using RStudio (R Core Team, 2023).

Birds

We used the point-count method to sample birds along the transects in the seven intervention sites, as described by Ayebare et al. (2018). This point count sampling method is widely recognized for its effectiveness in surveying birds in tropical forest ecosystems and in assessing changes in abundance over time and space (Yip et al. 2017). To conduct point counts, we walked along each transect and stopped every 250m along the transect for the next point count (Wilson et al., 2000). Each point-count location was surveyed for 10 minutes (Alldredge et al., 2007), during which all birds seen or heard within an estimated 50-meter radius were identified and recorded by trained observers who were equipped with experience in bird identification (Buron et al., 2022). Additionally, we maintained a list of species encountered while walking between point-count stations (Drake et al., 2021).

The habitat type each point count was also documented (Hutto et al., 1986), with pre-determined habitat type categories based on site visits and agreement on key characteristics (such as the plant community, water bodies sources and sylvopastoral lands).To minimize detectability differences among different habitat types and reduce biases in species identifications and distance estimates, observation counts were limited to the 50-meter radius (Martínez-Lanfranco et al., 2022). Surveys were not conducted on days with heavy rain or strong wind, as these factors adversely affect bird activity and detectability (O'Connor & Hicks, 1980). For each bird species observed, we noted endemic status, migrant status, IUCN Red List status, and categorized the functional group including Insectivorous, Carnivorous, Granivorous, Omnivorous, Frugivorous, Nectivorous, Piscivorous, Herbivorous, and Scavenger for each species that we identified. Abundance data were utilized to calculate diversity using the Shannon-Weiner index of diversity (Magurran, 1988).

Mammals

The mammals were surveyed in the seven intervention sites. The mammals were surveyed through a combination of direct and indirect approaches. An effective way to survey medium and large-sized mammals in rapid assessments consists of combining line transects surveys with indirect surveys which can help increase the list of species; indirect signs include fresh tracks, feces, burrows, and feeding signs (Larsen, 2016). Line transects and indirect surveys are more effective for larger mammals than terrestrial small mammals (rodents and shrews). The core data for mammals were recorded as noted by Larsen (2016), such as date, observers, site name, transect identifier, type of record (direct or indirect), recorded species and associated data (measurements, number of individuals.

Active search of both mammals and their signs were performed along the transects or reconnaissance trails to detect signs of mammals (dung, footprints, tracks) and all records were georeferenced. Photos were taken where necessary to illustrate the observations and for further identification. We followed the transects that were designed and georeferenced in advance at the intervention sites, and we recorded data as we walked along the transects. Records occasionally sighted outside the transect, for example while going to the transect or shifting from one transect to another, were recorded for the overall species checklists.

The data were analyzed in RStudio (R Core Team, 2023). For data analysis, frequency of occurrence for each species observed or recorded evaluated to enable comparisons between site type. Checklists and presence/absence records were generated from the PivotTable function of Microsoft Excel. Endemics and species with particular ecological indication were evaluated.

Threats

This survey was conducted to investigate the threats and disturbances that exist in the seven intervention sites. The knowledge of existing threats will help to know the types and prevalence of the threats and plan proper measures to address them while mitigating further effects of those threats on ecosystems and human livelihoods. The established linear strip transects were used to survey the seven intervention sites. Signs of threats and human disturbance such as wood cutting, grazing, fires, trails, snares, and garbage were recorded to enable frequency of occurrence analyses. While targeting any threat that could be seen in two meters at each side of the transect, we also recorded any record seen at longer distance when correctly identifiable. We recorded the number of individual observations for each threat. When a threat occurrence covered a surface, such as agriculture or wildfire, we estimated the area covered in square meters. Geographic coordinates were recorded for each observation.

Realizing that the plastics were the most frequently occurring threat, we could count individual occurrences if they were distant of at least 5 meters between them; otherwise, for one record, the number of plastic materials were counted. When more than 10 plastics were accumulated at one place, which often corresponds to an intentional action, we recorded it as waste dumping. We distinguished tree cutting events from forest undergrowth vegetation to highlight the different nature of those threats.

To characterize the threats and score them for recommendation of priority actions, we assigned each type of threat a total score considered as overall significance of the threat. We describe the threats with respect to their scope or extent (especially the space or area it covered in comparison with other threats), intensity or severity which refers to the actual and potential harm that they can cause to the habitat and biodiversity, and the length or duration referring to the possible length of impact (or capacity of reversibility) in absence of human action. Each of those impacts were given a maximum of 2 where 0.5 is “low”, 1 is “medium”, 1.5 is “high”, and 2 is “very high”. The threats that had an overall frequency of occurrence generally below 10 were not indicated in the list of significant threats, even if reported in the general results for each forest. The total significance of the threat was provided as a sum of the characteristics of each particular threat; therefore, the value range was between 0 and the maximum which is 6.

For the analysis, we compiled the data using Excel sheets and they were transformed into CSV files used in RStudio (R Core Team, 2023), where gglot2 and other operational tools were used to produce bar plots to show the occurrence of threats quantitatively. Boxplots were also used to compare frequencies of occurrences between site types and among different sites.

Results

1. Production Forests

Four production forests of the Eastern Province were sampled: Nyakariro 3, Bibare, Gatunga, and Kamugozi (Figure 3). Below are the details from the biodiversity baseline survey presented for each taxon group and the threats assessment.

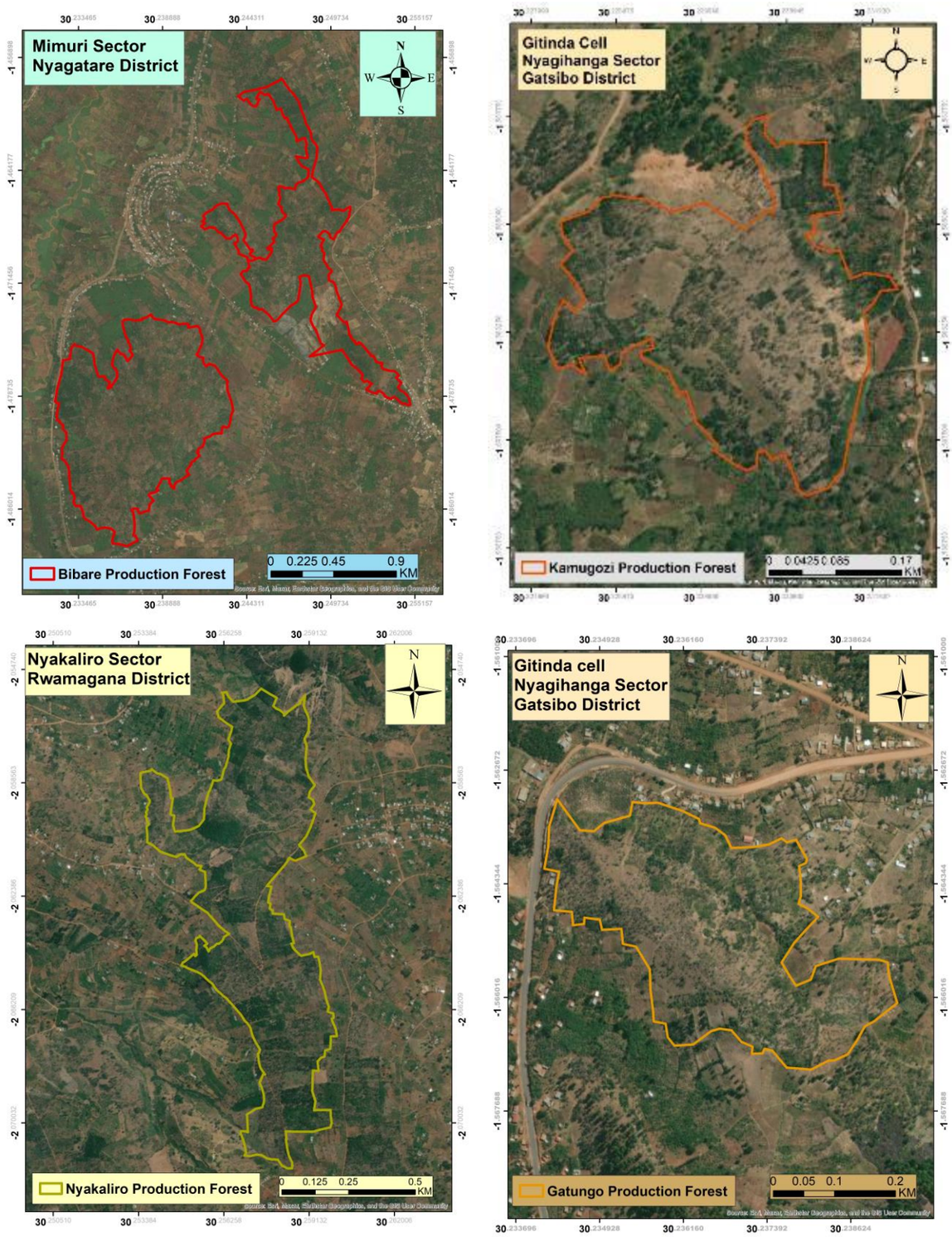

Figure 3. Maps of the boundaries of each of the four production forests sampled.

Plants

In our survey of the four Production Forests, we found a total of 45 different species across 20 families (see the following Table 3 for details). Among these families, both the Fabaceae and Malvaceae families stood out the most, representing 13.33% of all species, followed by the Rubiaceae family at 8.88%, and the Asteraceae family at 6.66%. Interestingly, the majority of these species, about 68.9%, are native to Rwanda and nearby regions, while the rest, 31.1%, are introduced species. Moreover, a good portion of these species, 57.77%, are considered to be of Least Concern according to the IUCN Red List, while 2.22% are classified as Endangered. However, 33.33% of the species we identified haven't been evaluated by the IUCN Red List yet.

Table 3. Families and species of plants found in the Production Forests, Eastern Province, Rwanda

ID	Family	Scientific name	IUCN status	National status	Native or introduced	Life form
Bibare Production Forest						
1	Bignoniaceae	*Markhamia lutea*	LC	NA	Native	tree
		Jacaranda mimosifolia	VU	NA	Introduced	tree
2	Euphorbiaceae	*Euphorbia candelabrum*	LC	NA	Native	tree
3	Fabaceae	*Erythrina abyssinica*	LC	NA	Native	tree
		Albizia gummifera	LC	NA	Native	tree
4	Lauraceae	*Persea americana*	LC	NA	Introduced	tree
5	Moraceae	*Ficus thonningii*	LC	NA	Native	tree
6	Myrtaceae	*Eucalyptus saligna*	LC	NA	Introduced	tree
7	Proteaceae	*Grevillea robusta*	LC	NA	Introduced	tree
Gatunga Production Forest						
1	Fabaceae	*Vachellia sieberiana*	LC	NA	Native	tree
2	Myrtaceae	*Eucalyptus saligna*	LC	NA	Introduced	tree
		Psidium guajava	LC	NA	Introduced	tree
3	Phyllanthaceae	*Phyllanthus fischeri*	NA	NA	Native	tree
4	Rubiaceae	*Tarenna pavettoides*	LC	NA	Native	tree
		Coffea arabica	EN	NA	Introduced	tree
		Afrocanthium lactescens	LC	EN	Native	tree
Kamugozi Production Forest						
1	Fabaceae	*Erythrina abyssinica*	LC	NA	Native	tree
2	Myrtaceae	*Eucalyptus saligna*	LC	NA	Introduced	tree
3	Phyllanthaceae	*Phyllanthus fischeri*	NA	NA	Native	tree
4	Rubiaceae	*Coffea arabica*	EN	NA	Introduced	tree
Nyakariro Production Forest						
1	Hypericaceae	*Harungana montana*	VU	NA	Native	tree
2	Myrtaceae	*Eucalyptus saligna*	LC	NA	Introduced	tree
		Syzygium guineense	LC	NA	Native	tree
3	Proteaceae	*Grevillea robusta*	LC	NA	Introduced	tree
4	Rubiaceae	*Afrocanthium lactescens*	LC	EN	Native	tree

Herpetofauna: Amphibians and Reptiles

Two species of amphibians, *Sclerophrys gutturalis* (Bufonidae) and *Ptychadena nilotica* (Ptychadenidae) and three species of reptiles *Trachylepis striata* (Scincidae), *Adolfus jacksoni* (Lacertidae), and *Acanthocercus kiwuensis* (Agamidae) were recorded. According to the IUCN Red List of threatened species, all the recorded species are Least Concerned (Table 4).

Table 4. Amphibians and reptiles species recorded from the Production Forests in Eastern Province, Rwanda. For each species in the table, the IUCN Category both global and national Red list was provided. LC: Least Concerned and ND: Not determined.

	Family	Scientific name	Common name	Global IUCN status	National IUCN status
AMPHIBIANS					
1	**Bufonidae**	*Sclerophrys gutturalis (Power, 1927)*	African Common Toad	LC	LC

2	**Ptychadenidae**	*Ptychadena nilotica (Seetzen, 1855)*	Nile grass frog	LC	LC
REPTILES					
1	**Scincidae**	*Trachylepis striata (Peters, 1844)*	African Striped Mabuya	LC	ND
2	**Lacertidae**	*Adolfus jacksoni (Boulenger, 1899)*	Jackson's Forest Lizard	LC	ND
3	**Agamidae**	*Acanthocercus kiwuensis (Klausewitz, 1957)*	Kivu Blue-headed tree agama	LC	ND

LC: Least Concerned; ND: Not Determined

Findings show that for amphibian species, Bibare Production Forest had more species (n=2) than the remaining sites each with one species observed. Among the species, *Sclerophrys gutturalis* was widespread and mostly abundant among all four Production Forests while *Ptychadena nilotica* was only observed in Bibare Production Forest. For reptiles, the highest species richness was observed at Gatunga Production Forest (n=2) while the remaining forests had only one species observed.

Among the species, *Adolfus jacksoni* in two sites including Bibare and Gatunga Production Forests while *Trachylepis striata* and *Acanthocercus kiwuensis* were seen at one locality each including Nyakariro 3 and Kamugozi respectively (Figure 4). Photos of some the amphibians and reptiles captured are in Annex 1 and 2.

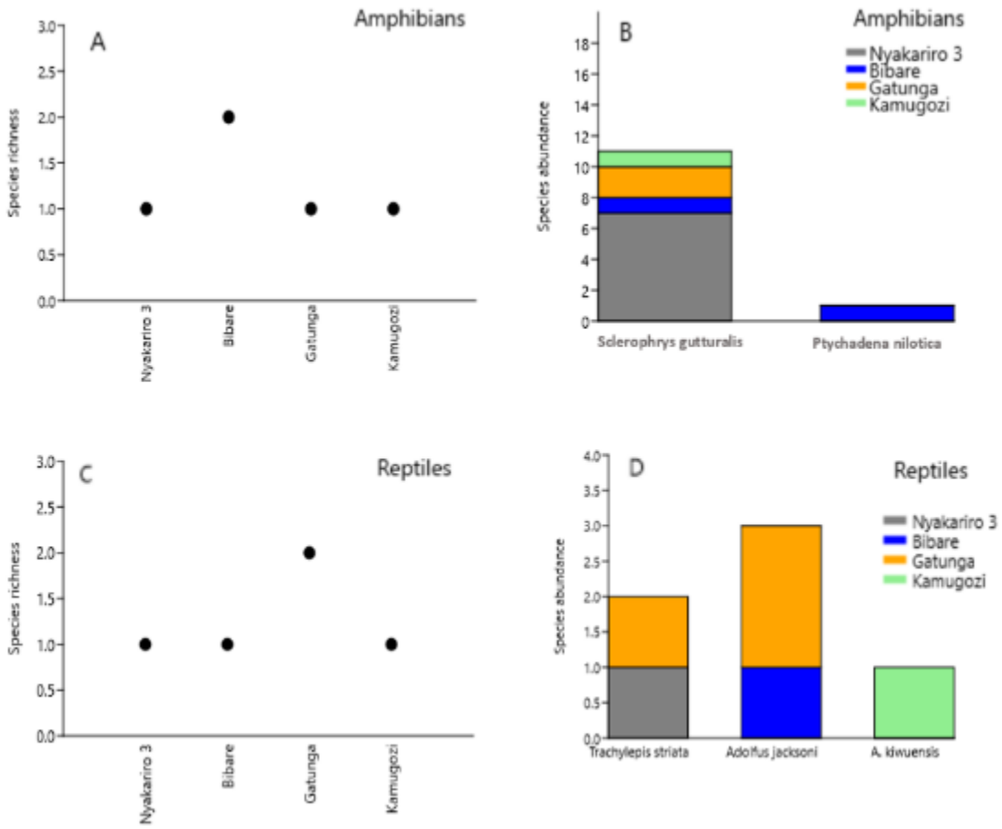

Figure 4. Amphibian and reptile species richness (A, C) and species occurrence and abundance (B, D) among sampled Production Forests. The dots represent the number of species per sampled site and the colored bars represent a sample site. The bar heights depend on the relative abundance of the recorded species in that site.

Flying Insects

A total of 36 butterfly species were recorded from the Production Forests, with 18 species in Bibale production forest, 23 from Gatunga production forest, seven from Kamugozi Production Forest and 16 from Nyakariro production forest. The species richness at each production forest is shown

in Figure 5. More information about the species names and their IUCN Red List status can be found in Annex 3.

These butterflies were distributed into five families namely Nymphalidae, Pieridae, Lycaenidae, Hesperiidae and Papilionidae. Four butterfly families were recorded from Bibare production forest with the most abundant family Nymphalidae (54.17%) followed by Pieridae (25%), Lycaenidae (16.67%) and the last abundant was Hesperiidae (4.17%). In Gatunga production forest, butterfly composition and abundance followed this order: Hesperidae (2.04%), Lycaenidae (12.24%), Nymphalidae (63.27%), Papilionidae (2.04), and Pieridae (20.41). Two butterfly families, Lycaenidae (16.67%) and Nymphalidae (83.33%) were recorded from Kamugozi production forest whereas four families including Lycaenidae (6.90%), Nymphalidae (58.62%), Papilionidae (3.45%) and Pieridae (31.03%) were found in Nyakariro3 production forest.

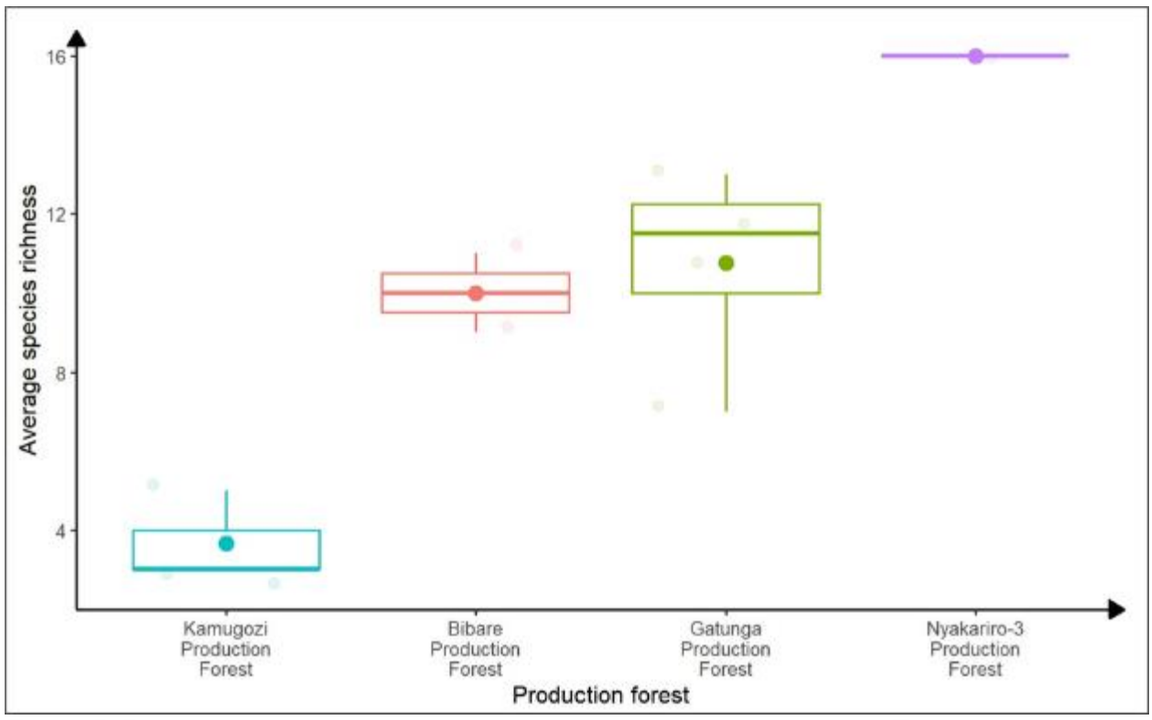

Figure 5. Butterfly richness distribution across the four production forests. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represent the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR.

Considering the species diversity and their abundance based on recorded data at each production forest, Figure 6A indicates that Bibare production forest had the highest species richness and the last in species richness was Kamugozi production forest. Figure 6B shows us that additional sampling effort would yield more species.

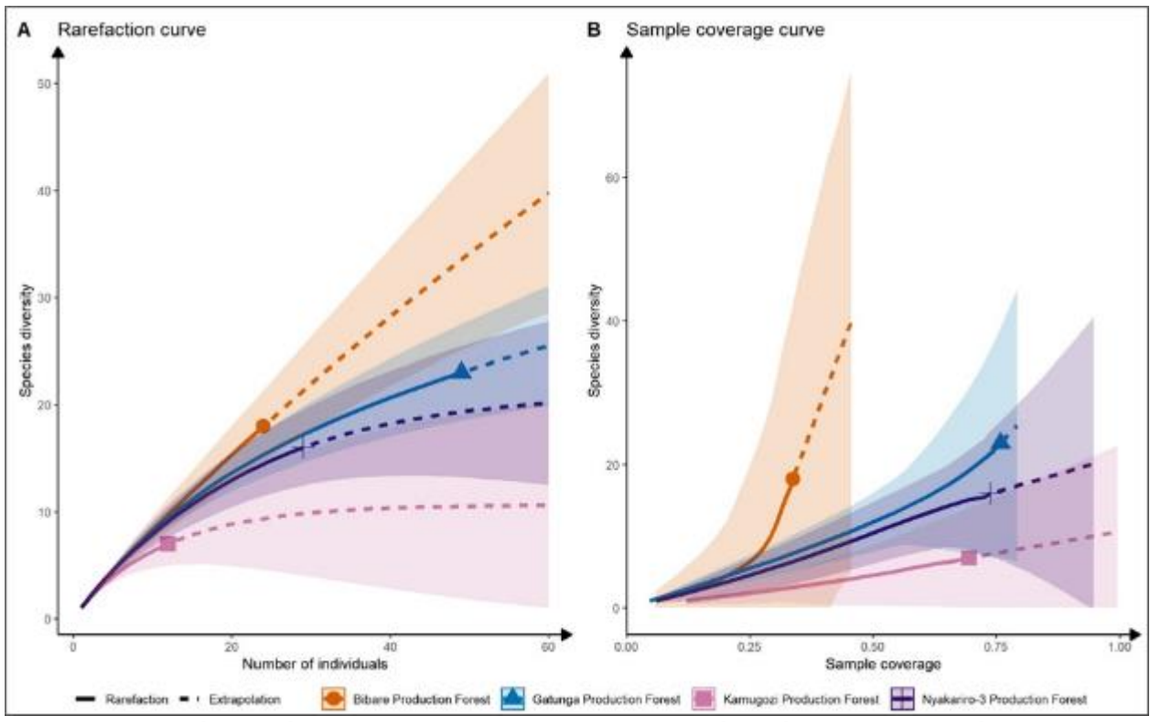

Figure 6. Butterfly rarefaction and extrapolation curves (A) from four Production forests and their sample coverage curves based on butterfly richness (Hill numbers of order 0). Solid lines represent the curves based on sample data, and the dashed lines represent the extrapolations. Shaded areas represent the 95% confidence intervals surrounding the curves.

A total of 16 pollinating insects including managed bees (*Apis mellifera*), wild bees (*Amegilla* sp, *Hypotrigona* sp and *Xylocopa flavorufa*), butterflies (*Mylothris agathina, Junonia oenone, Lampides boeticus, Junonia hierta, Hypolimnas misippus and Biblia anvatara*), flies (*Eristalis sp,* flies from Sarcophadidae family, *Asarkina sp* and flies from Syrphidae) and wasp (*Synagris analis*) were recorded from the four production forests. The pollinators' host plant species were also recorded (Figure 7). We observed *Lantana camara* to be the most visited species by pollinators, followed by *Bidens pilosa* (Figure 7). The most abundant pollinator was the bee (*Apis mellifera*).

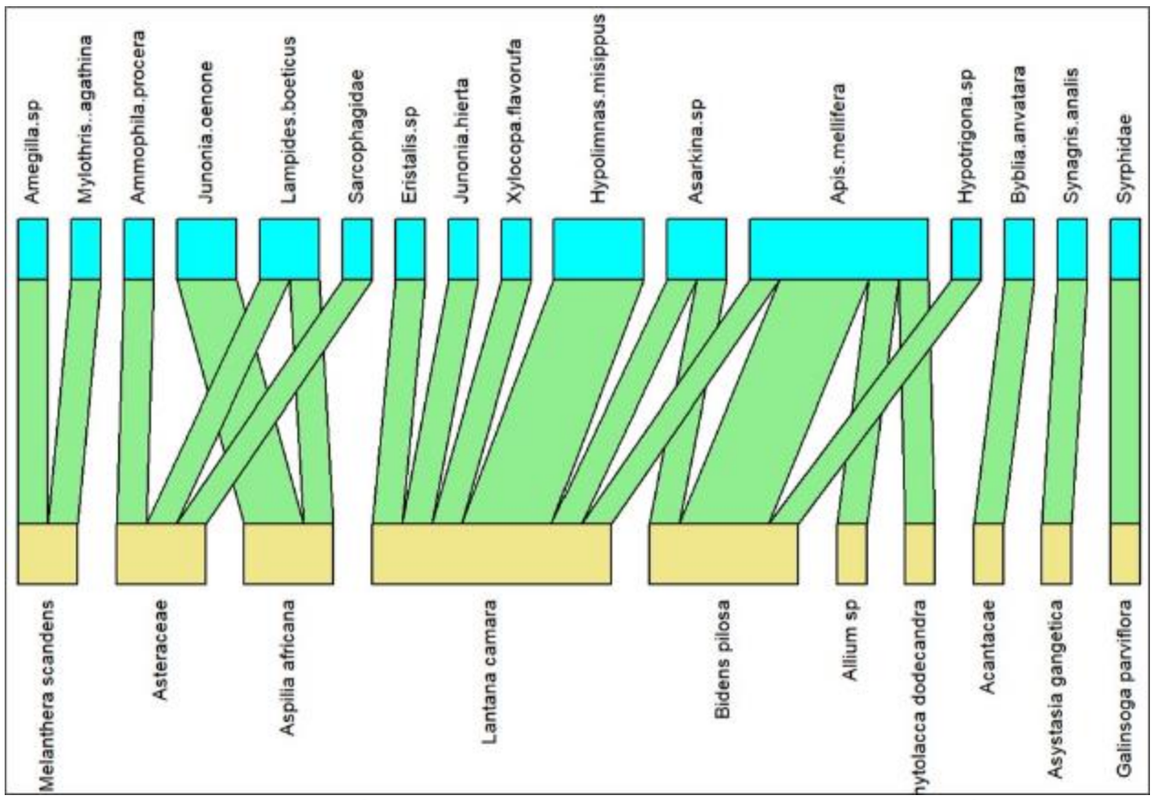

Figure 7. Network structure of Plants and their pollinating insects recorded from four production forests. The upper band in dark turquoise color represents the flower visitors while the lower band in yellow color represents plant diversity (host plants). The vertical bars in the middle of the figure (in green color) represent the linkage (which plant was visited by which insect) between plants and their pollinating insects.

Terrestrial Arthropods

A total of 660 individuals belonging to 44 families were recorded in the production forests; Formicidae was the dominant family at 26%, followed by Salticidae at 10%, Acrididae at 9% and Cercopidae at 6% (Table 5). According to the IUCN Red List the families are not evaluated. Bibare had a slightly higher species richness compared to the other production forest sites (Figure 8).

Table 5. Most abundant terrestrial arthropod families across all intervention sites.

	Order	**Family**	**Common name**	**Function Group**
1	Hymenoptera	Formicidae	Ants	Omnivorous
2	Coleoptera	Coccinellidae Tenebrionidae Chrysomelidae	Lady bug Darkling beetle Leaf beetles	Carnivorous Scavengers Herbivorous
3	Hemiptera	Cercopidae Pentatomidae Cicadellidae Miridae	Froghopper Stink bug Leafhopper Plant bug	Herbivorous Herbivorous Herbivorous Herbivorous
4	Orthoptera	Acrididae Gryllidae Tettigoniidae	Grasshopper Cricket Katydid	Herbivorous Herbivorous Herbivorous
5	Aranea	Salticidae	Jumping spider	Carnivorous
6	Isoptera	Termitidae	Termites	Detritivorous

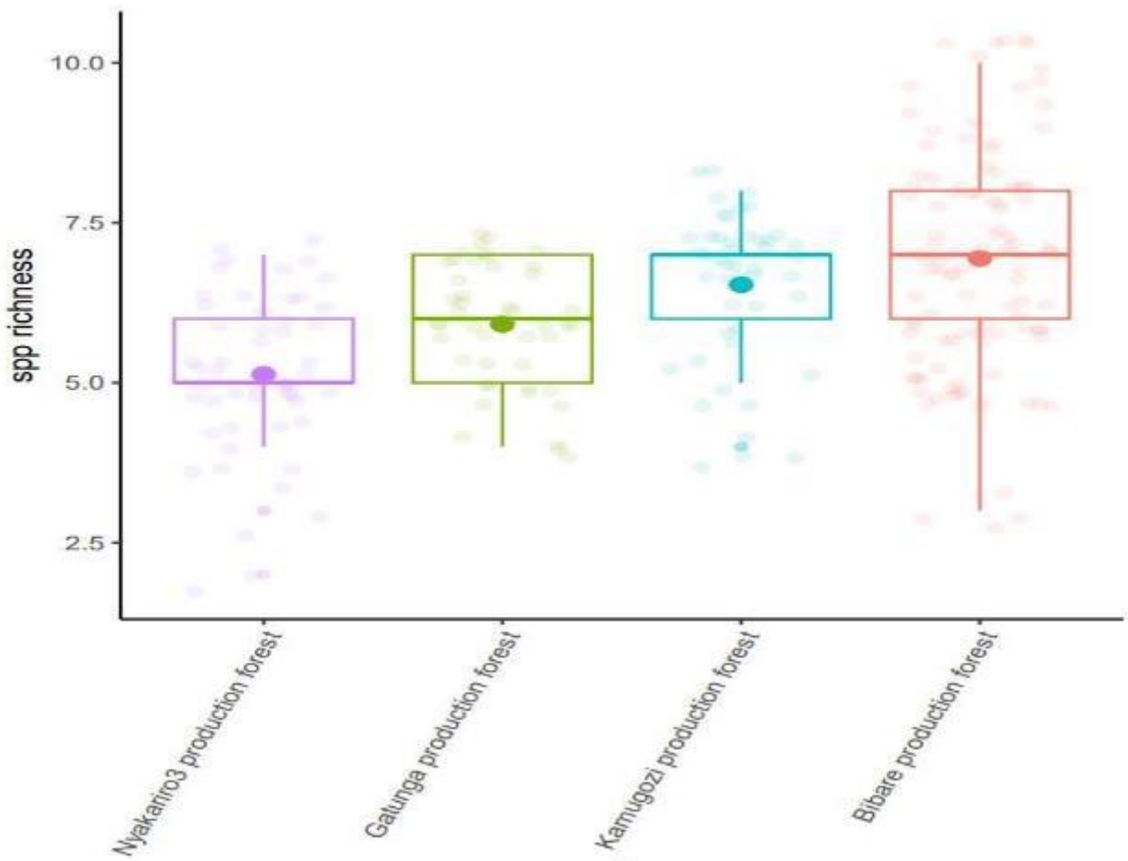

Figure 8. Terrestrial arthropods richness distribution across the four production forests. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represents the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to sampling stations on sampling sites.

Birds

A total of 51 bird species, representing 22 families were observed in the production forests sampled for this study (Figure 9). One of the highlights of our survey was the observation of nine migratory species across all production forests. These migrant species have been noted to appear consistently in most production forests, underscoring the importance of these habitats for migratory bird populations.

Furthermore, our study revealed the presence of six distinct functional groups among the observed bird species. These functional groups include granivorous (seed-eating), omnivorous (eating both plant and animal matter), nectivorous (nectar-feeding), insectivorous (insect-eating), frugivorous (fruit-eating), and carnivorous (meat-feeding) species.

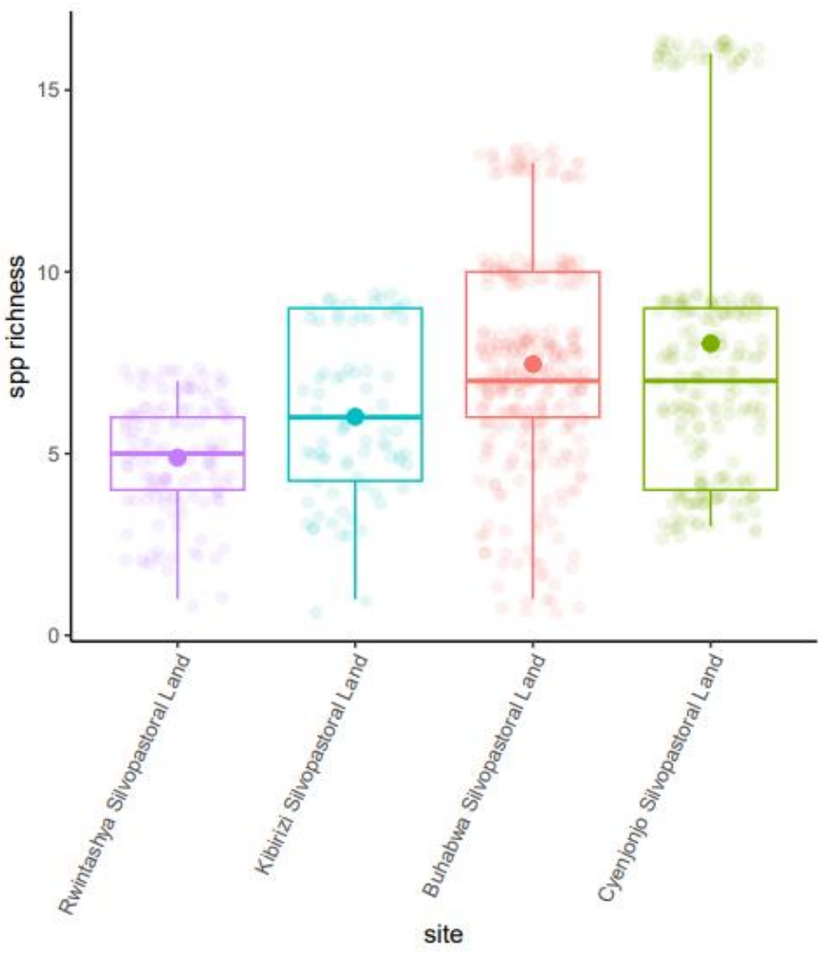

Figure 9. Figure compares species richness for birds between four selected Production Forest sites in Eastern Province. Boxes represent the inter-quartile range (IQR), and lines in the center represent the median. Whiskers correspond to the largest/smallest value less/greater than the upper/lower quartile minus 1.5 times IQR. Points correspond to sampling units of point counts.

Mammals

No mammal or mammal sign was observed in the Production Forests during the survey.

Threats

More threats were observed in Nyakariro-3 Production Forest (56%), followed by Gatunga Production Forest (24%), Kamugozi Production Forest (12%) and Bibare Production Forest (8%). The frequency of threats was evaluated between the sites and the frequencies of threats did not differ significantly among the Production Forests (Figure 10). Charcoal making was the most common threat observed, followed by the presence of plastic waste (Figure 10). Charcoal making at Nyakariro-3 Production Forest is shown in Figure 11) and mining at Gatunga Production Forest is shown in Figure 12.

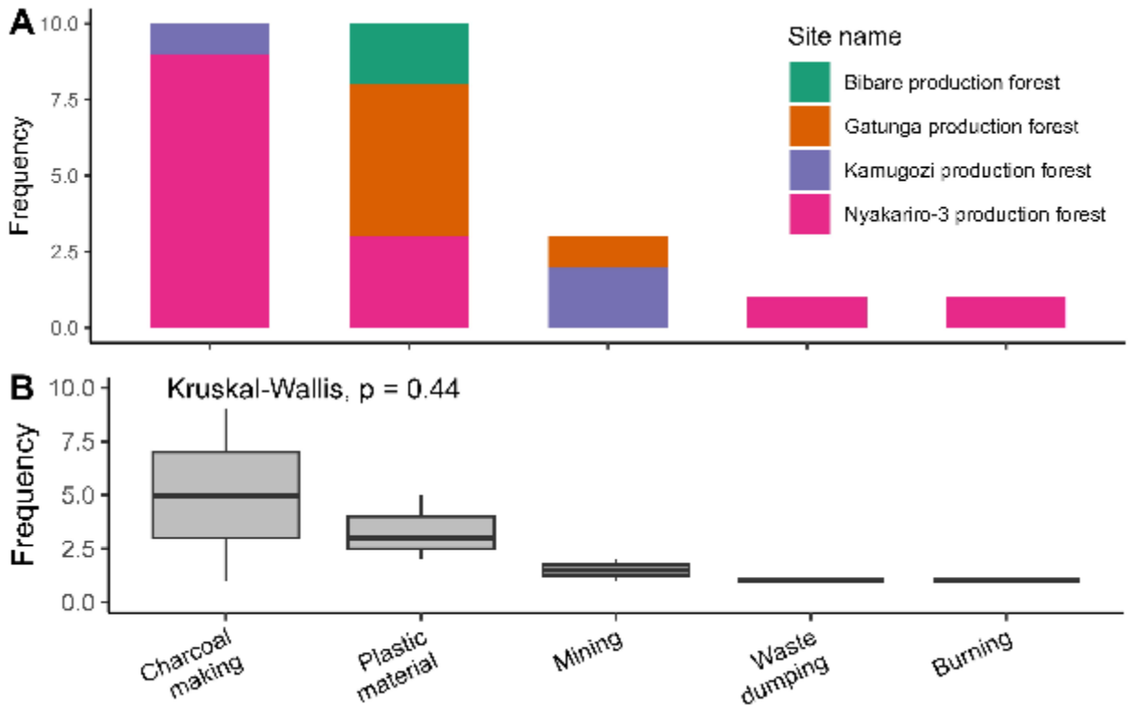

Figure 10. Frequency of threats and disturbances in Production Forests (PFMUs) sites, with A showing total abundance and B showing frequency by site summarized with box plots with the median value; the difference between sites was not significant (Kruskal-Wallis test, p = 0.44).

Figure 11. Charcoal making at Nyakariro-3 Production Forest

Figure 12. Mining at Gatunga Production Forest in Gatsibo

2. Sylvopastoral lands

There are four sylvopastoral lands surveyed in this biodiversity baseline assessment: Cyenjojo, Gahabwa, Rwintashya, and Kibirizi sylvopastoral lands (Figure 13). Data from the biodiversity baseline assessment for sylvopastoral lands are presented below.

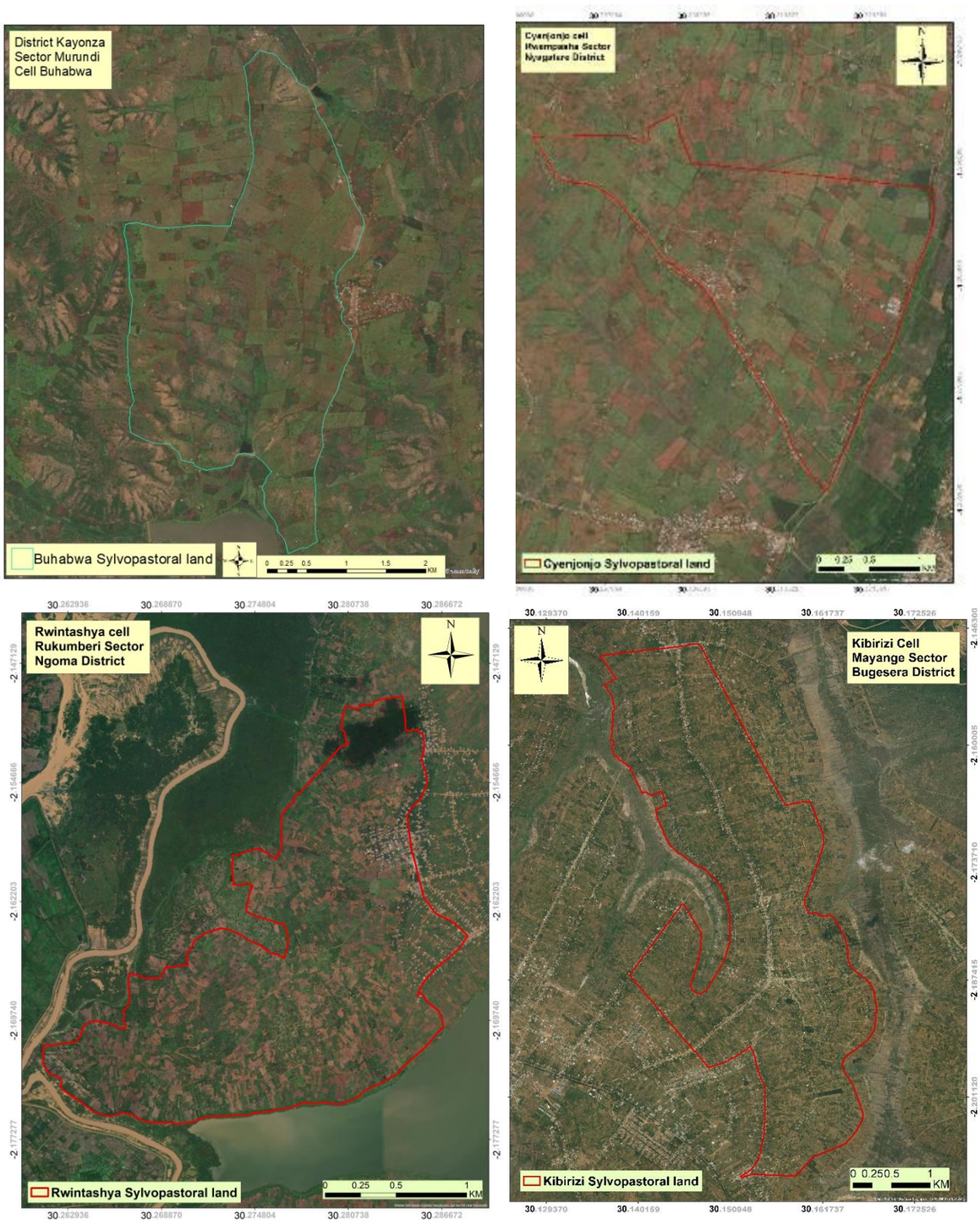

Figure 13. Maps of the four sylvopastoral lands sampled in the Eastern Province, Rwanda.

Plants

There were 60 plant species from 23 families found in Sylvopastoral lands (Table 6). The Fabaceae family comprised 60% of the recorded flora, followed by the Malvaceae at 11.66%, and both Rubiaceae, Lamiaceae, and Asteraceae at 5% each. The majority, accounting for 65%, are indigenous to Rwanda and the surrounding region, underscoring the critical role of these Sylvopastoral lands in preserving native flora. However, 35% of the species recorded in this forest are of introduced origins, signaling potential challenges in maintaining ecosystem integrity. While 51.66% of the identified species are classified as Least Concern according to the IUCN Red List,

3.33% were recorded as vulnerable, 1.66% as endangered, and 1.66% as Data Deficient on the IUCN Red List, while 41.66% were not evaluated on the IUCN Red List.

Table 6. Families and species of plants found in the Sylvopastoral lands, Eastern Province, Rwanda

ID	Family	Scientific name	IUCN status	Native or introduced	Life form
1	Anacardiaceae	*Mangifera indica*	DD	Introduced	tree
		Ozoroa insignis	LC	Native	tree or shrub
		Searsia natalensis	LC	Introduced	tree or shrub
2	Apocynaceae	*Acokanthera schimperi*	LC	Native	tree or shrub
		Carissa spinarum	LC	Native	tree or shrub
3	Asparagaceae	*Asparagus flagellaris*	NE	Native	shrub
4	Asteraceae	*Gymnanthemum amygdalinum*	NE	Native	tree or shrub
		Microglossa densiflora	NE	Native	shrub
		Vernonia sp.	NE	Native	N/A
5	Celastraceae	*Gymnosporia heterophylla*	LC	Introduced	shrub
		Gymnosporia senegalensis	LC	Introduced	tree or shrub
6	Combretaceae	*Combretum molle*	NE	Native	shrub
		Combretum pisoniiflorum	NE	Native	tree or shrub
7	Euphorbiaceae	*Euphorbia tirucalli*	LC	Introduced	tree or shrub
		Alchornea floribunda	LC	Native	tree or shrub
		Euphorbia candelabrum	LC	Native	tree
8	Fabaceae	*Albizia adianthifolia*	LC	Native	tree
		Albizia petersiana	LC	Native	tree or shrub
		Cajanus cajan	NT	Introduced	shrub
		Calliandra houstoniana var. calothyrsus	NE	Introduced	tree
		Crotalaria retusa	NE	Introduced	shrub
		Erythrina abyssinica	LC	Native	tree
		Indigofera brevicalyx	NE	Native	perennial
		Jacaranda mimosifolia	VU	Introduced	tree
		Markhamia lutea	LC	Native	tree
		Senna didymobotrya	LC	Native	tree or shrub
		Senna spectabilis	LC	Introduced	tree or shrub
		Vachellia sieberiana	LC	Native	tree
		Tephrosia vogelii	LC	Native	shrub
9	Hypericaceae	*Harungana montana*	VU	Native	tree
10	Lamiaceae	*Hoslundia opposita*	NE	Native	shrub
		Ocimum gratissimum subsp. gratissimum	NE	Native	shrub
		Tetradenia riparia	LC	Native	tree or shrub
11	Lauraceae	*Persea americana*	LC	Introduced	tree

12	Malvaceae	*Grewia similis*	NE	Native	tree or shrub
		Grewia trichocarpa	NE	Native	tree or shrub
		Hibiscus aponeurus	NE	Native	shrub
		Pavonia urens var. irakuensis	NE	Native	shrub
		Sida ovata	NE	Native	shrub
		Sida rhombifolia subsp. rhombifolia	NE	Native	shrub
		Triumfetta rhomboidea	NE	Native	shrub
		Hibiscus diversifolius	LC	Native	shrub
13	Moraceae	*Artocarpus heterophyllus*	NE	Introduced	tree
14	Moringaceae	*Moringa oleifera*	LC	Introduced	tree
15	Myrtaceae	*Eucalyptus saligna*	LC	Introduced	tree
16	Phyllanthaceae	*Bridelia brideliifolia*	LC	Native	tree
		Phyllanthus fischeri	NE	Native	tree
17	Phytolaccaceae	*Phytolacca dodecandra*	NE	Native	shrub
18	Proteaceae	*Grevillea robusta*	LC	Introduced	tree
19	Rhamnaceae	*Maesopsis eminii*	LC	Introduced	tree
20	Rubiaceae	*Coffea arabica*	EN	Introduced	tree
		Gardenia ternifolia	LC	Native	tree or shrub
		Tarenna pavettoides	LC	Native	tree
		Afrocanthium lactescens	LC	Native	tree
21	Rutaceae	*Citrus × limon*	LC	Introduced	tree
22	Solanaceae	*Solanum aculeastrum*	LC	Native	tree or shrub
		Solanum nigriviolaceum	LC	Introduced	shrub
23	Verbenaceae	*Lantana trifolia*	NE	Introduced	shrub
		Lantana camara	NE	Introduced	shrub
		Acanthus polystachyus	NE	Native	shrub

Herpetofauna: Amphibians and Reptiles

Four Sylvopastoral lands were surveyed for amphibians and reptiles including Cyenjojo 1, Buhabwa, Rwintashya 2 and Kibirizi. No amphibians were observed in Kibirizi sylvopastoral land, and no reptiles in Kibirizi and Buhabwa. The following observations are for sites where species occurrence was recorded. Four amphibian families were recorded including Phrynobatrachidae and Ptychadenidae with two species each, and Bufonidae and Hyperoliidae with one species each. Among reptiles, one species was recorded for each family (Table 7).

Table 7. Amphibian and reptile species recorded in the Sylvopastoral lands, with both the IUCN Category global and national status. LC: Least Concerned, DD: Data Deficient. ND: Not Determined.

	Family	**Scientific name**	**Common name**	**Global IUCN status**	**National IUCN status**
AMPHIBIANS					
1	Bufonidae	*Sclerophrys gutturalis (Power, 1927)*	African Common Toad	LC	LC
2	Hyperoliidae	*Kassina senegalensis (Duméril & Bibron, 1841)*	Bubbling Kassina	LC	LC

3	Phrynobatrachidae	*Phrynobatrachus kakamikro Schick, Zimkus, Channing, Köhler & Lötters, 2010*	Kakamega Puddle Frog	DD	LC
		Phrynobatrachus natalensis (Smith, 1849)	Common Toad-frog	LC	LC
4	Ptychadenidae	*Ptychadena anchietae (Bocage, 1868)*	Anchieta's Frog	LC	LC
		Ptychadena nilotica (Seetzen, 1855)	Nile grass frog	LC	LC
REPTILES					
1	Scincidae	*Trachylepis striata (Peters, 1844)*	African Striped Mabuya	LC	ND
2	Lacertidae	*Adolfus jacksoni (Boulenger, 1899)*	Jackson's Forest Lizard	LC	ND
3	Elapidae	*Unidentified cobra species (shade)*	Cobra	-	-

Findings revealed that the highest richness of amphibian species was observed at Buhabwa (n=4) and for reptiles at Rwintashya (n=3) sylvopastoral lands. Among the amphibian species, *Ptychadena nilotica* was recorded in three sites followed by *Sclerophrys gutturalis* and *Phrynobatrachus natalensis* observed in two sites each. The most abundant species included *Ptychadena nilotica* (n=41), followed by *Ptychadena anchietae* (n=10) then *Phrynobatrachus natalensis.* (n=10) (Figure 14).

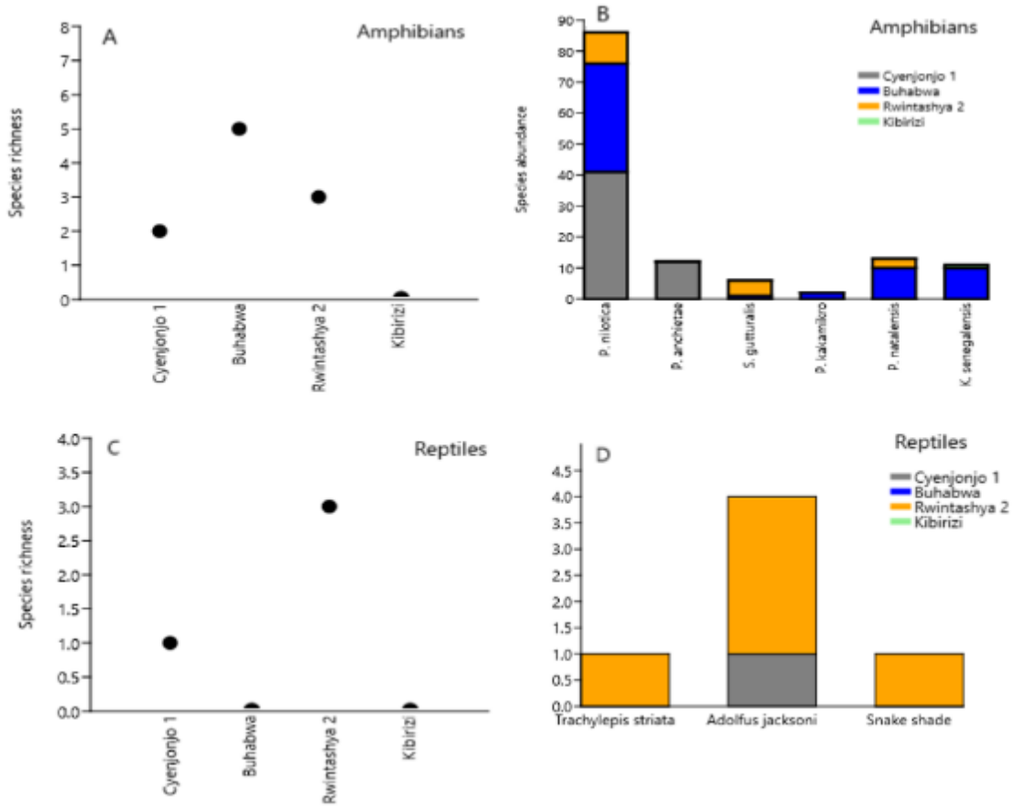

Figure 14. Amphibian and reptile species richness (A, C), species occurrence and abundance (B, D) per sylvopastoral land. The dots represent the number of species per sampled site. The colored bars represent the abundance data of the species per site.

Flying Insects

Four sylvopastoral lands were surveyed and a total of 38 butterfly species were recorded across all the sites. These butterflies were distributed into five families namely Nymphalidae, Pieridae, Lycaenidae, Hesperiidae and Papilionidae. We found 25 species of butterflies in Cyenjonjo sylvopastoral land from four families namely Hesperiidae (4.55%), Lycaenidae (13.64%),

Nymphalidae (27,27%) and, Pieridae (54.55%), 19 species from three families (Lycaenidae (17.95%), Nymphalidae (43.59%) and Pieridae (38.46%)) in Gahabwa sylvopastoral land, four from Kibilizi sylvopastoral land in two families (Pieridae (66.67%) and Nymphalidae (33.33%)) and 21 species from four families (Hesperiidae (2.94%), Lycaenidae (5.88%), Nymphalidae (35.29%) and Pieridae 55.88%) from Rwintashya sylvopastoral land (Figure 15). Information about the species names and their IUCN Red List information are found in Annex 3.

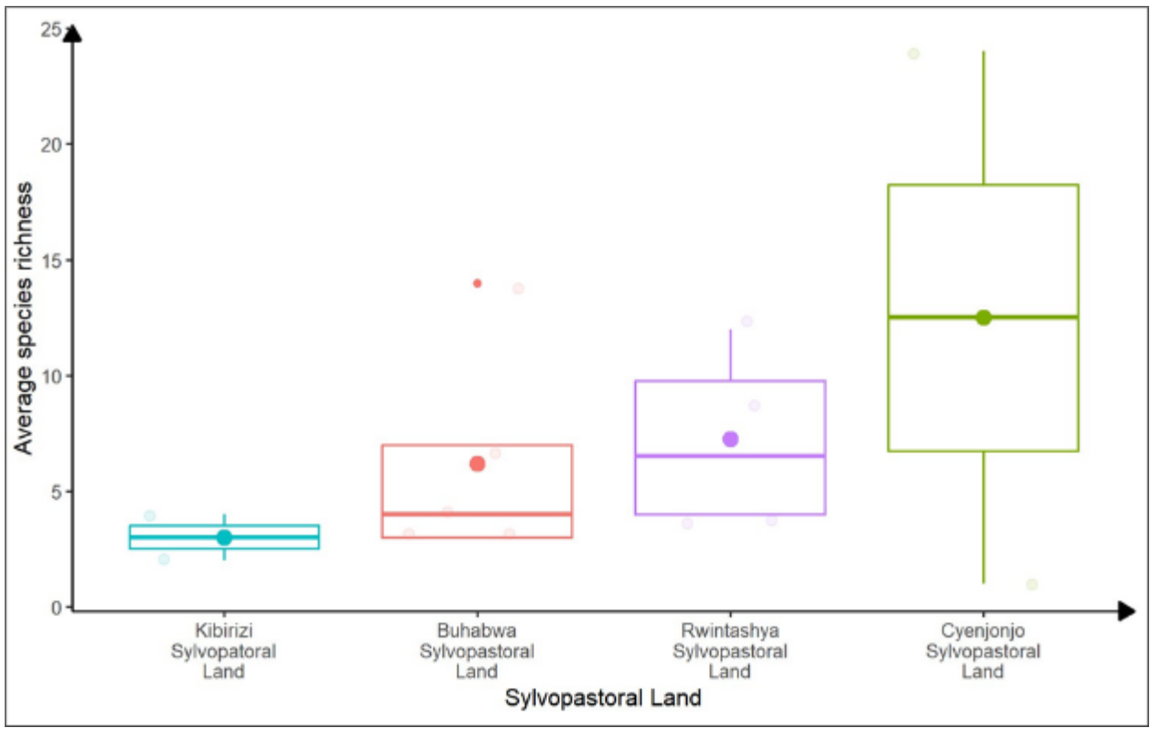

Figure 15. Butterfly richness distribution across the four Sylvopastoral land. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represent the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR.

By comparing both butterfly diversity and abundance, the highest species richness was recorded from Cyenjonjo, followed by Rwintashya, Buhabwa and then Kibilizi (Figure 16A). For all sites, the sampling effort did not reach the maximum level (Figure 16B) and more sampling would likely uncover more species.

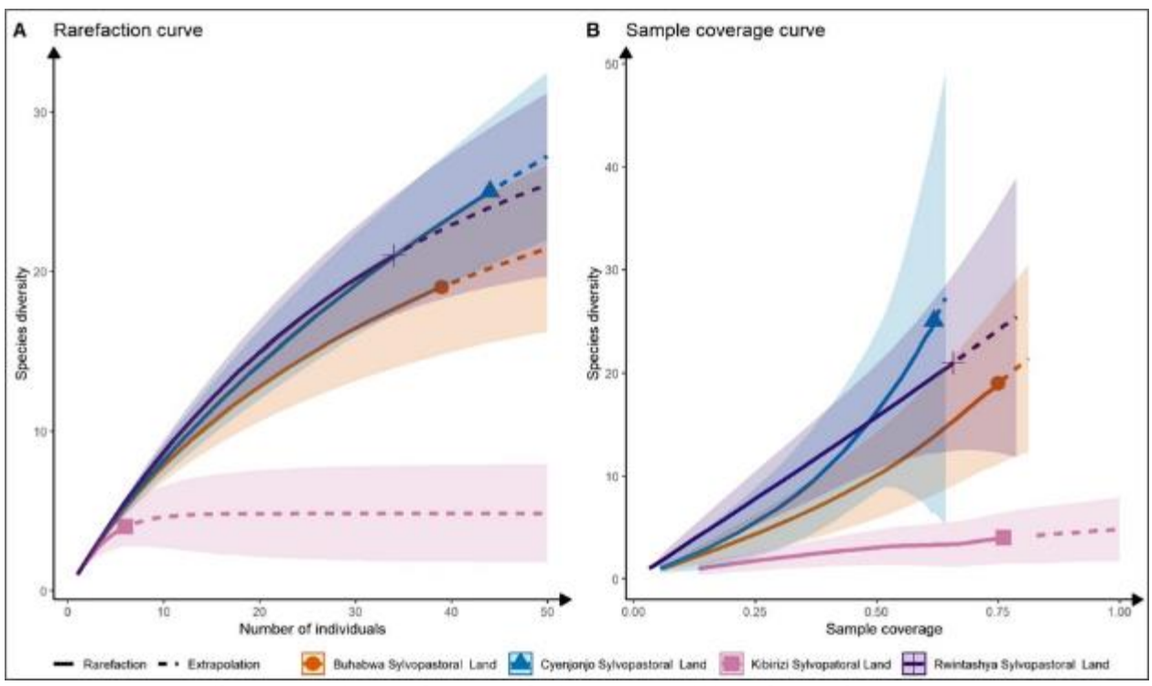

Figure 16. Butterfly rarefaction and extrapolation curves (A) and sample coverage curves using butterfly richness (Hill numbers of order 0) across the four sylvopastoral lands. Solid lines represent the curves based on sample data, and the dashed lines represent the extrapolations. Shaded areas represent the 95% confidence intervals surrounding the curves.

Across three sylvopastoral lands (Rwintashya, Buhabwa and Cyenjonjo), a total of 12 pollinating insects were recorded. Those species were distributed into managed bees (*Apis mellifera*), wild bees (*Xylocopa nigrita*, *Xylocopa caffra* and *Xylocopa flavorufa*), stingless bees from *Lasioglossum* genus, butterflies (*Anthene definita, Boribo fatuellus, Belenois creona, Colotis evagore* and *Eurema hecabe)* and flies (*Eristalis sp* from the Syrphidae) were recorded. We observed *Lantana camara* and *Bidens pilosa* to be the most visited species by pollinators (Figure 17) whereas the most abundant pollinator was the bee (*Apis mellifera*). There were no pollinating insects recorded from Kibilizi.

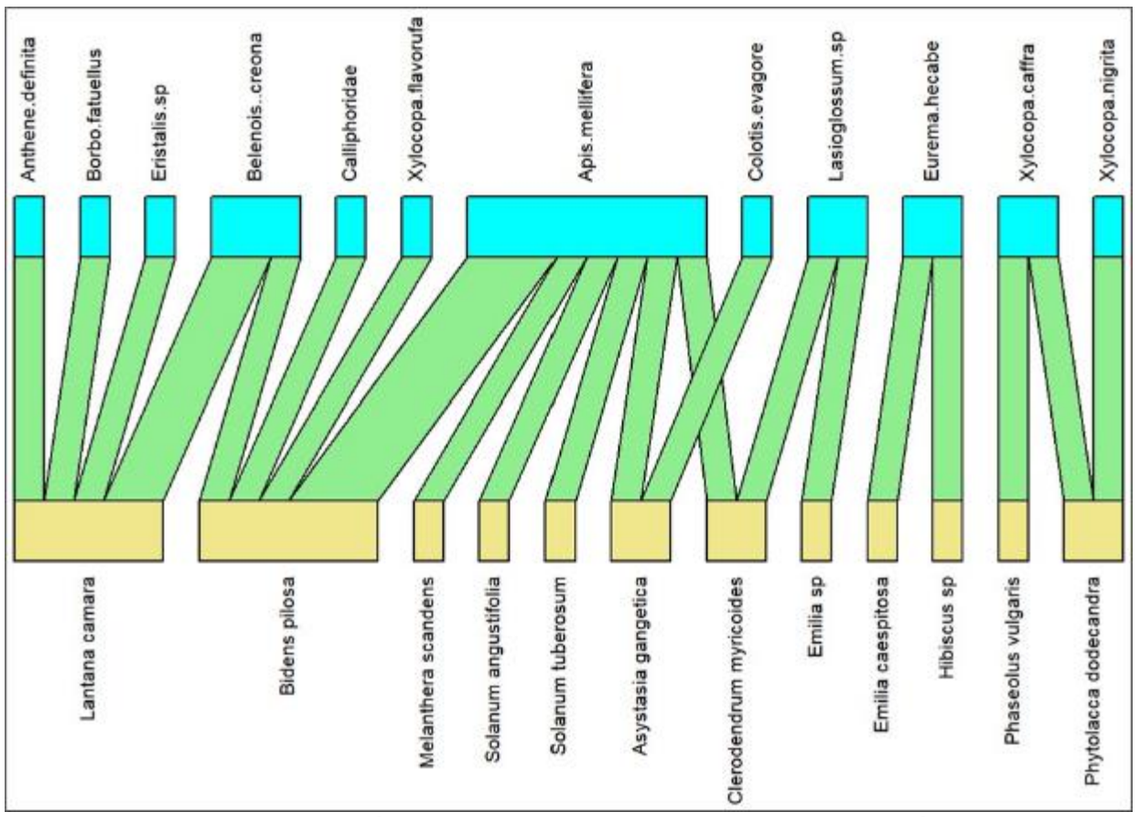

Figure 17. Network structure of plants and their pollinating insects recorded from three sylvopastoral lands (Rwintashya, Cyenjonjo and Buhabwa). The upper band in dark turquoise color represents the flower visitors while the lower band in yellow color represents plant diversity (host plants). The vertical lines in the middle of the figure (in green color) represent the linkage (which plant was visited by which insect) between plants and their pollinating insects.

Terrestrial arthropods

Terrestrial arthropod survey was carried out in the four sylvopastoral lands: Cyenjojo, Buhabwa, Rwintashya and Kibirizi (Figure 18). A total of 55 families dominated by Formicidae (Omnivorous) at 30%, Termitidae (Detritivorous) at 11%, Salticidae (Predators) at 9% and Chrysomelidae (Herbivorous) at 6% were found (Table 8). All recorded families are not yet evaluated on the IUCN Red List.

Table 8. Terrestrial arthropods recorded in the sylvopastoral lands, including the family with common name and functional group.

	Order	**Family**	**Common name**	**Functional Group**
1	Hymenoptera	Formicidae	Ants	Omnivorous
2	Isoptera	Termitidae	Termite	Detritivorous
3	Aranea	Salticidae	Jumping Spider	Predators
4	Coleoptera	Chrysomelidae Coccinellidae	Leaf Beetle Ladybug	Herbivorous Carnivorous

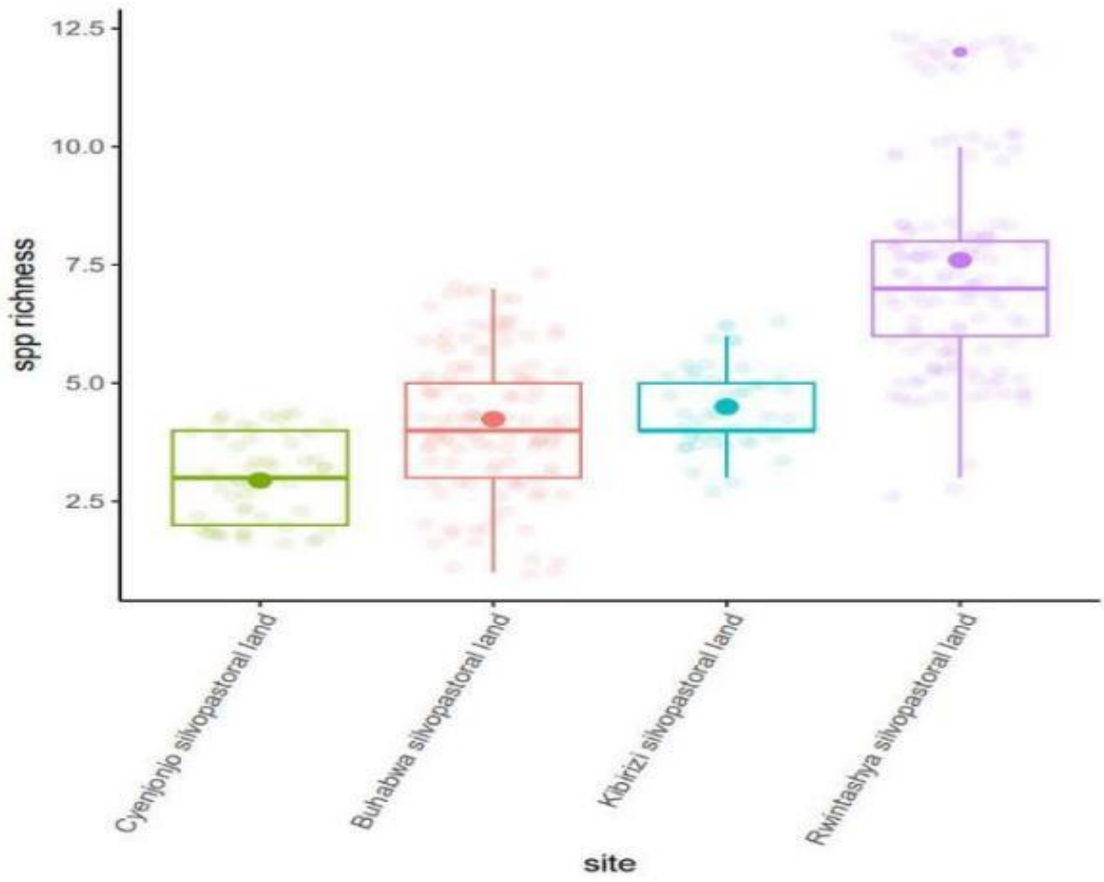

Figure 18. Terrestrial arthropods richness distribution across the four Sylvopastoral Lands. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represents the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/ smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to sampling stations on sampling sites.

Birds

The survey of birds in sylvopastoral lands including Cyenjojo, Buhabwa, Rwintashya and Kibirizi found a total of 83 bird species from 38 families (Figure 19). One of the notable discoveries during the survey was the presence of two endangered species, the Gray-crowned crane (*Balearica regulorum*) in Cyenjonjo sylvopastoral land, and the Grey Parrot (*Psittacus erithacus*) in Buhabwa sylvopastoral land. Additionally, we observed 14 migratory species across all sylvopastoral lands, indicating the potential significance of these areas as important stopover sites for migratory birds.

The study also revealed the presence of eight distinct functional groups among the observed bird species, including Granivorous (seed-eating), Omnivorous (eating both plant and animal matters), Nectivorous (nectar-feeding), Insectivorous (insect-eating), Frugivorous (fruit-eating), Herbivorous (plant-feeding), Piscivorous (fish-feeding), and Carnivorous (meat-feeding) species. The most common functional group was insect-feeding birds with 26 bird species (31%).

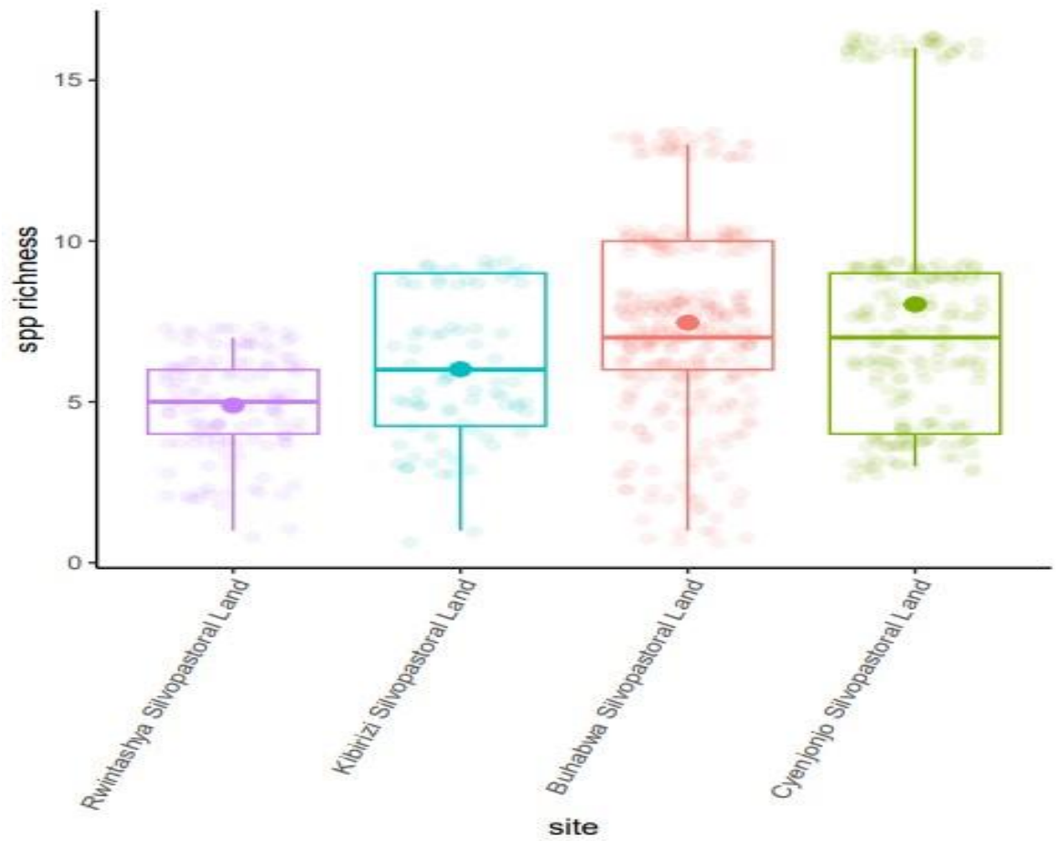

Figure 19. Species richness between four selected Sylvopastoral Land sites in Eastern Province. Boxes represent the inter-quartile range (IQR), lines in the center represent the median. Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to sampling units of point counts.

Mammals

In Buhabwa sylvopastoral land in Nyagatare district, one species of mammal was recorded, the African savannah hare *Lepus vitoriae* which was sighted in *Lantana camara* bushes within a farmland. No other mammals were observed during the sylvopastoral lands surveys.

Threats

Only two threats were observed in sylvopastoral lands: nine records of plastics (90% of the observations of threats) and one record of waste dumping (10%). In order of decreasing frequencies of threats presence, Buhabwa had the highest (60%), then Kibirizi (20%), and lastly Rwintashya (20%).

3. Dam Buffer

Four dam buffer sites were sampled: Bugugu dam, Kampima Dam, Rugende Dam, and Nyirabidibiri Dam (Figure 20)). The details of the biodiversity surveys are presented below.

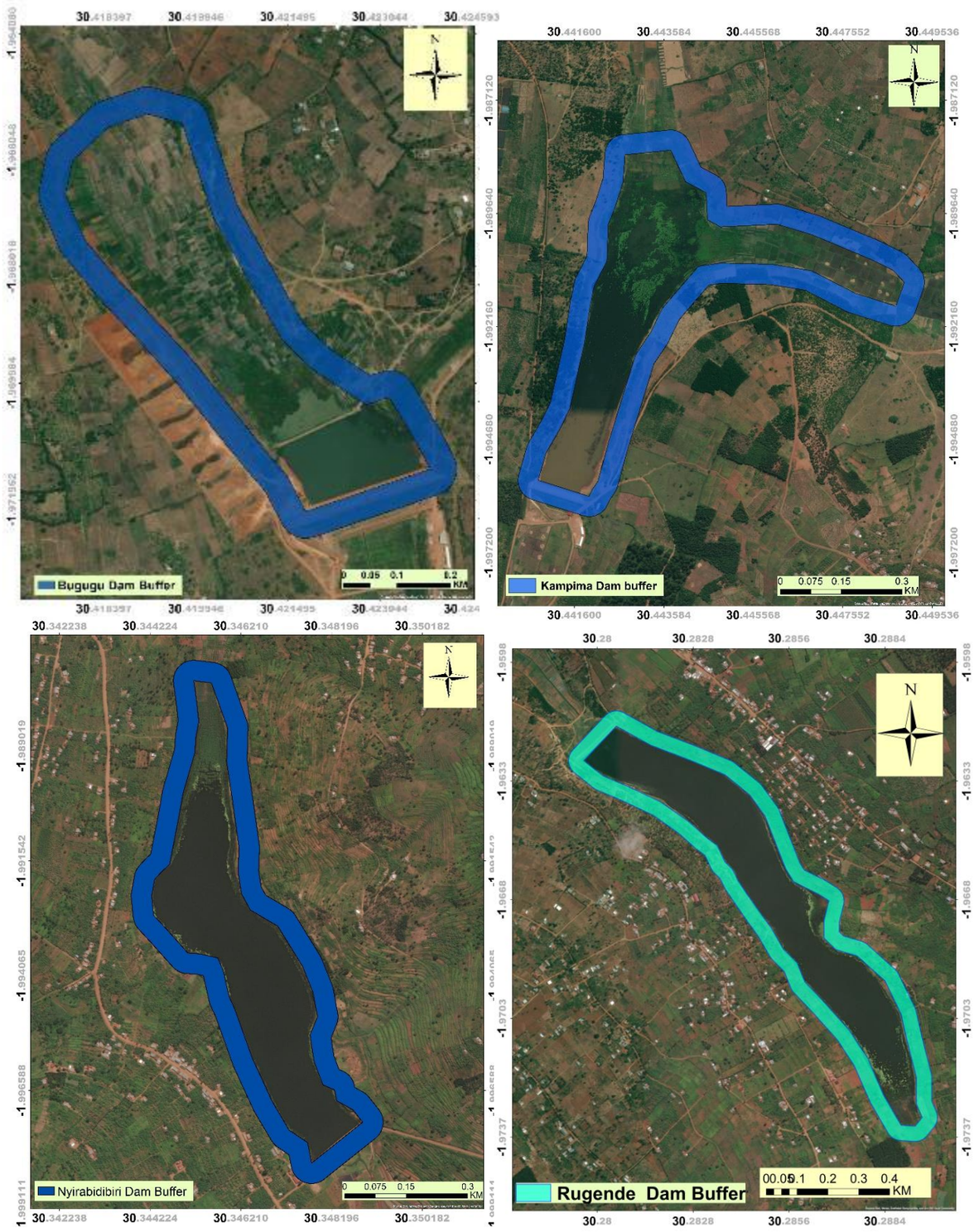

Figure 20. Maps of the four dam buffers sampled in the Eastern Province, Rwanda.

Plants

The survey conducted within the buffer zones of four dams, including Bugugu, Kampima, Rugende, and Nyirabidibiri found a total of 70 species from 35 families (Table 9). Notably, our analysis highlights the prevalence of the Fabaceae family as the most dominant, with 15.71% of the observations, closely followed by Asteraceae family at 14.28%. Acanthaceae and Malvaceae families exhibited significant presence, each comprising 5.71% of the recorded species. Of the species observed, 55.71% are native to Rwanda and the surrounding region, and 44.28% are introduced species. Furthermore, our assessment of conservation status reveals that 41% of the species are listed as Least Concern on the IUCN Red List, 4.28% classified as Data Deficient, and 1.42% identified as Endangered and Vulnerable, each. Notably, a significant portion, 51.42%, remains unevaluated according to the IUCN Red List criteria. These findings suggest that the Eastern Province's dam buffers host important plant diversity.

Table 9. Families and species of plants found in the sampled dam buffers, Eastern Province, Rwanda

ID	Family	Scientific Name	IUCN Status	Native or introduced	life form
1	Acanthaceae	*Dicliptera colorata*	NE	Native	herb
		Acanthus polystachyus	NE	Native	tree or shrub
		Asystasia gangetica	NE	Introduced	herb
		Thunbergia alata	NE	Native	herb
2	Amaranthaceae	*Amaranthus sp*	NE	Introduced	herb
3	Anacardiaceae	*Lannea fulva*	NE	Native	tree or shrub
		Mangifera indica	DD	Introduced	tree
4	Apiaceae	*Centella asiatica*	LC	Native	herb
5	Apocynaceae	*Carissa spinarum*	LC	Native	Tree or shrub
6	Araliaceae	*Hydrocotyle mannii*	LC	Native	herb
7	Asteraceae	*Acmella caulirhiza*	NE	Introduced	herb
		Ageratum conyzoides	NE	Introduced	herb
		Bidens pilosa	NE	Introduced	herb
		Crassocephalum vitellinum	NE	Native	herb
		Galinsoga parviflora	NE	Introduced	herb
		Gymnanthemum amygdalinum	NE	Native	tree or shrub
		Lipotriche scandens	NE	Native	herb
		Microglossa pyrifolia	NE	Native	shrub
		Vernonia sp.	NE	N/A	shrub
		Tridax procumbens	NE	Introduced	herb
8	Bignoniaceae	*Markhamia lutea*	LC	Native	tree
		Jacaranda mimosifolia	VU	Introduced	tree
9	Casuarinaceae	*Casuarina glauca*	LC	Introduced	tree
		Casuarina equisetifolia	LC	Introduced	tree
10	Celastraceae	*Gymnosporia heterophylla*	LC	Introduced	shrub
11	Commelinaceae	*Commelina africana*	LC	Native	herb
		Commelina longifolia	NE	Introduced	herb
12	Convolvulaceae	*Dichondra micrantha*	LC	Introduced	herb
		Ipomoea batatas	DD	Introduced	herb
13	Conyza	*Conyza pallidiflora*	NE	Native	herb
14	Cyperaceae	*indet.*	NE	N/A	N/A
15	Euphorbiaceae	*Manihot esculenta*	DD	Introduced	shrub
		Euphorbia tirucalli	LC	Introduced	tree or shrub
16	Fabaceae	*Acacia mearnsii*	NE	Introduced	tree
		Biancaea decapetala	LC	Introduced	shrub
		Calliandra houstoniana var. calothyrsus	NE	Introduced	tree
		Crotalaria cylindrica	LC	Native	shrub
		Crotalaria spinosa	LC	Native	herb
		Erythrina abyssinica	LC	Native	tree
		Indigofera brevicalyx	NE	Native	perennial
		Phaseolus vulgaris	LC	Introduced	herb
		Senegalia occidentalis	NE	Introduced	Tree or shrub
		Senna spectabilis	LC	Introduced	tree or shrub
		Vigna parkeri	LC	Native	herb
17	Lamiaceae	*Clerodendrum johnstonii*	LC	Native	tree or shrub
		Leonotis nepetifolia	NE	Native	shrub
18	Lauraceae	*Persea americana*	LC	Introduced	tree

19	Malvaceae	*Hibiscus calyphyllus*	LC	Native	shrub
		Pavonia urens var. irakuensis	NE	Native	shrub
		Sida rhombifolia subsp. rhombifolia	NE	Native	shrub
		Triumfetta rhomboidea	NE	Native	shrub
20	Menispermaceae	*Hyalosepalum caffrum*	NE	Native	herb
21	Myrtaceae	*Eucalyptus saligna*	LC	Introduced	tree
		Psidium guajava	LC	Introduced	tree
22	Nymphaeaceae	*Nymphaea sp.*	LC	N/A	herb
23	Onagraceae	*Ludwigia abyssinica*	LC	Native	herb
25	Oxalidaceae	*Oxalis latifolia*	NE	Introduced	herb
		Oxalis obliquifolia	NE	Native	herb
26	Phyllanthaceae	*Phyllanthus fischeri*	NE	Native	tree
27	Phytolaccaceae	*Phytolacca dodecandra*	NE	Native	shrub
28	Poaceae	*indet.*	NE	N/A	N/A
29	Polygonaceae	*Persicaria decipiens*	LC	Native	herb
		Rumex abyssinicus	NE	Native	herb
30	Proteaceae	*Grevillea robusta*	LC	Introduced	tree
31	Rhamnaceae	*Maesopsis eminii*	LC	Rwanda	tree
		Scutia myrtina	LC	Native	shrub
32	Rubiaceae	*Coffea arabica*	EN	Introduced	tree
33	Rutaceae	*Citrus × limon*	LC	Introduced	tree
34	Solanaceae	*Solanum mauense*	NE	Native	shrub
35	Verbenaceae	*Lantana camara*	NE	Introduced	shrub

Herpetofauna: Amphibians and Reptiles

Four dam buffer areas were surveyed where three four amphibian and two reptile families were recorded. Among amphibians, Phrynobatrachidae and Ptychadenidae recorded more species (n=2) than the remaining families where each had a single species (Table 10). For reptiles, each recorded family had one species observed. All recorded species are listed as Least Concerned by the National IUCN Red list of threatened species (Dehling & Sinsch, 2023).

Table 10. Amphibians and reptiles species recorded from Dam buffers. The global and national IUCN status for each observed species is indicated. LC: Least Concerned, ND: Not Determined.

	Family	**Scientific name**	**Common name**	**Global IUCN status**	**National IUCN status**
AMPHIBIANS					
1	Bufonidae	*Sclerophrys gutturalis (Power, 1927)*	African Common Toad	LC	LC
2	Hyperoliidae	*Hyperolius viridiflavus (Duméril & Bibron, 1841)*	Common Reed Frog	LC	LC
3	Phrynobatrachidae	*Phrynobatrachus kakamikro Schick, Zimkus, Channing, Köhler & Lötters, 2010*	Kakamega Puddle Frog	DD	LC
		Phrynobatrachus natalensis (Smith, 1849)	Common Toad-frog	LC	LC
4	Ptychadenidae	*Ptychadena anchietae (Bocage, 1868)*	Anchieta's Frog	LC	LC
		Ptychadena nilotica (Seetzen, 1855)	Nile grass frog	LC	LC
REPTILES					
1	Scincidae	*Trachylepis striata (Peters, 1844)*	African Striped Mabuya	LC	ND

2	Pelomedusidae	*Pelusios sp*	African hinged terrapin	-	-
3	Elapidae	*Pelomedusa sp*	African helmeted turtle	-	-

Among the surveyed dam buffer areas, species richness was equal (n=4) for Bugugu, Kampima and Rugende dam buffer while Nyirabidiridiri dam buffer recorded three species (n=3). Among the amphibian species, *Ptychadena nilotica* was widespread as it was found in all surveyed dam buffers followed by *Hyperolius viridiflavus*, *Sclerophrys gutturalis* and *Ptychadena anchietae* which were recorded in three sites. The most abundant species recorded was *Ptychadena nilotica* in all sites. For reptiles, Kampima dam recorded the highest richness of species (n=3) while remaining sites had only one species observed. Among the observed species of reptiles, *Trachylepis striata* was widespread. All species had the same recorded abundance (n= 2) in all sites except at Rugende where the number of *Trachylepis striata* was only one individual observed. However, no species was recorded among the observations made at Nyirabidiridiri dam (Figure 21).

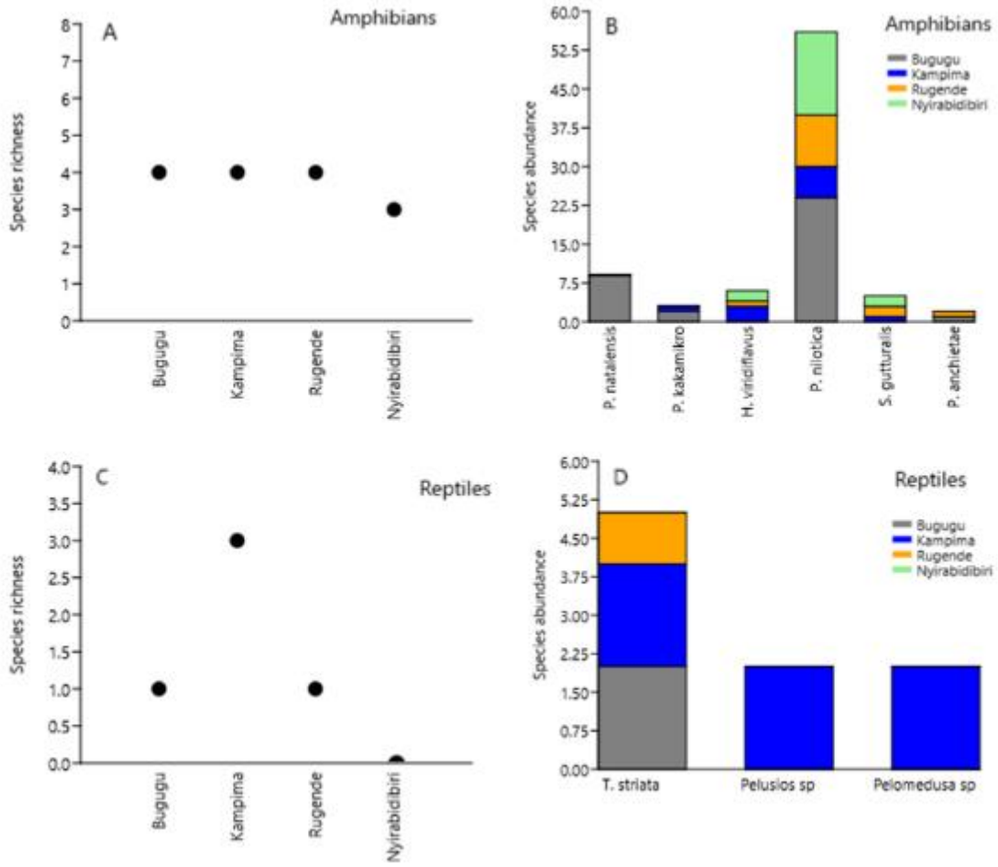

Figure 21. Amphibian and reptile species richness (A, C), species occurrence and abundance (B, D) per dam buffer. The dots represent the number of species per sampled site. The colored bars represent the abundance data of the species per site.

Flying Insects

Four dam buffers were surveyed and a total of 33 butterfly species were recorded across this entire site type. Nine species of butterflies were recorded from Bugugu Dam Buffer, 11 species were recorded from Kampima, 17 species from Nyirabidibili Dam Buffer and 25 species from Rugende Dam Buffer (Figure 22). More information about the species names and their IUCN Red List information are found in Annex 3.

The butterflies were distributed into five families namely Nymphalidae, Pieridae, Lycaenidae, Hesperiidae and, Papilionidae. Three butterfly families: Hesperiidae (6.67%), Nymphalidae (33.33%) and, Pieridae (60.00%) were recorded from Bugugu Dam Buffer. Three butterfly families were recorded from Kampima Dam Buffer: Hesperiidae (28.57%), Nymphalidae (23.81%) and Pieridae (47.62%). The families recorded from Nyirabidibiri included Hesperiidae (15.63%), Lycaenidae (3.13%), Nymphalidae (59.38%) and Pieridae (21.88%). From the

remaining Rugende Dam Buffer, the surveyed butterflies were only distributed intowere from only four families and the most abundant family at this site was Nymphalidae (50.82%), followed by Hesperiidae (19.67%); both Pieridae and Lycaenidae were represented by 14.75%. The distribution of just the butterfly species by dam site is shown in Figure 23.

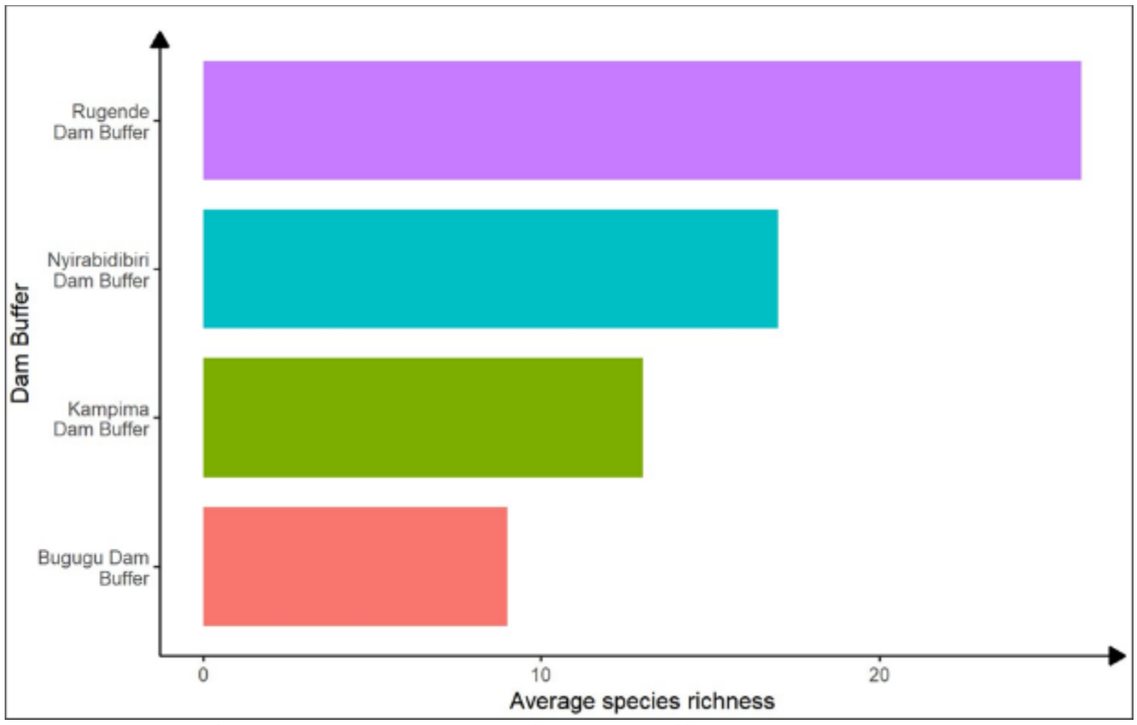

Figure 22. Butterfly species richness across four dam buffer sites sampled in the Eastern Province, Rwanda

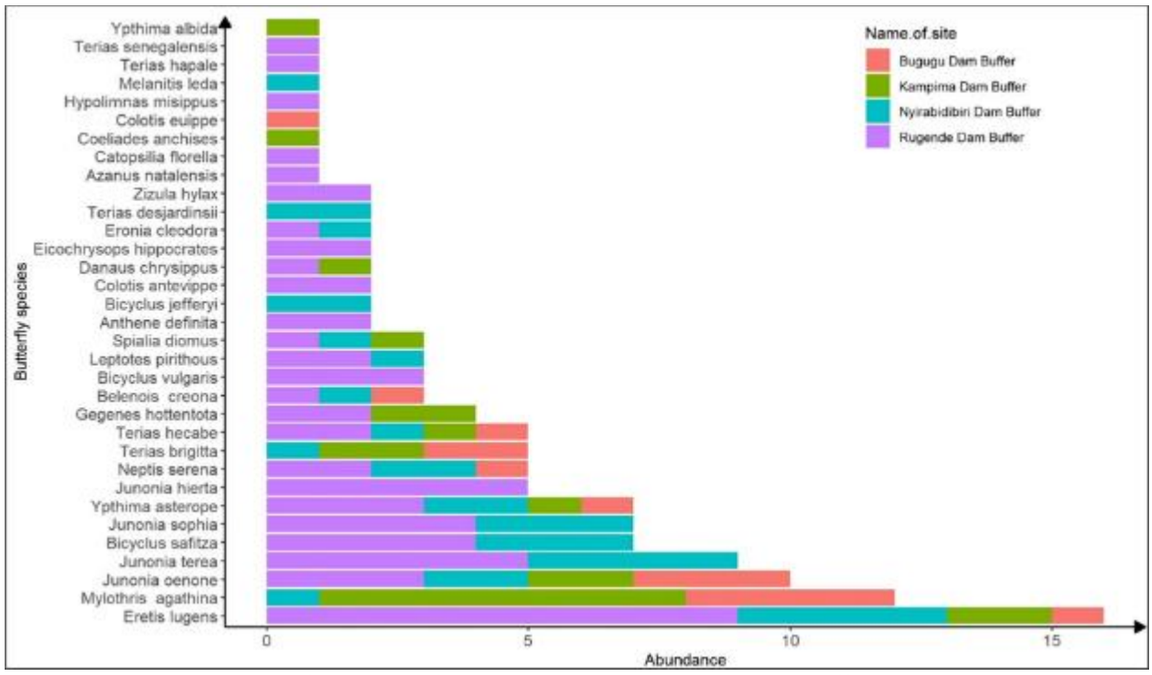

Figure 23. Distribution of the butterfly species observed at the dam buffer sites in the Eastern Province, Rwanda

By comparing both butterfly diversity and abundance, the highest butterfly species richness was recorded from Rugende Dam Buffer and the lowest species richness was from Kampima Dam Buffer (Figure 24A). For all sites, the sampling effort did not reach the maximum level and more sampling would identify more species present (Figure 24B).

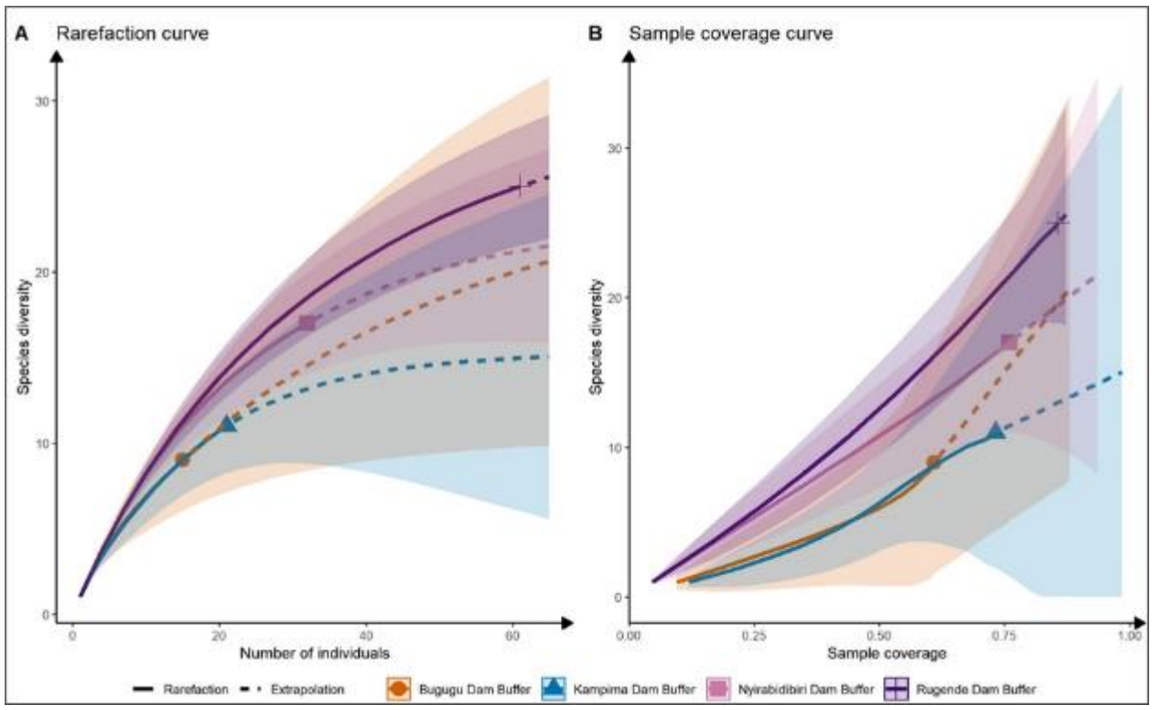

Figure 24. Butterfly rarefaction and extrapolation curves (A) and sample coverage curves using butterfly richness (Hill numbers of order 0) across four dam buffer sites. Solid lines represent the curves based on sample data, and the dashed lines represent the extrapolations. Shaded areas represent the 95% confidence intervals surrounding the curves.

A total of 15 pollinating insects were recorded from the four dam buffers. These species include managed bees (*Apis mellifera*), wild bees (*Xylocopa virginica, Xylocopa sp, Lasioglossum sp, Xylocopa caffra, Thyreus nitidilus* and *Xylocopa nigrita*), Wasps (*Synagris analis* and Sphecidae), flies from Calliphoridae family, butterflies (*Coeliades anchises, Junonia oenone* and *Eurema desjardinsii*) and beetles (*Mylabris* sp). We observed *Bidens pilosa* to be the most visited species by pollinators *Bidens pilosa* whereas the most abundant pollinator was the bee (*Apis mellifera*) (Figure 25).

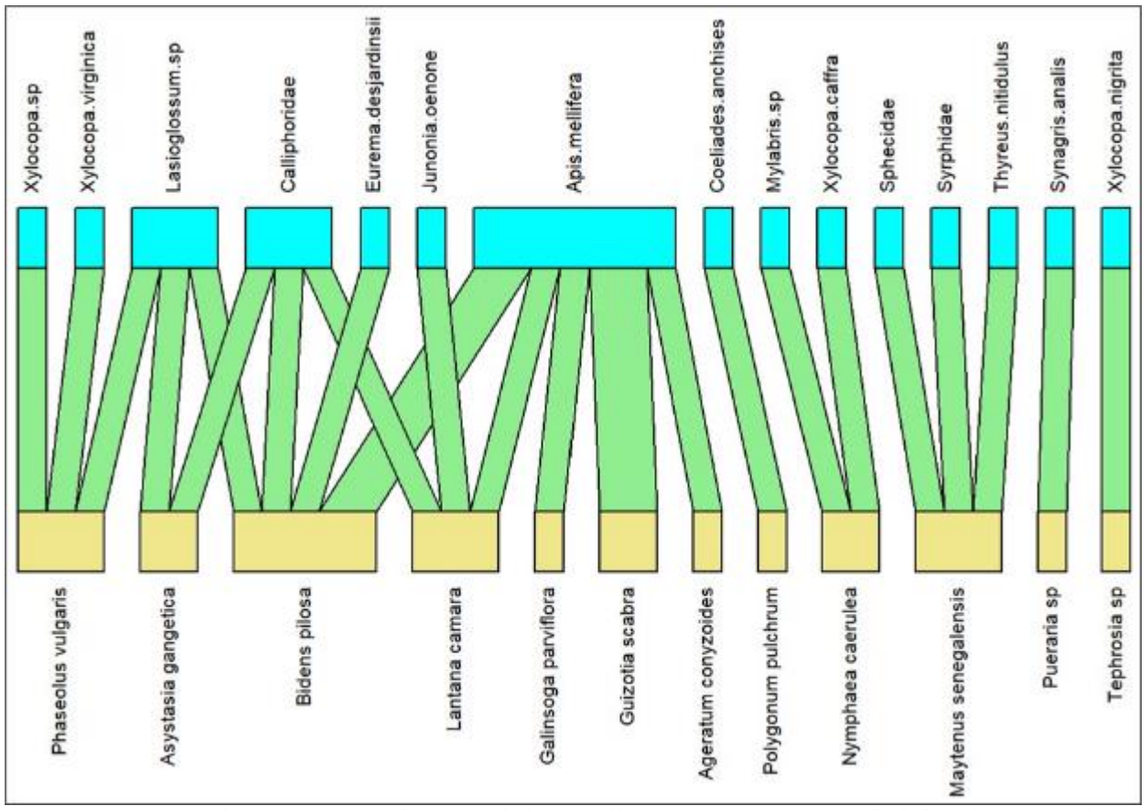

Figure 25. Network structure of plants and their pollinating insects recorded dam buffers. The upper band in dark turquoise color represents the flower visitors while the lower bands in yellow color represent plant diversity (host plants). The vertical lines in the middle of the figure (in green color) represent the linkage (which plant was visited by which insect) between plants and their pollinating insects.

Terrestrial Arthropods

Terrestrial arthropods were surveyed at the four selected dam buffers and 50 families were recorded (Figure 26). Among the recorded families, the most dominant families are: Formicidae at 31 %, Salticidae at 9%, Acrididae at 7% and Cercopidae at 6% (Table 11). All recorded families are not yet evaluated on the IUCN Red List.

Table 11. Terrestrial arthropod families recorded in the Dam Buffers

	Order	**Family**	**Common name**	**Functional group**
1	Hymenoptera	Formicidae	Ants	Omnivorous
2	Orthoptera	Acrididae Gryllidae Tetrigidae	Grasshopper (MacLeay, W.S. (1821) Cricket (Laicharting, J.N.E. (1781)) Groundhopper	Herbivorous Omnivorous Herbivorous
3	Coleoptera	Chrysomelidae Tenebrionidae	Leaf beetle Darkling beetle	Herbivorous Omnivorous
4	Blattodea	Blattellidae	Cockroach	Scavengers
5	Hemiptera	Cercopidae	Froghopper	Herbivorous
6	Aranea	Salticidae	Jumping spider	Predators

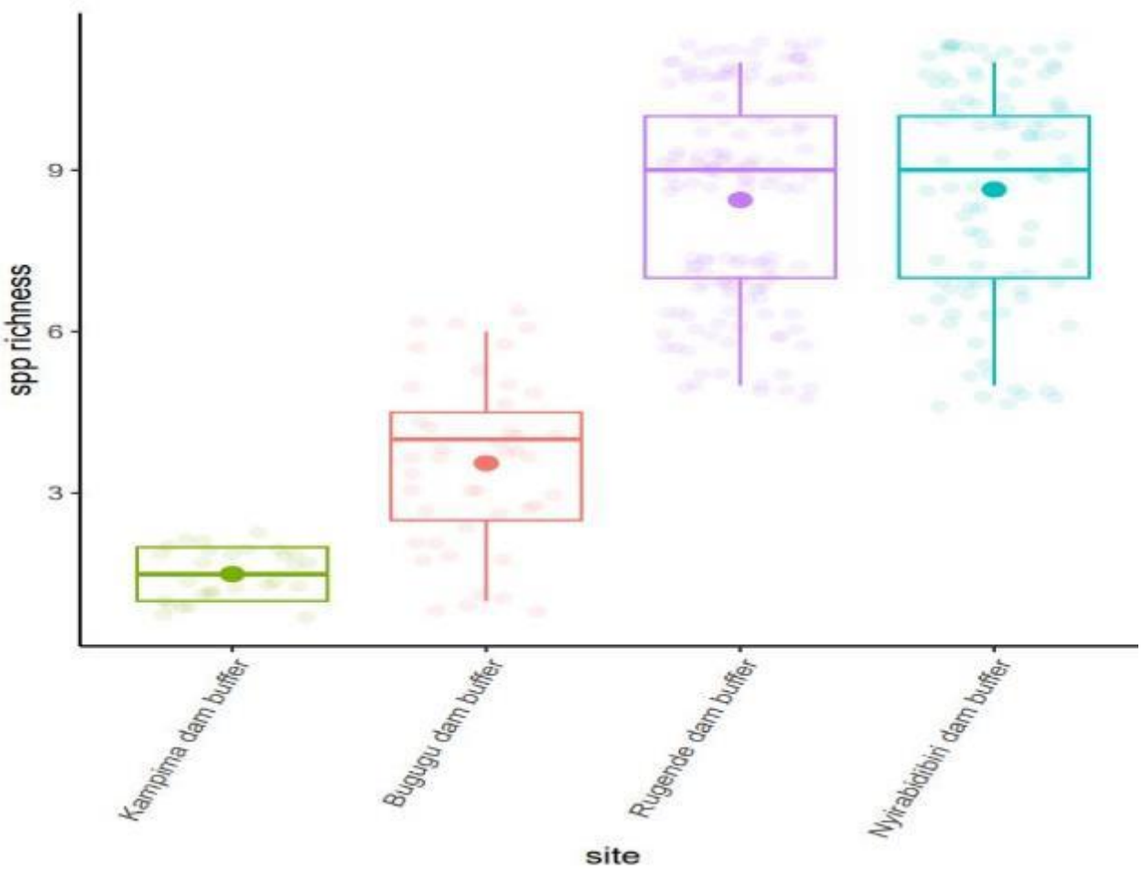

Figure 26. Terrestrial arthropods richness distribution across the four Dam Buffers. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represents the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to sampling stations at sampling sites.

Birds

The bird survey in dam buffers of Bugugu, Nyirabidibiri, Rugende, and Kampima identified a total of 90 bird species, representing 36 families (Figure 27). We observed 5 migratory species across

all dam buffers. Eight functional groups were identified including Granivorous (seed-eating), Omnivorous (eating both plant and animal matter), Nectivorous (nectar-feeding), Insectivorous (insect-eating), Frugivorous (fruit-eating), Herbivorous (plant-feeding), Piscivorous (fish-feeding), and Carnivorous (meat-feeding) species. Among these groups, the most common were Granivorous and Insectivorous.

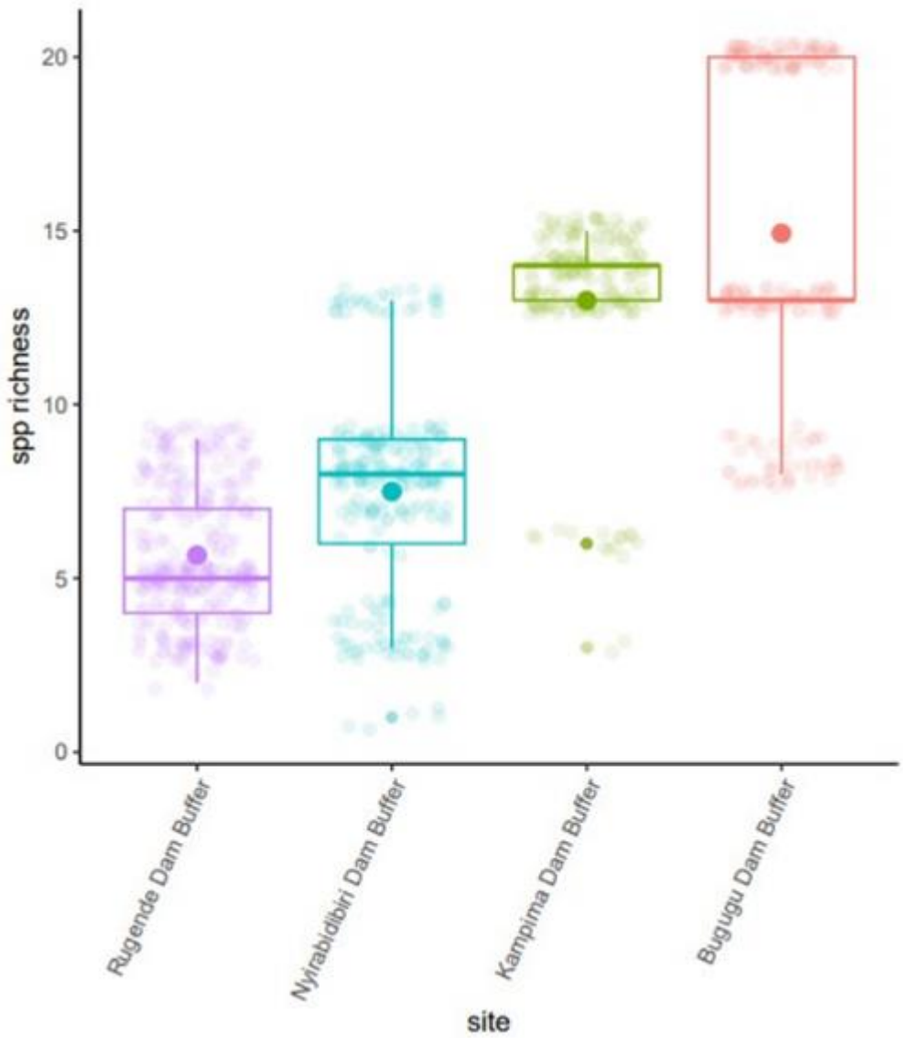

Figure 27. Bird species richness by site. Figures compare species richness between four selected Dam Buffers. Boxes represent the inter-quartile range (IQR), and lines in the center represent the median. Whiskers correspond to the largest/smallest value less/greater than the upper/lower quartile minus 1.5 times IQR. Points correspond to sampling units of point counts.

Mammals

Only a jackal *Canis adustus* was recorded at Rugende dam buffer in Rwamagana district through observation of footprints.

Threats

The relative frequency of threats in each of the dam buffers was: Kampima dam buffer (46.7%), Rugende dam buffer (20.9%), Bugugu dam buffer (17.91%) and Nyirabidibiri dam buffer (14.93%) (Figure 28). No significant difference in the frequency of threats was found between the dam sites (Figure 29). Plastic waste was the most dominant at surveyed dam buffers except for Nyirabidibiri dam buffer.

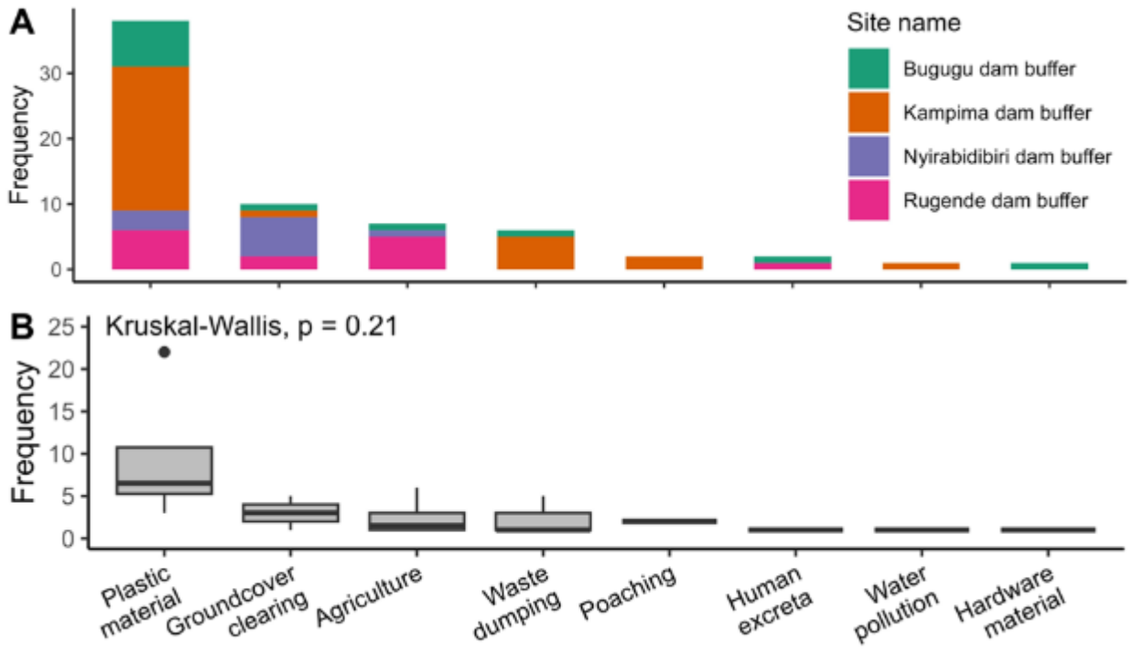

Figure 28. Frequency of threats and disturbances in dam buffers, with A showing total abundance and B showing frequency by site summarized with box plots with the median value; the difference between sites was not significant (Kruskal-Wallis test, p = 0.21).

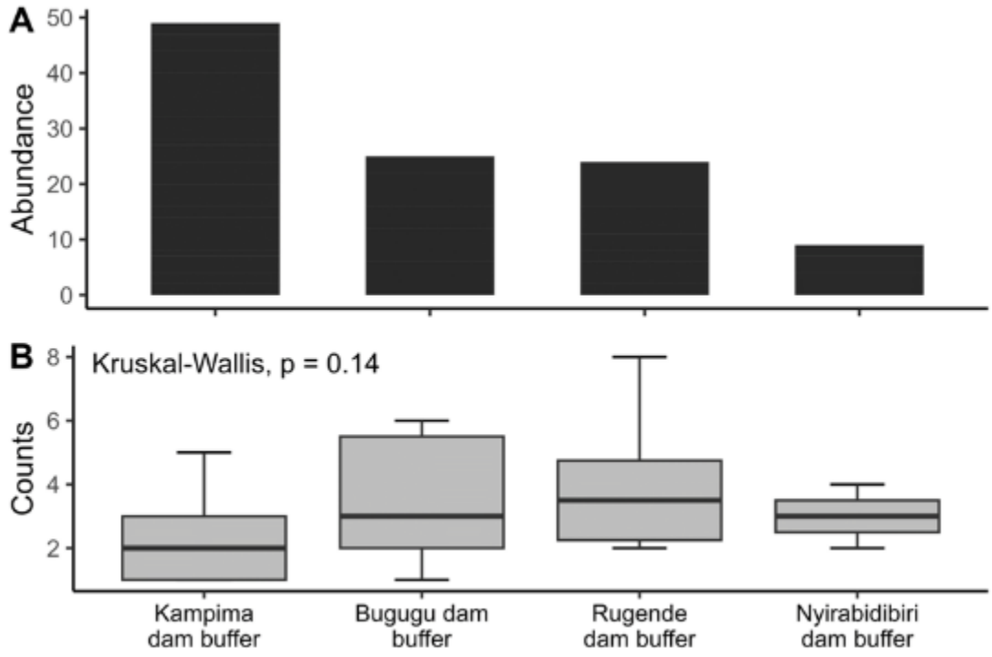

Figure 29. Comparative abundance of plastics in different dam buffers with A showing total abundance by site and B denoting the frequency per site summarized in box plots.

4. Lake Buffer

There were two lake buffers sampled in this study, Muhazi Lake and Cyambwe Lake buffers. Figure 30 shows the maps of each site. Following are the details of the biodiversity and threats found at these lake buffer sites.

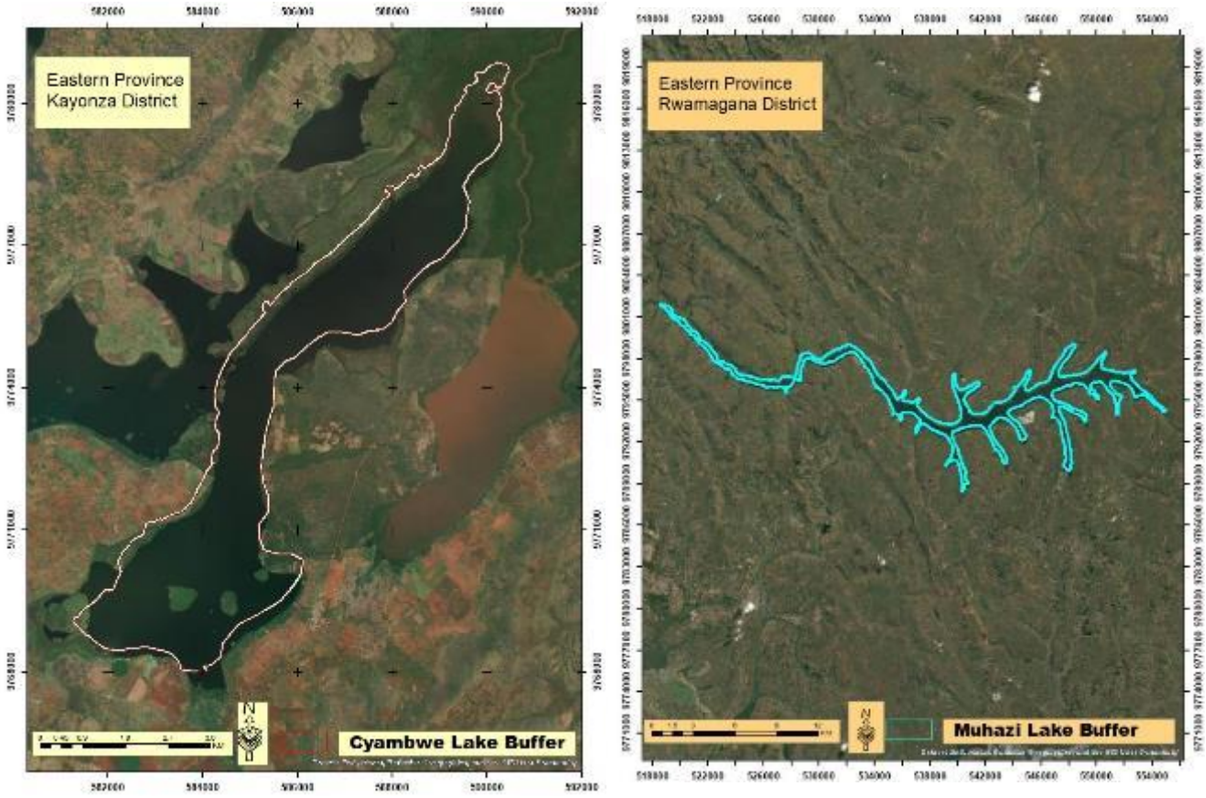

Figure 30. The two lake buffers sampled in the Eastern Province, Rwanda

Plants

Our survey of two lake areas, Muhazi Lake and Cyambwe Lake in the Eastern Province, showed that there is a diverse range of plant species. We found 58 species belonging to 27 families (Table 12). The Fabaceae family was the most common, representing 13.79% of the total species, followed by Asteraceae at 10.34%, Malvaceae and Solanaceae each at 5.17%. Most of the plants we found (67.23%) are native to Rwanda and the region, while the rest (32.75%) were introduced. About 31.03% of the plants, we found are listed as least concern according to the IUCN Red List. However, nearly 68.95% of the plants have not yet been evaluated, so their conservation status is unknown. These findings highlight the importance of protecting these lake areas to preserve their biodiversity and role in climate adaptation.

Table 12. Families and species of plants found in Muhazi Lake and Cyambwe Lake buffers, Eastern Province, Rwanda

ID	Family	Scientific name	IUCN status	Native or introduced	Life form
1	Acanthaceae	*Acanthus polystachyus*	NE	Native	shrub
		Dicliptera colorata	NE	Native	herb
		Asystasia gangetica	NE	Introduced	herb
		Thunbergia alata	NE	Native	herb
2	Amaranthaceae	*Achyranthes aspera*	NE	Native	shrub
3	Apiaceae	*Centella asiatica*	LC	Native	herb
4	Araliaceae	*Hydrocotyle mannii*	LC	Native	herb
5	Asparagaceae	*Asparagus africanus*	NE	Native	shrub
6	Asteraceae	*Ageratum conyzoides*	NE	Introduced	herb
		Bidens pilosa	NE	Introduced	herb
		Gymnanthemum amygdalinum	NE	Native	tree or shrub
		Lipotriche scandens	NE	Native	herb
		Melanoseris atropurpurea	NE	Introduced	herb
		Microglossa densiflora	NE	Native	shrub

7	Commelinaceae	*Commelina africana*	LC	Native	herb
		Commelina longifolia	NE	Introduced	herb
8	Convolvulaceae	*Dichondra micrantha*	LC	Introduced	herb
		Ipomoea pileata	NE	Native	herb
9	Cucurbitaceae	*Momordica foetida*	NE	Native	shrub
10	Cyperaceae	*indet.*	NE	N/A	N/A
11	Dimi	*Dichondra repens*	NE	Introduced	herb
12	Euphorbiaceae	*Acalypha volkensii*	NE	Native	shrub
		Tragia brevipes	NE	Native	herb
		Euphorbia tirucalli	LC	Introduced	tree or shrub
		Ricinus communis	NE	Native	shrub
13	Fabaceae	*Albizia adianthifolia*	LC	Native	Tree
		Crotalaria spinosa	LC	Native	herb
		Indigofera brevicalyx	NE	Native	shrub
		Mimosa pigra	LC	Introduced	shrub
		Phaseolus vulgaris	LC	Introduced	herb
		Senna spectabilis	LC	Introduced	Tree or shrub
		Vachellia sieberiana	LC	Native	tree
		Vigna parkeri	LC	Native	herb
		Senegalia polyacantha	NE	Native	tree
14	Conyza	*Conyza pallidiflora*	NE	Native	herb
15	Lamiaceae	*Clerodendrum johnstonii*	LC	Native	shrub
		Coleus melleri	NE	Native	shrub
		Ocimum lamiifolium	NE	Native	shrub
16	Malvaceae	*Pavonia urens var. irakuensis*	NE	Native	shrub
		Sida rhombifolia	NE	Native	shrub
		Sida rhombifolia subsp. rhombifolia	NE	Native	shrub
		Triumfetta rotundifolia	NE	Native	shrub
17	Moringaceae	*Moringa oleifera*	LC	Introduced	tree
18	Myrtaceae	*Eugenia uniflora*	LC	Introduced	shrub
19	Oleaceae	*Jasminum schimperi*	NE	Native	shrub
20	Oxalidaceae	*Oxalis latifolia*	NE	Introduced	shrub
		Oxalis obliquifolia	NE	Native	herb
21	Phyllanthaceae	*Flueggea virosa*	LC	Native	Tree or shrub
		Phyllanthus fischeri	NE	Native	shrub
22	Phytolaccaceae	*Phytolacca dodecandra*	NE	Native	shrub
23	Poaceae	*indet.*	NE	N/A	grass
24	Proteaceae	*Grevillea robusta*	LC	Introduced	tree
25	Solanaceae	*Solanum nigriviolaceum*	LC	Introduced	shrub
		Solanum nigrum	NE	Native	herb
		Solanum tuberosum	NE	Introduced	herb
26	Verbenaceae	*Lantana camara*	NE	Introduced	shrub
		Lantana trifolia	NE	Introduced	shrub
27	Vitaceae	*Cyphostemma maranguense*	NE	Native	herb

Herpetofauna: Amphibians and Reptiles

Two families of amphibians and three of reptiles were recorded between the two surveyed lake buffers: Muhazi and Cyambwe Lake buffer (Table 13). For amphibians, Hyperoliidae had two species recorded while remaining families both amphibian and reptiles, recorded one species each. All observed species are listed as Least Concerned except those not evaluated.

Table 13. Amphibians and reptiles recorded from surveyed lake buffers. For each species, the IUCN Red List category both global and national status are provided.

	Family	**Scientific name**	**Common name**	**Global IUCN status**	**National IUCN status**
AMPHIBIANS					
1	Hyperoliidae	*Hyperolius kivuensis Ahl, 1931*	Kivu Reed Frog	LC	LC
		Hyperolius viridiflavus (Duméril & Bibron, 1841)	Common Reed Frog	LC	LC
2	Phrynobatra-chidae	*Phrynobatrachus sp.*	-	-	-
3	Ptychadenidae	*Ptychadena nilotica (Seetzen, 1855)*	Nile grass frog	LC	LC
REPTILES					
1	Scincidae	*Trachylepis striata (Peters, 1844)*	African Striped Mabuya	LC	ND
2	Gekkonidae	*Hemidactylus mabouia (Moreau De Jonnès, 1818)*	Afro-American House Gecko	LC	ND
3	Colubridae	*Grayia tholloni Mocquard, 1897*	Tholloni's African Water Snake	LC	ND

Among the surveyed lake buffers, both Muhazi and Cyambwe buffers had similar species richness (n=3) and for reptiles Cyambwe Lake recorded the highest richness (n=3). Among these species, it was observed that *Ptychadena nilotica* was most common followed by *Hyperolius viridiflavus* as they were recorded from both lake buffers. For reptiles, *Trachylepis striata* and *Hemidactylus mabouia* were recorded in both lake buffers (Figure 31). Among the abundant species, *Ptychadena nilotica* and *Phrynobatrachus sp* were observed among amphibian species and *Trachylepis striata* was the most abundant reptile species at both lake buffers.

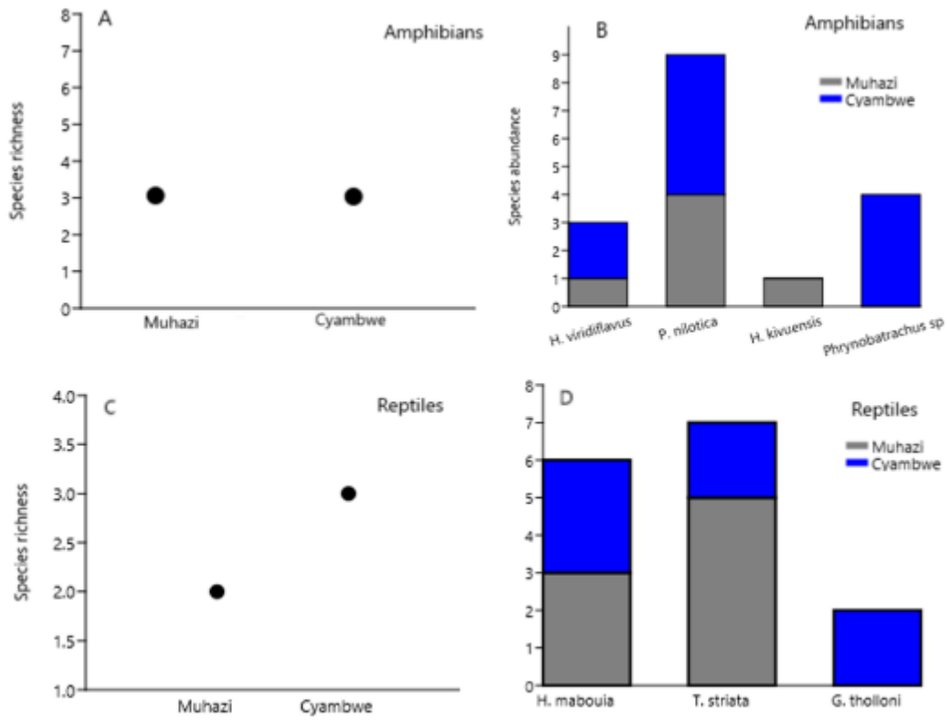

Figure 31. Amphibian and reptile species richness (A, C), and species occurrence and abundance (B, D) per lake buffer sampled in Eastern Province, Rwanda. The dots represent the number of species per sampled site. The colored bars represent the abundance data of the species per site.

Flying insects

A total of 22 butterfly species were recorded across lake buffer site types. We separated the Muhazi lake buffer into three sections when presenting the data. Their diversity and distribution across these different lake buffers in order from highest to lowest is Cyambwe Lake Buffer (n=13), Muhazi Lake Buffer1 (n=8), Muhazi Lake Buffer2 (n=3), and Muhazi Lake Buffer3 (n=13). Species richness at each lake buffer is shown in Figure 32 and more information about the species names and their IUCN Red List information are found in Annex 3.

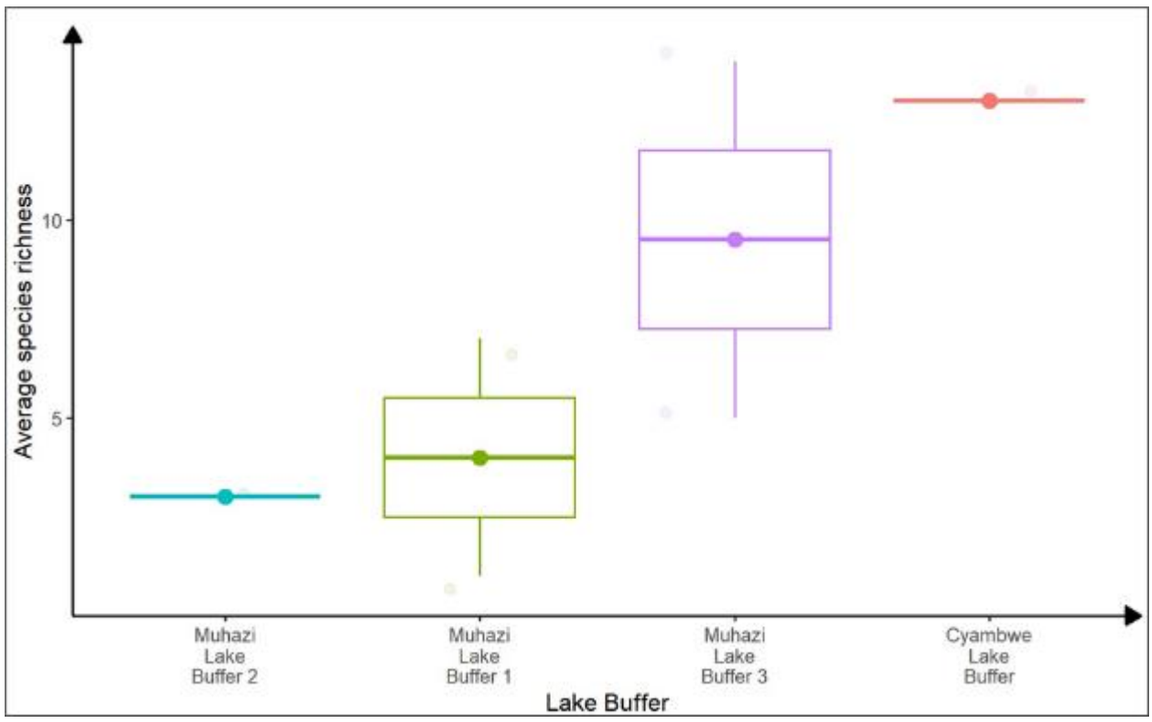

Figure 32. Butterfly richness distribution across the four lake buffers. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represent the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR.

The butterflies are from five families: Nymphalidae, Pieridae, Lycaenidae, Hesperiidae and Papilionidae. Four butterfly families were recorded from Cyambwe Lake Buffer Buffer; Lycaenidae (9.09%), Nymphalidae (45.45%), and Pieridae (45.45%%) were recorded from Muhazi Lake Buffer 1; Nymphalidae family (100%) were recorded from Muhazi Lake Buffer 2; Hesperiidae (11.63%), Nymphalidae (34.88%), Papilionidae (2.33%) and Pieridae (51.16%) were recorded from Muhazi Lake Buffer 1.

Looking on both butterfly diversity and abundance, the highest butterfly species richness was recorded from Muhazi Lake Buffer 1, followed by Muhazi Lake Buffer 3, Cyambwe Lake Buffer and the less richness was recorded from Muhazi Lake buffer 2 (Figure 33A). For all sites, the sampling effort did not reach the maximum level as the sample coverage is between 0 (minimum) and 1 (maximum) (Figure 33B).

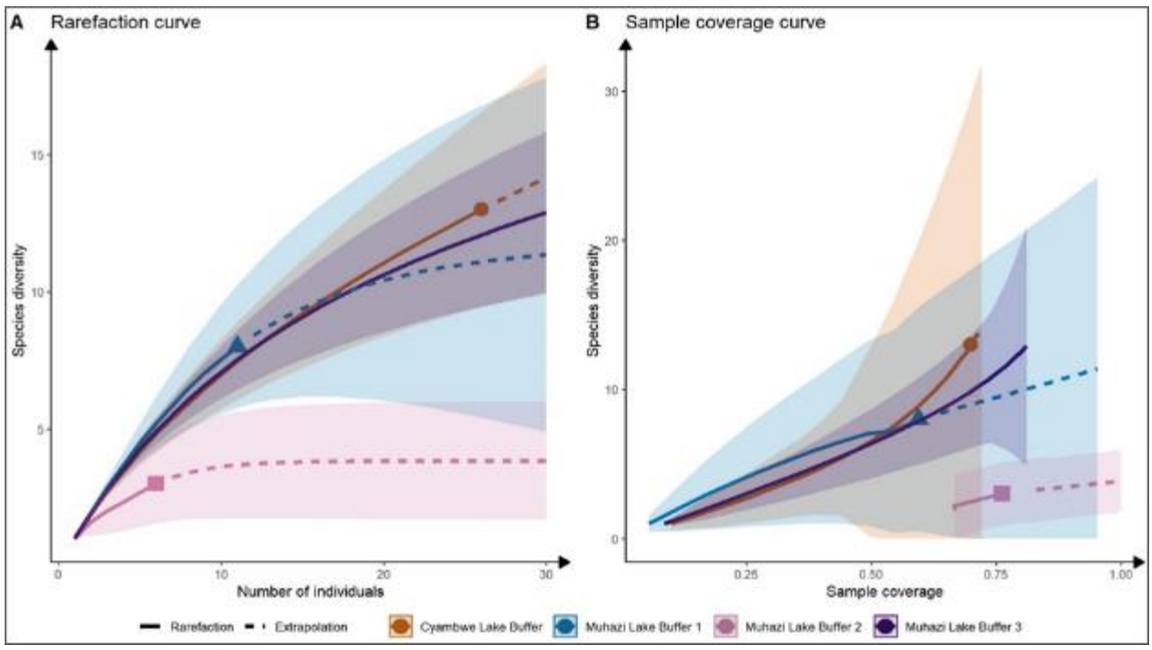

Figure 33. Butterfly rarefaction and extrapolation curves (A) and sample coverage curves using butterfly richness (Hill numbers of order 0) across four lake buffers. Solid lines represent the curves based on sample data, and the dashed lines represent the extrapolations. Shaded areas represent the 95% confidence intervals surrounding the curves.

A total of 13 pollinating insects were recorded from the four lake buffers. These species include managed bees (*Apis mellifera*), wild bees (*Augochlora pura*, *Amegilla* sp and *Lasioglossum* sp), flies (*Eristalinus* sp, *Eristalis* sp, *Asarkina* sp), butterflies (*Catopsilia florella*, *Hypolimnas missipus*, *Ypthima aesterope*, *Danaus chrysippus* and *Mylothris agathina*) and *Cephonodes hylas* from Sphingidae family. We observed *Lantana camara* to be the most visited species by pollinators (Figure 34) followed by *Maytenus senegalensis* whereas the most abundant pollinator was bees (*Apis mellifera*) followed by stingless bee (*Lasioglossum* sp) (Figure 34).

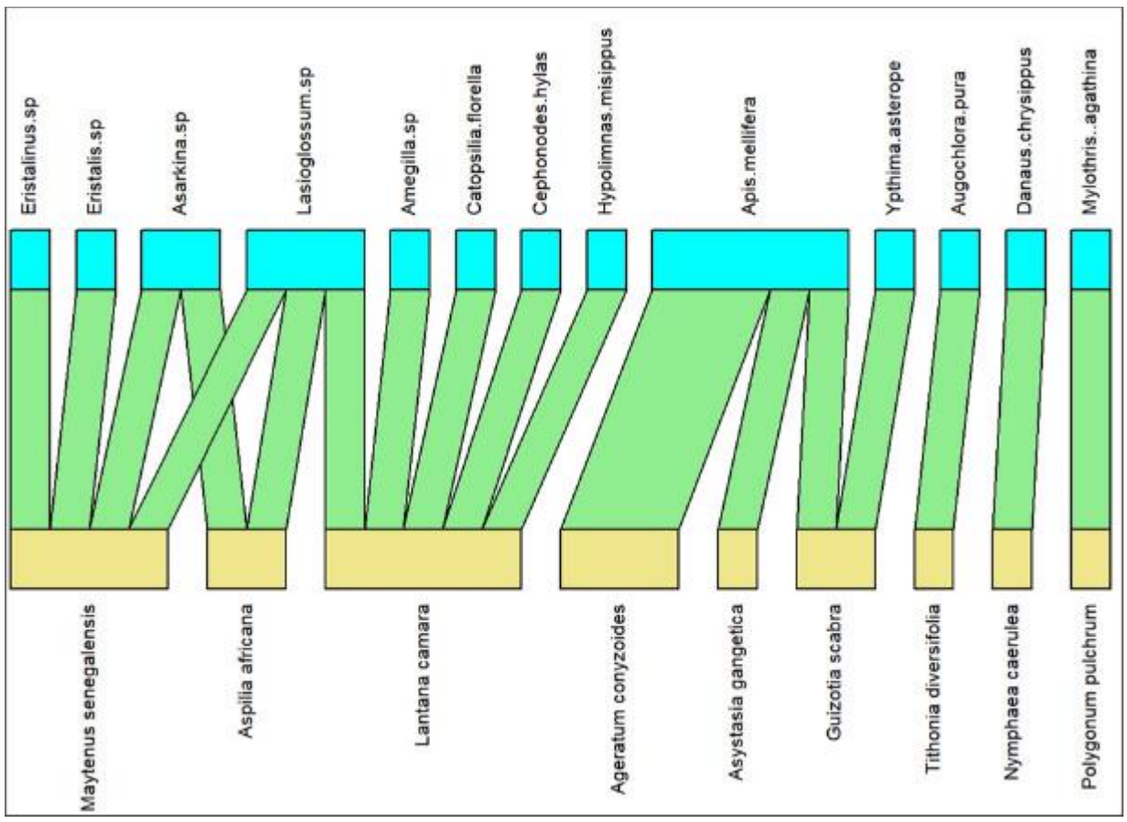

Figure 34. Network structure of plants and their pollinating insects recorded at lake buffers. The upper band in dark turquoise color represents the flower visitors while the lower band in yellow color represents plant diversity (host plants). The vertical lines in the middle of the figure (in green color) represent the linkage (which plant was visited by which insect) between plants and their pollinating insects.

Terrestrial Arthropods

The terrestrial arthropods survey at the lake buffers found 43 families. We separated the Muhazi lake buffer into three sections when presenting the data. The most dominant families are: Formicidae at 29 %, Chrysomelidae at 12%, Salticidae at 8%, and Cercopidae at 6% (Table 14). All recorded families are not yet evaluated on the IUCN Red List. Cyambwe had the highest species richness (Figure 35).

Table 14. The most common terrestrial arthropod families recorded in the lake buffers

	Order	**Family**	**Common name**	**Functional group**
1	Hymenoptera	Formicidae	Ants	Omnivorous
2	Coleoptera	Chrysomelidae Staphylinidae	Leaf beetle Rove beetle	Herbivorous
3	Orthoptera	Acrididae Gryllidae Tetrigidae	Grasshopper (MacLeay, W.S. (1821) Cricket (Laicharting, J.N.E. (1781)) Groundhopper	Herbivorous Omnivorous Herbivorous
4	Aranea	Salticidae	Jumping spider	Predators
5	Hemiptera	Cercopidae	Froghopper	herbivorous

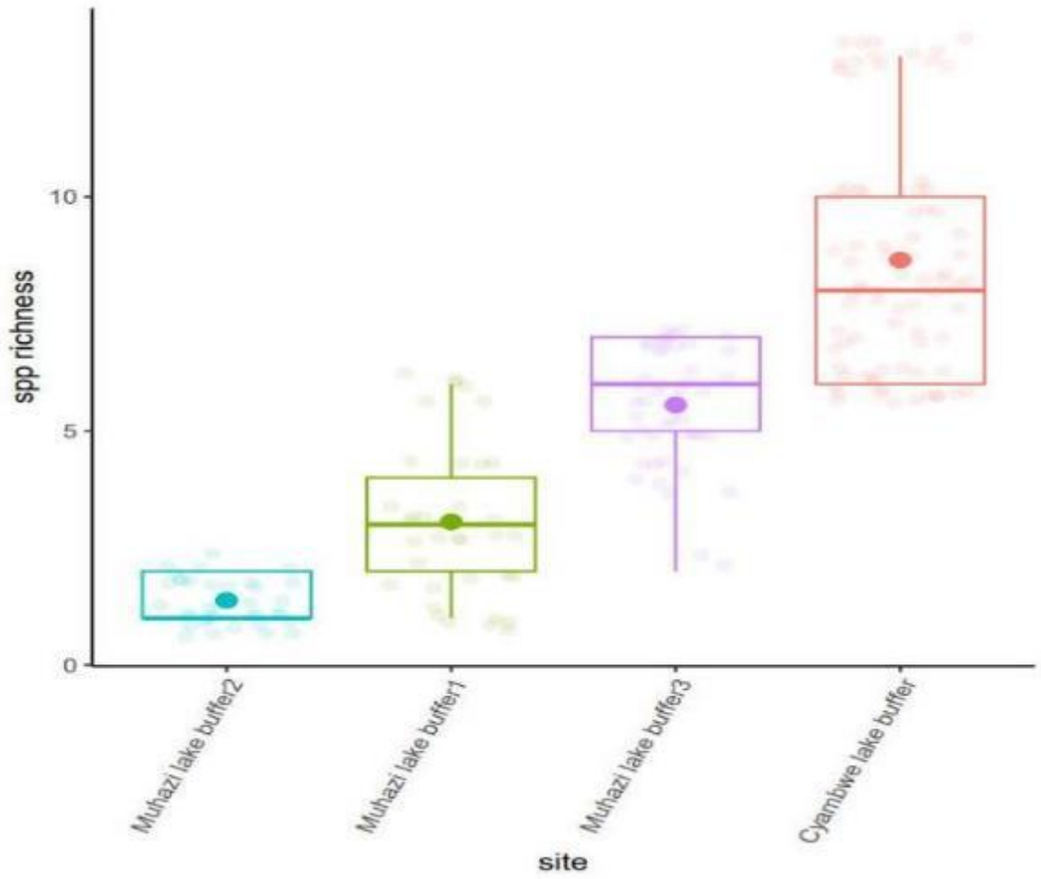

Figure 35. Terrestrial arthropod species richness distribution across the four lake buffers. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represents the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to sampling stations on sampling sites.

Birds

The bird surveys carried out in the two lake buffers found 76 bird species belonging to 40 families. Lake Muhazi buffer was higher in species richness than the other site (Figure 36). Finding the Gray-crowned Crane (*Balearica regulorum*), an endangered bird according to the IUCN Red List, in Cyambwe Lake Buffer was one of the survey's highlights. In addition, we were able to observe and identify seven migratory species in each of the lake buffers. Our study also identified eight functional groups among the observed bird species, including Granivorous (seed-eating), Omnivorous (eating both plant and animal matter), Nectivorous (nectar-feeding), Insectivorous (insect-eating), Frugivorous (fruit-eating), Herbivorous (plant-feeding), Piscivorous (fish-feeding), and Carnivorous (meat-feeding) species. It is noteworthy that the most common functional groups observed were Insectivorous and Omnivorous species.

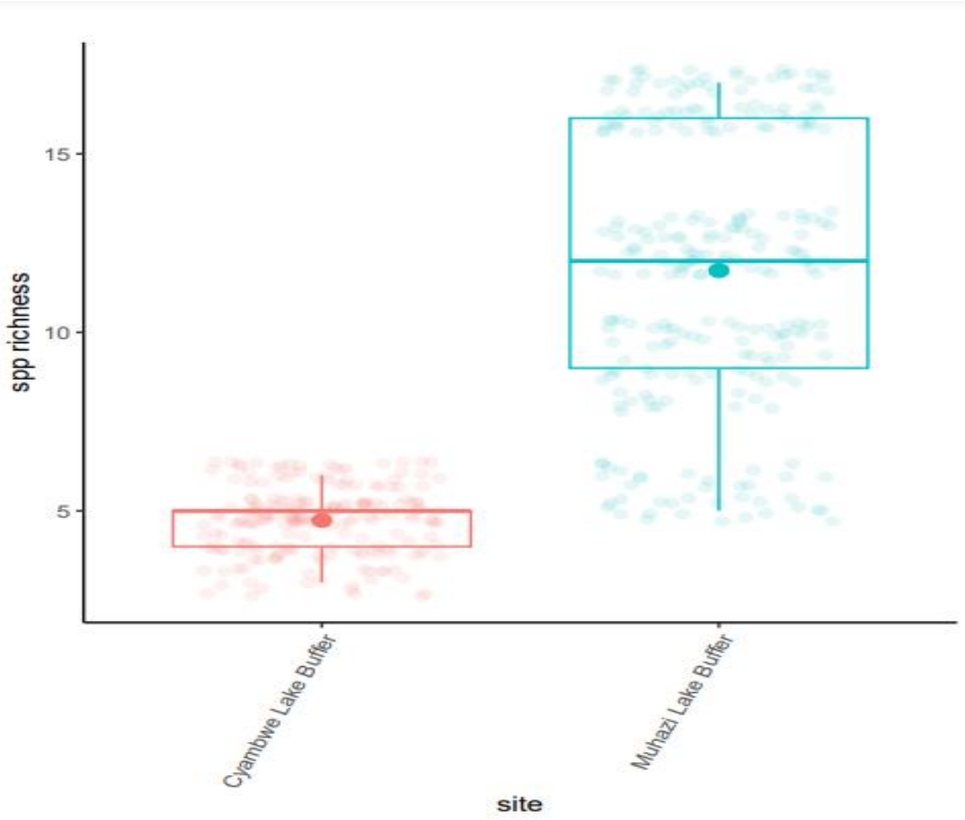

Figure 36. Figure compares species richness between two selected Lake Buffer sites in Eastern Province. Boxes represent the inter-quartile range (IQR), and lines in the center represent the median. Whiskers correspond to the largest/smallest value less/greater than the upper/lower quartile minus 1.5 times IQR. Points correspond to sampling units of point counts.

Mammals

The hippopotamus was the only mammal recorded at Cymbwe Lake Buffer in Kirehe through observation of footprints, with some occurrence near banana plantations.

Threats

We separated the Muhazi lake buffer into three sections when presenting the data. The relative frequency of threats in lake buffers from highest to lowest is: Muhazi lake buffer 3 (38.1%), Muhazi lake buffer 1 (28.57%), Muhazi lake buffer 2 (26.19%) and Cyambwe lake buffer (7.14%) (Figure 37). Plastic materials were the most dominant threat in all lake buffers (Figure 37). There was a marginally significant difference in frequency of threats among the sites (p=.058; Figure 38B).

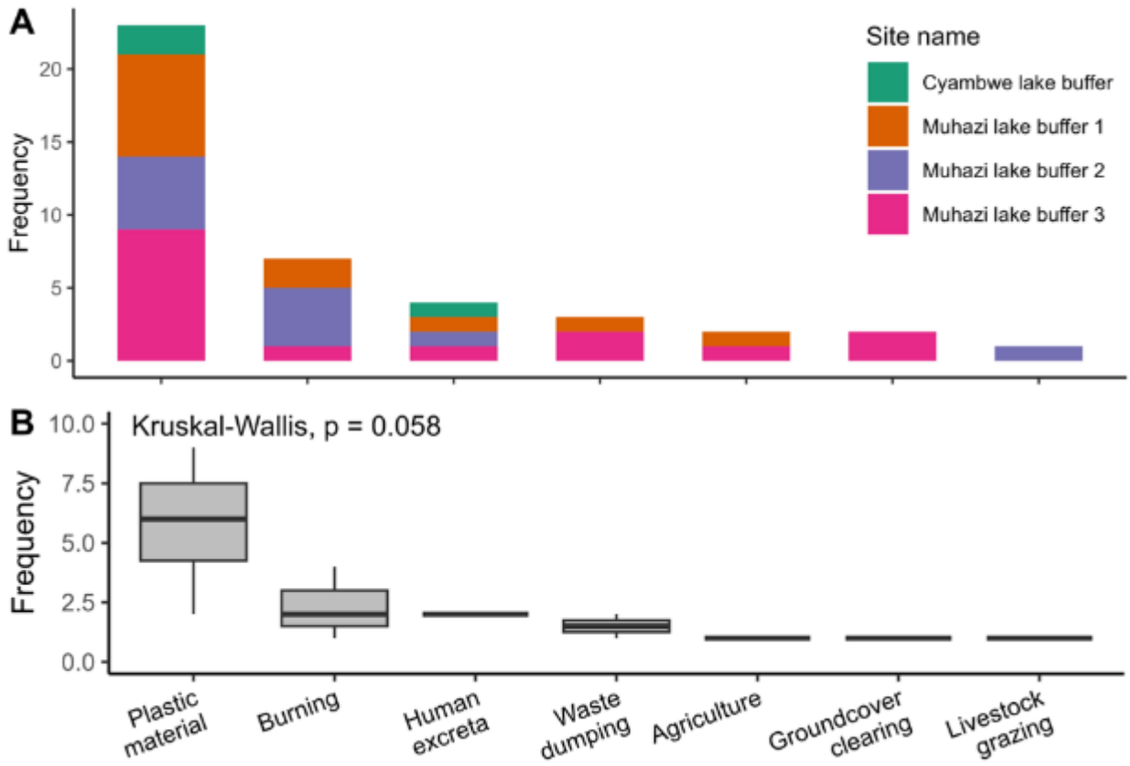

Figure 37. Frequency of threats and disturbances in lake buffers, with A showing total abundance and B showing frequency by site summarized with box plots with the median value; the difference between sites was not significant (Kruskal-Wallis test, p = 0.058).

In a comparison of frequency of plastic waste across the lake buffer sites, Muhazi Lake Buffer 1 had the highest frequency and this was statistically significant (p= 0.049; Figure X).

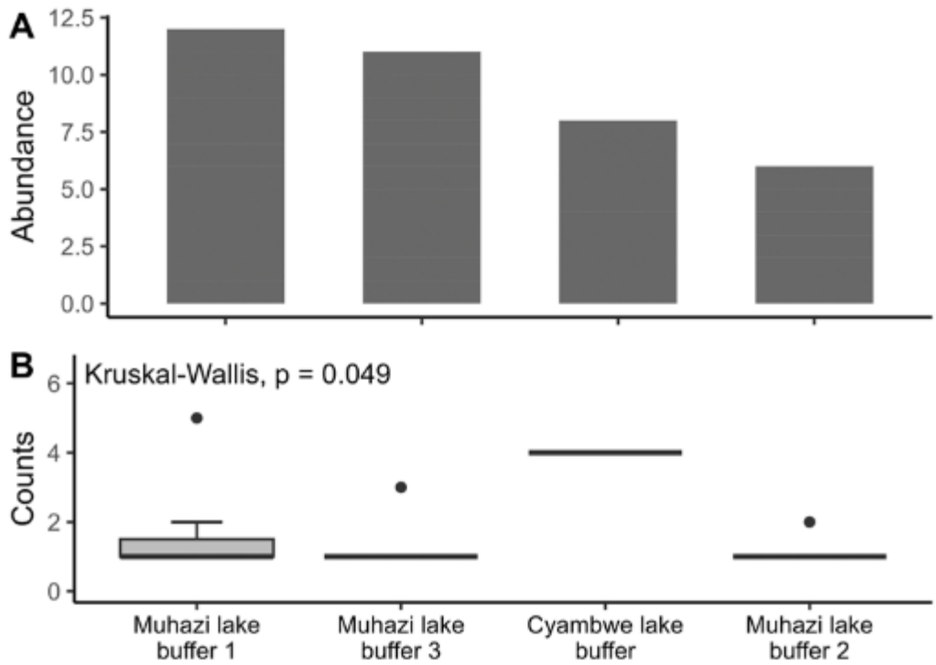

Figure 38. Comparative abundance of plastics in different lake buffers with A showing total abundance by site and B denoting the frequency per site summarized in box plots with the median value.

5. Community Biodiversity Sanctuaries (CBS)

There were seven community biodiversity sanctuaries or CBSs sampled in this study: Nyamata, Karushuga, Rusumo, Muhazi, Zaza, Ryarubamba and Gahini. Maps for each sanctuary are presented in Figure 39, and details of the findings from sampling of each taxon group and threat assessment are presented below.

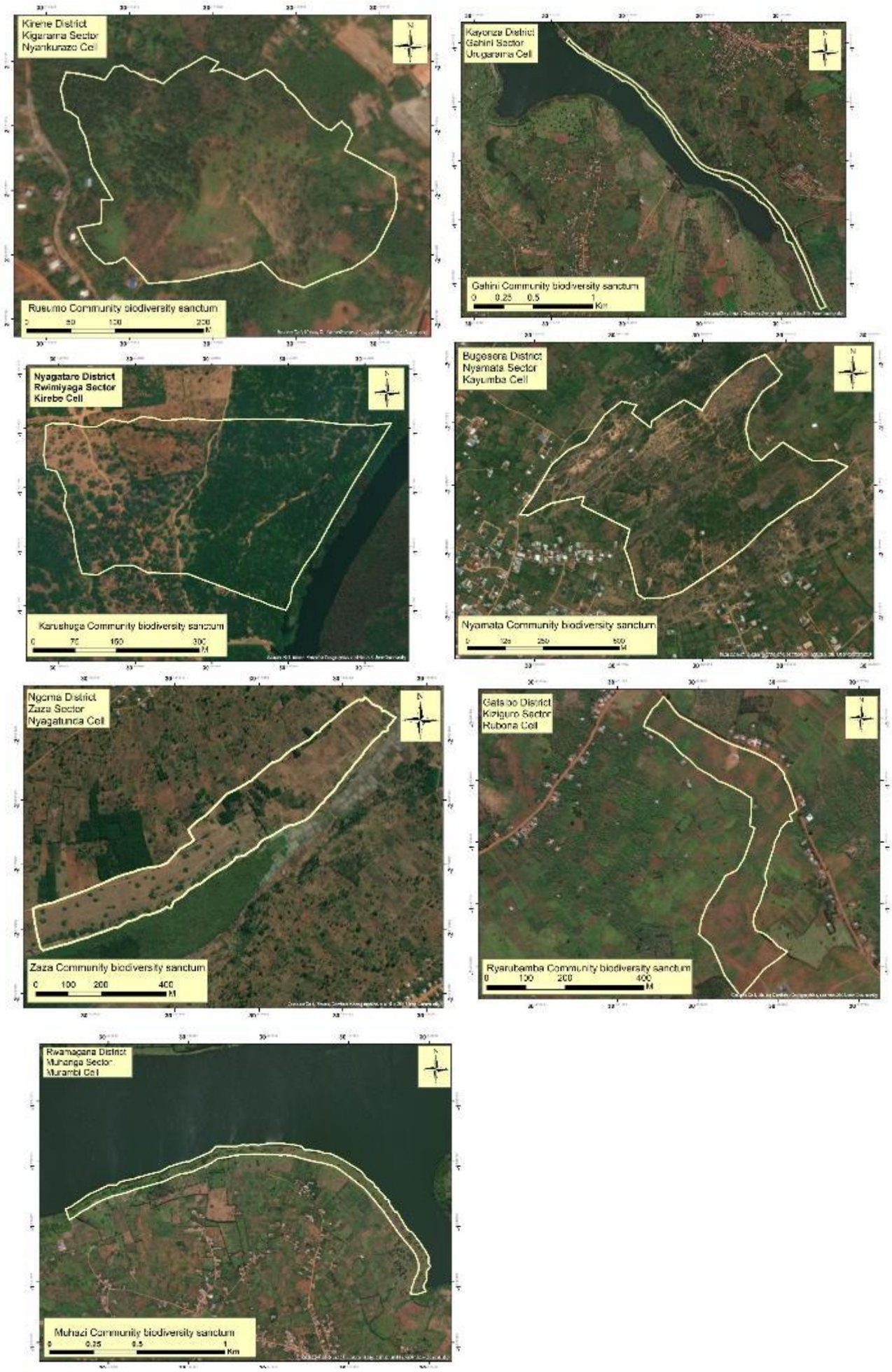

Figure 39. The seven community biodiversity sanctuaries sampled in the Eastern Province, Rwanda

Plants

The survey of seven Community Based Sanctuaries across the Eastern Province, including Nyamata, Karushuga, Rusumo, Muhazi, Zaza, Ryarubamba and Gahini CBSs, found 133 plant species across 41 families (Table 15). The Fabaceae family is the most dominant, with a species richness of 13.71%, followed by the Malvaceae family at 9.02%, with Asteraceae and Rubiaceae families following at 8.27% and 6.01%, respectively. Almost 56% of the recorded species are indigenous to Rwanda and the region, while 37.6% are introduced species. Our findings indicate that 42.85% of the recorded species are classified as "Least Concern" on the IUCN Red List, with 2.25% categorized as Data Deficient, and 1.5% identified as Vulnerable. A large number, 53.38% of the species found at these sites, remain unevaluated on the IUCN Red List, underscoring the need for continued monitoring and conservation efforts to safeguard the biodiversity of these sanctuaries.

Table 15. Families and species of plants found in the seven Community Biodiversity Sanctuaries sampled in the Eastern Province, Rwanda

ID	Family	Scientific Name	IUCN status	National status	Native or introduced	Life form
Nyamata Community Based Sanctuary						
1	Combretaceae	*Combretum molle*	LC	NA	Native	tree
2	Fabaceae	*Albizia adianthifolia*	LC	NA	Native	tree
		Senegalia polyacantha	NA	NA	Native	tree
3	Myrtaceae	*Eucalyptus saligna*	LC	NA	Introduced	tree
4	Phyllanthaceae	*Phyllanthus fischeri*	NA	NA	Native	shrub
5	Rubiaceae	*Afrocanthium lactescens*	LC	EN	Native	tree
Gahini Community Based Sanctuary						
1	Acanthaceae	*Dicliptera colorata*	NA	NA	Native	herb
		Asystasia angetica	NA	NA	Introduced	herb
2	Apiaceae	*Centella asiatica*	LC	NA	Native	herb
3	Asteraceae	*Bidens pilosa*	NA	NA	Introduced	herb
4	Bignoniaceae	*Markhamia lutea*	LC	NA	Native	tree
		Jacaranda mimosifolia	VU	NA	Introduced	tree
5	Casuarinaceae	*Casuarina glauca*	LC	NA	Introduced	tree
6	Commelinaceae	*Commelina africana*	LC	NA	Native	herb
		Commelina longifolia	NA	NA	Introduced	herb
7	Convolvulaceae	*Dichondra micrantha*	LC	NA	Introduced	herb
8	Euphorbiaceae	*Tragia brevipes*	NA	NA	Native	shrub
9	Fabaceae	*Erythrina abyssinica*	LC	NA	Native	tree
		Senegalia polyacantha	NA	NA	Native	tree
		Senegalia occidentalis	NA	NA	Introduced	tree
		Senna occidentalis	LC	NA	Introduced	tree
		Senna spectabilis	LC	NA	Introduced	Tree or shrub
10	Lauraceae	*Persea americana*	LC	NA	Introduced	tree
11	Malvaceae	*Sida rhombifolia*	NA	NA	Native	shrub
12	Meliaceae	*Toona sinensis*	LC	NA	Introduced	tree
13	Moraceae	*Morus alba*	LC	NA	Introduced	tree

		Ficus thonningii	LC	NA	Native	tree
14	Myrtaceae	*Psidium guajava*	LC	NA	Introduced	tree
		Eucalyptus saligna	LC	NA	Introduced	tree
15	Oxalidaceae	*Oxalis obliquifolia*	NA	NA	Native	herb
		Oxalis latifolia	NA	NA	Introduced	shrub
		Oxalis corniculata	NA	NA	Introduced	herb
16	Phyllanthaceae	*Phyllanthus fischeri*	NA	NA	Native	tree
17	Primulaceae	*Maesa lanceolata*	LC	NA	Native	tree
18	Proteaceae	*Grevillea robusta*	LC	NA	Introduced	tree
19	Rutaceae	*Clausena anisata*	LC	NA	Native	tree
20	Verbenaceae	*Lantana camara*	NA	NA	Introduced	shrub
Karushuga Community Based Sanctuary						
1	Fabaceae	*Millettia dura*	NA	NA	Native	tree
2	Phyllanthaceae	*Phyllanthus fischeri*	NA	NA	Native	tree
3	Rubiaceae	*Afrocanthium lactescens*	LC	EN	Native	tree
		Psydrax schimperiana	NA	NA	N/A	tree
		Rytigynia kigeziensis	LC	NA	Native	tree
4	Rutaceae	*Teclea nobilis*	LC	NA	Native	tree
5	Sapindaceae	*Haplocoelum foliolosum subsp. strongylocarpum*	NA	NA	Native	tree
Rusumo Community Based Sanctuary						
1	Anacardiaceae	*Mangifera indica*	DD	NA	Introduced	tree
2	Fabaceae	*Senegalia polyacantha*	NA	NA	Native	tree
		Vachellia sieberiana	LC	NA	Native	tree
		Albizia adianthifolia	LC	NA	Native	tree
3	Myrtaceae	*Eucalyptus saligna*	LC	NA	Introduced	tree
		Psidium guajava	LC	NA	Introduced	tree
4	Stilbaceae	*Nuxia floribunda*	LC	NA	Native	tree
Muhazi Community Based Sanctuary						
1	Acanthaceae	*Asystasia gangetica*	NA	NA	Introduced	herb
		Justicia sp.	NA	NA	NA	herb
2	Apiaceae	*Centella asiatica*	LC	NA	Native	herb
3	Asteraceae	*Vernonia sp.*	NA	NA	NA	shrub
		Aspilia africana	NA	NA	Native	herb
		Tagetes minuta	NA	NA	Introduced	herb
		Bidens pilosa	NA	NA	Introduced	herb
		Galinsoga parviflora	NA	NA	Introduced	herb
		Bothriocline longipes	NA	NA	Native	shrub
4	Celastraceae	*Gymnosporia heterophylla*	LC	NA	Introduced	shrub
5	Commelinaceae	*Commelina longifolia*	NA	NA	Introduced	herb
		Commelina africana	LC	NA	Native	herb
6	Convolvulaceae	*Dichondra micrantha*	LC	NA	Introduced	herb
		Ipomoea cairica	LC	NA	Native	herb

7	Fabaceae	*Indigofera pretoriana*	NA	NA	Introduced	shrub
		Crotalaria spinosa	NA	NA	Native	herb
		Crotalaria retusa	NA	NA	Introduced	herb
		Vachellia sieberiana	LC	NA	Native	Tree
8	Lamiaceae	*Ocimum gratissimum subsp. gratissimum*	NA	NA	Native	shrub
		Clerodendrum johnstonii	LC	NA	Native	shrub
9	Malvaceae	*Sida tenuicarpa*	NA	NA	Native	shrub
		Triumfetta rotundifolia	NA	NA	Native	shrub
		Sida rhombifolia	NA	NA	Native	shrub
10	Oxalidaceae	*Oxalis corniculata*	NA	NA	Introduced	herb
11	Phyllanthaceae	*Phyllanthus fischeri*	NA	NA	Native	shrub
12	Rubiaceae	*Tarenna pavettoides*	LC	NA	Native	shrub
13	Solanaceae	*Solanum incanum*	LC	NA	NA	shrub
14	Verbenaceae	*Lantana camara*	NA	NA	Introduced	shrub
Zaza Community Based Sanctuary						
1	Acanthaceae	*Acanthus polystachyus*	NA	NA	Native	Shrub
		Dicliptera colorata	NA	NA	Native	herb
2	Apiaceae	*Centella asiatica*	LC	NA	Native	herb
3	Araceae	*Colocasia esculenta*	LC	NA	Introduced	NA
4	Asteraceae	*Galinsoga parviflora*	NA	NA	Introduced	herb
		Tagetes minuta	NA	NA	Introduced	herb
		Bidens pilosa	NA	NA	Introduced	herb
		Tithonia diversifolia	NA	NA	Introduced	shrub
5	Commelinaceae	*Commelina longifolia*	NA	NA	Introduced	herb
6	Convolvulaceae	*Dichondra micrantha*	LC	NA	Introduced	herb
7	Dennstaedtiaceae	*Pteridium aquilinum*	LC	NA	Introduced	herb
8	Euphorbiaceae	*Manihot esculenta*	DD	NA	Introduced	shrub
9	Fabaceae	*Caesalpinia decapetala*	LC	NA	Introduced	NA
10	Malvaceae	*Sida rhombifolia*	NA	NA	Native	shrub
		Pavonia urens var. irakuensis	NA	NA	Native	shrub
11	Myrtaceae	*Eucalyptus saligna*	LC	NA	Introduced	Tree
12	Oxalidaceae	*Oxalis latifolia*	NA	NA	Introduced	herb
13	Phyllanthaceae	*Phyllanthus fischeri*	NA	NA	Native	shrub
14	Verbenaceae	*Lantana camara*	NA	NA	Introduced	shrub
		Lantana trifolia	NA	NA	Introduced	NA
Ryarubamba Community Based Sanctuary						
1	Asteraceae	*Bidens pilosa*	NA	NA	Introduced	herb
2	Fabaceae	*Phaseolus vulgaris*	LC	NA	Introduced	herb
3	Poaceae	*Zea mays*	LC	NA	Introduced	herb
4	Solanaceae	*Solanum tuberosum*	NA	NA	Introduced	herb

Amphibians and Reptiles

A total of seven Community Biodiversity Sanctuaries (CBS) were surveyed for both amphibians and reptiles; only two sanctuaries had no species recorded (Ryarubamba CBS and Karushuga CBS) for amphibians and one (Muhazi CBS) for reptiles (Figure 40). For the sanctuaries where species were observed, four amphibian and three reptile families were recorded. For amphibians, the family Hyperoliidae and Phrynobatrachidae are the most common species, each with three observed species followed by the family Ptychadenidae (two species) and Bufonidae with one species recorded. For reptiles, the family Colubridae recorded three species followed by Scincidae then Gekkonidae. All the species observed and identified to species level are listed as Least Concerned by the Global IUCN Red List of threatened species.

Table 16. Amphibians and reptiles recorded in the surveyed sanctuaries. For each species, the Global and National IUCN Red List status is provided. LC: Least Concerned: ND: Not Determined.

	Family	**Scientific name**	**Common name**	**Global IUCN status**	**National IUCN status**
AMPHIBIANS					
1	Bufonidae	*Sclerophrys gutturalis (Power, 1927)*	African Common Toad	LC	LC
2	Hyperoliidae	*Hyperolius kivuensis Ahl, 1931*	Kivu Reed Frog	LC	LC
		Hyperolius viridiflavus (Duméril & Bibron, 1841)	Common Reed Frog	LC	LC
		Kassina senegalensis (Duméril & Bibron, 1841)	Bubbling Kassina	LC	LC
3	Phrynobatrachidae	*Phrynobatrachus bequaerti (Barbour & Loveridge, 1929)*	Vissoke River Frog	LC	LC
		Phrynobatrachus kakamikro Schick, Zimkus, Channing, Köhler & Lötters, 2010	Kakamega Puddle Frog	DD	LC
		Phrynobatrachus natalensis (Smith, 1849)	Common Toad-frog	LC	LC
4	Ptychadenidae	*Ptychadena anchietae (Bocage, 1868)*	Anchieta's Frog	LC	LC
		Ptychadena nilotica (Seetzen, 1855)	Nile grass frog	LC	LC
REPTILES					
1	Scincidae	*Trachylepis striata (Peters, 1844)*	African Striped Mabuya	LC	ND
		Trachylepis sp.	-	-	-
2	Gekkonidae	*Hemidactylus mabouia (Moreau De Jonnès, 1818)*	Afro-American House Gecko	LC	ND
		Lygodactylus sp	-	-	-
3	Colubridae	*Unidentified brown snake*	-	-	-
		Crotaphopeltis hotamboeia (Laurenti, 1768)	Red-lipped Snake	LC	ND

		Natriciteres olivacea (Peters, 1854)	Olive Marsh Snake	LC	ND

Among the sampled Community Biodiversity Sanctuaries (CBS), the species richness for amphibians was highest at Muhazi CBS (n=6), followed by Zaza CBS (n=5). For reptiles, highest species richness was observed at Nyamata CBS (n=4) followed by Gahini CBS (n=3). There was no species of reptile recorded at Gahini CBS (Figure 40). Looking at the species occurrence among sampled sanctuaries, *Ptychadena nilotica* was the most common species followed by *Hyperolius viridiflavus* and for reptiles, *Trachylepis striata* was the most common species followed by *Hemidactylus mabouia* (Figure 40). The remaining species for both herpertofauna were uncommon at the sampled sites.

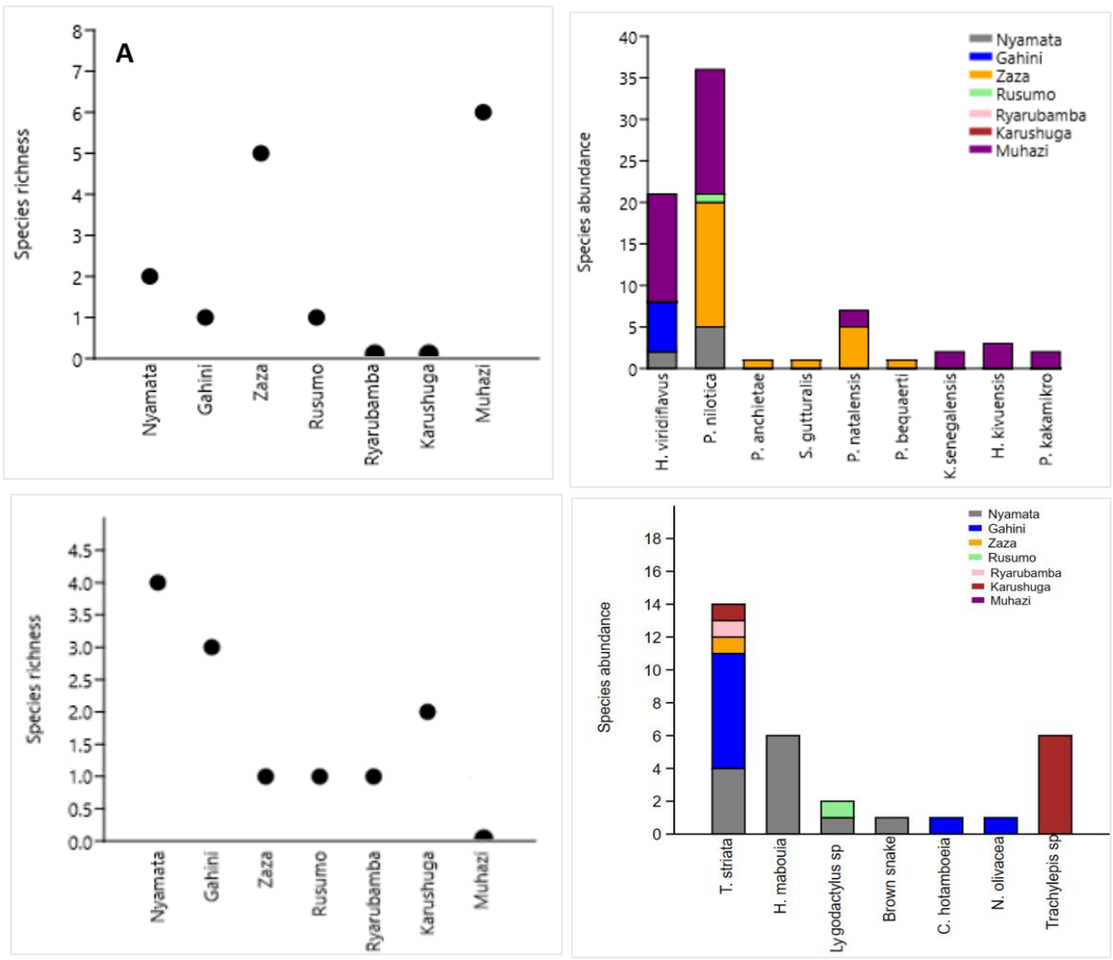

Figure 40. Amphibian and reptile species richness (A, C), species occurrence and abundance (B, D) per Community Biodiversity Sanctum sampled in the Eastern Province, Rwanda. The dots represent the number of species per sampled site. The colored bars represent the abundance data of the species per site.

Flying Insects

A total of 35 butterfly species were recorded across six CBSs from the entire intervention sites. Butterfly species across these eight sanctuaries are: Nyamata CBS (n=18), Gahini CBS (n=18), Rusumo CBS (n=6), Muhazi CBS (n=23), Zaza CBS (n=9) and Ryarubamba CBS (n=2). Species richness at each sanctuary is shown in Figure 41 and more information about the species names and their IUCN Red List information are found in Annex 3.

The butterflies are from five families: Nymphalidae, Pieridae, Lycaenidae, Hesperiidae and Papilionidae. Five family were recorded from Buhonde CBS 1 & 2: Hesperiidae (14.71%), Lycaenidae (11.76%), Nymphalidae (50%), Papilionidae (2.94%) and Pieridae (20.59%). The butterfly families recorded from Jambo Beach-Gahini Sanctum were Hesperiidae (13.04%), Nymphalidae (34.78%) and, Pieridae 52.17%). Karambi Sanctum included Hesperiidae (15.38%), Lycaenidae (19.23%), Nymphalidae (23%), Papilionidae (3.85%) and Pieridae (38.46%). Nymphalidae (75.86%), Papilionidae (13.79%) and Pieridae (10.34%) were recorded from Kigarama Sanctum 2. Hesperiidae (5%), Lycaenidae (15%), Nymphalidae (50%) and Pieridae

(30%) were recorded from Murambi Sanctum. Nymphalidae family was the only one recorded from Ryarubamba Sanctum and in Ngoma Sanctum we found Hesperiidae (6.67%), Lycaenidae (13.33%), Nymphalidae (40%) and Pieridae (40%).

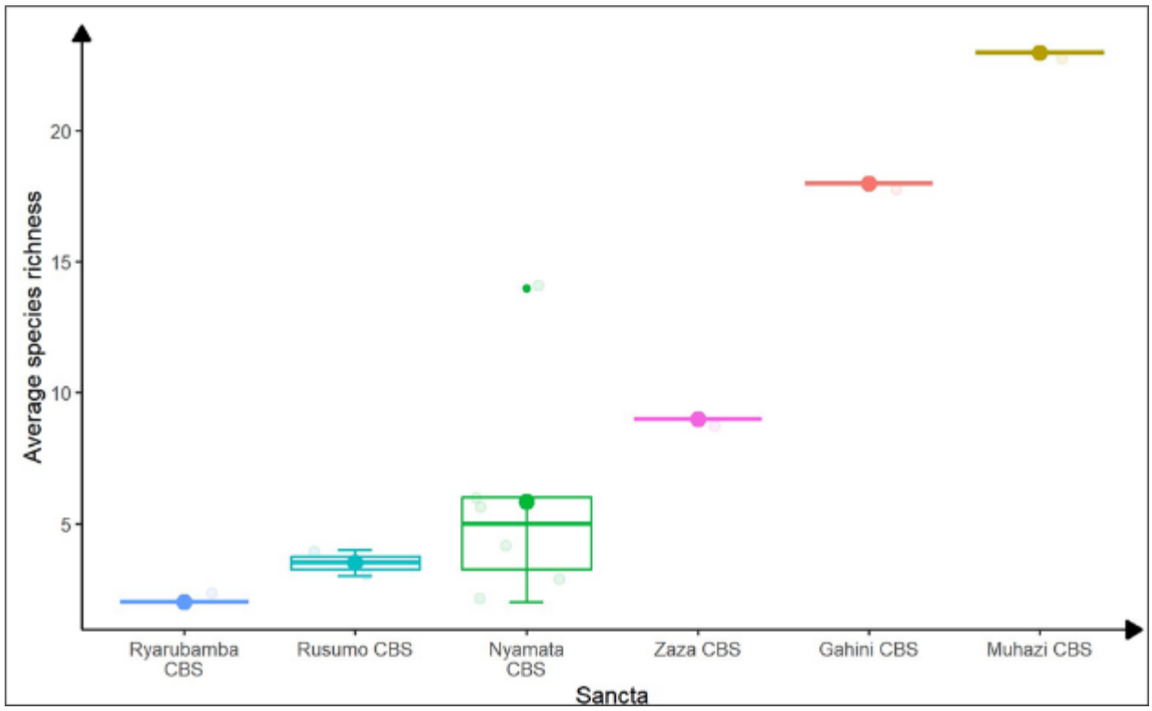

Figure 41. Butterfly richness distribution across the six sanctuaries. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represent the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR.

In comparing pollinator insect diversity and abundance, the highest species richness was recorded from Murambi CBS and the least richness was recorded from Ryarubamba CBS (Figure 42A). For all sites, the sampling efforts did not reach the maximum level as the sample coverage is between 0 (minimum) and 1 (maximum) (Figure 42B).

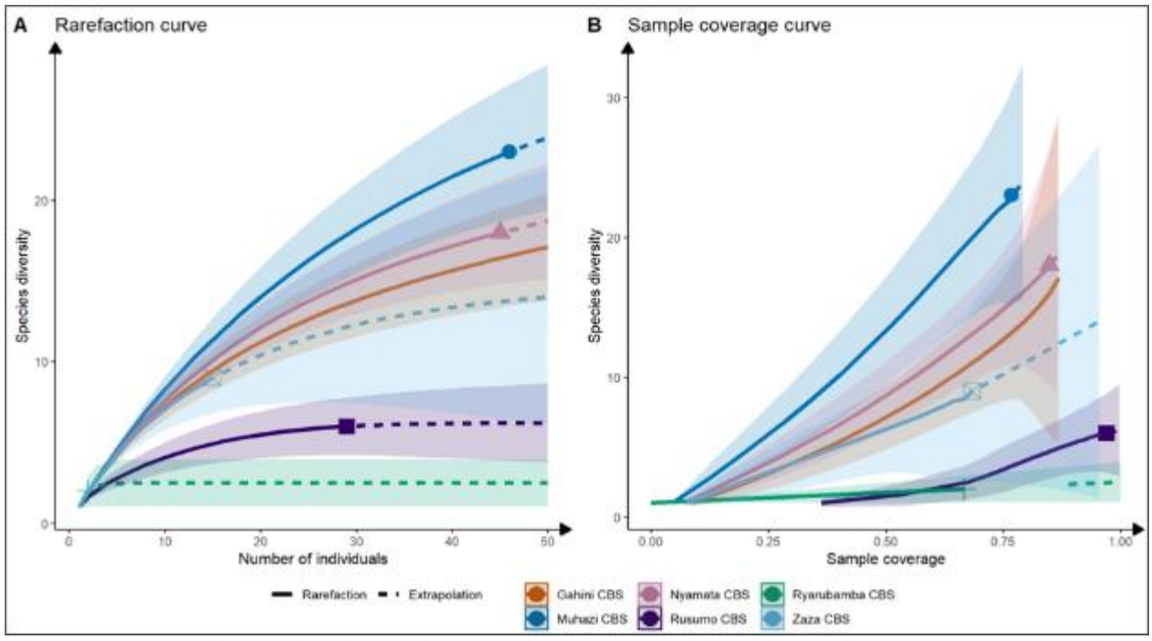

Figure 42. Butterfly rarefaction and extrapolation curves (A) and sample coverage curves using butterfly richness (Hill numbers of order 0) across the sanctuaries. Solid lines represent the curves based on sample data, and the dashed lines represent the extrapolations. Shaded areas represent the 95% confidence intervals surrounding the curves.

Pollinating insect diversity recorded from the sanctuaries was 20 in total. These species include managed bees (*Apis mellifera*), wild bees (*Hypotrigona sp, Thyreus nitidulus, Amegilla sp, Xylocopa virginica, Xylocopa caffra* and *Lasioglossum* sp), flies from Calliphoridae family,

butterflies (*Erestis lugens, Junonia oenone, Lampides boeticus, Papilio demodocus, Zizula hylax, Eurema brigitta, Ypthima aesterope* and *Mylothris agathina*) and *Cephonodes hylas* from Sphingidae family, wasps (*Synagris analis, Sphecidae sp* and *Ammophila procera*). We observed *Lantana camara* to be the most visited plant species by pollinators (Figure 43) followed by *Asystasia gangetica* whereas the most abundant pollinator was the bee (*Apis mellifera*) followed by a butterfly (*Junonia oenone*) (Figure 43).

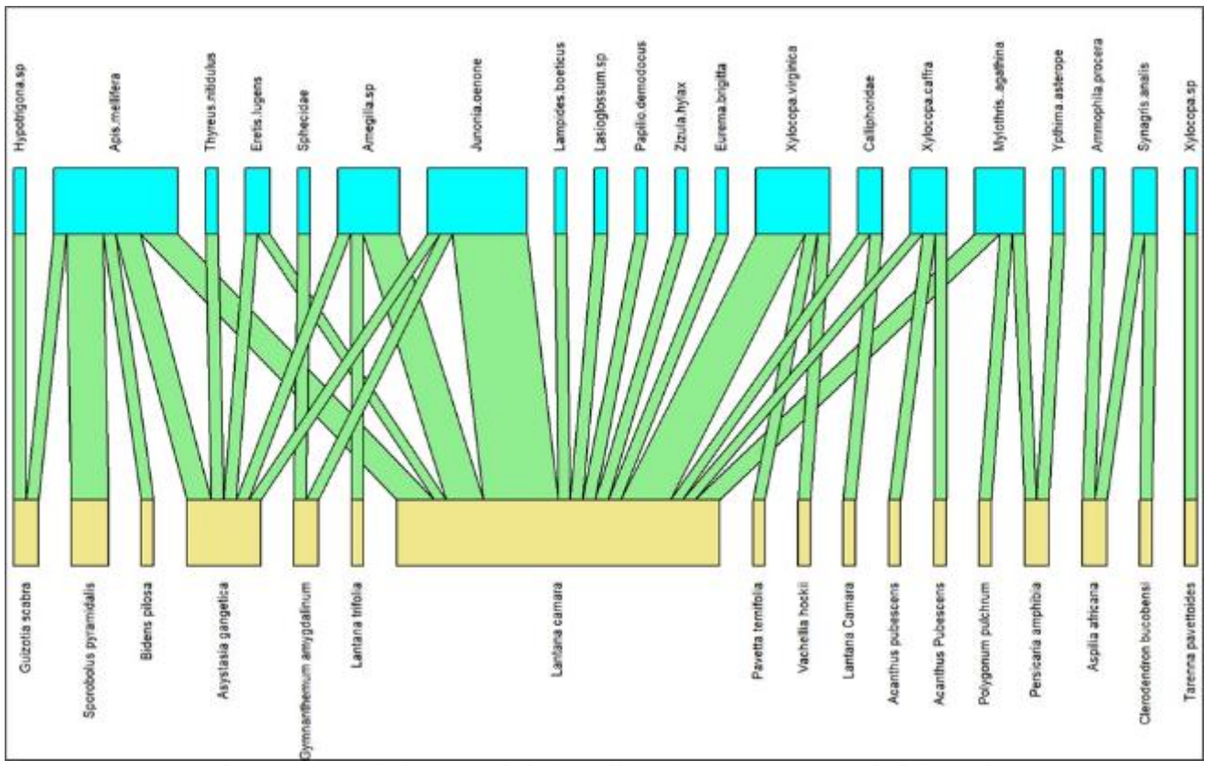

Figure 43. Network structure of plants and their pollinating insects recorded from the sanctuaries. The upper band in dark turquoise color represents the flower visitors while the lower band in yellow color represents plant diversity (host plants). The vertical lines in the middle of the figure (in green color) represent the linkage (which plant was visited by which insect) between plants and their pollinating insects.

Considering only butterflies, the most common species was *Junonia oenone* found in all but one of the sanctuaries (Figure 44). There were 11 species that were only observed in one CBS each.

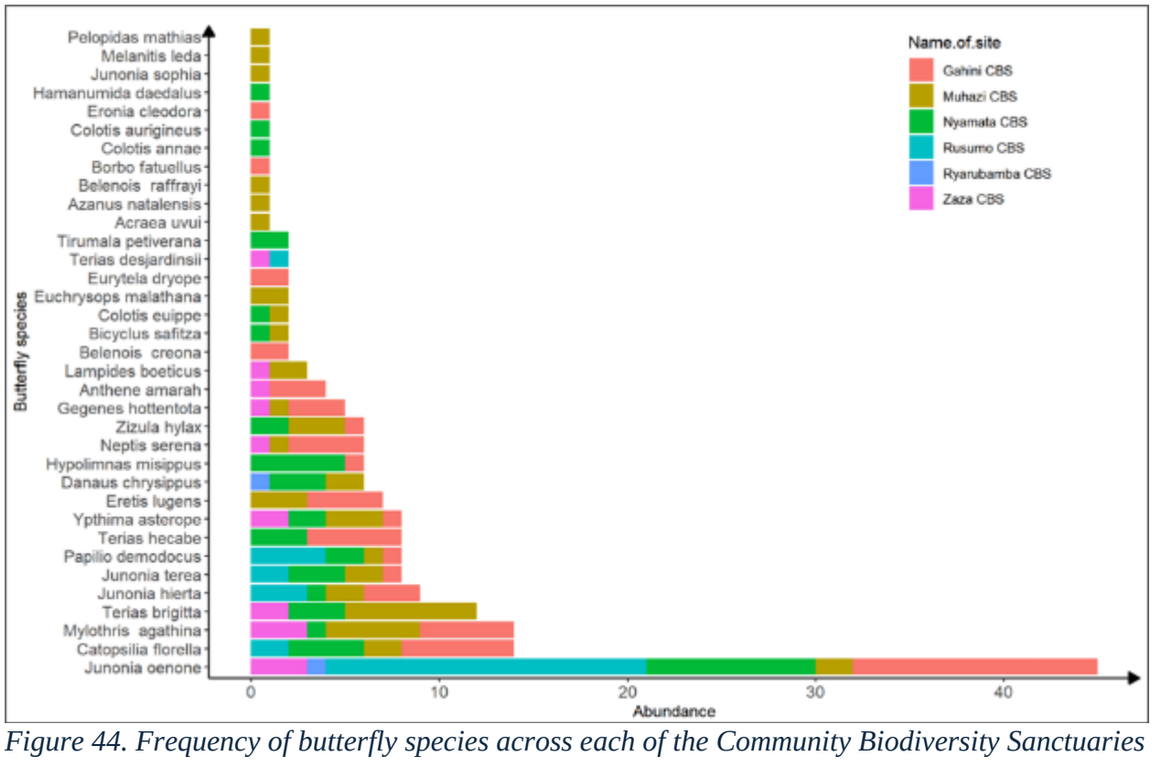

Figure 44. Frequency of butterfly species across each of the Community Biodiversity Sanctuaries sampled in the Eastern Province, Rwanda.

Terrestrial Arthropods

Across all seven Community Biodiversity Sanctuaries (CBS) surveyed for terrestrial arthropods, 56 families dominated by Formicidae, Salticidae, Acrididae and Cercopidae were recorded, and each family was recorded in all CBS. All families observed and identified are not evaluated by IUCN Red List. Muhazi CBS, followed by Gahini CBS had the highest taxon richness while Karushuga CBS and Rusomo CBS have the lowest taxon richness (Figure 45).

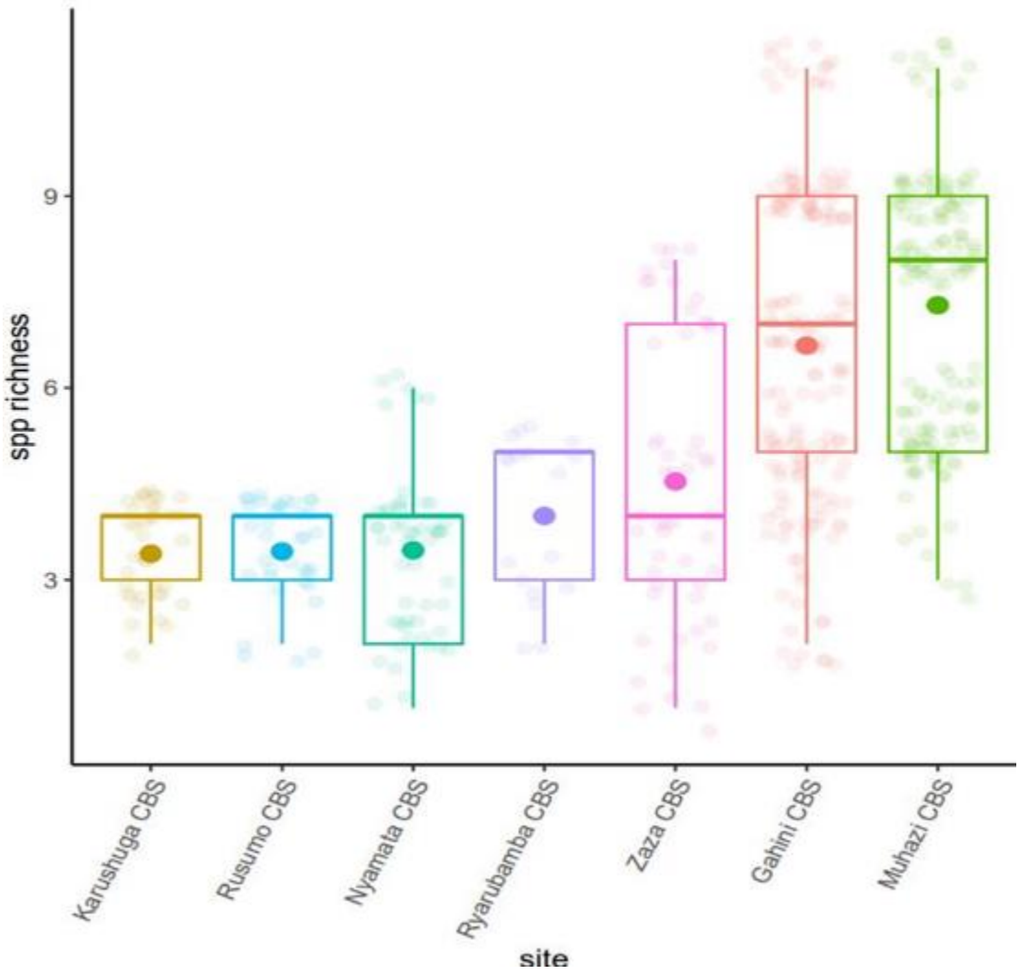

Figure 45. Terrestrial arthropod taxon richness distribution across seven Community Biodiversity Sanctuaries. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represents the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to sampling stations on sampling sites.

Birds

The bird survey carried out in the seven selected Community Based Sanctuaries (CBS) found 121 bird species belonging to 47 families. There were nine migratory species observed across all sancta. Zaza CBS had the highest species richness (Figure 46). We also identified eight functional groups among the observed bird species, including Granivorous (seed-eating), Omnivorous (eating both plant and animal matter), Nectivorous (nectar-feeding), Insectivorous (insect-eating), Frugivorous (fruit-eating), Herbivorous (plant-feeding), Piscivorous (fish-feeding), and Carnivorous (meat-feeding) species. It is noteworthy that the most common functional group observed was Insectivorous.

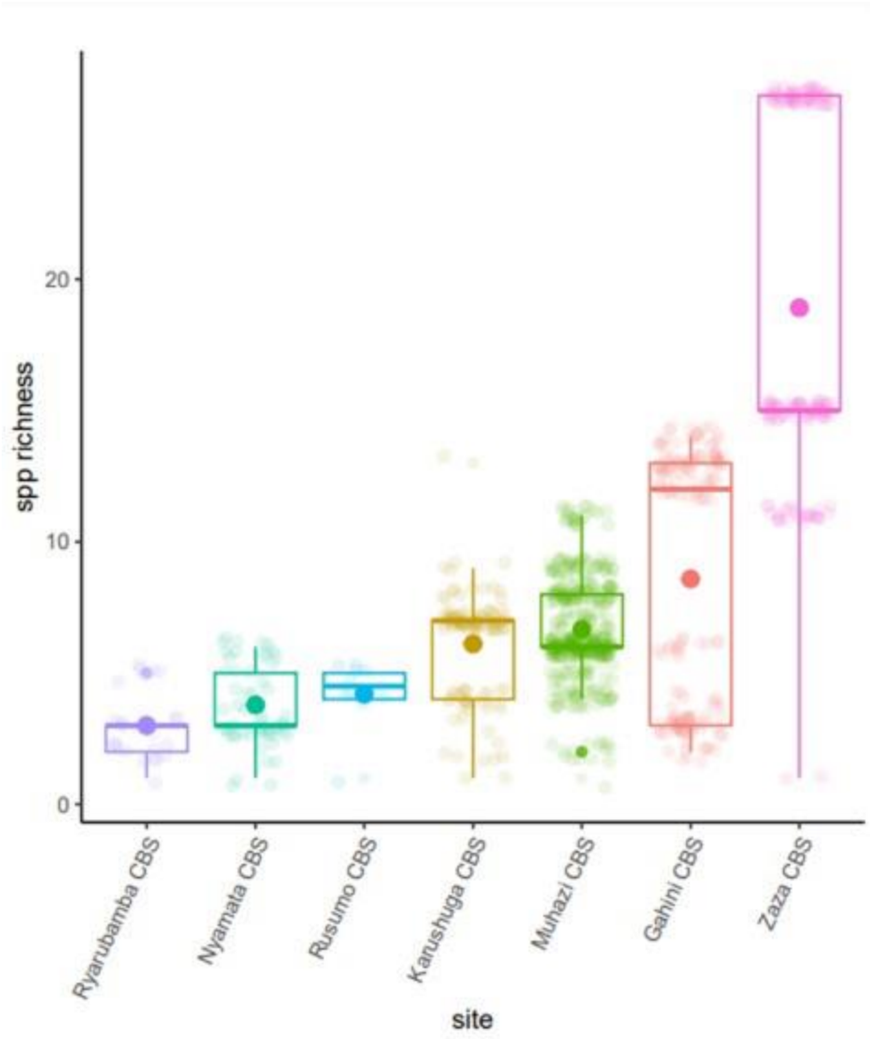

Figure 46. Bird species richness by site. Boxes represent the inter-quartile range (IQR), and lines in the center represent the median. Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to sampling units of point counts

Mammals

Most of the mammals were found in sanctuaries compared to the other intervention sites sampled for this study. Three species of carnivores and two species of rodents were recorded in three sanctuaries (Table 17).

Table 17. List of mammals observed in community biodiversity sanctuaries in the Eastern Province, Rwanda

	Order	Family		Site where recorded	IUCN status
1	Carnivora	Herpestidae	*Herpestes sp.*	Nyamata CBS and Rusumo CBS	LC
2	Carnivora	Felidae	*Leptailurus serval*	Gahini CBS	LC
3	Carnivora	Felidae	*Felis silvestris*	Rusumo CBS	LC
4	Rodentia	Muridae	*Mus minutoides*	Gahini CBS	LC
5	Rodentia	Muridae	*Lemniscomys striatus*	Nyamata CBS	LC

Threats

Many threats with high levels of frequencies were observed at Jambo Beach-Gahini sanctum (39.46%) among the eight sanctuaries that were surveyed (Figure 47 & 48); this difference was not significant. Buhonde 1 & 2 sanctum was not sampled for threats. Plastic materials (including pastics in the waste dumping) were the most frequently occurring threat in sanctuaries for all the sites sampled and this difference was marginally significant (p=0.055; Figure 49). Plastic materials were the most dominant in all lake buffers, and Figure 49 shows the relative frequencies of occurrence across all the dam buffers. Figure 50 shows images of the waste dumped at the sites, and agriculture in the dam buffer is shown in Figure 51.

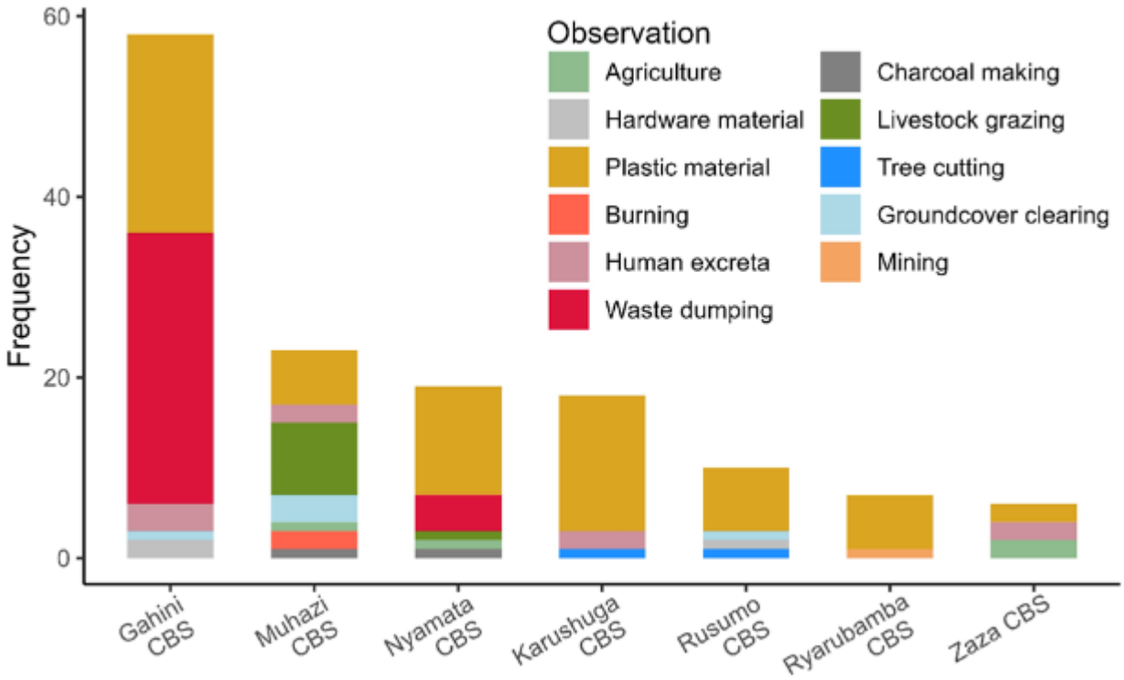

Figure 47. Frequency of threats and disturbances by sanctuaries, showing the relative frequencies of occurrence.

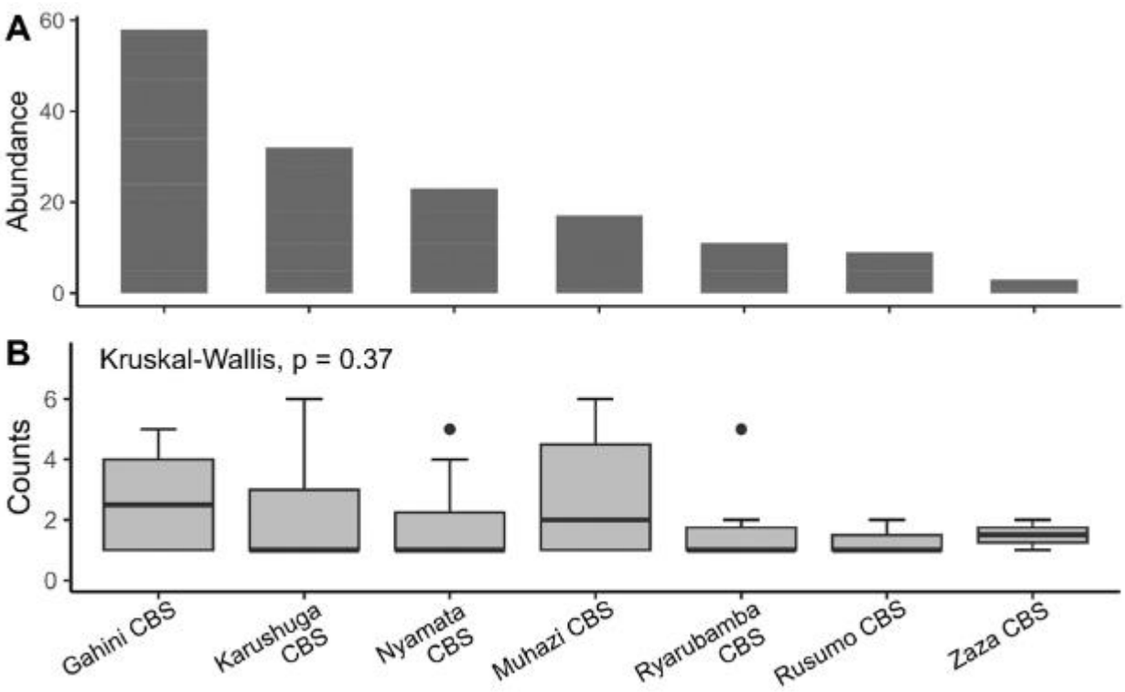

Figure 48. Comparative abundance of plastic materials in different sanctuaries with A showing total abundance by site and B denoting the frequency per site summarized in box plots with the median value; the difference between sites was not significant (Kruskal-Wallis test, p = 0.39).

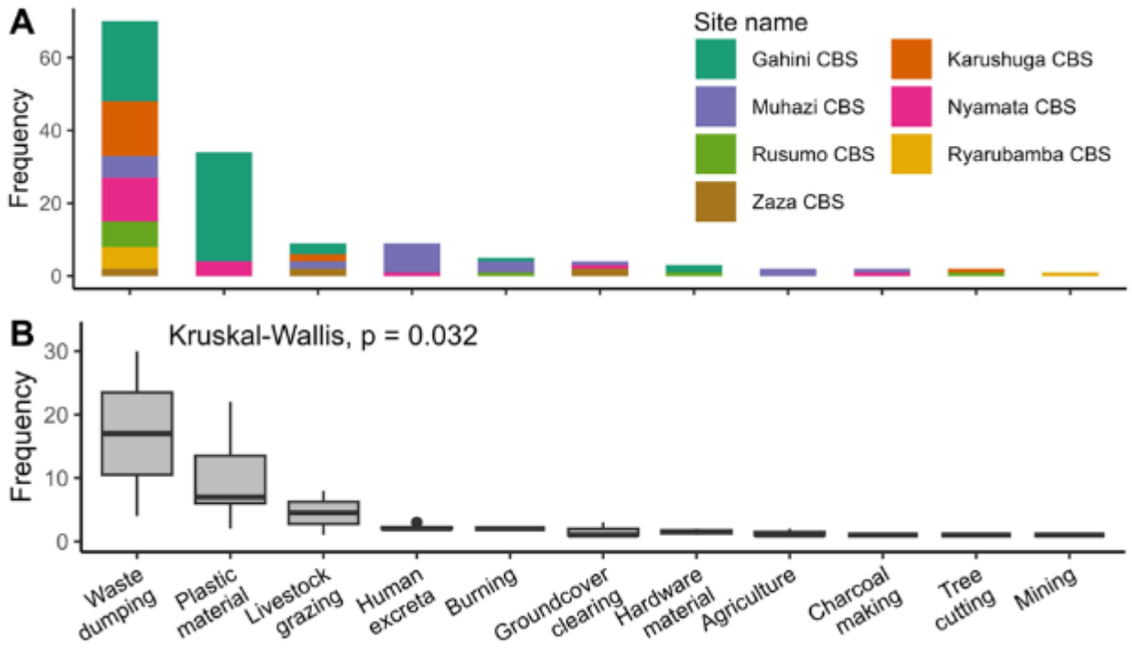

Figure 49. Frequency of threats and disturbances in sanctuaries, with A showing total abundance and B showing frequency by site summarized with box plots with median values and a test of comparison (the value 0.055 indicates that the difference between threat types is statistically significant at p = 0.05).

Figure 50. Dumping sites at Gahini CBS towards Jambo Beach in Nyagatare district showing plastic materials mixed with other garbage

Figure 51. Agriculture practice in the lake buffer at Muhazi CBS, Eastern Province, Rwanda

6. River buffer

Two river buffers were sampled for this study (Figure 52). The details for biodiversity and threats in the river buffers are presented below.

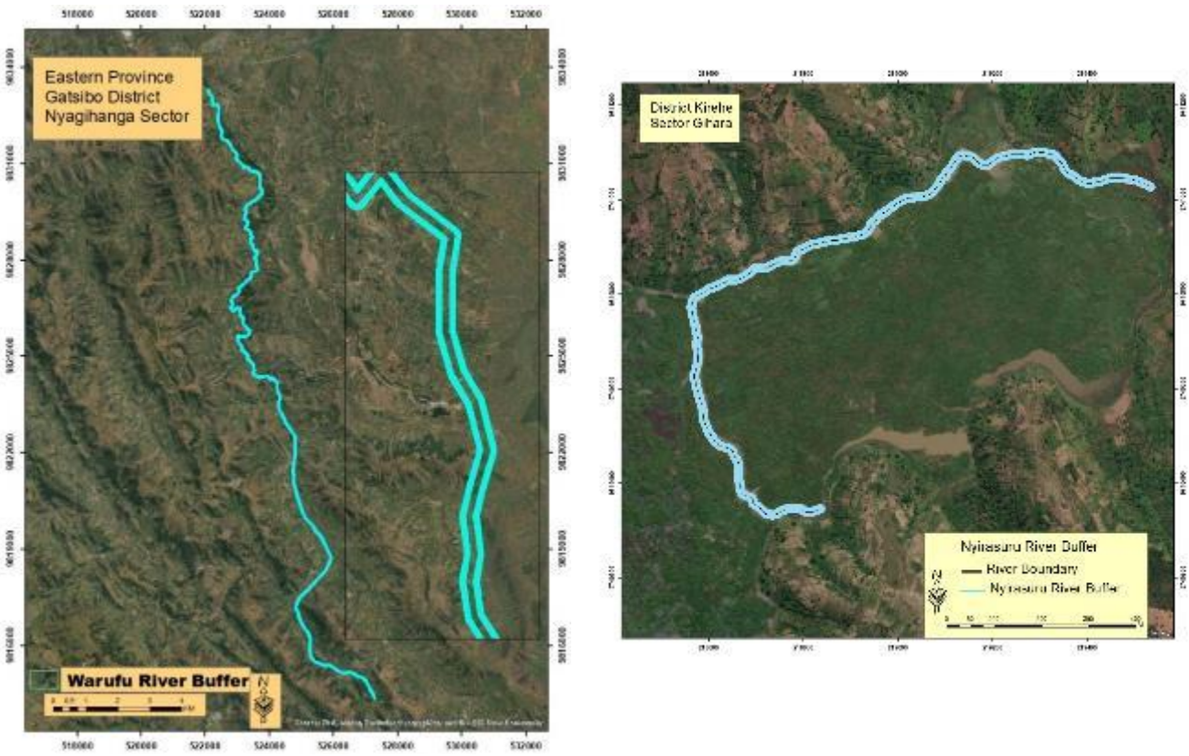

Figure 52. The two river buffers sampled in the Eastern Province, Rwanda

Plants

Plants were surveyed in two river buffers, Warufu and Nyirasuru, situated within the Eastern Province. A total of 17 plant species across 12 families were observed (Table 18). Fabaceae and Malvaceae families were the most common families in the river buffers, each with 17.64% of the species observed. Of particular significance is the observation that 64.70% of the recorded species are indigenous to Rwanda and the surrounding region, while 35.29% represent introduced species. Moreover, 58.82% of the recorded species are categorized as Least Concern on IUCN Red List, 5.88% flagged as Vulnerable, and 35.29% of the species are not evaluated on the IUCN Red List, hinting at the potential for further discoveries and conservation imperatives within these river buffers.

Table 18. Families and species of plants found in sampled river buffers, Eastern Province, Rwanda

ID	Family	Scientific name	IUCN Status	Native or introduced	life form
1	Acanthaceae	*Acanthus polystachyus*	NE	Native	tree or shrub
2	Asteraceae	*Gymnanthemum amygdalinum*	NE	Native	tree or shrub
3	Bignoniaceae	*Markhamia lutea*	LC	Native	tree
4	Celastraceae	*Gymnosporia heterophylla*	LC	Introduced	shrub
5	Euphorbiaceae	*Euphorbia tirucalli*	LC	Introduced	tree or shrub
6	Fabaceae	*Erythrina abyssinica*	LC	Native	tree
		Senna didymobotrya	LC	Native	tree or shrub
		Senna spectabilis	LC	Introduced	tree or shrub
		Tephrosia vogelii	LC	Native	shrub
7	Hypericaceae	*Harungana montana*	VU	Native	tree
8	Lauraceae	*Persea americana*	LC	Introduced	tree

9	Malvaceae	*Sida ovata*	NE	Native	shrub
		Sida rhombifolia subsp. rhombifolia	NE	Native	shrub
		Triumfetta rhomboidea	NE	Native	shrub
10	Myrtaceae	*Eucalyptus saligna*	LC	Introduced	tree
11	Primulaceae	*Maesa lanceolata*	LC	Native	tree
12	Verbenaceae	*Lantana camara*	NE	Introduced	shrub

Herpetofauna: Amphibians and Reptiles

Two river buffers were sampled where three amphibian and three reptile families were recorded. For amphibians, the family Phrynobatrachidae has more species (two) than the remaining Hyperoliidae and Ptychadenidae, each having one species (Table 19). Among the reptile families, each had one species recorded. All the observed species are listed as Least Concerned according to the IUCN Red List.

Table 19. Amphibian and reptile species recorded in the surveyed river buffers, each species with its IUCN Category for both Global and National status.

	Family	**Scientific name**	**Common name**	**Global IUCN status**	**National IUCN status**
AMPHIBIANS					
1	Hyperoliidae	*Hyperolius viridiflavus (Duméril & Bibron, 1841)*	Common Reed Frog	LC	LC
2	Phrynobatrachidae	*Phrynobatrachus kakamikro Schick, Zimkus, Channing, Köhler & Lötters, 2010*	Kakamega Puddle Frog	DD	LC
		Phrynobatrachus natalensis (Smith, 1849)	Common Toad-frog	LC	LC
3	Ptychadenidae	*Ptychadena nilotica (Seetzen, 1855)*	Nile grass frog	LC	LC
REPTILES					
1	Scincidae	*Trachylepis striata (Peters, 1844)*	African Striped Mabuya	LC	ND
2	Gekkonidae	*Hemidactylus mabouia (Moreau De Jonnès, 1818)*	Afro-American House Gecko	LC	ND
2	Lacertidae	*Adolfus jacksoni (Boulenger, 1899)*	Jackson's Forest Lizard	LC	ND

Further, findings showed that for amphibians, Nyirasuru river buffer has more species richness (n=3) than Warufu river buffer (n=2). However, there was no single observation of reptiles for the Nyirasuru river buffer as all recorded reptiles were observed in the Warufu river buffer (n=3). For amphibian occurrence, *Ptychadena nilotica* and *Phrynobatrachus kakamikro* are the most widespread species since they were recorded in both river buffers and *P. nilotica* was the most abundant species. Among the species of reptiles, *Trachylepis striata* and *Hemidactylus mabouia* are predominant (Figure 53).

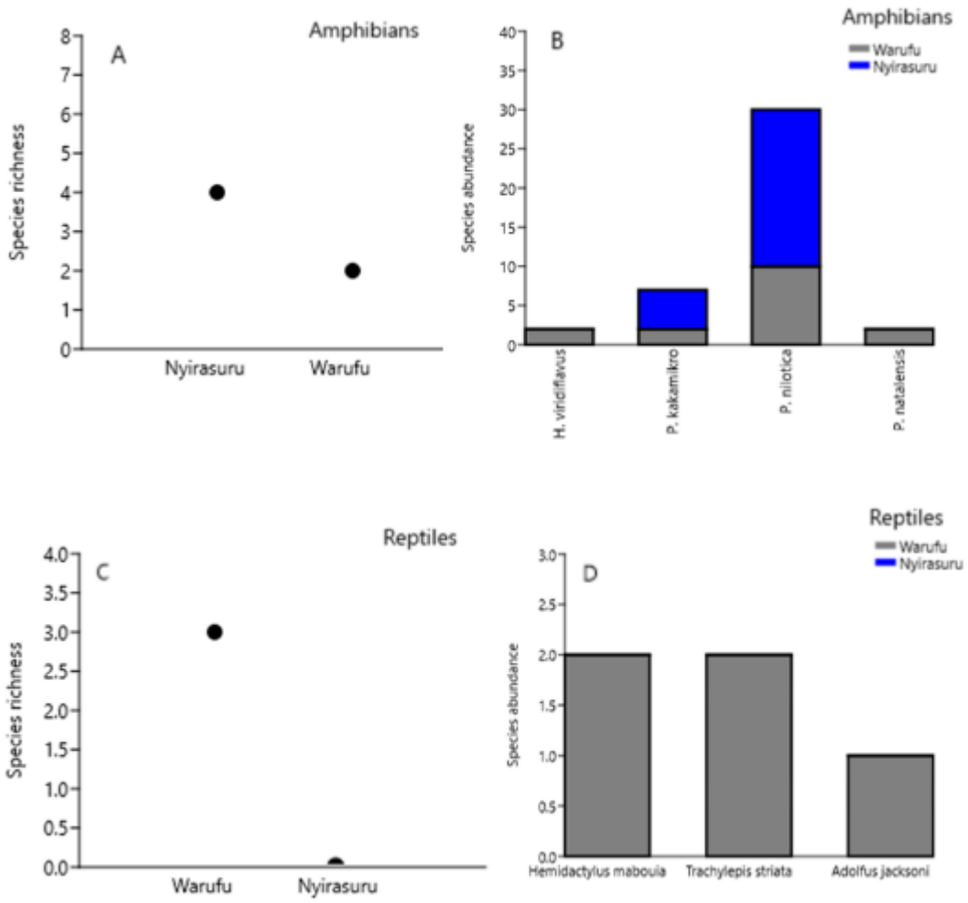

Figure 53. Amphibian and reptile species richness (A, C), species occurrence and abundance (B, D) per river buffer. The dots are the species number per each sampled site. The colored bars represent the abundance data of the recorded species per site.

Flying Insects

A total of 26 butterfly species were recorded across this entire site type. During the surveying period, 12 species were recorded from Nyirasuru River Buffer and 19 species were recorded from Warufu River Buffer (Figure 54). More information about the species names and their IUCN Red List information are found in the appendix table X.

These butterflies were distributed into four families namely Nymphalidae, Pieridae, Lycaenidae, and Hesperiidae. Hesperiidae (5.88%), Nymphalidae (64.71%) and, Pieridae (29.41%) were recorded from Nyirasuru River Buffer. The butterflies recorded from Warufu River Buffer were in Hesperiidae (17.24%), Lycaenidae (10.34%), Nympharidae (55.17%) and, Pieridae (17.24%) families.

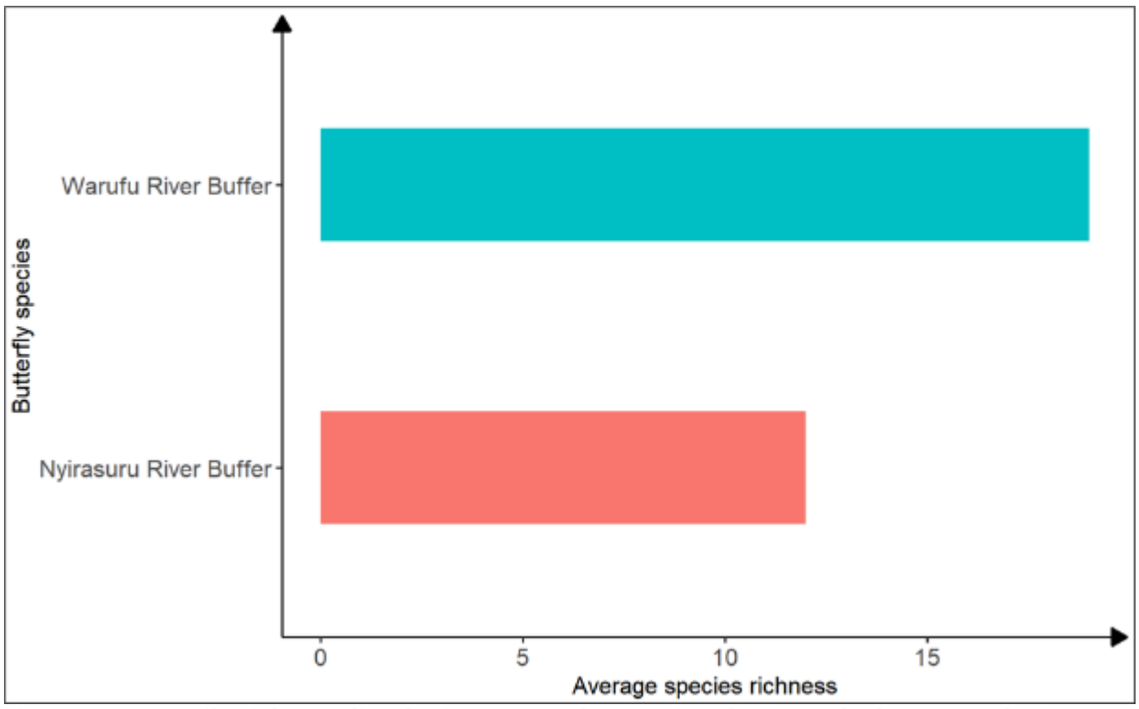

Figure 54. Butterfly richness distribution across the two river buffers. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represent the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR.

By comparing both butterfly diversity and abundances, the highest species richness was recorded from Warufu River Buffer (Figure 55A). For all sites, the sampling efforts did not reach the maximum level as the sample coverage is between 0 (minimum) and 1 (maximum) (Figure 55B).

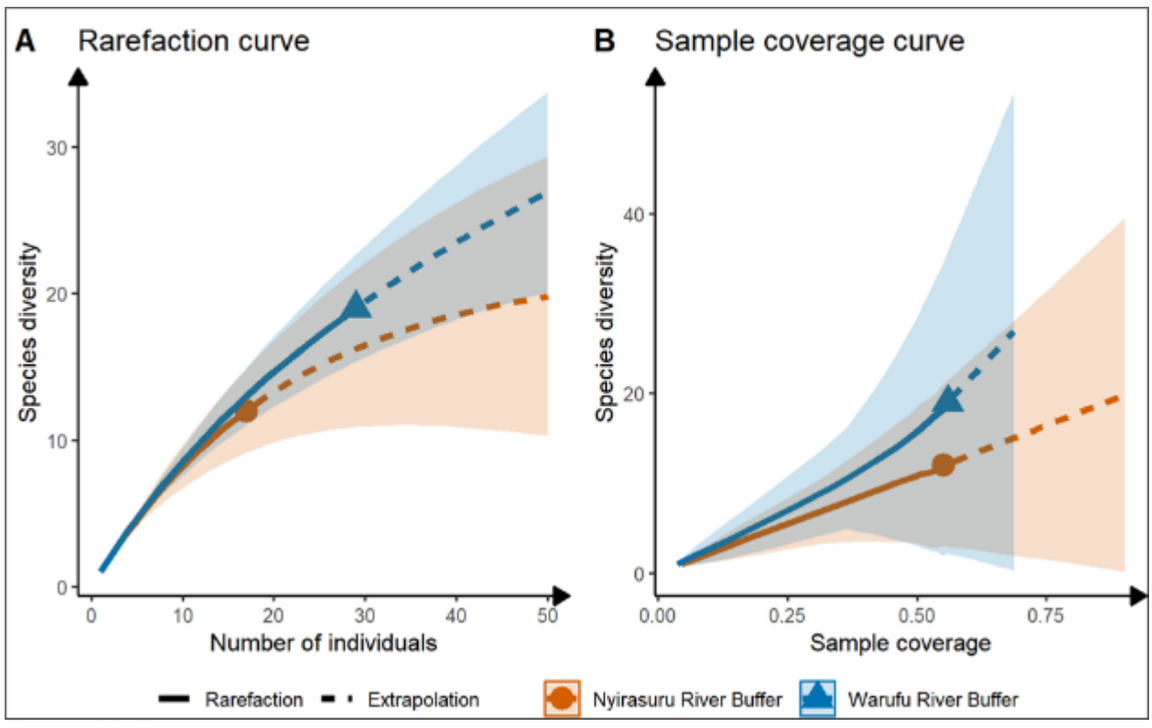

Figure 55. Butterfly species rarefaction and extrapolation curves (A) and sample coverage curves using butterfly richness (Hill numbers of order 0) across the two river buffers. Solid lines represent the curves based on sample data, and the dashed lines represent the extrapolations. Shaded areas represent the 95% confidence intervals surrounding the curves.

Four pollinating insects were recorded from the four river buffers. These species include the managed bees (*Apis mellifera*), Wasps (Sphecidae), butterflies (*Eretis lugens and Junonia sophia*). We observed *Bidens pilosa* to be the most visited plant species by pollinators whereas the most abundant pollinator was the bee (*Apis mellifera*) (Figure 56).

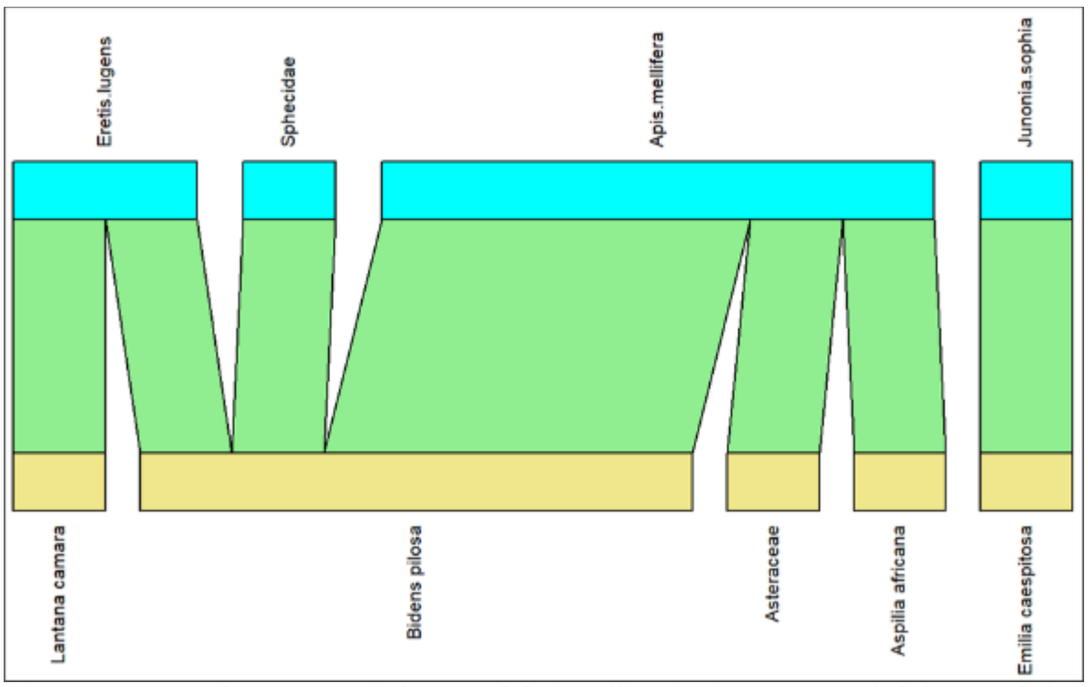

Figure 56. Network structure of plants and their pollinating insects recorded the sampled river buffers. The upper band in dark turquoise color represents the flower visitors while the lower band in yellow color represents plant diversity (host plants). The vertical bars in the middle of the figure (in green color) represent the linkage (which plant was visited by which insect) between plants and their pollinating insects.

Terrestrial Arthropods

A total of two river buffers were surveyed for terrestrial arthropods, and a total of 42 families were observed, dominated by Formicidae (Omnivorous) at 17%, followed by Salticidae (Predators) at 15%, Chrysomelidae (Herbivorous) at 12%, Acrididae (Herbivorous) at 7% and Oniscidae at 7% (Table 20). All families are not yet evaluated on the IUCN Red List.

Table 20. Most abundant terrestrial arthropods families in the river buffers.

	Order	**Family**	**Common name**	**Functional group**
1	Hymenoptera	Formicidae	Ants	Omnivorous
2	Aranea	Salticidae	Jumping spider	Predator
3	Coleoptera	Chrysomelidae	Leaf beetle	Herbivorous
4	Orthoptera	Acrididae	Cricket	Herbivorous
5	Isopoda	Oniscidae	woodlice	Detritivorous

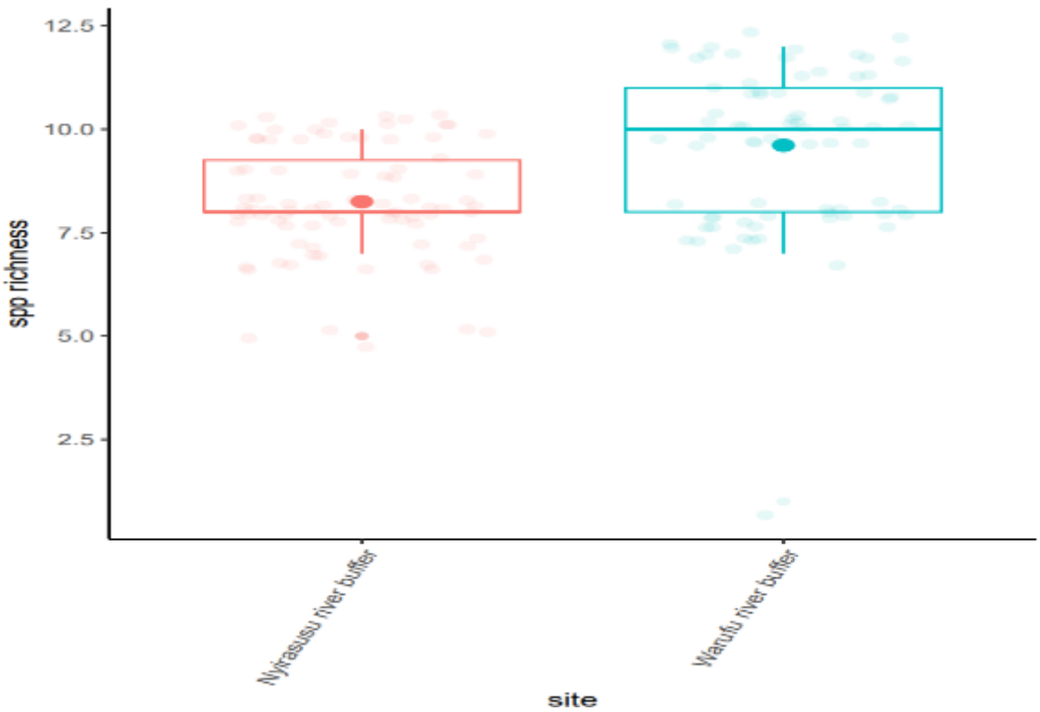

Figure 57. Terrestrial arthropods richness distribution across two river buffers. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represents the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to sampling stations on sampling sites.

The Warufu River buffer has higher species richness in comparison to the Nyirasusu River buffer (Figure 57). However, it is noteworthy that both buffers share some taxonomic families, notably Formicidae, Acrididae, and Salticidae. These families are most prevalent occurrence within the confines of both river buffers.

Birds

For the bird surveys conducted in Nyirasuru River Buffer and Warufu River Buffer, our team discovered a total of 40 bird species, representing 24 families. Warufu River Buffer had greater species richness than Nyirasuru River Buffer (Figure 58). We found 3 migratory species in the river buffers. There were seven functional groups among the observed bird species: granivorous (seed-eating), omnivorous (eating both plant and animal matter), nectivorous (nectar-feeding), insectivorous (insect-eating), frugivorous (fruit-eating), piscivorous (fish-feeding), and carnivorous (meat-feeding) species. The most common functional groups were insectivorous and omnivorous.

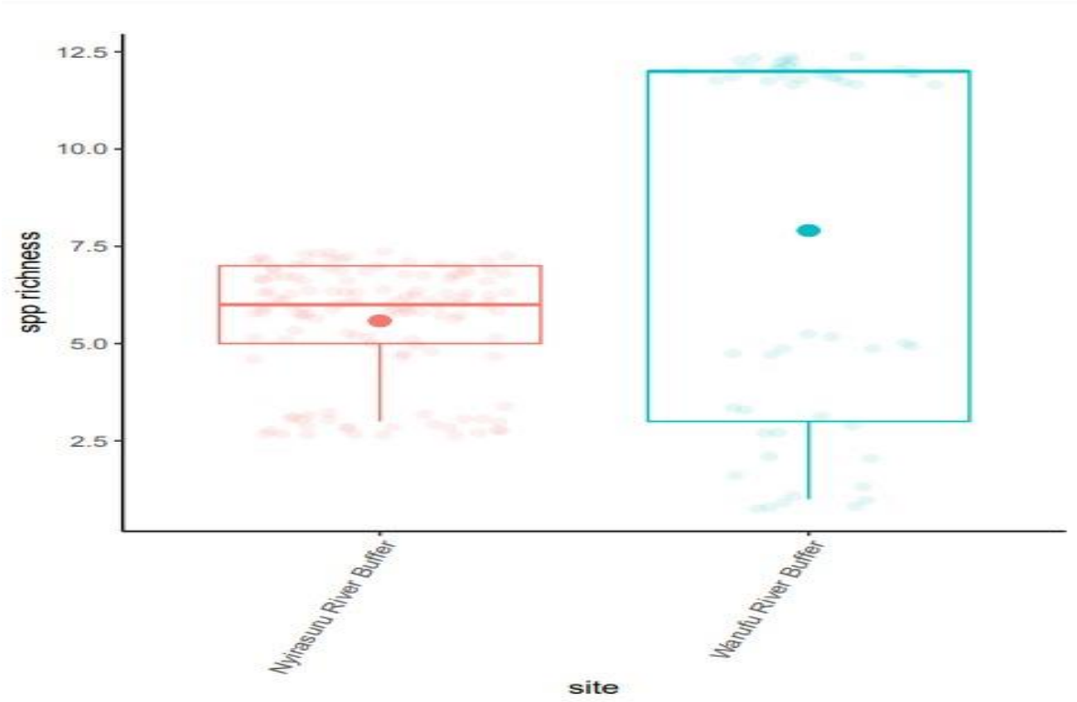

Figure 58. Bird species richness at the two river buffers sampled in the Eastern Province, Rwanda

Mammals

No record of mammals was observed in river buffers.

Threats

In the two rivers buffers that were surveyed there were few records of threats, and these were comprised of plastic materials and agriculture activities inside the river buffer. Four records of threats were documented on each at Nyirasuru river buffer in Kirehe district and four at Warufu river buffers in Gatsibo district.

7. Road buffer

There were 12 road buffers sampled. The sampling area was strips of three to six meters, depending on how much area was available from the road (sometimes private land with agriculture was adjacent to the road buffer, for example). Below are details of the biodiversity and threats surveyed in the road buffers.

Plants

A survey was conducted across 12 road buffer sites in the Eastern Province, encompassing key routes such as Gare-Kariyeri Road, Bugesera Road, and Ruhuha-Nyamata Road, among others. We found a total of 91 plant species identified across 34 families (refer to Table 21 for detailed breakdown). The Fabaceae family was the most dominant, with 14.28% of all species recorded, followed by the Asteraceae family at 13.18%. About 50% of the recorded species are indigenous to Rwanda and the surrounding region, and about 50% are introduced species. Furthermore, our findings indicate that 40.65% of the recorded species are classified as Least Concern on the IUCN Red List. However, 2.19% of the species are Data Deficient. Almost 60% of the species remain unevaluated on the IUCN Red List, highlighting the need for continued monitoring and conservation efforts in the region.

Table 21. Families and species of plants found in Road Buffer, Eastern Province, Rwanda

ID	Family	Scientific Name	IUCN status	Native or introduced	Life form
1	Acanthaceae	*Acanthus polystachyus*	NE	Native	shrub
		Dicliptera colorata	NE	Native	herb

		Asystasia gangetica	NE	Introduced	herb
		Asystasia mysorensis	NE	Native	herb
		Thunbergia alata	NE	Native	herb
2	Amaranthaceae	*Amaranthus sp*	NE	Introduced	herb
		Psilotrichum patulum	NE	Native	herb
		Achyranthes aspera	NE	Native	herb
		Gomphrena celosioides	NE	Introduced	herb
3	Anacardiaceae	*Searsia longipes*	LC	Native	shrub
4	Apiaceae	*Centella asiatica*	LC	Native	herb
5	Apocynaceae	*Carissa spinarum*	LC	Native	N/A
		Cascabela thevetia	LC	Introduced	shrub
6	Asparagaceae	*Dracaena fragrans*	LC	Native	shrub
7	Asteraceae	*Ageratum conyzoides*	NE	Introduced	N/A
		Bidens pilosa	NE	Introduced	herb
		Bothriocline longipes	NE	Native	shrub
		Crassocephalum vitellinum	NE	Native	herb
		Distephanus biafrae	NE	Native	tree or shrub
		Galinsoga parviflora	NE	Introduced	herb
		Gymnanthemum amygdalinum	NE	Native	shrub
		Melanoseris atropurpurea	NE	Introduced	herb
		Solanecio mannii	LC	Native	shrub
		Tagetes minuta	NE	Introduced	herb
		Tithonia diversifolia	NE	Introduced	shrub
		Tridax procumbens	NE	Introduced	N/A
		Acmella caulirhiza	LC	Introduced	herb
8	Bignoniaceae	*Markhamia lutea*	LC	Native	tree
9	Celastraceae	*Gymnosporia heterophylla*	LC	Introduced	shrub
10	Commelinaceae	*Commelina africana*	LC	Native	herb
		Commelina longifolia	NE	Introduced	herb
11	Convolvulaceae	*Dichondra micrantha*	LC	Introduced	herb
		Ipomoea batatas	DD	Introduced	herb
		Ipomoea pileata	NE	Native	herb
		Ipomoea cairica	LC	Native	herb
12	Conyza	*Conyza pallidiflora*	NE	Native	herb
13	Cucurbitaceae	*Cucurbita pepo*	LC	Introduced	herb
14	Euphorbiaceae	*Euphorbia hirta*	NE	Introduced	herb
		Euphorbia tirucalli	LC	Introduced	tree or shrub
		Manihot esculenta	DD	Introduced	shrub
		Ricinus communis	NE	Introduced	tree or shrub
15	Fabaceae	*Arachis hypogaea*	NE	Introduced	herb
		Chamaecrista usambarensis	NE	Native	herb
		Crotalaria cylindrica	LC	Introduced	herb
		Crotalaria spinosa	LC	Native	herb
		Erythrina abyssinica	LC	Native	tree
		Indigofera brevicalyx	NE	Native	shrub
		Indigofera pretoriana	NE	Introduced	shrub

		Phaseolus vulgaris	LC	Introduced	herb
		Senegalia occidentalis	NE	Introduced	tree or shrub
		Senegalia polyacantha	NE	Native	tree
		Senna occidentalis	LC	Introduced	herb
		Senna spectabilis	LC	Introduced	tree
		Vigna parkeri	LC	Native	herb
		Caesalpinia decapetala	LC	Introduced	shrub
		Mimosa pudica	LC	Introduced	shrub
		Senna didymobotrya	LC	Native	tree or shrub
16	Poaceae	*unidentified*	NE	NA	N/A
17	Cyperaceae	*unidentified*	NE	N/A	N/A
18	Lamiaceae	*Clerodendrum johnstonii*	LC	Native	shrub
		Coleus melleri	NE	Native	shrub
		Leonotis ocymifolia	NE	Native	shrub
		Ocimum lamiifolium	NE	Native	shrub
19	Linderniaceae	*Craterostigma plantagineum*	NE	Native	herb
20	Malvaceae	*Hibiscus calyphyllus*	LC	Native	shrub
		Pavonia urens var. irakuensis	NE	Native	shrub
		Sida rhombifolia	NE	Native	shrub
		Triumfetta rotundifolia	NE	Native	shrub
21	Menispermaceae	*Hyalosepalum caffrum*	NE	Native	N/A
22	Moringaceae	*Moringa oleifera*	LC	Introduced	tree
23	Myrtaceae	*Psidium guajava*	LC	Introduced	tree
24	Nyctaginaceae	*Mirabilis jalapa*	NE	Introduced	shrub
25	Oxalidaceae	*Oxalis corniculata*	NE	Introduced	herb
		Oxalis latifolia	LC	Introduced	herb
		Oxalis obliquifolia	NE	Native	herb
26	Phyllanthaceae	*Flueggea virosa*	LC	Native	tree or shrub
		Phyllanthus fischeri	NE	Native	shrub
27	Poaceae	*Zea mays*	LC	Introduced	herb
28	Polygonaceae	*Persicaria amphibia*	LC	Introduced	herb
		Persicaria decipiens	LC	Native	herb
29	Proteaceae	*Grevillea robusta*	LC	Introduced	tree
30	Rubiaceae	*Ixora clerodendron*	NE	Introduced	tree or shrub
		Richardia brasiliensis	NE	Introduced	herb
		Richardia brasiliensis	NE	Introduced	herb
31	Santalaceae	*Osyris lanceolata*	LC	Native	shrub
32	Solanaceae	*Solanum mauense*	LC	Native	shrub
		Solanum nigrum	NE	Introduced	herb
		Solanum tuberosum	NE	Introduced	herb
		Solanum tettense	LC	Native	shrub
33	Verbenaceae	*Lantana camara*	NE	Introduced	shrub
34	Vitaceae	*Cyphostemma maranguense*	NE	Native	herb

Herpetofauna: Amphibians and reptiles

Ten road buffers were surveyed for both amphibians and reptiles. Four families of amphibians and four of reptiles were recorded from the sampled road buffers. For amphibians, Bufonidae Family had one species, and the remaining families had two species each (Table 22). In reptiles, Gekonnidae had two species whereas the remaining recorded only one species each. All observed species are Least Concerned according to the IUCN Red List.

Table 22. Amphibian and reptile species recorded from the sampled road buffers. For each observed species, the IUCN Red List category both Global and National status was provided.

	Family	**Scientific name**	**Common name**	**Global IUCN status**	**National IUCN status**
AMPHIBIANS					
1	Bufonidae	*Sclerophrys gutturalis (Power, 1927)*	African Common Toad	LC	LC
2	Hyperoliidae	*Hyperolius rwandae Dehling, Sinsch, Rodel & Channing, 2013*	Rwanda Long Reed Frog	LC	LC
		Hyperolius viridiflavus (Duméril & Bibron, 1841)	Common Reed Frog	LC	LC
3	Phrynobatrachidae	*Phrynobatrachus kakamikro Schick, Zimkus, Channing, Köhler & Lötters, 2010*	Kakamega Puddle Frog	DD	LC
		Phrynobatrachus natalensis (Smith, 1849)	Common Toad-frog	LC	LC
4	Ptychadenidae	*Ptychadena anchietae (Bocage, 1868)*	Anchieta's Frog	LC	LC
		Ptychadena nilotica (Seetzen, 1855)	Nile grass frog	LC	LC
REPTILES					
1	Scincidae	*Trachylepis striata (Peters, 1844)*	African Striped Mabuya	LC	ND
2	Colubridae	*Crotaphopeltis hotamboeia (Laurenti, 1768)*	Red-lipped Snake	LC	ND
3	Gekkonidae	*Lygodactylus sp*	-	-	-
		Hemidactylus mabouia (Moreau De Jonnès, 1818)	Afro-American House Gecko	LC	ND
4	Lacertidae	*Adolfus jacksoni (Boulenger, 1899)*	Jackson's Forest Lizard	LC	ND

The study also showed that among the sampled sites, Kirehe 1 and Gacundezi road buffers had no amphibian species observed. For reptiles, Gare-Kariyeri, Kirehe 1, Gacundezi, Kirehe-Mushikiri and Gatore-Mutenderi had no species recorded. Figure X shows the results for the species richness among sites where amphibians and reptiles were observed. For reptiles, all sites had four species each except Ngoma road with one species observed (Figure 59). Among the amphibian species, *Ptychadena nilotica* was the most abundant and widespread. The least occurring species was *Hyperolius rwandae*, the only recorded endemic species to Rwanda. Among the reptiles, *Trachylepis striata* was recorded as the most widespread and abundant species followed by *Hemidactylus mabouia*.

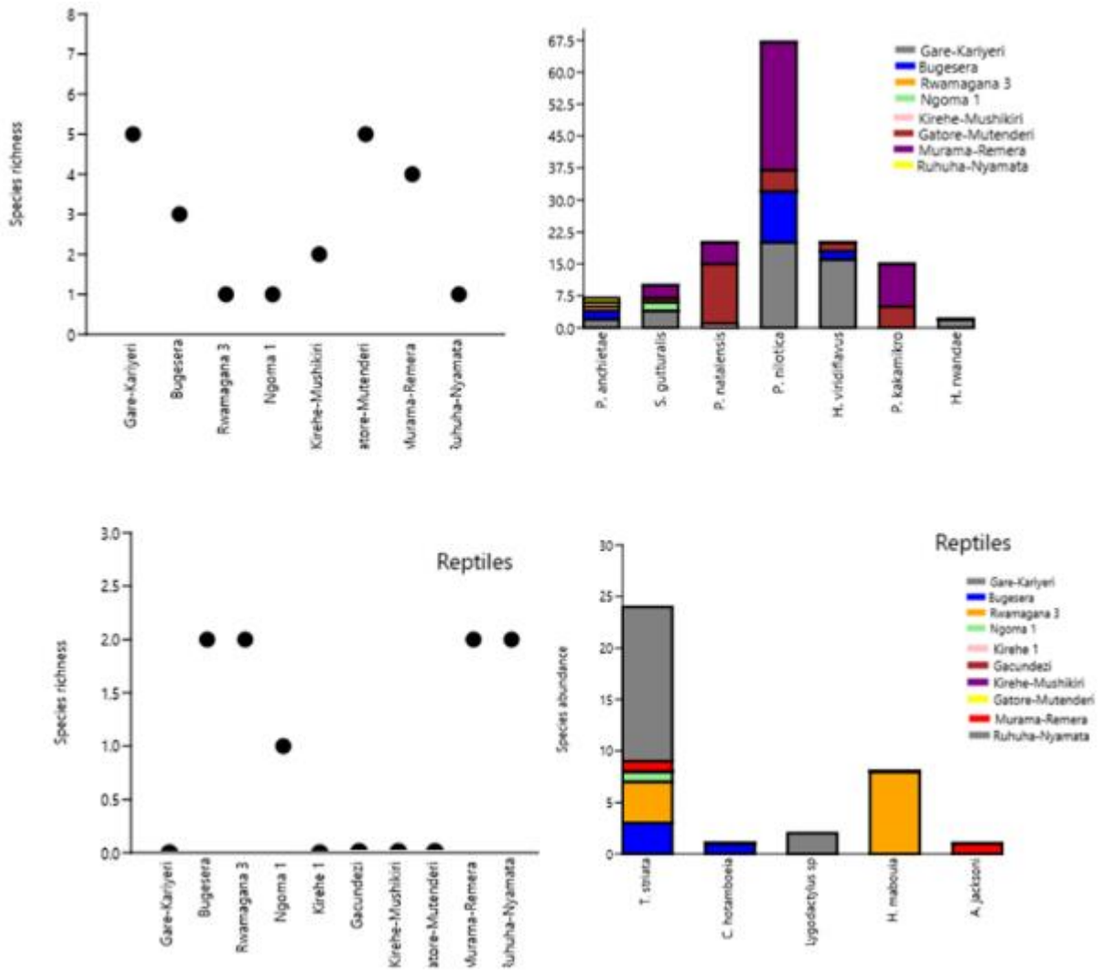

Figure 59. Amphibian and reptile species richness (A, C), species occurrence and abundance (B, D) per road buffer. The dots are the species number per each sampled site. The colored bars represent the abundance data of the species per site.

Flying Insects

A total of 31 butterfly species in five families (Nymphalidae, Pieridae, Lycaenidae, Hesperiidae and Papilionidae) across the 10 road buffers. The distribution of the species richness is shown in Figure 60. More information about the species names and their IUCN Red List status can be found in Annex 3.

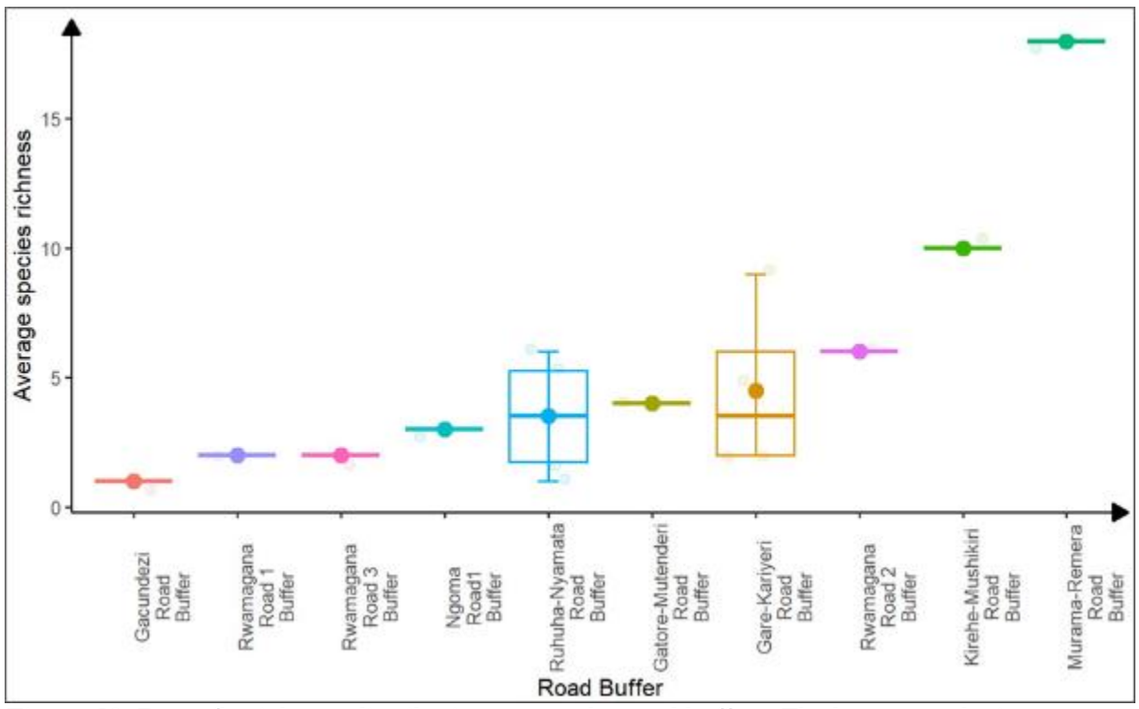

Figure 60. Butterfly richness distribution across the road buffers. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represent the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR.

Considering butterfly diversity and abundances, the highest butterfly species richness was recorded from Murama-Remera Road Buffer, followed by Kirehe-Mushikiri Road Buffer, and the lowest richness was recorded from Gacundezi Road Buffer (Figure 61A). For all sites, the sampling efforts did not reach the maximum level as the sample coverage is between 0 (minimum) and 1 (maximum) (Figure 61B).

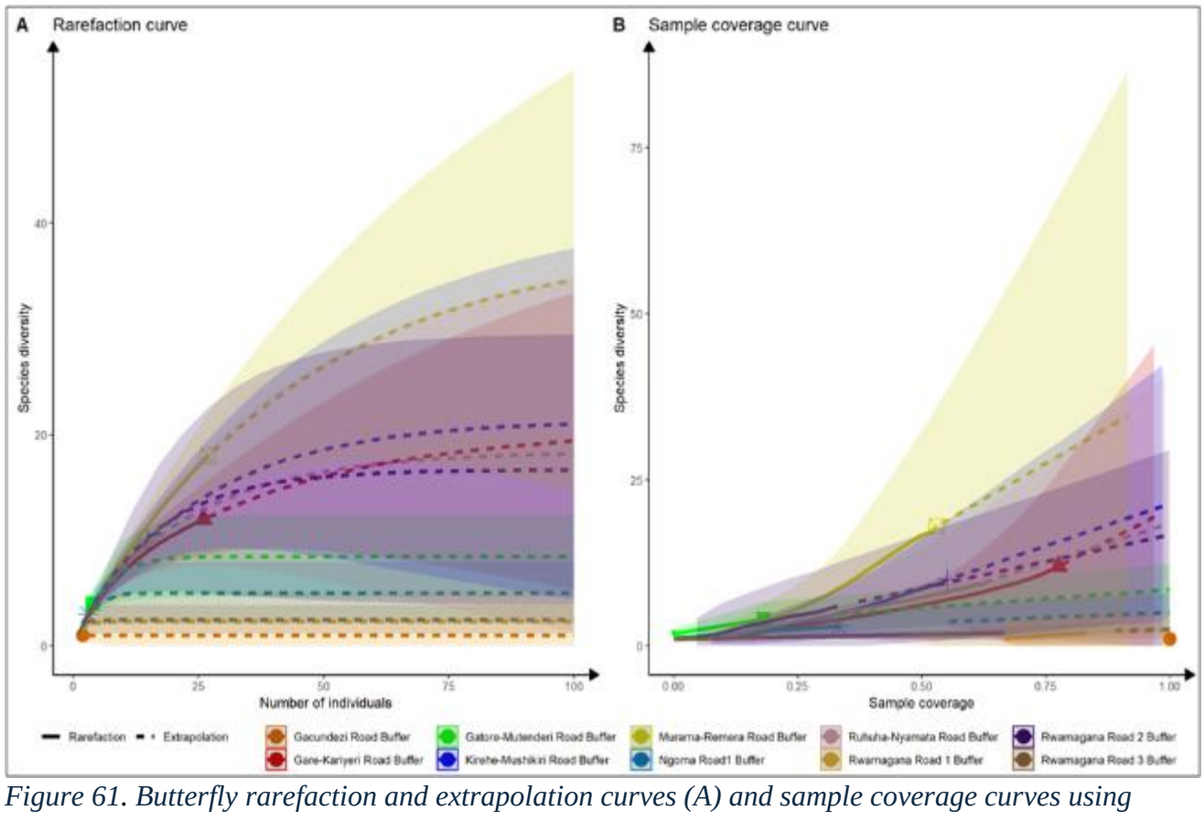

Figure 61. Butterfly rarefaction and extrapolation curves (A) and sample coverage curves using butterfly richness (Hill numbers of order 0) across the road buffers. Solid lines represent the curves based on sample data, and the dashed lines represent the extrapolations. Shaded areas represent the 95% confidence intervals surrounding the curves.

A total of 18 pollinating insects were recorded from the roads buffers. The species include managed bees (*Apis mellifera*), wild bees (*Hypotrigona sp, Thyreus nitidulus, Amegilla sp,*

Xylocopa species), flies (*Syrphidae, Eristalis sp, Eristalinus sp*), butterflies (*Bicyclus safitza, Junonia terea, Eurema brigitta, Ypthima aesterope, Eurema hecabe, Hpolimnas misipus, Boribo fatuellus, Catopsilia florella, Colotis euippe* and *Mylothris agathina*) and *Cephonodes hylas* from Sphingidae family, wasps (*Sphecidae*). We observed *Lantana camara* to be the most visited species by pollinators followed by *Asystasia gangetica* whereas the most abundant pollinator was the bee (*Apis mellifera*) followed by a wild bee (*Hypotrigona sp*) (Figure 62).

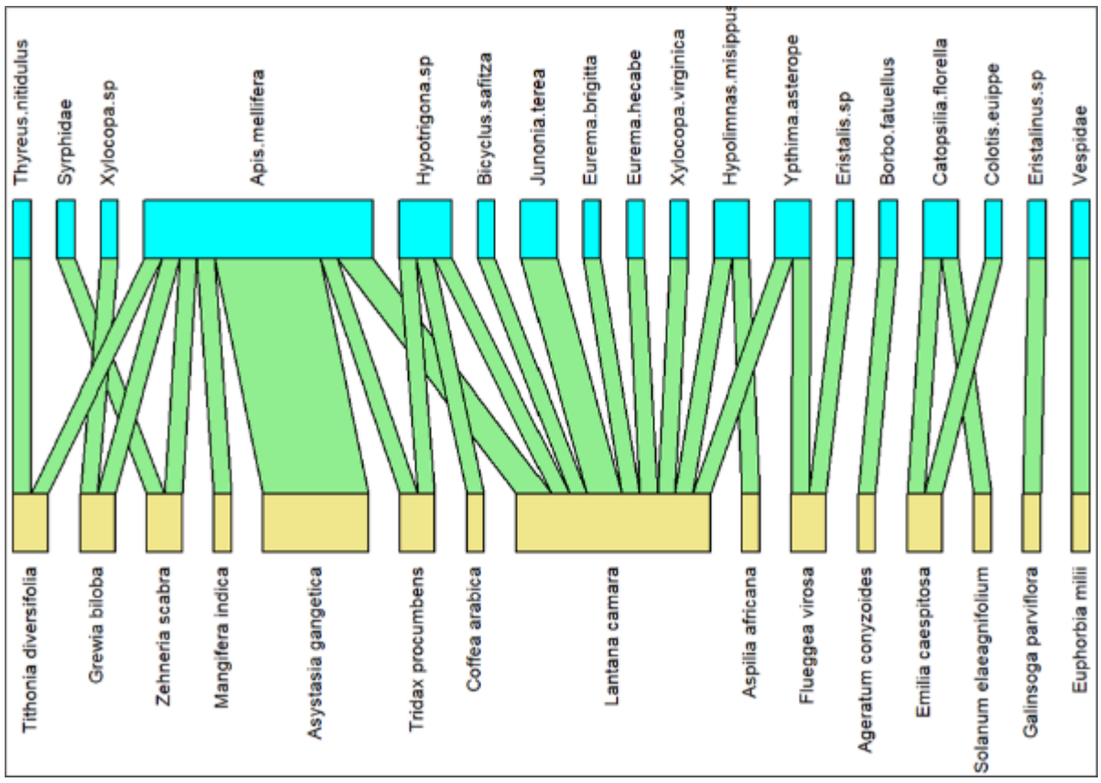

Figure 62. Network structure of plants and their pollinating insects recorded in road buffers. The upper band in dark turquoise color represents the flower visitors while the lower band in yellow color represents plant diversity (host plants). The vertical bars in the middle part of the figure (in green color) represent the linkage (which plant was visited by which insect) between plants and their pollinating insects.

Terrestrial Arthropods

The terrestrial arthropod survey included thirteen road buffers (the addition of Mukarange road buffer is the 13th). The survey found 58 arthropod families across all road buffers. Bugesera road buffer had the highest species richness (Figure 63). The most common families are Formicidae at 37%, Cercopidae at 7%, Acrididae at 6%, Salticidae at 5%, and Cicadellidae at 5%. All recorded families are not yet evaluated on the IUCN Red List.

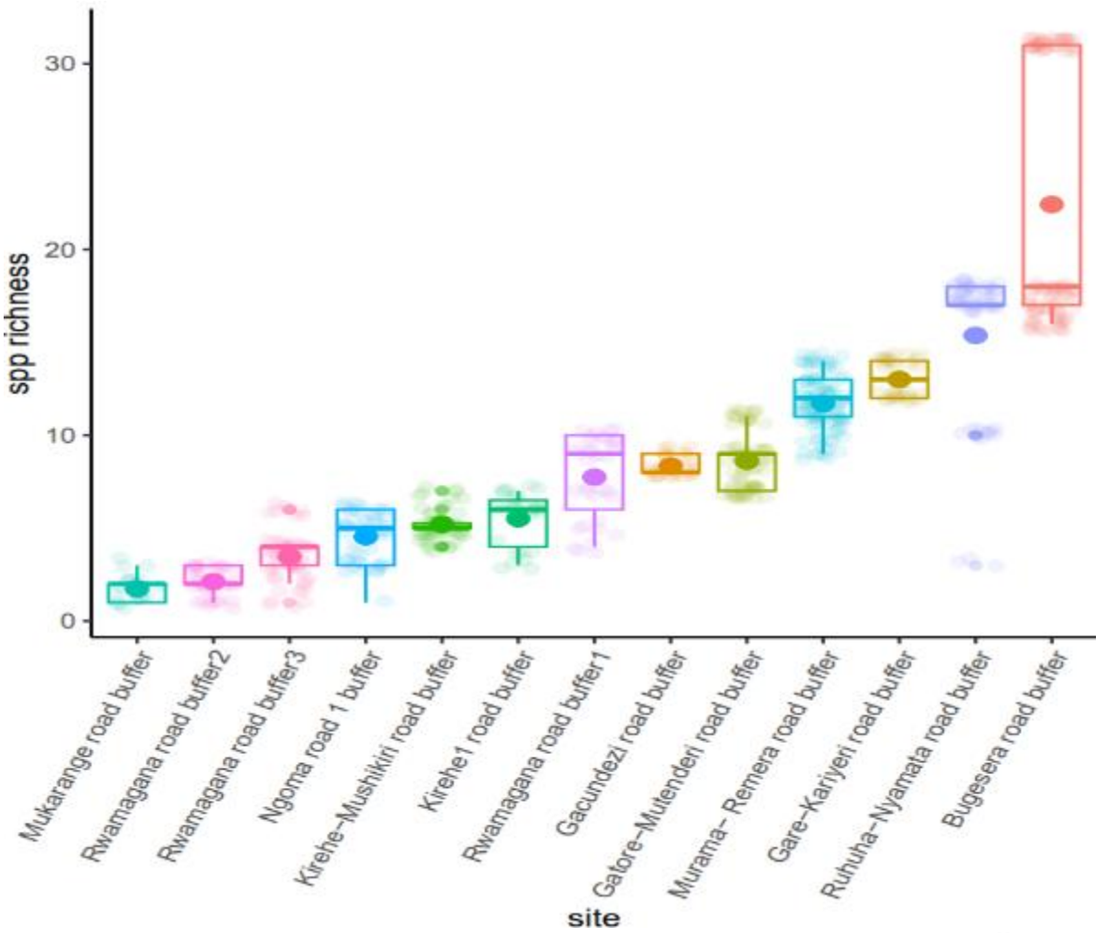

Figure 63. Terrestrial arthropod taxon richness distribution across thirteen road buffers. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represents the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to sampling stations on sampling sites.

Birds

The bird surveys in 13 road buffers (Mukarange Road buffer is the 13th) found a total of 100 bird species, representing 41 families. We observed 11 migratory species across all road buffers. The study revealed the presence of eight functional groups among the observed bird species, including Granivorous (seed-eating), Omnivorous (eating both plant and animal matter), Nectivorous (nectar-feeding), Insectivorous (insect-eating), Frugivorous (fruit-eating), Herbivorous (plant-feeding), Piscivorous (fish-feeding), and Carnivorous (meat-feeding) species. All the road buffer sites are presented in Figure 64. Mukarange Road buffer had the highest richness among all the road buffers sampled.

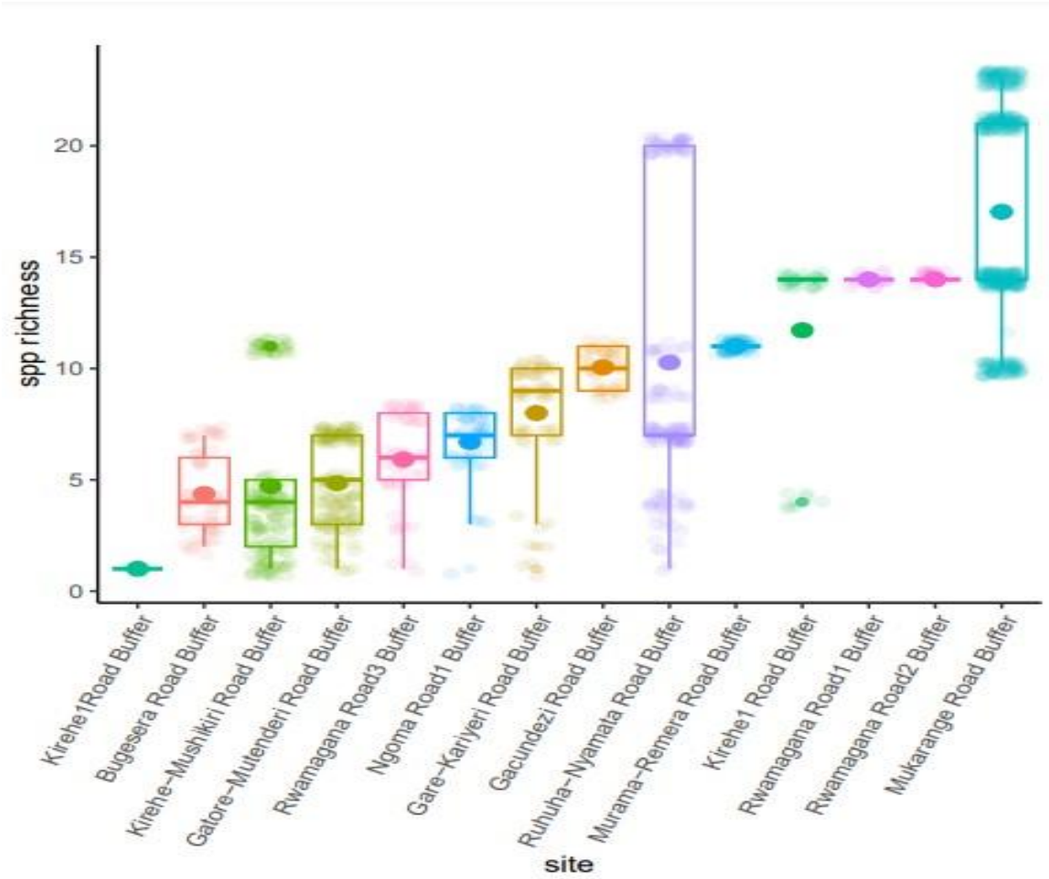

Figure 64. Bird species richness by site. Boxes represent inter-quartile range (IQR), lines in the center represent the median. Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to sampling units of point counts.

Mammals

Shrews of *Crocidura sp.* were recorded in Kirehe-Mushikiri road buffer in Kirehe district and Murama-Remera road buffer in Ngoma district (Figure 65). No other mammals were detected in any of the other road edges.

Figure 65. Two individual shrews of Crocidura sp. observed along the Murama-Remera road in Ngoma district.

Threats

For three road edges sampled, the recorded threats were waste materials or garbage in general, which include plastic materials, waste dumping, and hardware material. The total frequency (16) of waste dumping materials for the three roads compared to the frequency of plastic materials (16 records, for 80 individual plastic pieces) indicates how waste dumping is a problem on the road.

A Synthesis of Biodiversity Information for the seven intervention sites

Plants

A total of 201 plant species from 60 families were recorded across all intervention sites. Sixty percent are native to Rwanda and the region, while 40% are introduced to Rwanda. Of these species, 42.28% are listed as Least Concern on the IUCN Red List, 1.49% are reported as Data Deficient on the IUCN Red List, 0.49% are reported as Endangered, and 2% are reported as Vulnerable on the IUCN Red List, while 53.23% have not been evaluated by the IUCN Red List yet. Across all intervention sites, sylvopastoral sites had the highest species richness, followed by the Community Based Sanctuaries, with lake buffer having the least species richness. Among the Sylvopastoral lands, Buhabwa had the highest species richness while Jambo Beach CBS exhibited the highest species richness (Figure 66).

Figure 67 shows the rarefaction curves which help understand the species richness while accounting for the sampling effort. Curves that accumulate species at a more rapid rate (i.e., curves that are higher up on the graph) have higher species richness. In Figure 67, sanctuaries in blue had the highest species richness, followed by sylvopastoral lands in yellow. Sample coverage curves are used to assess the completeness of the biodiversity sampling. Curves that reach 1.00 for sampling coverage (i.e. curves that plateau and come to vertical lines at the right of the graph) represent sample coverage of 100%, indicating that the sampling effort captured the entirety of the community. Almost all of our curves reached the maximum 1.00 value, except for Lake Buffer and Road buffer, which was very close to achieving sampling completeness.

Of the intervention sites, Dam buffer sites had the highest number of introduced species, followed by CBSs, and River buffers had the least introduced species richness (Figure 68). Rugende dam buffer had the highest among other dam buffers, and Gahini CBS has the highest introduced plant species richness from among the CBSs sampled. Table 23 shows that the CBSs had the highest native tree stem density followed by sylvopastoral lands, from among the seven intervention sites.

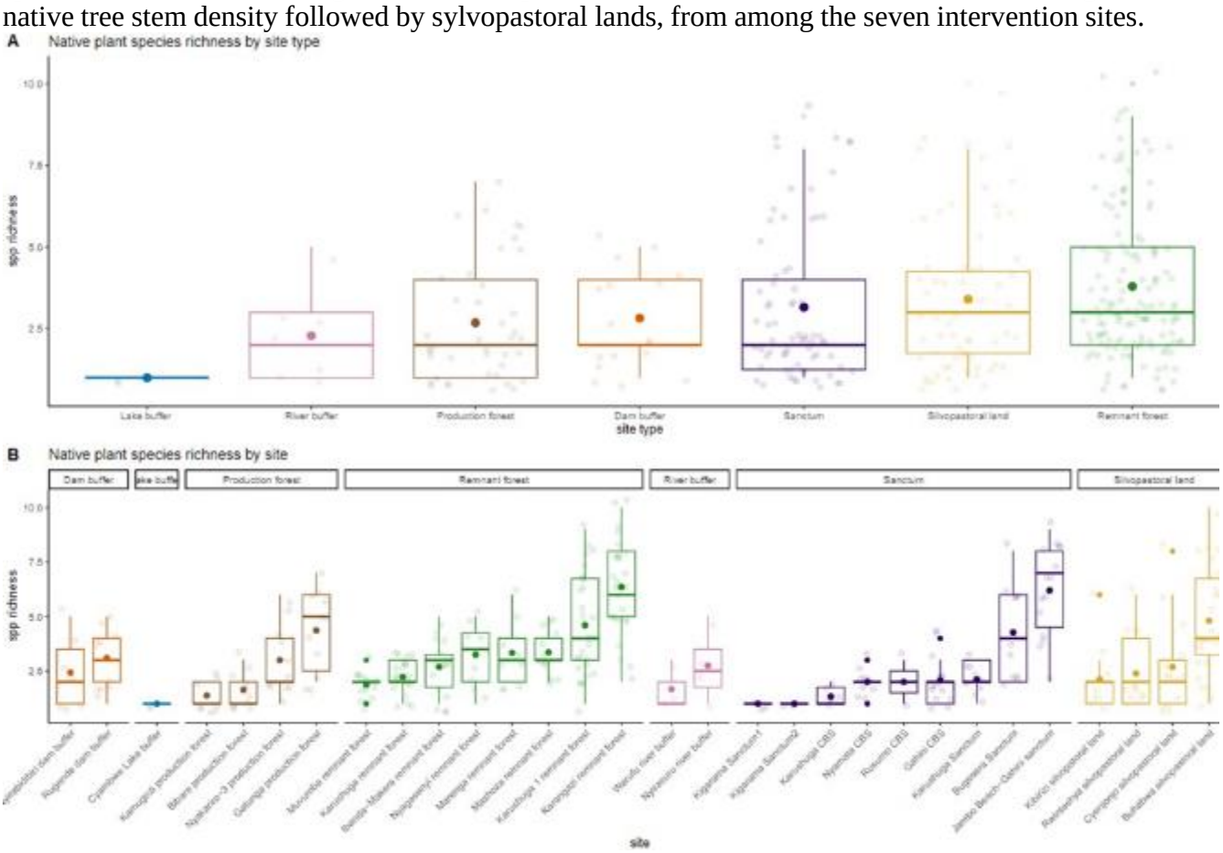

Figure 66. Native species richness by (A) site type and (B) by site in 10×10 m forest sampling plots. Figures compare species richness between seven different sites: dam buffer (red), lake buffer (blue), natural forest (green), production forest (brown), river buffer (pink), sanctuaries (purple), and sylvopastoral land (yellow). Boxes represent inter-quartile range (IQR), lines in the center represent the median. Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to 10×10 m forest sampling plots. Kruskal-Wallis test denotes no statistically significant differences between forest and sanctum sites ($p > 0.05$).

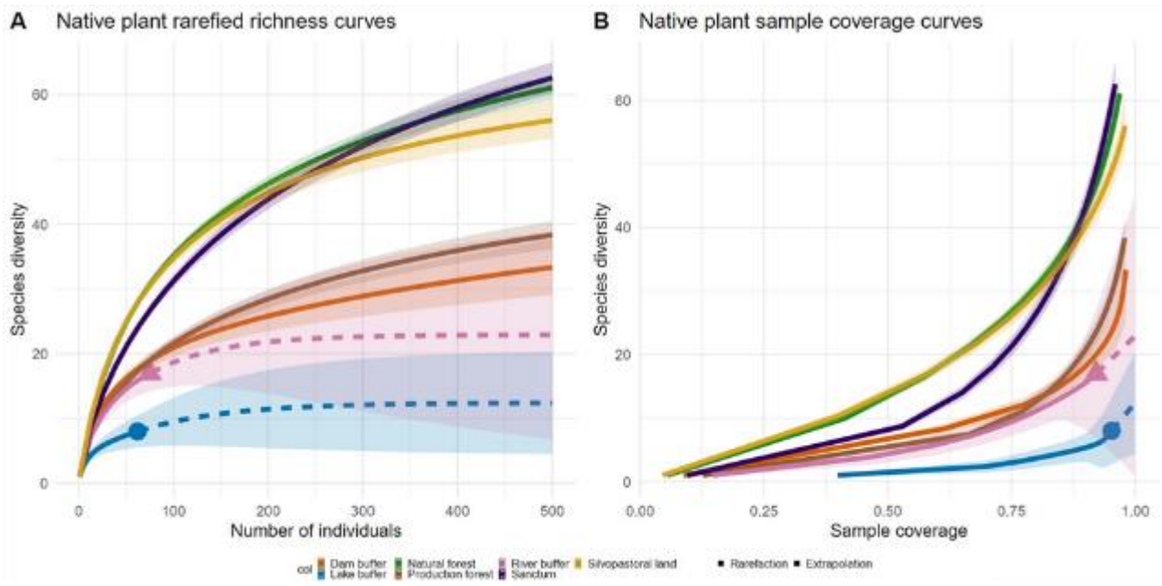

Figure 67. Sample-based (a) rarefaction and extrapolation curves and (b) sample coverage curves using native species richness (Hill numbers of order 0), comparing seven different sites: dam buffer (red), lake buffer (blue), natural forest (green), production forest (brown), river buffer (pink), sanctuaries (purple), and sylvopastoral land (yellow). Solid lines represent curves based on sample data, , while dashed lines represent extrapolations. Shaded areas represent the 95% confidence intervals surrounding the curves.

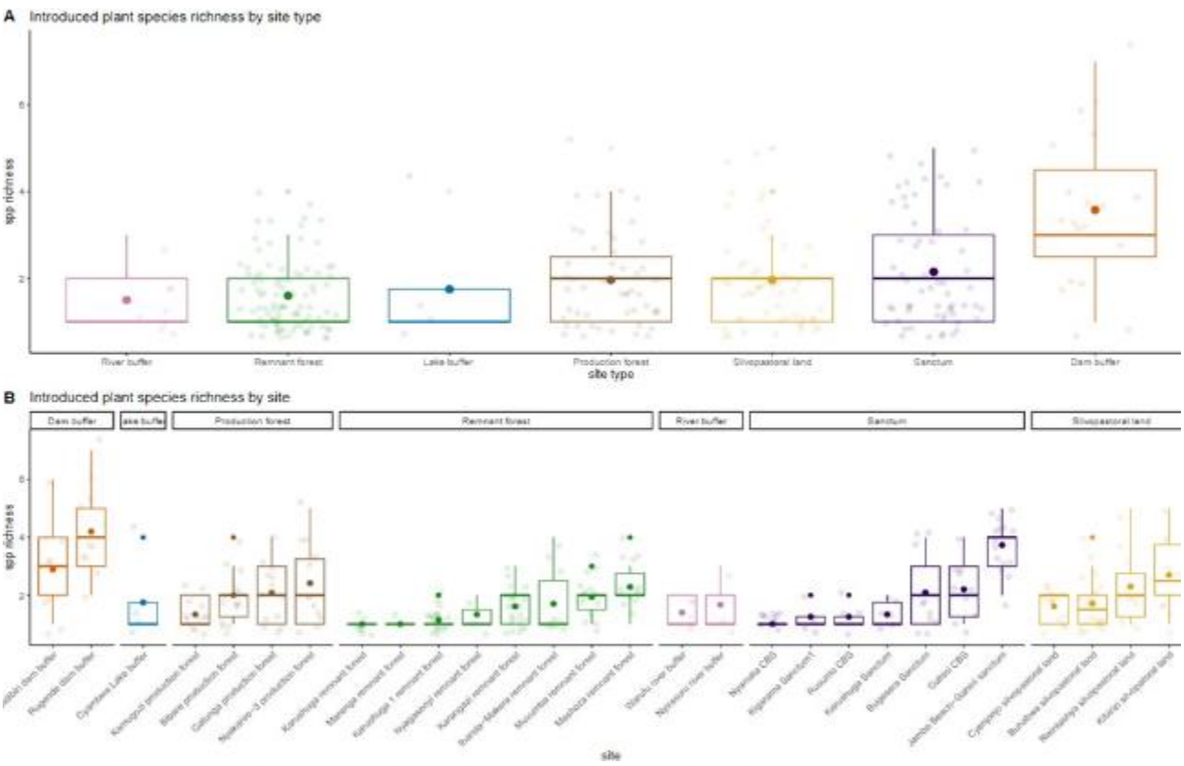

Figure 68. Introduced species richness by (A) site type and (B) by site in 10×10 m forest sampling plots. Figures compare species richness between seven different sites: dam buffer (red), lake buffer (blue), natural forest (green), production forest (brown), river buffer (pink), sanctuaries (purple), and sylvopastoral land (yellow). Boxes represent inter-quartile range (IQR), lines in the center represent the median. Whiskers correspond to largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to 10×10 m forest sampling plots. Kruskal-Wallis test denotes no statistically significant differences between forest and sanctum sites ($p > 0.05$).

Table 23. Plant species richness, diversity, diameter at breast height (DBH), native and introduced tree stem densities, mean wood density (WD) and rarity index for each intervention site in the Eastern Province, Rwanda. Natural forest remnants are included as a reference.

Site type	Spp richness	Shannon diversity	Mean DBH	Native stem density	Introduced Stem density	Mean WD	Rarity index
CBS	60	3.02	0.18	1699	1625	1.60	0.02
Natural forest remnants	73	3.48	2.24	2544	992	1.47	0.01
Dam buffer	17	1.77	3.48	250	343	1.55	0.02
Production forest	33	2.52	1.12	647	693	1.70	0.01
River buffer	11	2.07	8.41	42	33	1.57	0.02
Lake buffer	2	0.69	0.00	13	49	1.68	0.02
Sylvopastoral land	43	3.19	1.17	910	446	1.47	0.02
Road buffer	52	3.20	0.08	235	433	0.60	0.08

Herpetofauna – Amphibians and reptiles

Generally, fifteen amphibian and seventeen reptile species were recorded among the seven intervention sites. Among the recorded amphibian species only one species (*Hyperolius rwandae*) is endemic to Rwanda. Concerning the IUCN Red List of threatened species, except for one species of the genus *Phrynobatrachus* that was not identified to species level to determine its IUCN status, and one that is Data Deficient, all other species detected are Least Concerned at the Global and National IUCN Status (Dehling and Sinsch, 2023). Among the reptiles, only one species of snake (*Python sebae*) is reported Near Threatened under the IUCN Red List of threatened species. We were able to identify most specimens to the species level except for two terrapins (*Pelomedusa sp* and *Pelusios sp*) that were identified to genus level, three snake species: one to the genus level (*Philothamnus sp*) and two unidentified species (a cobra species and an unidentified brown snake that escaped observation). Further, we were not able to identify two lizards to species level that included *Trachylepis sp* and *Lygodactylus sp.*

Among the sampled sites, the highest richness of amphibians was recorded from the Forests (n=14) and reptiles from the CBS (n=7). The lowest richness was observed at the River Buffer for amphibians (n=2) and for reptiles, from the Managed Forests, sylvopastoral land, Dam Buffer, Lake Buffer, and River Buffer, with three species respectively (n=3) (Figure 69).

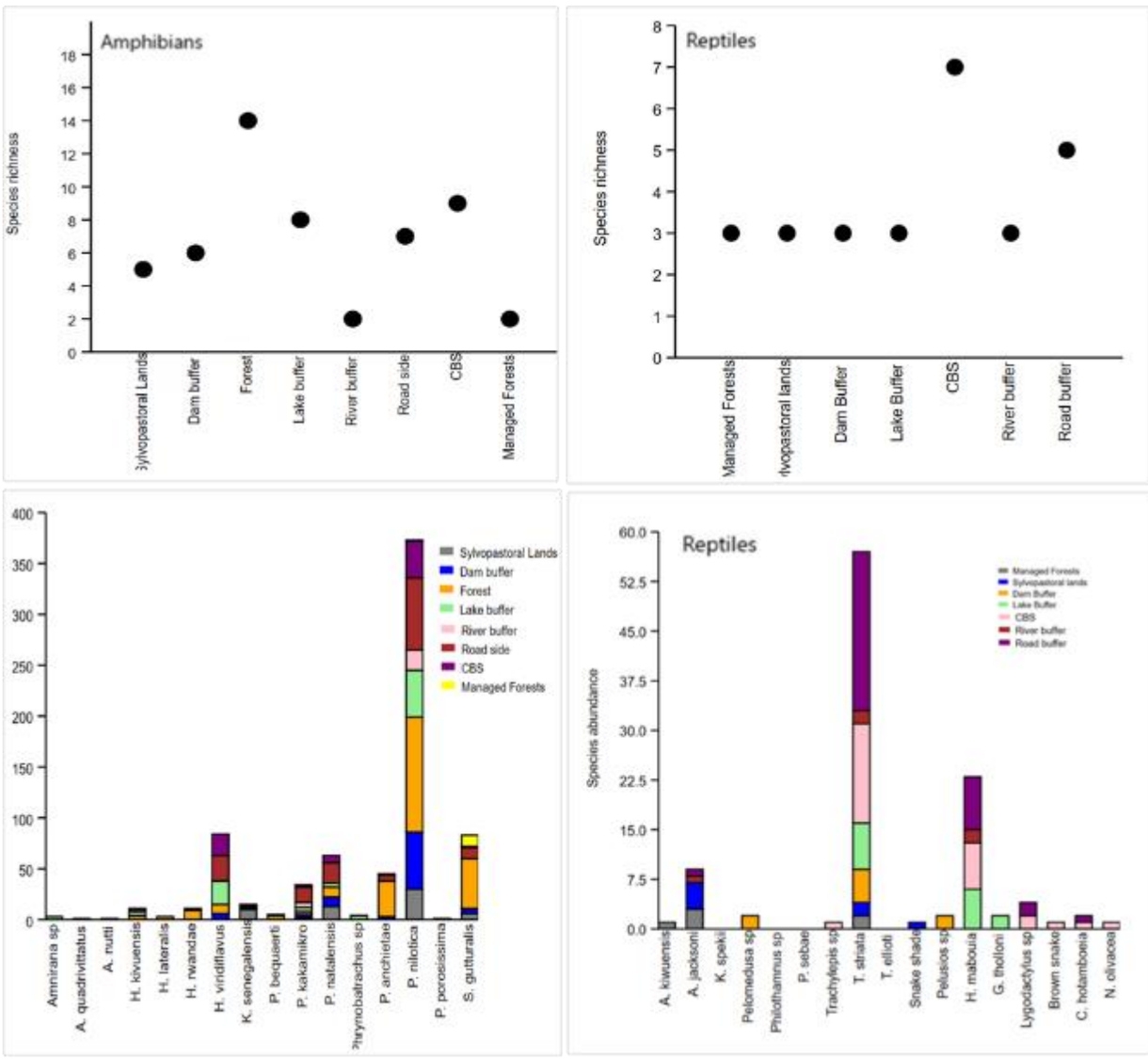

Figure 69. Species richness of both amphibian (above) and species occurrence (bottom) among the sampled sites. The dots are the species number per each sampled site. The colored bars represent the abundance data of the species per site.

Based on species occurrence among sampled sites, among amphibian species the most abundant species included *Ptychadena nilotica*. The least abundant included *Amnirana sp*, *Afrixalus quadrivittatus*, *Phrynobatrachus*, *Amietia nutti* and *H. lateralis*. The most occurring species in addition to *P. nilotica* included *Phrynobatrachus kakamikro, Phrynobatrachus natalensis, Hyperolius viridiflavus*, and *Sclerophry gutturalis.* For reptiles, the most abundant species include *Trachylepis striata* followed by *Hemidactylus mabouia.* These two species in addition to *Adolfus jacksoni* were also the most occurring species among the sampled intervention sites (Figure 69).

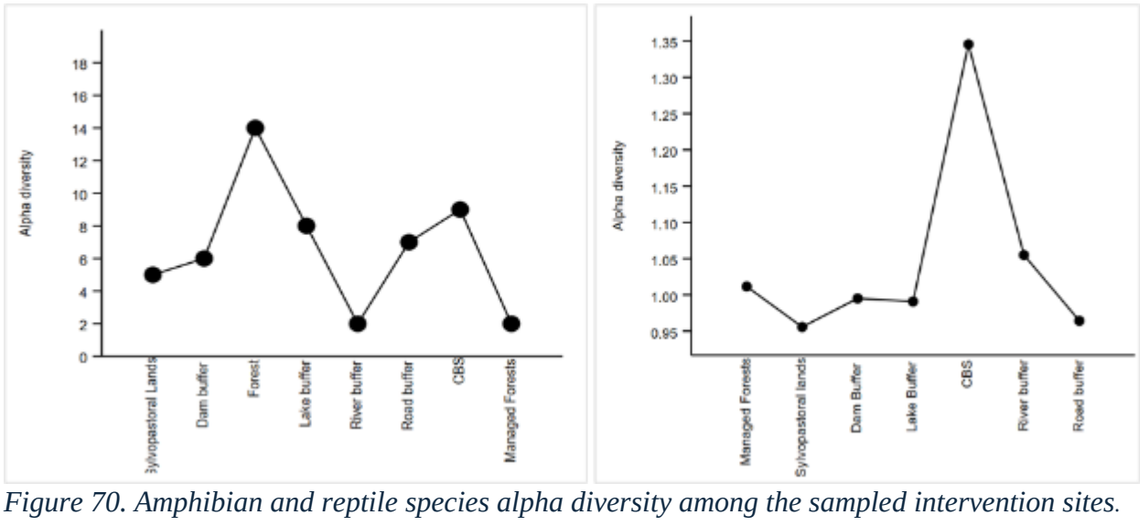

Figure 70. Amphibian and reptile species alpha diversity among the sampled intervention sites.

Among the amphibian species, Forest sites have the highest diversity of species (α=1.7), followed by Lake Buffer (α=1.4). The least diversity was observed from the Managed Forests (α=0.2). For reptiles, highest species diversity was observed at the Community Biodiversity sanctuaries (CBS) (α=1.3) and the least at the sylvopastoral land and road buffer with α=0.9 respectively (Figure 70).

However, among the observed species of amphibians, no species found are indicators of healthy ecosystems among the sampled intervention sites. Indicator species are those whose presence or absence in a particular ecosystem indicate changes in terms of disturbance or health (Hilty & Merenlender, 2000). The study by Tumushimire et al. (2020) revealed a list of amphibian species considered generalists due to their tolerance to anthropogenic disturbance and ability to occupy diversity of habitats in an ecosystem following the nature of a disturbance. Same findings were demonstrated in a study by Mindje et al. (2020) and Dehling and Dehling, (2023) where amphibians that tolerate disturbance have an increased diversity in disturbed ecosystems and the community assemblage consists merely of species that are habitat generalists. Though *Hyperolius rwandae* is known to inhabit natural vegetation such as reeds (Cyeperacae), a number of studies have also shown that the species can co-occur with those that tolerate disturbance (Sinsch et al. 2012; Mindje et al. 2020). For reptiles, though studies are still yet to indicate species that are disturbance-tolerant and those that are intolerant, in this study we observed a few species that most likely occur in all disturbed sites. Based on the frequency of species occurrence, we observed that *Trachylepis striata, Hemidactylus mabouia* and *Adolfus jacksoni* occurred more frequently in disturbed habitats that included bare soils, road edges, tree barks, holes and dried vegetation (Figure **xaD**). With this study, we suggest to consider these species as indicators of disturbance.

A number of studies have explained the relationship between richness in anuran species and types of habitats (Keller et al. 2009; Menin et al. 2005; Parris, 2004; Vasconcelos & Rossa-Feres, 2008) where, locally, anuran species presence in a particular habitat can be driven by how long water is available in a habitat (Vasconcelos & Rossa-Feres, 2009), its depth (Burne & Griffin, 2005; Gonçalves et al. 2015) and also by the structure of the habitat in terms of vegetation type within and nearby the water body (Gonçalves et al. 2015; Keller et al. 2009). This is due to the fact that amphibians need water such as ponds, streams, dams and irrigation channels marshes throughout their life cycle for breeding and developments of tadpoles (Provete et al. 2016) and later require terrestrial environment for the growth of juveniles (Knutson et al. 1999; Price et al. 2005). For reptiles, distribution factors include temperature, landscape structure and the ecological processes (Atauri and Lucio, 2001). This is the case of this study where surveyed sites consisted of different features in terms of water availability, vegetation and general ecological processes. The Eastern Province of Rwanda is known to be an area of high temperature (Seshaba et al. 2024). Temperature variation importantly affects reptile distribution and diversity where the diversity of reptiles increases with increasing temperature (McCain, 2010; Schwartz et. 2019).

Among the observed reptile species, despite scarcity of information in Rwanda about their potential use as biological indicators, this study suggests three species of reptiles *Adolfus jacksoni* (Lacertidae), *Trachylepis striata* (Scincidae) and *Hemidactylus mabouia* (Gekkonidae) to be considered as species indicator of disturbance. This is because these species are well adaptable to disturbed habitats and generally found in most habitats that constitute an ecosystem. In this study, we observed the species on bare grounds in holes, dried vegetation, in *Lantana camara*, on tree bark especially dried barks and in trenches near road edges.

This study reports for the first time the herpetofauna of the Eastern Province of Rwanda, an area of low elevation (<1900masl) that has remained unsurveyed or poorly surveyed. We have attempted to record different species of amphibians and reptiles from different intervention sites, we are certain that we have maximized the species richness for each site but still recommend further surveys for reptile species to complement the current reported list.

The accumulation curve represents the sampling effort to ensure capturing the diversity of the site. The species accumulation curve for amphibians shows a plateau which suggests the current study has reached the maximum of species to expect from the surveyed intervention sites (Figure 71). However, Production Forests can be further surveyed to fully cover the amphibian species richness of the area.

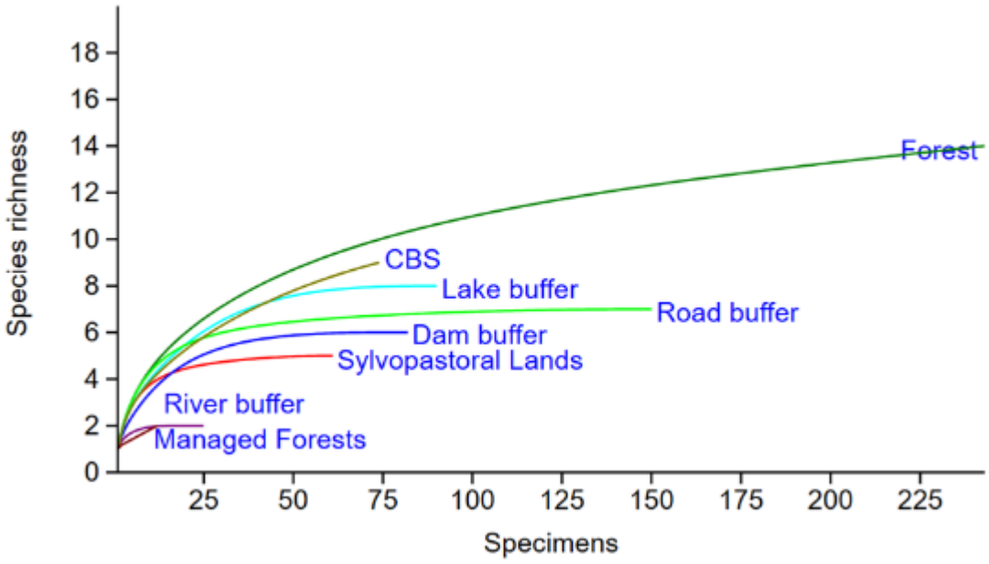

Figure 71. Amphibian species accumulation curves for each intervention site.

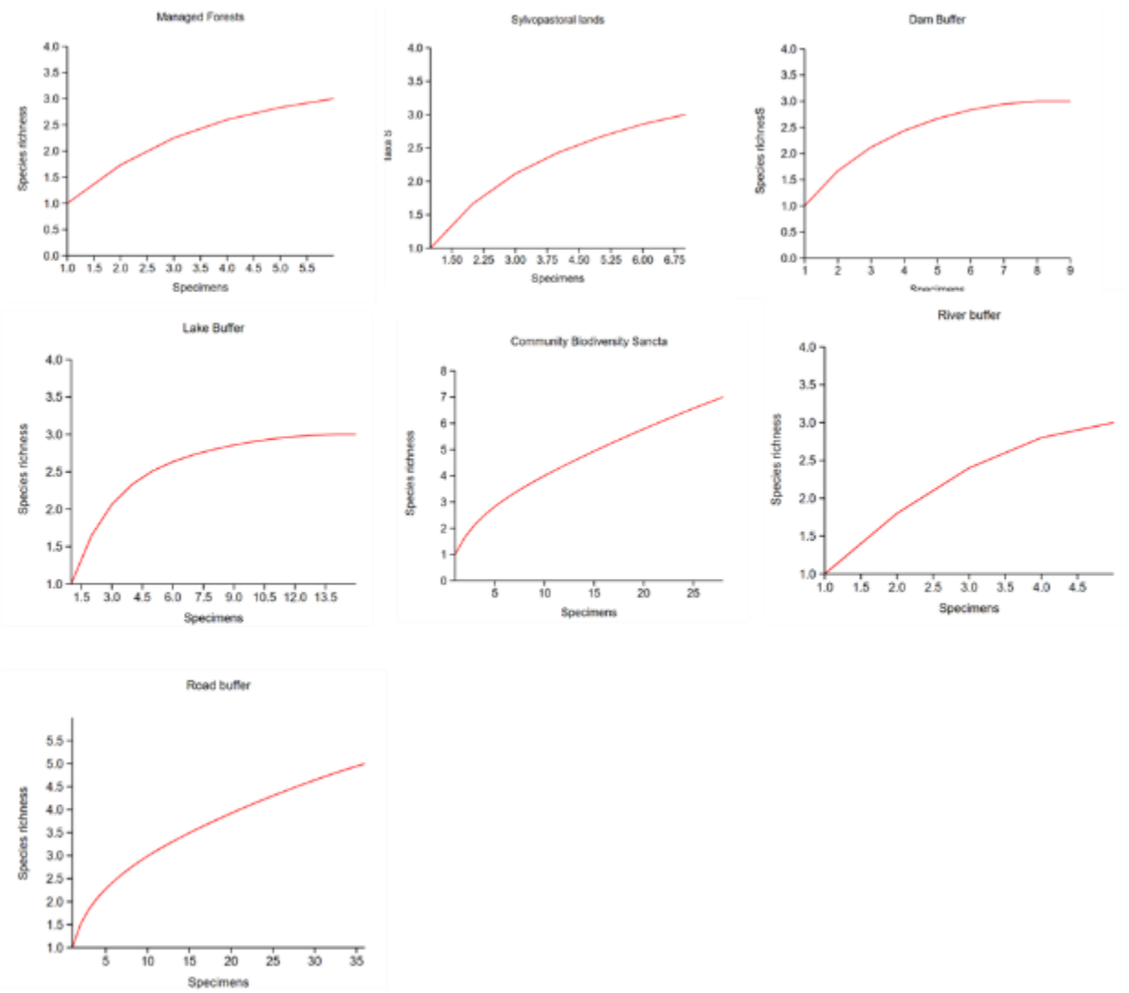

Figure 72. Reptile species accumulation curves for intervention sites.

The reptile accumulation curves show that the Dam and Lake buffers have species coverage that reached the maximum coverage, other remaining intervention sites still need to be further surveyed to fully maximize the species richness of the areas (Figure 72).

Based on the findings of this study, the seven intervention sites are in a disturbed state and hence need proper intervention for management such as restoring degraded habitats. This includes removal of invasive species found in each site and halt human exploitation of the sites to allow recovery or restoration effectiveness.

Flying insects

Seven intervention sites (Dam Buffer, Lake Buffer, Production Forest, River Buffer, Road Buffer, Sanctum and Sylvopastoral land) were visited and a total of 69 butterfly species from five families (Hesperiidae, Nymphalidae, Lycaenidae, Papilionidae and, Pieridae) were observed (Figure 73). A total of 33 butterfly species were collected from the Dam Buffer, 22 species were recorded from Lake Buffer, 35 species from Production Forest, River Buffer (n=26), Road Buffer (n=31), Community Based Sanctuaries (n=35) and 38 species from Sylvopastoral land.

In Dam Buffer, the majority of the butterflies were classified as Least Concern (LC) (75.42%) while the remaining 42.56 were under the Near Threatened (NE) category of the IUCN. The IUCN conservation status distribution across the Lake buffer is Least Concern (89.3%) and Not Evaluated (10.05%); Least Concern (87.72%) and Not Evaluated (15.59%) for the Production Forest; Least Concern (58.70%) and Not Evaluated (32.37%) for the river Buffer; Least Concern (87.62%) and Not Evaluated (14.84%) for the Road Buffer; Least Concern (90.72%) and Not Evaluated (9.28%) for the Sanctum; Least Concern (86.99%) and Not Evaluated (18.39%) for Sylvopastoral Land. More information about the species and associated information including IUCN Red List status are found in the Annex 3.

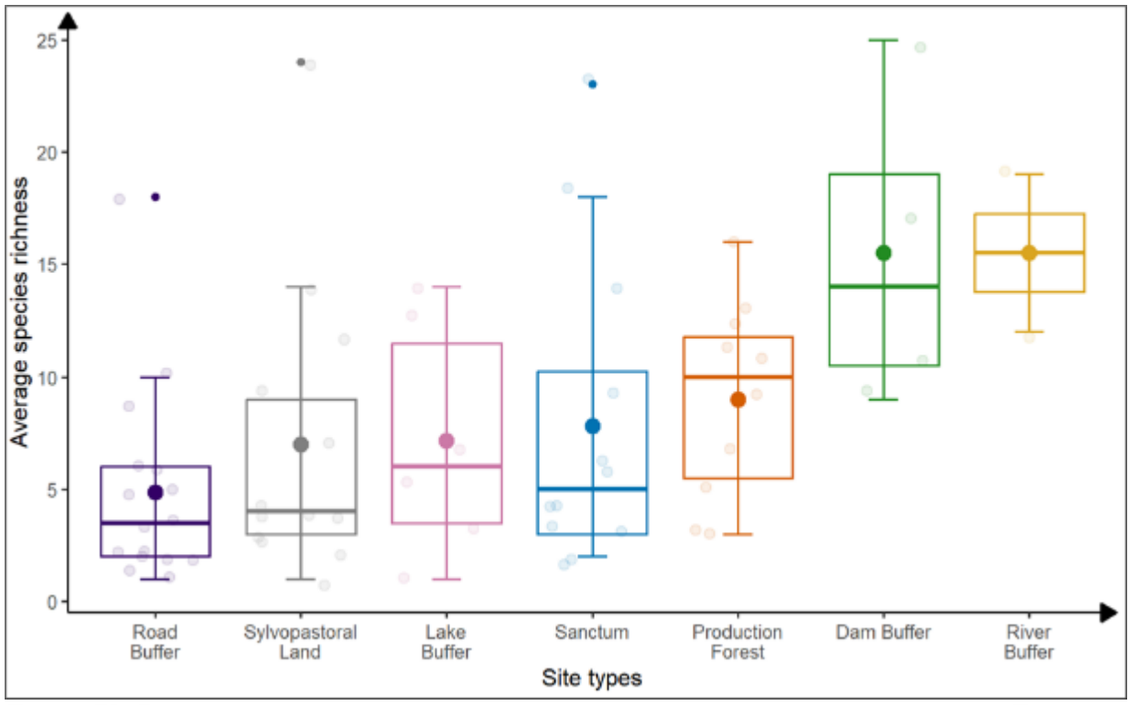

Figure 73. Butterfly richness distribution across the selected seven intervention sites. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represent the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR.

Terrestrial Arthropods

Overall, the survey revealed a total of 78 families from 14 orders in all seven intervention sites. Among the recorded families only three families - Formicidae, Salticidae and Acrididae - were recorded in all sites. Concerning the IUCN status, all families are not yet evaluated. We have been able to identify all collected terrestrial arthropods to family level. Among the sampled intervention sites, the highest taxon richness was recorded in the sanctuaries, production forest, and river buffers respectively, while the lowest richness was observed from road buffers and lake buffers (Table 24). Among the terrestrial arthropods recorded, sanctuaries have both higher species richness and diversity compared to the remaining intervention sites and least diversity observed at the road buffers.

Table 24. Taxon richness and Shannon Diversity in the Intervention sites.

	Intervention sites	**Taxon richness**	**Shannon Diversity**
1	Road Buffers	58	2.742

2	Dam Buffers	75	2.756
3	Lake Buffers	73	2.72
4	Production Forests	77	2.809
5	River Buffers	77	2.785
6	Community Based Sanctuaries (CBS)	102	3.179
7	Sylvopastoral Lands	76	2.775

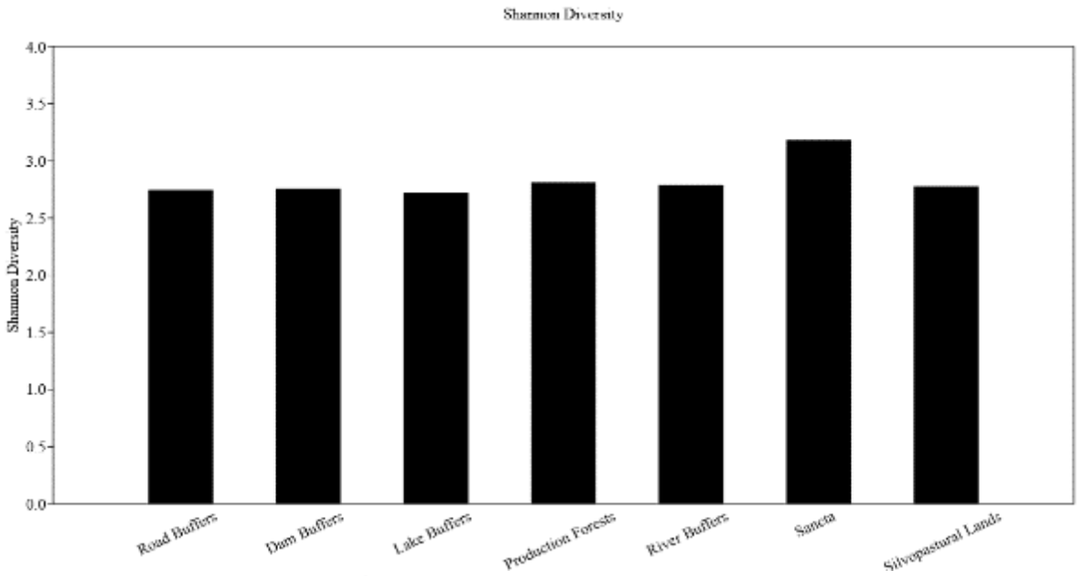

Figure 74. Shannon diversity of terrestrial arthropods among the intervention sites.

Even though road buffers were reported in this study to have lower taxon richness (n=58) findings revealed road buffers to have almost the same Shannon diversity with other interventions sites except sanctuaries (Figure 74). Since there are no indices developed yet in Rwanda to get the specific terrestrial arthropod indicators of ecosystem health, the study has relied on the abundance and diversity in the ecosystem since it gives insights of ecosystem health and integrity (Siddig et al., 2016).

Although there is no single arthropod families we can rely on to indicate the health status of an ecosystem, some species of certain families have been reported to be intolerant of pollution specifically pesticides (Ghannem et al., 2017) and we can also use functional groups of arthropods to provide information about the health of ecosystems. The more an ecosystem holds species of different functional groups, there better the ecosystem health may be, and better able to sustain various organisms. Thus assessing the health of an ecosystem can be achieved through the examination of its arthropod functional groups. Arthropods play crucial roles in ecosystem functioning, including pollination, decomposition, and nutrient cycling, and the presence and diversity of arthropods serve as indicators of ecosystem resilience and integrity (Cardoso et al., 2020). A study conducted by Harvey et al. (2023) revealed that the abundance and diversity of arthropod functional groups directly correlates with ecosystem health. An ecosystem which holds a variety of arthropod function groups indicates greater ecological stability and capacity to support different organisms across trophic levels.

Birds

The bird surveys conducted in the Eastern Province of Rwanda across seven intervention sites, including Production Forests, Sylvopastoral Lands, Dam Buffers, Lake Buffers, River Buffers, Community Based Sanctuaries, and Road Buffers has provided valuable insights into the avian biodiversity of the region. The survey aimed to shed light on the various bird species and their distribution across these sites. The survey not only contributed to the documentation of avian life in the region but also played a crucial role in understanding the ecological significance of the bird population in the Eastern Province.

The survey documented a total of 214 bird species, representing 56 families distributed in all seven intervention sites. The distribution varied (Figure 75 and see Annex 4), and understanding these variations is crucial for developing tailored conservation strategies that address the specific needs of each area (Tingley et al., 2014). One notable aspect of our findings is the presence of migratory

species, with 20 such species observed across all sites. The occurrence of migratory birds highlights the international significance of these sites as stopover points or wintering grounds for species undertaking long-distance migrations (Baillie et al., 2004).

Furthermore, our study revealed the existence of eight distinct functional groups among the observed bird species. These functional groups encompass a range of dietary preferences and ecological roles, including granivorous (seed-eating), omnivorous (eating both plant and animal matter), nectivorous (nectar-feeding), insectivorous (insect-eating), frugivorous (fruit-eating), herbivorous (plant-feeding), piscivorous (fish-feeding), and carnivorous (meat-feeding) species. The diversity of feeding strategies underscores the complex interplay of species interactions and resource utilization (Whelan et al., 2008) and is a useful indicator for the Eastern Province ecosystems.

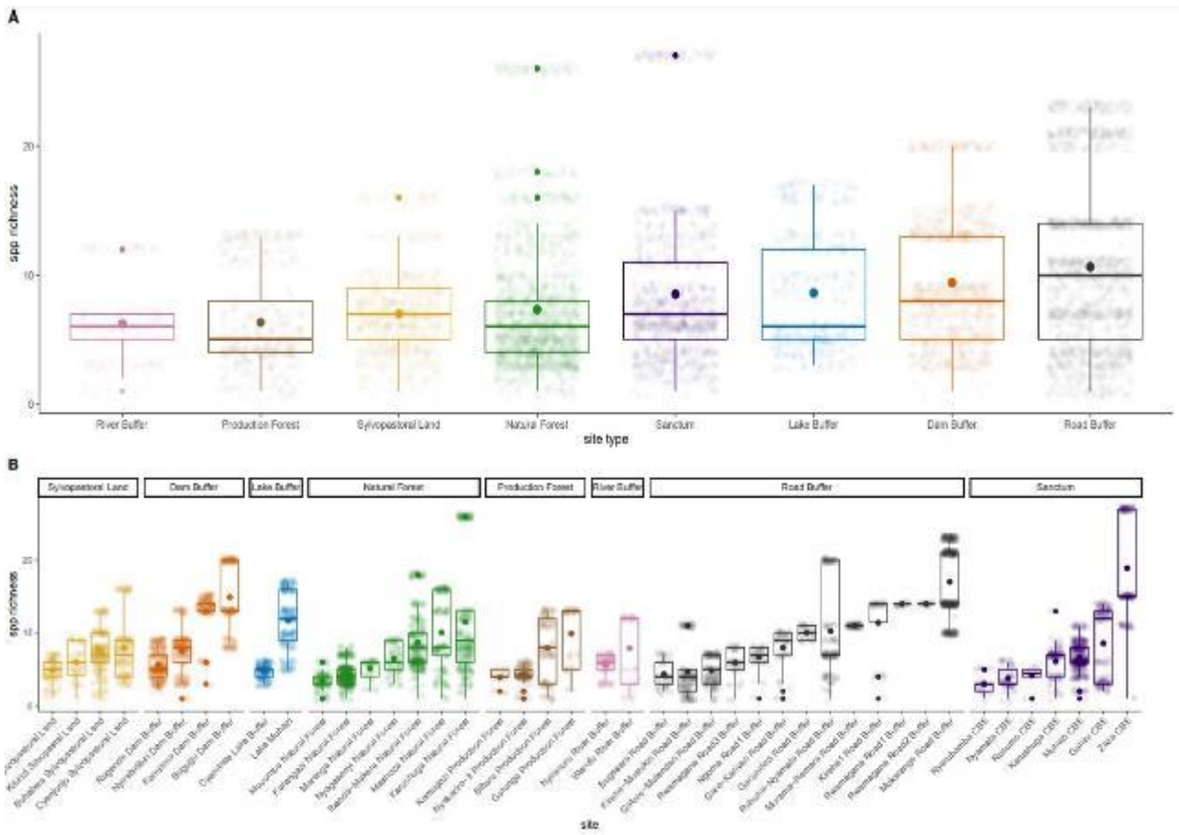

Figure 75. Bird species richness by site in each of the seven intervention sites as well as natural forest remnants of the Eastern Province (A) and richness for each site sampled with each intervention site type as well as the seven natural remnant forests (B). Boxes represent the inter-quartile range (IQR), and lines in the center represent the median. Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to sampling units of point counts.

With particular significance are the observations of two endangered species, *Psittacus erithacus* (African Grey Parrot) and *Balearica regulorum* (Grey Crowned Crane), as per the IUCN Red List criteria, as well as the near threatened species, *Laniarius mufumbiri* (Papyrus Gonoleck). These findings highlight the conservation importance of the surveyed sites and emphasize the need for targeted conservation efforts to safeguard these vulnerable species and their habitats (Waliczky et al., 2019). The bird survey provides a comprehensive overview of the avian diversity, functional ecology, and conservation significance for Eastern Province intervention sites. These findings serve as a valuable baseline for future monitoring and management initiatives aimed at preserving the region's biodiversity and ensuring the long-term sustainability of its avian communities.

Mammals

Nine species of mammals were recorded in five of the seven site types, with each species occurring in one type of site (Figure 76). Apart from the sanctuaries where five of those mammal species were recorded, single species were recorded on other site types. The species observed include four species of carnivores (*Leptailurus serval, Felis silvestris, Canis adustus, Herpestes sp.*), the hippopotamus *Hippopotamus amphibius*, a species of shrew *Crocidura sp.*, two species of rodents (*Mus minutoides, Lemniscomys striatus*) and the African savannah hare *Lepus victoriae*. The rare

records are the savannah hare and the serval. Except for the hippopotamus classified as Vulnerable (VU) on the Red List, other species recorded are in the category of Least Concern (LC). There is no endemic species observed in these sites. The site types where no mammals were observed are Production Forests and river buffers.

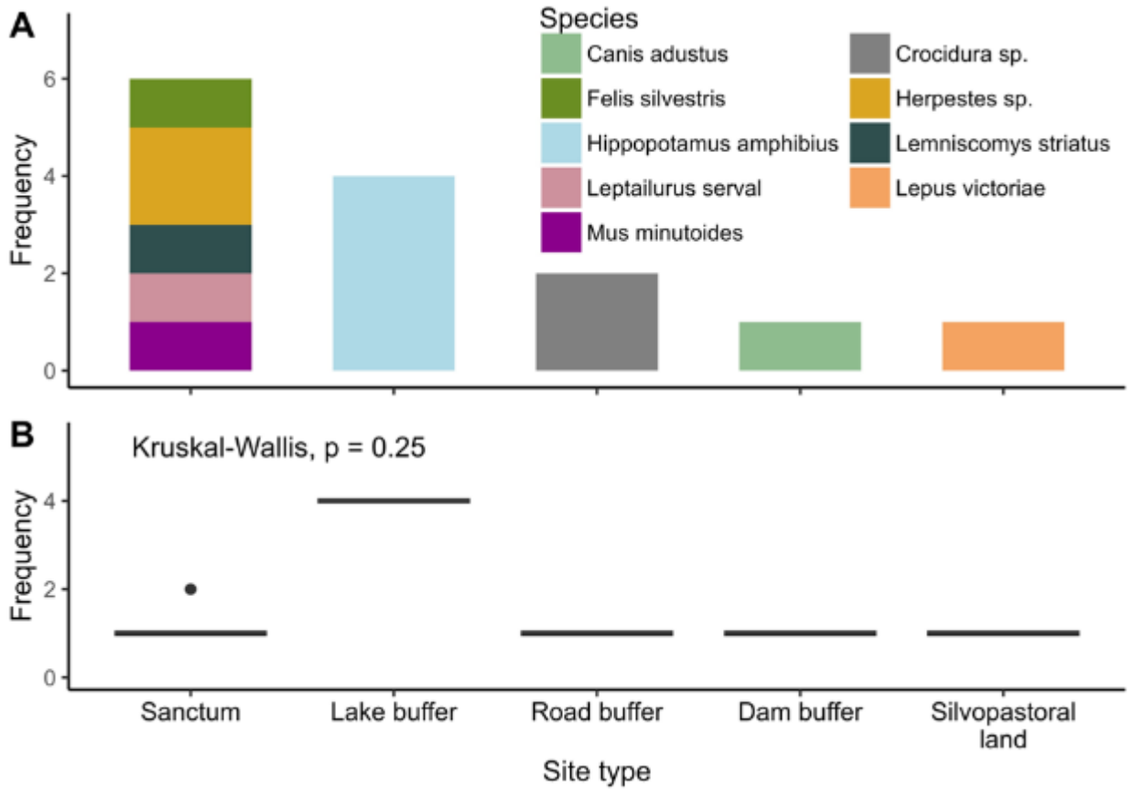

Figure 76. Frequency of mammals recorded in seven site types that were surveyed in the Eastern Province of Rwanda; no mammal was recorded in Production Forests and river buffers. A shows the abundance accumulated by species of mammal. B shows frequency of occurrence by site type summarized in a box plot; thick line shows the median value, with no significant difference between site types (Kruskal-Wallis test, p = 0.25).

Mammals include the most common organisms among vertebrates due to their roles in natural ecosystems and the interests a large fraction of people attach to them for ecological science, nature exploration, and ecotourism. Increasing amount, quality and habitat connectivity of semi-natural habitats are important to address the problems associated with negative anthropogenic effects which affect mammal species presence (Fuentes-Montemayor et al. 2020). Tognelli (2005) defined four groups of mammal indicator species: IUCN listed species, geographically rare species, flagship species, and large mammals.

While other important categories were not found in our survey, we have sufficient information about rare species. Unlike other wildlife groups used as biological indicators, mammals have been affected by people through hunting or illegal killing, so sometimes their decline is not related to changes in ecological conditions over a place, with the exception of wetland mammals (Schneider, 2010). A study of indicator species of small mammals showed that species richness and diversity decline with habitat degradation, and there is a dominance of at least one species at low ecological integrity (Horváth et al. 2011). Hippopotamus can be good indicators of climate change among large mammals, mainly due to their requirement for rather specialized habitat or microhabitat requirements which will likely be adversely affected by climate change (Shilla, 2014), which also could be measured alongside the habitat restoration practices.

Our sampling of the intervention sites did not find generally known indicator species for the region; the assumption is that terrestrial small mammals are good indicator species for habitat quality and suitability (Avenant, 2000; Horváth et al. 2011; Leis et al. 2008; Root-Bernstein et al. 2014). Future monitoring of these sites should include a variety of mammal species (Chase et al. 2000), representing various taxa and life histories (Carignan & Villard, 2002), or response-guild approaches (Croonquist & Brooks, 1991). We recommend more studies of small mammals which will likely provide more species that can be used as ecological indicators. For example, it is likely to find the *Rattus sp.* in highly disturbed ecosystems. *Rattus norvegicus* is an introduced species which has been mentioned as an indicator species of disturbed ecosystems (Lee & Rudd, 2003);

some commensals of human habitations, settlements, and agriculture such as the *Rattus sp*. and the mole rat *Tachyoryctes* may be considered in monitoring.

Threats

The most dominant threat for all the sites is plastic materials (172 records, with 423 individual plastics pieces) (Figure 77). The other prevalent threat is waste dumping, which was composed mostly of plastic mixed with other types of garbage. Other threats are sequentially, in their decreasing order of frequency of occurrence: agriculture, charcoal making, human excreta, groundcover clearing, burning, livestock grazing, hardware material, mining, poaching, tree cutting, and water pollution. Thirteen types of threats were recorded in the seven intervention sites; plastic materials were the most commonly observed, and the most affected sites are the CBSs.

Frequency of occurrence of threats in the sanctuaries was more than double that of the other site types. Fewer threats were encountered in river buffers. The main threat encountered during the survey and found at each site type is plastics; no other threat was cross-cutting for every site type. Together, plastics and waste dumping comprised the bulk of the threats that were encountered.

Other main observations:

1) Many agriculture activities still occur on sites where they are formally prohibited as in buffer zones of lakes, rivers, and dams
2) Most human excreta occurrences were in sanctuaries, where are also found most occurrence of plastics, which highlight frequent of access and use by people
3) Livestock grazing occurs most abundantly in sanctuaries in comparison to other sites
4) Charcoal making occurs mostly in the Production Forests
5) Burning has occurred mostly in the lake buffer sites

Plastics have been a pervasive threat throughout the country and national efforts through Rwanda Environment Management Authority (REMA) have been advocating in the regulation of their use. In places outside protected areas or public spaces, efforts to reduce plastic use and dumping need to be enhanced. Livestock grazing has negative effects on small mammal species living in woodland habitats (Fuentes-Montemayor et al. 2020).

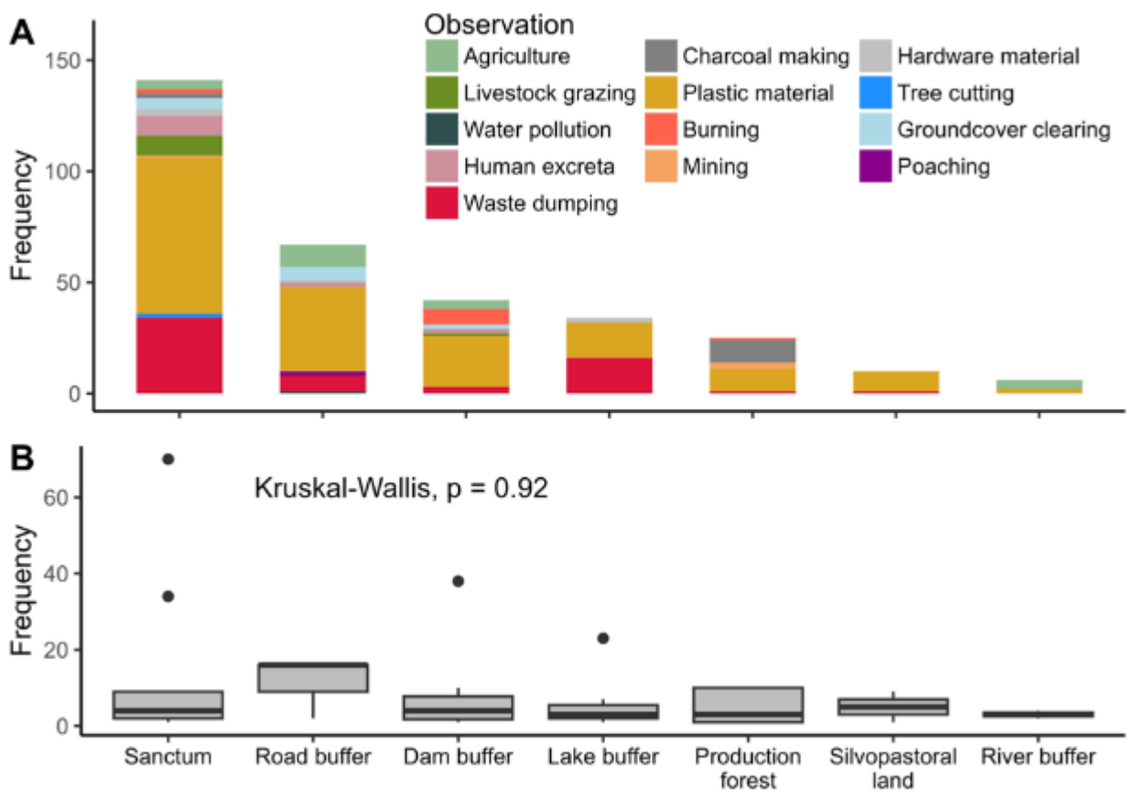

Figure 77. Abundance of the threats and human disturbances recorded in the seven site types that were surveyed in the Eastern Province of Rwanda. Figure A shows the abundance accumulated by the categories of threats. Figure B shows frequencies by site type summarized in box plots, where the thick line shows the median value; the difference between sites was not significant (Kruskal-Wallis test, p = 0.11).

Conclusions and Recommendations for Monitoring

We have summarized the taxon and threats information into table format across the intervention sites to enable users of this report to capture the status of each site based on key biodiversity elements (Table 25). These include scores for presence and number of invasive plant species (a higher score means fewer invasive species), presence of late successional plant species (which indicates a healthy forest with older, larger canopy tree species present), an amphibian tolerance score based on number of amphibians present that are tolerant to pollution and disturbed ecosystems, presence and number of endangered or threatened herpetofauna (with high scores for forests harboring more endangered or threatened species based on the IUCN Red List), number of migratory species with higher scores for more migratory species observed in a forest, number of endangered or threatened bird species with high score for more of these species observed in a forest, number of butterfly and terrestrial arthropod functional groups (diversity of different functional groups is an indicator of ecosystem integrity and the more functional groups present the higher the score), number of mammal species observed in each forest, mammal score based on rarity and value as an indicator of forest ecosystem integrity (with higher scores for more species that are rare or indicate integrity). Threats were also scored, with higher scores for intervention sites with less presence of human activities and threats.

These scores were summed for each intervention site to give an indication of the overall 'biodiversity score' for each of the seven sites. These scores are qualitative and this table can be used to guide future restoration and monitoring activities. The tables provide information about the baseline of the intervention sites and can help to track their trajectory over time as protection, conservation and rehabilitation activities are implemented. The monitoring could target all or a subset of the taxon groups surveyed in this report. Table 25 also includes recommendations for interventions for each forest remnant based on the findings.

Table 26 presents specific species across all taxon groups sampled that can be used to help monitor status and restoration trajectory over time. The table provides species names and what they indicate in the forest, either forest health and integrity, or disturbed forest ecosystems. These are species to pay attention to in the process of restoration and conservation.

The recommendation for the monitoring plan for these intervention sites should include a suite of the taxon groups included in this baseline assessment which serve as indicators of restoration and ecosystem integrity or health. Specifically: presence of invasive species, density or frequency of native species using the checklists in annex as the baseline, diversity of birds and butterflies which represent indicator groups for ecosystem integrity, presence of sensitive or intolerant amphibian species (from checklist in annex) which indicate ecosystem integrity, and presence of threats which can be compared to the baseline data presented in this report. The scores can be generated in resampling campaigns (e.g., migratory bird species presence, amphibian tolerant species, late successional native tree species) and compared with the baselines in Table 4. Monitoring should be conducted at least once a year; if more funds are available it can be done more frequently, every six months for example. The main constraints are time and funds. Community members can be involved in monitoring of different taxon groups with basic training and recording materials provided. In addition, monitoring of change in land cover should be combined with these biodiversity elements and the threats and disturbances assessments.

The team from the Center of Excellence in Biodiversity and Natural Resource Management that completed this work is shown in Annex 5. These individuals may be contacted regarding taxonomy or other aspects of their respective taxon groups.

Table 25. Status of the seven intervention sites based on the biodiversity baseline sampling (high score means healthier forest in better condition)

	Production Forests	**Sylvopastoral Lands**	**Dam buffer**	**Lake buffer**	**Community Based Sanctuaries**	**River buffer**	**Road buffer**
Plant invasive spp score	2	3	1	2	2	2	1
Plant late successional spp status	1	1	2	1	2	2	1
Amphibian tolerance score	0	0	0	0	0	0	0
Herp Threatened or Endangered spp	0	0	0	0	0	0	0
Butterflies functional group score	4	4	4	1	3	4	3
Terrestrial Arthropod functional group score	1	2	2	3	3	2	2
Bird migratory spp score	3	0	2	3	3	1	3
Bird Threatened or Endangered spp score	0	1	0	1	0	0	0
Mammal encounter rate score	0	1	1	1	5	0	1
Mammal indicator score	0	1	0	1	2	0	0

Threats encounter rate score	3	4	2	2	1	4	3
Biodiversity status score	**13**	**14**	**16**	**17**	**25**	**12**	**14**
Comments	These forests were seen to be logged by humans and the vegetation grazed by cattle	These lands are mostly exploited by agriculture and cattle farming.	These areas were found to be used for cattle grazing and human use of dam water for fishing and waste dumping. Pollution of water comes from human activities such as agriculture and laundry.	These areas were found to be used for cattle grazing.	CBSs were merely dominated by livestock farming and logging of trees by humans.	These are areas used by amphibians and reptiles for shading and predation. Most buffers were used for cattle grazing, plastic wastes dumping.	The buffer areas were found to be dominated by agriculture, especially banana plantations.
Recommendations	Community awareness on the importance of conserving biodiversity in Production forests	Removing agriculture activities will contribute to the management and conservation of the site	Halting human activities to reduce pollution which will improve the health of aquatic biodiversity	Halting cattle grazing to contribute to regeneration of vegetation and recovery of biodiversity in the place	There is a need to improve the management of CBSs such as the restoration of vegetation to recover species of the area and ecosystem functions.	Improve site management through removing threats that stop biodiversity from using the habitats	Road buffer should be governed by special policies to set a distance that has to be respected before human exploitation of the area.

Table 26. Species to pay attention to in future monitoring of intervention sites

Taxon group	**Category (invasive, endemic, threatened or endangered)**	**Indicator species (write in what it indicates: disturbed or undisturbed)**	
Plants	Invasive	*Lantana camara, Biancaea decapetala, Mimosa pigra, Agave sisalana, Searsia natalensis*	Disturbed ecosystems
	Endangered or threatened	*Osyris lanceolata, Prunus africana, Euphorbia grantii, Mimusops bagshawei*	Healthy ecosystems
Herps	Endemic species Vulnerable Near Threatened	*Hyperolius rwandae* *Hyperolius lateralis* *Hyperolius cinnamomeoventris* *Python sebae*	Healthy ecosystems
	Tolerant species	*Afrixalus quadrivittatus, Amietia nutti, Hyperolius kivuensis, Hyperolius viridiflavus, Hyperolius rwandae, Kassina senegalensis, Ptychadena nilotica, Ptychadena anchietae, Ptychadena porosissima, Phrynobatrachus natalensis, Phrynobatrachus kakamikro, Sclerophrys gutturalis, Sclerophrys kisoloensis* **We also suggest to include these species for reptiles:** *Trachylepis striata, Hemidactylus mabouia, Adolfus jacksoni*	Disturbed ecosystems
Flying insects	Pollinators, fruit-feeders and generally flagships for insect conservation as they indicate the health of the environment (Barrios et al., 2016; Hayet et al., 2021).	*Acraea asboloplintha, Acraea uvui, Afrodryas leda, Amauris niavius, Anthene amarah, Anthene definite, Appias epaphia, Atelica galene, Xylocopa nigrita, Xylocopa flavorufa, Xylocopa caffra, Xylocopa virginica, Amegilla sp, Synagris analis, Thyreus*	Healthy ecosystems

		nitidulus, Augochlora pura, Apis mellifera Syrphidae, Vespidae, Graphium sp, Danaus chrysippus,Cacyreus lingeus, , Charaxes, Charaxes acuminatus, Charaxes candiope, Junonia chorimene Junonia stygia, Leptosia alcesta, Leptosia nupta,, Mimacraea marshalli, Monza punctata, Mylothris agathina, Nepheronia argia, Neptidopsis ophione, Pontia helice, , Uranothauma heritsia, Vanessula milcaerope, Ypthimomorpha itonia,	
Terrestrial Arthropods	Invasive	Cerambycidae Family (Asian longhorned beetle) Bupresidae Family (Jewel beetle) (Jeffrey et al., 2013)	Disturbed ecosystems. Some species of the Cerambycidae family, such as Mango tree borer (*Batocera rufomaculata*) and Citrus Longhorned beetle (*Xylotrechus chinensis*) were reported to be invasive in neighboring regions of Rwanda. But these species are not yet studied nor widely reported in Rwanda (Walther et al., 2009).
	Pesticide intolerant Pest predators Pest predators	Coccinelidae family (Lady bugs) Important in pest control; intolerant to pesticides. (Ghannem et al., 2017) Curculionidae family (Weevil) (Jeffrey et al., 2013)	Healthy ecosystem
Birds	Endangered	*Psittacus erithacus* *Balearica regulorum*	Healthy ecosystem
	Threatened	**Intra-Africa migrant**	Healthy ecosystems

	Migratory species are threatened due to the global shift in considering Convention on the Conservation of Migratory Species of Wild Animals (CMS or Bonn Convention; 1983; universal) (Baillie et al., 2004; Bauer & Hoye, 2015; Peñuelas & Filella, 2001)**.**	*Milvus aegyptius, Halcyon senegalensis, Cuculus solitaries, Cuculus solitaries* **Local migrant** *Cinnyris mariquensis* **Full-migrant** *Anthus cinnamomeus, Merops apiaster, Streptopelia semitorquata, Streptopelia capicola, Falco naumanni, Hirundo rustica, Apus caffer, Phylloscopus trochilus, Psalidoprocne pristoptera, Hieraaetus wahlbergi, Spilopelia senegalensis, Cecropis daurica, Chrysococcyx klaas, Moctacilla flava,* and *Cecropis daurica* **Partial migrant** *Balearica regulorum* **Winter migrant** *Falco tinnunculus*	
Mammals	Vulnerable	*Hippopotamus amphibius* Species depending on aquatic environment and in need of adjacent habitat for grazing; indicator of climate change effects on water quantity and availability and human disturbances on aquatic environments	Healthy aquatic ecosystem
	Least Concern	*Leptailurus serval* Rare species that need healthy habitat and aquatic environment around, often forested habitat or away from human encroachment	Healthy ecosystem
	Least Concern	*Lepus victoriae* Often dependent on open savannah or shrubby savannah, the African savannah hare; it can tolerate	Healthy ecosystem

		safe agriculture practices that do not fragment its habitat	
	Least Concern	*Canis adustus* The large carnivore still occurring in disturbed ecosystems only where large space in marginal lands or out of humans is available for shelter, often attracted outside natural habitat	Disturbed ecosystem
	Least Concern	*Lemniscomys striatus* Often dependent on grassy or savannah vegetation and attracted to agricultural or exploited lands, this species prefers modified ecosystems and is attracted to the edges; dried-up or drying wetlands are preferred	Disturbed ecosystem
	Least Concern	*Herpestes ichneumon* The Egyptian mongoose mostly needs a shelter and cover in its ecosystem; therefore, the main threat is habitat loss and fragmentation that limit its movements and leads to its exposure to hunting; it is occasionally found near human properties.	Moderately disturbed ecosystem

References

Assiel, M., Theodore, D., Manasse, N., & Jean De Dieu, I. (2022). Assessment of Water Quality and Suitability for Irrigation of Rugende Dam, Rwanda. *International Research Journal of Engineering and Technology*, *March*, 1–15. www.irjet.net

Atauri, J. A., & de Lucio, J. V. (2001). The role of landscape structure in species richness distribution of birds, amphibians, reptiles and lepidopterans in Mediterranean landscapes. Landscape ecology, 16, 147-159.

Avenant, N. (2000). The potential utility of rodents and other small mammals as indicators of ecosystem 'integrity' of South African grasslands. Wildlife Research, 38, 626–639.

Baillie, J., Hilton-Taylor, C., & Stuart, S. (2004). 2004 Red List of Threatened Species. A Global Species Assessment. In *International Union for Conservation of Nature* (Vol. 1). https://doi.org/10.2305/IUCN.CH.2005.3.en

Bayingana, G., Mupenzi, C., & Maniragaba, A. (2021). Potential effect assessment of agricultural activities on water quality of rivers in Rwanda : " Case of Muvu mba River in Nyagatare District ." *International Journal of Environment and Agriculture Research*, *7*(1), 42–53.

Burne, M. R., & Griffin, C. R. (2005). Habitat associations of pool-breeding amphibians in eastern Massachusetts, USA. Wetlands Ecology and Management, 13(3), 247–259. https://doi.org/10.1007/s11273-004-7519-4

Buron, R., Hostetler, M. E., & Andreu, M. (2022). Urban forest fragments vs residential neighborhoods: Urban habitat preference of migratory birds. *Landscape and Urban Planning*, *227*(11), 104538. https://doi.org/https://doi.org/10.1016/j.landurbplan.2022.104538

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

Chase, M. K., Kristan, W. B., Lynam, A. J., Price, M. V., & Rotenberry, J. T. (2000). Single species as indicators of species richness and composition in California coastal sage scrub birds and small mammals. Conservation Biology, 14(2), 474–487. https://doi.org/10.1046/j.1523-1739.2000.98312.x

Cheyne, S. M., Sastramidjaja, W. J., Muhalir, Rayadin, Y., & Macdonald, D. W. (2016). Mammalian communities as indicators of disturbance across Indonesian Borneo. Global Ecology and Conservation, 7(91), 157–173. https://doi.org/10.1016/j.gecco.2016.06.002

Cardoso, P., Barton, P. S., Birkhofer, K., Chichorro, F., Deacon, C., Fartmann, T., Fukushima, C. S., Gaigher, R., Habel, J. C., Hallmann, C. A., Hill, M. J., Hochkirch, A., Kwak, M. L., Mammola, S., Ari Noriega, J., Orfinger, A. B., Pedraza, F., Pryke, J. S., Roque, F. O., … Samways, M. J. (2020). Scientists' warning to humanity on insect extinctions. *Biological Conservation*, *242* (December 2019). https://doi.org/10.1016/j.biocon.2020.108426

Chave, J., Coomes, D., Jansen, S., Lewis, S.L., Swenson, N.G., Zanne, A.E., 2009. Towards a Worldwide Wood Economics Spectrum. Ecology Letters 12, 351–366. https://doi.org/10.1111/j.1461-0248.2009.01285.x.

Croonquist, M. J., & Brooks, R. P. (1991). Use of avian and mammalian guilds as indicators of cumulative impacts in riparian-wetland areas. Environmental Management, 15(5), 701–714.

Davide, C.G., Ansoms A., Murison J. (2016). Modernising agriculture through a 'new' green revolution : the limits of the crop intensification programme in Rwanda. *Review of African political economy*, p. 277-293 http://dx.doi.org/doi:10.1080/03056244.2016.1181053

Dehling, D. M. & Dehling, J. M. (2021). Elevated alpha diversity in disturbed sites obscures regional decline and homogenization of amphibian diversity (pp. 0–2).

Dehling, J. M., & Sinsch, U. (2023). Amphibians of Rwanda: Diversity, Community Features, and Conservation Status. Diversity, 15(4). https://doi.org/10.3390/d15040512

Drake, A., de Zwaan, D., Altamirano, T., Wilson, S., Hick, K., Bravo, C., Ibarra, J., & Martin, K. (2021). Combining point counts and autonomous recording units improves avian survey efficacy across elevational gradients on two continents. *Ecology and Evolution*, *00*(13), 1–29. https://doi.org/10.1002/ece3.7678

Drewes, R., Spawls, S., Howell, K., & Ashe, J. (2002). A Field Guide to the Reptiles of East Africa. Kenya, Tanzania, Uganda, Rwanda and Burundi. Princeton University Press.

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. *Environmental Monitoring and Assessment*, *191*(3), 139. https://doi.org/10.1007/s10661-019-7226-5

Frank, A. L. and V. (1990). Distribution of Lutra Maculicollis In Rwanda: Ecological Constraints. In *Distribution* (Issue March).

Fuentes-Montemayor, E., Ferryman, M., Watts, K., Macgregor, N. A., Hambly, N., Brennan, S., Coxon, R., Langridge, H., & Park, K. J. (2020). Small mammal responses to long-term large-scale woodland creation: the influence of local and landscape-level attributes. Ecological Applications, 30(2), 1–14. https://doi.org/10.1002/eap.2028

Ghannem, S., Touaylia, S., & Boumaiza, M. (2017). *Beetles (Insecta : Coleoptera) as bioindicators of the assessment of environmental pollution*. *7039*(October). https://doi.org/10.1080/10807039.2017.1385387

Gonçalves, D. S., Crivellari, L. B., & Conte, C. E. (2015). Linking environmental drivers with amphibian species diversity in ponds from subtropical grasslands. Anais Da Academia Brasileira de Ciencias, 87(3), 1751–1762. https://doi.org/10.1590/0001-3765201520140471

Habineza, E., Nsengiyumva, J. N., Ruzigamanzi, E., & Nsanzumukiza, M. V. (2020). Profitability Analysis of Small Scale Irrigation Technology Adoption to Farmers in Nasho Sector, Rwanda. *Journal of Agricultural Chemistry and Environment*, *09*(02), 73–84. https://doi.org/10.4236/jacen.2020.92007

Hammer, Ø., Harper, D. A. T., & Ryan, P. D. (2001). PAST - PAlaeontological STatistics (Issue 1999, pp. 1–31).

Harvey, J. A., Abarca, M., Abram, P. K., Kingsolver, J. G., Ode, P. J., Stork, N., Terblanche, J. S., & Thomas, M. B. (2023). *Scientists' warning on climate change and insects*. *June 2022*, 1–37. https://doi.org/10.1002/ecm.1553

Hilty, J., & Merenlender, A. (2000). Faunal indicator taxa selection for monitoring ecosystem health. Biological conservation, 92(2), 185-197.

Holstein, J. (2015). *Insects and allies of the Kakamega Forest National Reserve, Kenya. A Field Guide for tourists and naturalists*. Stuttgart. 290 pp.

Horváth, G., Herczeg, R., Tamási, K., & Sali, N. (2011). Nestedness of small mammal assemblages and role of indicator species in isolated marshland habitats. Natura Somogyiensis, 1908(19), 281–302. https://doi.org/10.24394/natsom.2011.19.281

Hutto, R. L., Pletschet, S. M., & Hendricks, P. (1986). A Fixed-radius Point Count Method for Nonbreeding and Breeding Season Use. *The Auk*, *103*(3), 593–602. https://doi.org/10.1093/auk/103.3.593

IFAD. (2019). *Kayonza Irrigation and Integrated Watershed Management Project (KIIWP1) -*

Phase I Supervision Report. https://webapps.ifad.org/members/eb/126/docs/EB-2019-126-R-22-Project-design-report.pdf

Ines, M. (2020). *Rwanda: Three irrigation dams serve 1174 farmers in Rwamagana*. News on Green Economy, the Environment and Sustainable Development in Africa. https://www.afrik21.africa/en/rwanda-three-irrigation-dams-serve-1174-farmers-in-rwamagana/

JICA. (2020). *On-time completion of three irrigation dams in Rwamagana District worth approximately 20 million USD constructed under Japanese Grand Aid [Press release]*. *3*, 1–2. https://www.jica.go.jp/Resource/rwanda/english/office/topics/c8h0vm0000f875db-att/press201105.pdf

Keller, A., Rödel, M. O., Linsenmair, K. E., & Grafe, T. U. (2009). The importance of environmental heterogeneity for species diversity and assemblage structure in Bornean stream frogs. Journal of Animal Ecology, 78(2), 305–314. https://doi.org/10.1111/j.1365-2656.2008.01457.x

Kim, S.K., Marshall, F. & Dawson, N.M. (2022). Revisiting Rwanda's agricultural intensification policy: benefits of embracing farmer heterogeneity and crop-livestock integration strategies. *Food Sec.* **14**, 637–656. https://doi.org/10.1007/s12571-021-01241-0

Kral, K., Harmon, J., Limb, R., & Hovick, T. (2018). Improving our science: the evolution of butterfly sampling and surveying methods over time. *Journal of Insect Conservation, 22(1), 1–14.* https://doi.org/10.1007/s10841-018-0046-z

Knutson, M. G., Sauer, J. R., Olsen, D. A., Mossman, M. J., Hemesath, L. M., & Lannoo, M. J. (1999). Conservation Biology, 13(6), 1437–1446.

Larsen B, T. (1992). The butterflies of Kenya and their natural history. Oxford University Press.

Larsen, T. H. (2016). Core standardized methods for rapid biological field assessment. In Conservation International. www.conservation.org

Lee, N., & Rudd, H. (2003). Conserving biodiversity in Greater Vancouver: indicator species and habitat quality (2nd ed.). Institute of Urban Ecology.

Leis, S. A., Leslie, D. M., Engle, D. M., & Fehmi, J. S. (2008). Small mammals as indicators of short-term and long-term disturbance in mixed prairie. Environmental Monitoring and Assessment, 137(1–3), 75–84. https://doi.org/10.1007/s10661-007-9730-2

Leroy B., Petillon J., Gallon R., Canard A., & Ysnel F. (2012) Improving occurrence-based rarity metrics in conservation studies by including multiple rarity cut-off points. *Insect Conservation and Diversity*, **5**, 159-168.

Martínez-Lanfranco, J. A., Vilella, F. J., & Miller, D. A. (2022). Avian community response to a novel environment: Commercial forestry in the Campos grasslands of South America. *Forest Ecology and Management*, *503*, 119765 https://doi.org/https://doi.org/10.1016/j.foreco.2021.119765

Martins, D. J. (2015). Struik Pocket Guide: Insects of East Africa. Penguin Random House South Africa.

Martins, D. J. & Collins S. (2016). *Butterflies of East Africa*. Penguin Random House South Africa.

Marques, F. C., Bochio, G. M., Lima, M. R., & Anjos, L. Dos. (2023). The selection of indicator species of birds and mammals for the monitoring of restoration areas in a highly fragmented forest landscape. Anais Da Academia Brasileira de Ciencias, 95(2), 1–19. https://doi.org/10.1590/0001-3765202320200922

McCain, C. M. (2010). Global analysis of reptile elevational diversity. Global Ecology and Biogeography, 19(4), 541-553.

McCravy, K. W. (2018). A review of sampling and monitoring methods for beneficial arthropods in agroecosystems. *Insects*, *9*(4). https://doi.org/10.3390/insects9040170

Menin, M., Rossa-Feres, D. de C., & Giaretta, A. A. (2005). Resource use and coexistence of two syntopic hylid frogs (Anura, Hylidae). Revista Brasileira de Zoologia, 22(1), 61–72. https://doi.org/10.1590/s0101-81752005000100008

Mikova, K. (2015). Effect of Climate Change on Crop Production in Rwanda. *Earth Sciences*, *4*(3), 120. https://doi.org/10.11648/j.earth.20150403.15

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.

Momo, S.T., Ploton, P., Martin-Ducup, O., Lehnebach, R., Fortunel, C., Sagang, L.B.T., Boyemba, F., 2020. Leveraging Signatures of Plant Functional Strategies in Wood Density Profiles of African Trees to Correct Mass Estimations from Terrestrial Laser Data. Scientific Reports 10, 2001. https://doi.org/10.1038/s41598-020-58733-w.

Morris, D. W., Kotler, B. P., Brown, J. S., Sundararaj, V., & Ale, S. B. (2009). Behavioral indicators for conserving mammal diversity. Annals of the New York Academy of Sciences, 1162, 334–356. https://doi.org/10.1111/j.1749-6632.2009.04494.x

Moise, M.L. (2023). Examining the agriculture-induced environment curve hypothesis and pollution haven hypothesis in Rwanda: the role of renewable energy. *Carbon Research* 2, 1-14. https://doi.org/10.1007/s44246-023-00076-y

Mugunga, C. P., Wali, U. G., & Nyandwi, E. (2021). Vachellia kirkii forest cover shrinkage and plant diversity in the Muvumba wetland, Nyagatare, Rwanda. *Forestist*, *71*(2), 70–77. https://doi.org/10.5152/forestist.2021.20045

Naranjo, S.E. (2008). Sampling Arthropods. In: Capinera, J.L. (eds) Encyclopedia of Entomology. pp 3231–3246. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-6359-6_4014

Ndayambaje, B., Amuguni, H., Coffin-Schmitt, J., Sibo, N., Ntawubizi, M., & Vanwormer, E. (2019). Pesticide application practices and knowledge among small-scale local rice growers and communities in rwanda: A cross-sectional study. *International Journal of Environmental Research and Public Health*, *16*(23). https://doi.org/10.3390/ijerph16234770

NISR. (2023). *Fifth Rwanda Population and Housing Census, Thematic Report: Migration and spatial mobility*.

NISR. (2022). Fifth Population and Housing Census. Accessed on line March 6, 2024. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjKlffX3vqEAxUVWEEAHQEFC04QFnoECC0QAQ&url=https%3A%2F%2Fstatistics.gov.rw%2Ffile%2F13775%2Fdownload%3Ftoken%3DzpRqCk04&usg=AOvVaw0hQAeQqkuRtWfShJD2fBfe&opi=89978449

Nsengimana, O., Becker, M., Ruhagazi, D., & Niyomwungeri, J. F. (2019). Minimum population size and distribution of Grey Crowned Cranes Balearica regulorum in Rwanda: an aerial and ground survey. *Ostrich*, *90*(1), 79–83. https://doi.org/10.2989/00306525.2018.1540445

Nsengimana, V. (2022). *Physico-Chemical Parameters Of Water And Heavy Metal Level* (Issue 218001905).

Ntayomba, J., Ying, L. X., Godfrey, B. M., & Gasasira, E. (2021). The application of Rainwater harvesting technology a water resource management method , for pertinently attaining an eminence of water and ecological conservancy The application of Rainwater harvesting technology a water resource management method , for p. *International Research Journal of Engineering and Technology (IRJET)*, *8*(February).

O'Connor, R. J., & Hicks, R. K. (1980). The influence of weather conditions on the detection of birds during Common Birds Census fieldwork. *Bird Study*, *27*(3), 137–151. https://doi.org/10.1080/00063658009476672

Oksanen, J., Simpson, G.L., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Peter Solymos, M.H.H.S., Szoecs, E., Wagner, H., Barbour, M., Bedward, M., Bolker, B., Borcard, D., Carvalho, G., Chirico, M., Caceres, M., Durand, S., Evangelista, H.B.A., FitzJohn, R., Friendly, M., Furneaux, B., Hannigan, G., O, M., Weedon, J., 2022. vegan: Community Ecology Package. R package version 2.6-4. https://CRAN.R-project.org/package=vegan.

Parris, K. M. (2004). Environmental and spatial variables influence the composition of frog assemblages in sub-tropical eastern Australia. Ecography 27(3), 392-400.

Picker, M. Griffiths C. & Weaving A. (2019). Field Guide to Insects of South Africa. 527 pages. Penguin Random House South Africa

Price, S. J., Marks, D. R., Howe, R. W., Hanowski, J. A. M., & Niemi, G. J. (2005). The importance of spatial scale for conservation and assessment of anuran populations in coastal wetlands of the western Great Lakes, USA. Landscape Ecology, 20(4), 441–454. https://doi.org/10.1007/s10980-004-3167-6

Provete, D. B., Gonçalves-Souza, T., Garey, M. V., Martins, I. A., & Rossa-Feres, D. D. C. (2014). Broad-scale spatial patterns of canopy cover and pond morphology affect the structure of a Neotropical amphibian metacommunity. Hydro, 734(1), 69–79. https://doi.org/http://dx.doi.org/10.1101/071704

R Core Team. (2023). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing.

REMA. (2008). *Rwanda state of environment and outlook.* Kigali, Rwanda

Roelke, C. E., & Smith, E. N. (2010). Herpetofauna, Parc National des Volcans, Republic of Rwanda. Check List 6(4), 6(4), 525–531.

Root-Bernstein, M., Bennett, M., Armesto, J. J., & Ebensperger, L. A. (2014). Small mammals as indicators of cryptic plant species diversity in the central Chilean plant endemicity hotspot. Global Ecology and Conservation, 2, 277–288. https://doi.org/10.1016/j.gecco.2014.10.006

RWAMAGANA. (2019). *7. The Marshlands in Rwamagana* (p. 75). http://197.243.22.137/rwamagana/fileadmin/user_upload/Rwamagana_Marshland.pdf

RWB. (2021). *Annual water storage status report for 2020-2021*. https://waterportal.rwb.rw/sites/default/files/2021-07/Water Storage Status_June 2021.pdf

RWB. (2023). *Annual Water Storage Status Report for 2022-2023*. 1–33. https://waterportal.rwb.rw/sites/default/files/2023-09/FINAL WATER STORAGE STATUS_AUGUST 2023.pdf#:~:text=Valley dams have been introduced in Eastern,during dry seasons%2C some of them get

Schneider, M. (2010). Freshwater mammals as indicators of habitat condition. In C. Hurford, M. Schneider, & I. Cowx (Eds.), Conservation monitoring in freshwater habitats: A practical guide and case studies (pp. 33–44). https://doi.org/10.1007/978-1-4020-9278-7

Schwarz, R., Stark, G., & Meiri, S. (2019). A shift in reptile diversity and abundance over the last 25 years. Israel Journal of Ecology and Evolution, 65(1-2), 10-20.

Seshaba, P., Singirankabo, E., & Nsabimana, D. (2024). Analysis of Extreme Temperature Variability in Rwanda. Journal of Atmospheric Science Research| Volume, 7(01).

Shilla, E. (2014). Large terrestrial mammals as indicator species for climate change effects in Tanzania: implications for policy. International Conference on Reducing Climate Change Challenges through Forestry and Other Land Use Practices, 211–223.

Siddig, A. A. H., Ellison, A. M., Ochs, A., Villar-leeman, C., & Lau, M. K. (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*, 223–230. https://doi.org/10.1016/j.ecolind.2015.06.036

Sinsch, U., Lümkemann, K., Rosar, K., Schwarz, C., & Dehling, J. M. (2012). Acoustic Niche Partitioning in an Anuran Community Inhabiting an Afromontane Wetland (Butare, Rwanda). African Zoology, 47(1), 60–73. https://doi.org/10.3377/004.047.0122

Spafford, R. D., & Lortie, C. J. (2013). Sweeping beauty: Is grassland arthropod community composition effectively estimated by sweep netting? *Ecology and Evolution*, *3*(10), 3347–3358. https://doi.org/10.1002/ece3.688

Taron, D. & Leslie, R. (2015). Butterfly Monitoring for Conservation. In J.C. Daniels (Ed.). Butterfly conservation in North America: Efforts to help save our charismatic microfauna. (pp. 35-57). Springer New York. ISBN: 978-94-017-9851-8 (hc); 978-94-017-9852-5 (eb).

Tattersall, F. H., MacDonald, D. W., Hart, B. J., Johnson, P., Manley, W., & Feber, R. (2002). Is habitat linearity important for small mammal communities on farmland? Journal of Applied Ecology, 39(4), 643–652. https://doi.org/10.1046/j.1365-2664.2002.00741.x

Theobald, B., & El-Sayed, N. B. (2019). Water Users Association and Irrigation Performance in Eastern Province of Rwanda. *J Environ Pollut Manage*, *2*(1), 104.

Tingley, M., Darling, E., & Wilcove, D. (2014). Fine- and coarse-filter conservation strategies in a time of climate change. *Annals of the New York Academy of Sciences*, *1322*(1), 92–109. https://doi.org/10.1111/nyas.12484

Tognelli, M. F. (2005). Assessing the utility of indicator groups for the conservation of South American terrestrial mammals. Biological Conservation, 121(3), 409–417. https://doi.org/10.1016/j.biocon.2004.05.013

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.

Umuntunundi, P., Wronski, T., Apio, A., & Hausdorf, B. (2017). The composition and richness of the land-snail fauna of gallery forest along the Muvumba River in Rwanda. *Journal of Molluscan Studies*, *83*(1), 106–110. https://doi.org/10.1093/mollus/eyw046

Usanzineza, D., Nhapi, I., Consultant, F., Wali, U. G., & Kashaigili, J. (2011). Nutrient inflows and levels in lake : A case study of Lake Nutrient Inflows and Levels in Lake : A Case Study of Lake Muhazi , Rwanda. *Inernational Journal of Ecology AndDevelopment*, *19*(January), 54–62

Uwizelimana, J. D., Nsabimana, D., & Wagner, T. (2021). A preliminary butterfly checklist (Lepidoptera : Papilionoidea) for Cyamudongo. Metamorphosis 32, 93–103.

Vasconcelos, T. D. S., & Rossa-Feres, D. D. C. (2009). Habitat heterogeneity and use of physical and acoustic space in anuran communities in Southeastern Brazil. Phyllomedusa, 7(2), 127–142.

Wali, U. (2011). Modelling of Nonpoint Source Pollution in Akagera Transboundary River in Rwanda. *The Open Environmental Engineering Journal*, *4*(1), 124–132. https://doi.org/10.2174/1874829501104010124

Waliczky, Z., fishpool, L. D. C., butchart, S. H. M., Thomas, D., Heath, M. F., Hazin, C., Donald, P. F., Kowalska, A., Dias, M. P., & Allinson, T. S. M. (2019). Important Bird and Biodiversity Areas (IBAs): their impact on conservation policy, advocacy and action. *Bird Conservation International*, *29*(2), 199–215. https://doi.org/DOI: 10.1017/S0959270918000175

Walther, G. R., Roques, A., Hulme, P. E., Sykes, M. T., Pyšek, P., Kühn, I., Zobel, M., Bacher, S., Botta-Dukát, Z., Bugmann, H., Czúcz, B., Dauber, J., Hickler, T., Jarošík, V., Kenis, M., Klotz, S., Minchin, D., Moora, M., Nentwig, W., … Settele, J. (2009). Alien species in a warmer

world: risks and opportunities. *Trends in Ecology and Evolution*, *24*(12), 686–693. https://doi.org/10.1016/j.tree.2009.06.008

Wanyonyi, S. N. (2015). Effects of Habitat Disturbance On Distribution And Abundance Of Papyrus Endemic Birds In Sio Port Swamp, *(B. Ed Science, Nairobi) A Thesis Submitted in Partial Fulfilment of the Requirements for the Award of the Degree of Masters of Science.*

Wilson, R. R., Twedt, D. J., & Elliott, A. B. (2000). Comparison of line transects and point counts for monitoring Spring migration in forested wetlands. Journal of Field Ornithology, *71*(2), 345–355. https://doi.org/10.1648/0273-8570-71.2.345

Whelan, C. J., Wenny, D. G., & Marquis, R. J. (2008). Ecosystem services provided by birds. In *Annals of the New York Academy of Sciences* (Vol. 1134, pp. 25–60). https://doi.org/10.1196/annals.1439.003

White, A., Zipkin, E., Manley, P., & Schlesinger, M. (2013). Conservation of Avian Diversity in the Sierra Nevada: Moving beyond a Single-Species Management Focus. *PloS One*, *8*, e63088. https://doi.org/10.1371/journal.pone.0063088

Zanne, A.E. Lopez-Gonzalez, G., Coomes, D.A., Ilic, J., Jansen, S., Lewis, S.L., Miller, R.B., Swenson, N.G., Wiemann, M.C., Chave, J. (2009). Global wood density database. Data from: Towards a worldwide wood economics spectrum. Towards a worldwide wood economics spectrum. Dryad Digital Repository https://doi.org/10.5061/dryad.234.

Annexes

Annex 1. ***Amphibian species recorded in the sampled intervention sites. A.*** *Hyperolius kivuensis;* ***B.*** *Hyperolius rwandae;* ***C.*** *Hyperolius viridiflavus;* ***D.*** *Kassina senegalensis;* ***E.*** *Phrynobatrachus bequaerti;* ***F.*** *Phrynobatrachus kakamikro.*

Annex 1 continued. ***Amphibian species recorded in the sampled intervention sites. G.*** *Phrynobatrachus natalensis;* ***H****. Phrynobatrachus sp;* ***I.*** *Ptychadena anchietae;* ***J.*** *Ptychadena nilotica;* ***K.*** *Sclerophrys gutturalis.*

Annex 2. ***Reptile species recorded in the sampled natural intervention sites. A.*** *Acanthocercus kiwuensis;* ***B.*** *Adolfus jacksoni;* ***C.*** *Pelomedusa sp;* ***D.*** *Trachylepis sp;* ***E.*** *Trachylepis striata;* ***F.*** *Pelusios sp;* ***G.*** *Hemidactylus mabouia;* ***H.*** *Grayia tholloni;* ***I.*** *Lygodactylus sp;* ***J.*** *Crotaphopeltis hotamboeia;* ***K.*** *Natriciteres olivacea.*

Annex 3. Checklist of flying insects for all intervention sites. The tick (✓) represents the presence of the species and an empty cell indicates absence. LC stands for Least Concern of the IUCN categories while the NE stands for Not Evaluated

Production Forests

#	Family	Row Labels	Common name	IUCN	Bibare production Forest	Gatunga production Forest	Kamuguzi production Forest	Nyakariro-3 production Forest
1	Hesperiidae	*Metisella orientalis*	Eastern sylph	NE	✓	✓		
2	Lycaenidae	*Anthene definita*	Common hairtail	LC		✓		
		Cacyreus lingeus	Bush Bronze	LC	✓			
		Eicochrysops hippocrates	White pipped blue	LC		✓		
		Euchrysops malathana	Common Smoky Blue	LC	✓			
		Lampides boeticus	Long-tailed Blue	LC	✓		✓	
		Leptotes pirithous	Common zebra blue	LC		✓	✓	✓
		Zizeeria knysna	African Grass Blue	LC				✓
		Zizula hylax	Gaika Blue	LC	✓	✓		
3	Nymphalidae	*Bicyclus ena*	Grizzled Bush Brown	LC	✓	✓		
		Bicyclus safitza	Black-haired Bush Brown	LC		✓		
		Byblia anvatara	African Joker	LC		✓		
		Danaus chrysippus	African queen butterfly	LC	✓	✓		
		Eurytela dryope	Golden Piper	LC		✓		
		Hypolimnas misippus	Danaid Eggfly	LC	✓	✓	✓	
		Junonia chorimene	Golden pansy	NE				✓
		Junonia hierta	Yellow pansy	LC	✓	✓		✓
		Junonia oenone	Blue Pansy	LC	✓	✓	✓	✓
		Junonia sophia	Little commodore	NE		✓		
		Junonia stygia	Brown pansy	NE		✓		
		Junonia terea	Soldier Pansy	LC	✓	✓	✓	✓
		Melanitis leda	Twilight Brown	LC	✓			
		Pardopsis punctatissima	Pardopsis punctatissima	LC				✓
		Phalanta phalanta	Common leopard	NE				✓
		Ypthima albida	Silver ringlet	NE			✓	✓
		Ypthima asterope	African ringlet	LC		✓	✓	✓
4	Papilionidae	*Papilio demodocus*	Citrus Swallowtail	NE		✓		✓
5	Pieridae	*Belenois creona*	African Caper White	LC	✓	✓		✓
		Catopsilia florella	African Migrant	LC	✓	✓		
		Colotis antevippe	Southern Red Tip	LC				✓
		Colotis aurigineus	African Arab Tip	NE				✓
		Colotis euippe	Round-winged Orange Tip	LC	✓	✓		✓
		Mylothris agathina	Eastern Dotted Border	LC	✓			
		Eurema brigitta	Broad-bordered Grass Yellow	LC	✓	✓		✓
		Eurema hecabe	Grass yellow	LC	✓	✓		

Sylvopastoral Lands

#	Family	Scientific names	Common name	IUCN	Buhabwa	Cyenjonjo	Kibirizi	Rwinta-shya
1	Hesperiidae	*Borbo fatuellus*	Long-horned Swift	LC		✓		✓

		Gegenes hottentota	Marsh Hottentot Skipper	LC		✓		
2	Lycaenidae	*Anthene amarah*	Black-striped Hairtail	LC	✓			✓
		Anthene definita	Common hairtail	LC	✓			
		Anthene ligures	Lesser indigo ciliate blue	NE		✓		
		Azanus natalensis	Natal Babul Blue	LC	✓	✓		
		Cacyreus lingeus	Bush Bronze	LC	✓			
		Eicochrysops hippocrates	White pipped blue	LC		✓		
		Euchrysops malathana	Common Smoky Blue	LC				✓
		Zizeeria knysna	African Grass Blue	LC		✓		
		Zizula hylax	Gaika Blue	LC	✓	✓		
3	Nymphalidae	*Acraea encedana*	Acraea encedana	NE				✓
		Danaus chrysippus	African queen butterfly	LC	✓			✓
		Eurytela dryope	Golden Piper	LC		✓		
		Hypolimnas misippus	Danaid Eggfly	LC	✓	✓		
		Junonia chorimene	Golden pansy	NE	✓	✓		
		Junonia hierta	Yellow pansy	LC	✓	✓		
		Junonia oenone	Blue Pansy	LC	✓	✓	✓	✓
		Junonia sophia	Little commodore	NE		✓		✓
		Junonia stygia	Brown pansy	NE	✓	✓		
		Junonia terea	Soldier Pansy	LC	✓	✓		✓
		Neptis serena	Serena sailor	LC	✓			✓
		Phalanta phalanta	Common leopard	NE				✓
		Ypthima asterope	African ringlet	LC		✓		
		Ypthima rhodesiana	Pale ringlet	NE		✓		
4	Pieridae	*Belenois calypso*	Calypso Caper White	LC				✓
		Belenois creona	African Caper White	LC	✓	✓		✓
		Catopsilia florella	African Migrant	LC	✓	✓	✓	✓
		Colotis antevippe	Southern Red Tip	LC		✓		✓
		Colotis auxo	Sulphur Orange Tip	LC				✓
		Colotis euippe	Round-winged Orange Tip	LC	✓	✓	✓	✓
		Colotis evagore	Desert Orange-tip	LC		✓		✓
		Eronia cleodora	Vine-leaf Vagrant	LC		✓		
		Mylothris agathina	Eastern Dotted Border	LC	✓			
		Nepheronia argia	Large Vagrant	LC				✓
		Eurema brigitta	Broad-bordered Grass Yellow	LC	✓	✓	✓	✓
		Eurema hecabe	Grass yellow	LC	✓	✓		✓
		Eurema regularis	Eurema regularis	NE				✓

Dam buffers

#	Family	Scientific names	Common name	IUCN	Bugugu	Kampima	Nyirabidibiri	Rugende
1	Hesperiidae	*Coeliades anchises*	One-pip Policeman	LC		✓		
		Eretis lugens	Savanna elf	NE	✓	✓	✓	✓
		Gegenes hottentota	Marsh Hottentot Skipper	LC		✓		✓
		Spialia diomus	Diomus grizzled skipper	NE		✓	✓	✓
2	Lycaenidae	*Anthene definita*	Common hairtail	LC				✓
		Azanus natalensis	Natal Babul Blue	LC				✓
		Eicochrysops hippocrates	White pipped blue	LC				✓
		Leptotes pirithous	Common zebra blue	LC			✓	✓
		Zizula hylax	Gaika Blue	LC				✓
3	Nymphalidae	*Bicyclus jefferyi*	Jeffery's Bush-brown	LC			✓	
		Bicyclus safitza	Black-haired Bush Brown	LC			✓	✓
		Bicyclus vulgaris	Vulgar bush brown	NE				✓
		Danaus chrysippus	African queen butterfly	LC		✓		✓
		Hypolimnas misippus	Danaid Eggfly	LC				✓
		Junonia hierta	Yellow pansy	LC				✓
		Junonia oenone	Blue Pansy	LC	✓	✓	✓	✓
		Junonia sophia	Little commodore	NE			✓	✓
		Junonia terea	Soldier Pansy	LC			✓	✓
		Melanitis leda	Twilight Brown	LC			✓	
		Neptis serena	Serena sailor	LC	✓		✓	✓
		Ypthima albida	Silver ringlet	NE		✓		
		Ypthima asterope	African ringlet	LC	✓	✓	✓	✓
4	Pieridae	*Belenois creona*	African Caper White	LC	✓		✓	✓
		Catopsilia florella	African Migrant	LC				✓
		Colotis antevippe	Southern Red Tip	LC				✓
		Colotis euippe	Round-winged Orange Tip	LC	✓			
		Eronia cleodora	Vine-leaf Vagrant	LC			✓	✓
		Mylothris agathina	Eastern Dotted Border	LC	✓	✓	✓	
		Eurema brigitta	Broad-bordered Grass Yellow	LC	✓	✓	✓	
		Eurema desjardinsii	Angled Grass Yellow	LC			✓	
		Eurema hapale						✓
		Eurema hecabe	Grass yellow	LC	✓	✓	✓	✓
		Eurema senegalensis	Eurema senegalensis	NE				✓

Lake buffers

#	Family	Scientific name	Common name	IUCN	Cyambwe Lake Buffer	Muhazi Lake Buffer 1	Muhazi Lake Buffer 2	Muhazi Lake Buffer 3
1	Hesperiidae	*Eretis lugens*	Savanna elf	NE	✓			✓
		Gegenes hottentota	Marsh Hottentot Skipper	LC	✓			✓
2	Lycaenidae	*Anthene definita*	Common hairtail	LC	✓			
		Zizula hylax	Gaika Blue	LC		✓		
3	Nymphalidae	*Bicyclus safitza*	Black-haired Bush Brown	LC	✓			
		Danaus chrysippus	African queen butterfly	LC	✓		✓	✓
		Hypolimnas misippus	Danaid Eggfly	LC	✓			✓
		Junonia oenone	Blue Pansy	LC	✓	✓	✓	✓
		Junonia sophia	Little commodore	NE	✓	✓		

		Junonia terea	Soldier Pansy	LC	✓			
		Neptis serena	Serena sailor	LC				✓
		Ypthima albida	Silver ringlet	NE				✓
		Ypthima asterope	African ringlet	LC	✓	✓	✓	✓
4	Papilion-idae	*Papilio demodocus*	Citrus Swallowtail	NE				✓
5	Pieridae	*Belenois creona*	African Caper White	LC	✓			
		Catopsilia florella	African Migrant	LC	✓	✓		✓
		Colotis euippe	Round-winged Orange Tip	LC				✓
		Leptosia alcesta	African Wood White	LC				✓
		Mylothris agathina	Eastern Dotted Border	LC	✓	✓		✓
		Eurema brigitta	Broad-bordered Grass Yellow	LC		✓		✓
		Eurema desjardinsii	Angled Grass Yellow	LC		✓		
		Eurema hecabe	Grass yellow	LC				✓

Community Based Sanctuaries

#		Scien-tific name	Common name	IU CN	Buge-sera	Buhon-de 1&2	Jambo Beach-Gahini	Kara-mbi	Kiga-rama 2	Mur-ambi	Ngo-ma	Ryaru-bamba 1
1	Hesperiidae	*Borbo fatuellus*	Long-horned Swift	LC		✓						
		Eretis lugens	Savanna elf	NE		✓	✓	✓				
		Gegenes hottentota	Marsh Hottentot Skipper	LC		✓	✓	✓			✓	
		Pelopidas mathias	Pelopidas mathias	LC						✓		
2	Lycaenidae	*Anthene amarah*	Black-striped Hairtail	LC		✓					✓	
		Azanus natalensis	Natal Babul Blue	LC				✓				
		Euchrysops malathana	Common Smoky Blue	LC				✓		✓		
		Lampides boeticus	Long-tailed Blue	LC				✓		✓	✓	
		Zizula hylax	Gaika Blue	LC	✓	✓		✓		✓		
3	Nymphalidae	*Acraea uvui*	Tiny acraea	NE						✓		
		Bicyclus safitza	Black-haired Bush Brown	LC	✓					✓		
		Danaus chrysippus	African queen butterfly	LC	✓					✓		✓
		Eurytela dryope	Golden Piper	LC			✓					
		Hamanumida daedalus	Guinea-fowl Butterfly	LC	✓							
		Hypolimnas misippus	Danaid Eggfly	LC	✓	✓						
		Junonia hierta	Yellow pansy	LC	✓	✓		✓	✓	✓		
		Junonia oenone	Blue Pansy	LC	✓	✓	✓	✓	✓	✓	✓	✓

		Junonia sophia	Little commodore	NE				✓				
		Junonia terea	Soldier Pansy	LC	✓	✓		✓	✓	✓		
		Melanitis leda	Twilight Brown	LC						✓		
		Neptis serena	Serena sailor	LC		✓	✓			✓	✓	
		Tirumala petiverana	Blue Monarch	LC	✓							
		Ypthima asteropе	African ringlet	LC	✓	✓		✓		✓	✓	
4	Papilionidae	*Papilio demodocus*	Citrus Swallowtail	NE	✓	✓		✓	✓			
5	Pieridae	*Belenois creona*	African Caper White	LC		✓						
		Belenois raffrayi	Raffrayi's caper	LC						✓		
		Catopsilia florella	African Migrant	LC	✓	✓	✓	✓	✓			
		Colotis annae	Scarlet tip	LC	✓							
		Colotis aurigineus	African Arab Tip	NE	✓							
		Colotis euippe	Round-winged Orange Tip	LC	✓			✓				
		Eronia cleodora	Vine-leaf Vagrant	LC		✓						
		Mylothris agathina	Eastern Dotted Border	LC	✓		✓	✓		✓	✓	
		Eurema brigitta	Broad-bordered Grass Yellow	LC	✓			✓		✓	✓	
		Eurema desjardinsii	Angled Grass Yellow	LC					✓		✓	
		Eurema hecabe	Grass yellow	LC	✓		✓					

River buffer

#	Family	Scientific name	Common name	IUCN	Nyirasuru River Buffer	Warufu River Buffer
1	Hesperiidae	*Eretis lugens*	Savanna elf	NE	✓	✓
		Gegenes hottentota	Marsh Hottentot Skipper	LC		✓
		Metisella orientalis	Eastern sylph	NE		✓
2	Lycaenidae	*Lampides boeticus*	Long-tailed Blue	LC		✓
		Leptotes pirithous	Common zebra blue	LC		✓
		Zizula hylax	Gaika Blue	LC		✓
3	Nymphalidae	*Acraea acerata*	yellow-banded acraea	NE	✓	
		Acraea uvui	Tiny acraea	NE	✓	
		Bicyclus jefferyi	Jeffery's Bush-brown	LC	✓	
		Bicyclus safitza	Black-haired Bush Brown	LC	✓	✓
		Bicyclus saussurei	Brush-footed butterflies	NE	✓	
		Bicyclus vulgaris	Vulgar bush brown	NE	✓	
		Danaus chrysippus	African queen butterfly	LC		✓
		Junonia oenone	Blue Pansy	LC	✓	✓

		Junonia sophia	Little commodore	NE		✓
		Junonia stygia	Brown pansy	NE		✓
		Junonia terea	Soldier Pansy	LC		✓
		Neptis serena	Serena sailor	LC		✓
		Phalanta phalanta	Common leopard	NE	✓	
		Ypthima albida	Silver ringlet	NE		✓
		Ypthima asterope	African ringlet	LC		✓
		Ypthimomorpha itonia	Ypthimomorpha itonia	NE	✓	
4	Pieridae	*Belenois creona*	African Caper White	LC		✓
		Catopsilia florella	African Migrant	LC		✓
		Mylothris agathina	Eastern Dotted Border	LC	✓	✓
		Eurema hecabe	Grass yellow	LC	✓	✓

Road buffer

#	Family	Scientific name	Common name	IUCN	Gacundezi Road Buffer	Gare-Kariyeri Road Buffer	Gatore-Mutenderi Road Buffer	Kirehe-Mushikiri Road Buffer	Murama-Remera Road Buffer	Ngoma Road1 Buffer	Ruhuha-Nyamata Road Buffer	Rwamagana Road 1 Buffer	Rwamagana Road 2 Buffer	Rwamagana Road 3 Buffer
1	Hesperiidae	*Borbo fatuellus*	Long-horned Swift	LC					✓					
		Eretis lugens	Savanna elf	NE	✓				✓		✓			
		Pelopidas mathias	Pelopidas mathias	LC				✓						
2	Lycaenidae	*Anthene amarah*	Black-striped Hairtail	LC						✓				
		Zizula hylax	Gaika Blue	LC			✓	✓	✓					✓
3	Nymphalidae	*Bicyclus ena*	Grizzled Bush Brown	LC				✓					✓	
		Bicyclus safitza	Black-haired Bush Brown	LC		✓	✓	✓						
		Bicyclus vulgaris	Vulgar bush brown	NE					✓					
		Danaus chrysippus	African queen butterfly	LC					✓					
		Eurytela dryope	Golden Piper	LC									✓	
		Hypolimnas misippus	Danaid Eggfly	LC							✓	✓	✓	
		Junonia hierta	Yellow pansy	LC				✓	✓	✓				
		Junonia natalica	Brown pansy	LC							✓			
		Junonia oenone	Blue Pansy	LC		✓	✓	✓	✓	✓	✓			✓
		Junonia sophia	Little commodore	NE					✓					

		Junonia terea	Soldier Pansy	LC		✓	✓	✓	✓					
		Melanitis leda	Twilight Brown	LC		✓					✓			
		Neptis serena	Serena sailor	LC		✓								
		Phalanta phalanta	Common leopard	NE					✓					
		Ypthima asterope	African ringlet	LC		✓								
4	Papilionidae	*Papilio demodocus*	Citrus Swallowtail	NE					✓		✓			
		Papilio phorcas	Green-banded swallowtail	NE							✓			
5	Pieridae	*Belenois creona*	African Caper White	LC		✓			✓					
		Catopsilia florella	African Migrant	LC		✓			✓		✓	✓	✓	
		Colotis antevippe	Southern Red Tip	LC		✓								
		Colotis euippe	Round-winged Orange Tip	LC		✓		✓	✓					
		Colotis evagore	Desert Orange-tip	LC					✓					
		Mylothris agathina	Eastern Dotted Border	LC					✓					
		Eurema brigitta	Broad-bordered Grass Yellow	LC		✓		✓	✓		✓		✓	
		Eurema desjardinsii	Angled Grass Yellow	LC									✓	
		Eurema hecabe	Grass yellow	LC		✓		✓	✓		✓			

Annex 4. Checklist of terrestrial arthropods found in the intervention site sampling in Eastern Province, Rwanda

Order	Family	Dam Buffer	Lake Buffer	Production Forest	River Buffer	Road Buffer	Community Based Sanctuaries	Sylvopastoral Land
Acarina	Ixodidae	✓	✓		✓	✓		
	Trombididae		✓	✓		✓	✓	✓
Aranea	Araneidae	✓	✓		✓	✓	✓	✓
	Pholcidae	✓	✓	✓	✓	✓	✓	✓
	Salticidae	✓	✓	✓	✓	✓	✓	✓
Blattodea	Blaberidae	✓		✓	✓	✓		✓
	Blattellidae	✓	✓	✓	✓	✓	✓	✓
	Blattidae	✓	✓		✓	✓	✓	
Callipodida	Callipodidea	✓			✓	✓	✓	✓
Coleoptera	Bostrichidae				✓	✓	✓	
	Buprestidae	✓						
	Cantharidae		✓					
	Carabidae	✓	✓	✓	✓	✓	✓	✓
	Cerambycidae		✓				✓	
	Chrysomelidae	✓	✓	✓	✓	✓	✓	✓
	Coccinelidae	✓	✓	✓	✓	✓	✓	✓
	Coreidae		✓					✓
	Curculionidae	✓	✓	✓	✓	✓	✓	✓
	Dermistidae	✓	✓	✓	✓	✓	✓	✓
	Elateridae		✓					✓
	Histeridae	✓	✓	✓	✓	✓	✓	
	Hydraenidae	✓	✓					
	Lycidae				✓		✓	✓
	Meloidae			✓		✓	✓	✓
	Melyridae						✓	
	Scarabaeidae	✓	✓	✓	✓	✓	✓	✓
	Scydmaenidae					✓		
	Staphylinidae	✓	✓	✓		✓	✓	✓
	Tenebrionidae	✓	✓	✓	✓	✓	✓	✓
Dermaptera	Spongiforidae		✓					
Hemiptera	Alydidae	✓	✓	✓	✓	✓	✓	✓
	Aphididae			✓	✓	✓	✓	✓
	Cercopidae	✓	✓	✓	✓	✓	✓	✓
	Cicadellidae	✓	✓	✓	✓	✓	✓	✓
	Cicadidae	✓	✓	✓	✓	✓	✓	✓
	Cimicidae					✓	✓	✓
	Cixiidae	✓				✓		
	Coreidae			✓		✓		✓
	Culicidae					✓		
	Cydinidae	✓	✓					✓
	Dictyopharidae	✓		✓			✓	✓
	Dinidoridae			✓				
	Hydrometridae					✓		
	Lygaeidae	✓	✓	✓	✓	✓	✓	✓
	Membracidae				✓		✓	
	Miridae	✓	✓	✓	✓	✓	✓	✓
	Pentatomidae	✓	✓	✓	✓	✓	✓	✓
	Plataspidae	✓	✓	✓		✓	✓	
	Pyrrhocoridae	✓		✓	✓	✓	✓	✓
	Reduviidae	✓		✓	✓	✓	✓	✓
	Scutelleridae	✓	✓					

	Tingidae			✓	✓	✓	✓	
Hymenoptera	Agaonidae					✓		
	Apidae	✓	✓	✓	✓	✓	✓	✓
	Braconidae	✓				✓	✓	
	Chrysididae	✓			✓	✓	✓	
	Eumenidae	✓	✓	✓		✓	✓	✓
	Formicidae	✓	✓	✓	✓	✓	✓	✓
	Ichnemonidae	✓	✓	✓	✓	✓	✓	✓
	Mutillidae			✓				
	Scoliidae						✓	
	Vespidae	✓		✓		✓	✓	✓
Isopoda	Oniscidae	✓	✓	✓	✓	✓	✓	✓
Isoptera	Hodotermitidae							✓
	Oniscidae					✓		
	Termitidae	✓	✓	✓		✓	✓	✓
Mantodea	Mantidae			✓		✓	✓	✓
	Thespidae					✓	✓	
Odonata	Coenagrionidae					✓		
	Lestidae	✓			✓	✓	✓	✓
	Libellulidae	✓			✓	✓	✓	✓
Orthoptera	Acrididae	✓	✓	✓	✓	✓	✓	✓
	Gryllidae	✓	✓	✓	✓	✓	✓	✓
	Gryllotalpidae	✓						
	Pyrgomorphidae	✓	✓	✓	✓	✓	✓	✓
	Tetrigidae	✓	✓	✓	✓	✓	✓	✓
	Tettigoniidae	✓	✓	✓	✓	✓	✓	✓

Annex 5. Checklist of birds observed at each of the seven intervention sites in Eastern Province, Rwanda

Family	Scientific name	IUCN	Migration Status	Sylvo-pastoral Land	Dam Buffer	Lake Buffer	Prod Forest	River Buffer	Road Buffer	Comm Based Sanctuaries
Accipitridae	*Accipiter minullus*	LC	Non-migrant						✓	✓
	Accipiter tachiro	LC	Non-migrant				✓			
	Aquila rapax	LC	Non-migrant						✓	
	Aquila spilogaster	LC	Non-migrant							✓
	Buteo augur	LC	Non-migrant	✓			✓		✓	✓
	Buteo buteo	LC	Non-migrant						✓	
	Circus aeruginosus	LC	Non-migrant						✓	
	Circus ranivorus	LC	Non-migrant			✓		✓		
	Elanus axillaris	LC	Non-migrant						✓	✓
	Gypohierax angolensis	LC	Non-migrant			✓				
	Haliaeetus vocifer	LC	Non-migrant	✓						✓
	Hieraaetus wahlbergi	LC	Full-migrant					✓	✓	
	Icthyophaga vocifer	LC	Non-migrant			✓				
	Lophaetus accipitalis	LC	Non-migrant		✓					
	Lophaetus occipitalis	LC	Non-migrant						✓	✓
	Micronisus gabar	LC	Non-migrant						✓	
	Milvus aegyptius	LC	Intra-Africa migrant	✓	✓	✓	✓		✓	✓
	Milvus migrans	LC	Non-migrant							✓
	Polyboroides typus	LC	Non-migrant	✓	✓		✓		✓	
	Acrocephalus arundinaceus	LC	Non-migrant			✓			✓	✓
	Acrocephalus gracilirostris	LC	Non-migrant		✓	✓				✓
	Acrocephalus rufescens	LC	Non-migrant		✓					
	Chloropeta natalensis	LC	Non-migrant							✓
	Iduna natarensis	LC	Non-migrant							✓
Alaudidae	*Melanocorypha yeltoniensis*	LC	Non-migrant						✓	
	Mirafra africana	LC	Non-migrant						✓	✓
Alcedinidae	*Ceryle rudis*	LC	Non-migrant	✓	✓✓	✓			✓	✓
	Corythornis cristatus	LC	Non-migrant		✓	✓		✓		✓
	Halcyon senegalensis	LC	Intra-Africa migrant						✓	
	Ispidina picta	LC	Non-migrant		✓					✓
Anatidae	*Anas erythrorhyncha*	LC	Non-migrant							✓
	Anas undulata	LC	Non-migrant		✓	✓		✓	✓	
	Dendrocygna viduata	LC	Non-migrant		✓					
	Plectropterus gambensis	LC	Non-migrant							✓
Apodidae	*Apus caffer*	LC	Full-migrant						✓	✓
	Cypsiurus parvus	LC	Non-migrant						✓	
Ardeidae	*Ardea alba*	LC	Non-migrant						✓	
	Ardea cinerea	LC	Non-migrant		✓	✓				
	Ardea intermedia	LC	Non-migrant		✓				✓	✓
	Ardea melanocephala	LC	Non-migrant			✓			✓	✓
	Ardeola rufiventris	LC	Non-migrant		✓			✓		
	Bubulcus ibis	LC	Non-migrant	✓	✓				✓	
	Butorides striatus	LC	Non-migrant					✓		
	Egretta garzetta	LC	Non-migrant			✓		✓		
Bucerotidae	*Tockus alboterminatus*	LC	Non-migrant							✓
	Bushshrike	LC	Non-migrant				✓			

	Tchagra senegala	LC	Non-migrant				✓			
Caprimulgidae	*Caprimulgus fossii*	LC	Non-migrant	✓						
	Veles binotatus	LC	Non-migrant							✓
Charadriidae	*Anarhynchus pecuarius*	LC	Non-migrant			✓				
	Charadrius tricollaris	LC	Non-migrant		✓					
	Vanellus coronatus	LC	Non-migrant							
	Vanellus crassirostris	LC	Non-migrant		✓				✓	
	Vanellus senegallus	LC	Non-migrant		✓	✓			✓	✓
	Vanellus spinosus	LC	Non-migrant	✓						
Ciconiidae	*Anastomus lamelligerus*	LC	Non-migrant		✓				✓	
	Anastomus oscitans	LC	Non-migrant						✓	
	Mycteria ibis	LC	Non-migrant		✓					
Cisticolidae	*Camaroptera brachyura*	LC	Non-migrant		✓					✓
	Camaroptera brevicaudata	LC	Non-migrant	✓		✓	✓	✓	✓	✓
	Cisticola brachypterus	LC	Non-migrant							✓
	Cisticola cantans	LC	Non-migrant	✓			✓			
	Cisticola chubbi	LC	Non-migrant		✓	✓				
	Cisticola galactotes	LC	Non-migrant		✓	✓			✓	
	Cisticola juncidis	LC	Non-migrant		✓					
	Cisticola woosnami	LC	Non-migrant	✓✓			✓✓			✓
	Eminia lepida	LC	Non-migrant		✓	✓		✓		✓
	Prinia subflava	LC	Non-migrant		✓		✓		✓	✓
	Schistolais leucopogon	LC	Non-migrant							✓
Coliidae	*Colius striatus*	LC	Non-migrant	✓	✓	✓	✓	✓	✓	✓✓
	Urocolius macrourus	LC	Non-migrant	✓					✓	✓
Columbidae	*Columba guinea*	LC	Non-migrant						✓	
	Spilopelia senegalensis	LC	Full-migrant	✓			✓		✓	✓
	Streptopelia capicola	LC	Full-migrant	✓	✓	✓	✓	✓	✓	✓
	Streptopelia semitorquata	LC	Full-migrant	✓	✓	✓	✓		✓	✓
	Treron calvus	LC	Non-migrant						✓	
	Turtur afer	LC	Non-migrant	✓	✓		✓	✓	✓	✓
	Turtur chalcospilos	LC	Non-migrant							✓
Corvidae	*Corvus albus*	LC	Non-migrant	✓	✓	✓	✓		✓	✓
Cuculidae	*Centropus monachus*	LC	Non-migrant	✓					✓	✓
	Centropus superciliosus	LC	Non-migrant	✓		✓	✓	✓	✓	✓
	Chrysococcyx cupreus	LC	Non-migrant							✓
	Chrysococcyx klaas	LC	Full-migrant	✓						
	Cossyzus americanus	LC	Non-migrant	✓						
	Cuculus solitarius	LC	Intra-Africa migrant	✓	✓		✓		✓	✓
Dicruridae	*Dicrurus adsimilis*	LC	Non-migrant	✓	✓		✓	✓	✓✓	✓
Emberizidae	*Emberiza flaviventi*	LC	Non-migrant	✓					✓	
	Estrildanonnula	LC	Non-migrant		✓					
	Uraeginthus bengalus	LC	Non-migrant		✓					
Estrildidae	*Estrilda astrild*	LC	Non-migrant	✓	✓				✓	✓
	Estrilda erythronotos	LC	Non-migrant						✓	
	Estrilda paludicola	LC	Non-migrant			✓			✓	✓
	Lagonosticta rubricata	LC	Non-migrant						✓	✓
	Lagonosticta senegala	LC	Non-migrant		✓	✓		✓	✓	✓
	Lonchura bicolor	LC	Non-migrant				✓			✓

	Pytilia melba	LC	Non-migrant	✓	✓	✓			✓	✓
	Spermestes bicolor	LC	Non-migrant		✓					
	Spermestes cucullata	LC	Non-migrant		✓	✓	✓		✓	✓
	Uraeginthus bengalus	LC	Non-migrant	✓	✓	✓	✓		✓	✓
Falconidae	*Falco ardosiaceus*	LC	Non-migrant						✓	
	Falco cuvierii	LC	Non-migrn			✓				
	Falco naumanni	LC	Full-migrant						✓	
	Falco tinnunculus	LC	Winter migrant	✓			✓			
Fringillidae	*Crithagra citrinelloides*	LC	Non-migrant		✓					
	Crithagra frontalis	LC	Non-migrant	✓	✓		✓			✓
	Crithagra leucopygia	LC	Non-migrant						✓	
	Crithagra mozambica	LC	Non-migrant	✓	✓	✓	✓	✓	✓✓	✓
	Crithagra sulphurata	LC	Non-migrant		✓		✓		✓	✓
	Serinus burtoni	LC	Non-migrant							
	Serinus striolatus	LC	Non-migrant	✓			✓	✓		
Gruidae	*Balearica regulorum*	EN	Partial migrant			✓				
Hirundinidae	*Cecropis daurica*	LC	Full-migrant				✓			
	Hirundo angolensis	LC	Non-migrant						✓	
	Hirundo rustica	LC	Full-migrant					✓	✓	✓
	Hirundo smithii	LC	Non-migrnt	✓			✓	✓	✓	✓
	Psalidoprocne albiceps	LC	Non-migrant						✓	✓
	Psalidoprocne pristoptera	LC	Full-migrant			✓	✓		✓	
	Ptyonoprogne fuligula	LC	Non-migrant				✓	✓	✓	
	Indicator Indicator	LC	Non-migrant							✓
	Indicator variegatus	LC	Non-migrant							✓
Jacanidae	*Actophilomis africanus*	LC	Non-migrant		✓	✓		✓		
	Actophilornis africanus	LC	Non-migrant		✓				✓	✓
	Gallinula chloropus	LC	Non-migrant		✓					
	Microparra capensis	LC	Non-migrant		✓					
Laniidae	*Lanius excubitoroides*	LC	Non-migrant	✓	✓	✓			✓	✓
	Lanius humeralis	LC	Non-migrant	✓	✓			✓	✓	✓
	Lanius mackinnoni	LC	Non-migrant					✓		
Leiothrichidae	*Argya caudata*	LC	Non-migrant							✓
	Turdoides jardineii	LC	Non-migrant	✓	✓	✓		✓	✓✓	✓
	Turdoides sharpei	LC	Non-migrant	✓	✓	✓		✓	✓	✓
Malaconotidae	*Laniarius aethiopicus*	LC	Non-migrant	✓	✓	✓	✓	✓	✓	✓
	Laniarius erythrogaster	LC	Non-migrant	✓		✓			✓	✓
	Laniarius mufumbiri	LC	Non-migrant							✓
	Malaconotus blanchoti	LC	Non-migrant			✓				
	Tchagra australis	LC	Non-migrant		✓					
	Tchagra senegala	LC	Non-migrant							✓
Meropidae	*Merops apiaster*	LC	Full-migrant	✓	✓	✓	✓		✓	✓
	Merops oreobate	LC	Non-migrant				✓			✓
	Merops pusillus	LC	Non-migrant						✓	✓
Monarchidae	*Terpsiphone Viridis*	LC	Intra-Africa migrant	✓		✓	✓	✓	✓	✓
Motacillidae	*Anthus cinnamomeus*	LC	Full-migrant	✓					✓	✓
	Macronyx croceus	LC	Non-migrant			✓				
	Motacilla aguimp	LC	Non-migrant		✓	✓			✓	✓

	Motacilla capensis	LC	Non-migrant					✓		
Muscicapidae	*Bradornis pallidus*	LC	Non-migrant							✓
	Cercotrichas hartlaubi	LC	Non-migrant	✓		✓	✓			✓
	Cercotrichas leucophrys	LC	Non-migrant	✓					✓	
	Cossypha heuglini	LC	Non-migrant	✓	✓	✓	✓		✓✓	✓
	Cossypha natalensis	LC	Non-migrant							✓
	Melaenornis pammelaina	LC	Non-migrant						✓	
	Muscicapa adusta	LC	Non-migrant						✓	
	Muscicapa aquatica	LC	Non-migrant		✓	✓				✓
	Myrmecocichla arnotti	LC	Non-migrant	✓					✓✓	
	Saxicola torquatus	LC	Non-migrant		✓	✓			✓	✓
	Terpsiphone Viridis	LC	Intra-Africa migrant		✓	✓			✓	
Musophagidae	*Crinifer personatus*	LC	Non-migrant	✓		✓			✓	
	Crinifer zonurus	LC	Non-migrant						✓	✓
	Musophaga rossae	LC	Non-migrant	✓		✓				✓
Nectariniidae	*Chalcomitra senegalensis*	LC	Non-migrant	✓	✓		✓		✓	✓
	Charcomitra senegalensis	LC	Non-migrant		✓	✓			✓	✓
	Cinnyris cupreus	LC	Non-migrant	✓			✓			✓
	Cinnyris erythrocerca	LC	Non-migrant		✓					
	Cinnyris erythrocercus	LC	Non-migrant	✓	✓	✓			✓	✓✓
	Cinnyris mariquensis	LC	Local migrant	✓		✓	✓		✓	
	Cyanomitra verticalis	LC	Non-migrant						✓	
	Cynnyris venustus	LC	Non-migrant	✓	✓	✓	✓	✓	✓✓	✓✓
	Hedydipna collaris	LC	Non-migrant							✓
	Nectarinia kilimensis	LC	Non-migrant	✓	✓	✓	✓	✓	✓	✓
Oriolidae	*Oriolus larvatus*	LC	Non-migrant			✓				
	Oriolus larvatus	LC	Non-migrant	✓						✓
Passeridae	*Passer griseus*	LC	Non-migrant	✓	✓		✓	✓	✓✓	✓
Phalacrocoracidae	*Microcarbo africanus*	LC	Non-migrant		✓	✓				✓
	Phalacrocorax carbo	LC	Non-migrant			✓				
Phasianidae	*francolin afer*	LC	Non-migrant	✓						
	Pternistis afer	LC	Non-migrant	✓						
	Pternistis squamatus	LC	Non-migrant							✓
Phylloscopidae	*Phylloscopus trochilus*	LC	Full-migrant							✓
Picidae	*Dendropicos fuscescens*	LC	Non-migrant							✓
Platysteiridae	*Batis molitor*	LC	Non-migrant				✓			
Ploceidae	*Amblyospiza albifrons*	LC	Non-migrant		✓		✓	✓		✓
	Euplectes axillaris	LC	Non-migrant		✓	✓			✓	✓
	Euplectes capensis	LC	Non-migrant				✓		✓	✓
	Euplectes orix	LC	Non-migrant	✓					✓	
	Euplectesaxillaris	LC	Non-migrant							✓
	Ploceus baglafecht	LC	Non-migrant		✓	✓	✓	✓	✓	✓
	Ploceus baglafetch	LC	Non-migrant				✓			
	Ploceus cucullatus	LC	Non-migrant	✓	✓	✓	✓	✓	✓	✓
	Ploceus melanocephalus	LC	Non-migrant	✓	✓✓	✓		✓		✓
	Ploceus ocularis	LC	Non-migrant		✓					
	Ploceus pelzelni	LC	Non-migrant		✓	✓			✓	✓
	Ploceus xanthops	LC	Non-migrant		✓	✓		✓		✓
	Quelea quelea	LC	Non-migrant						✓	✓

Psittacidae	*Poicephalus meyeri*	LC	Non-migrant	✓		✓			✓	✓
	Psittacus erithacus	LC	Non-migrant	✓						
Pycnonotidae	*Atimastillas flavicollis*	LC	Non-migrant			✓				✓
	Picnonotus barbatus	LC	Non-migrant							✓
	Pycnonotus barbatus	LC	Non-migrant	✓	✓	✓	✓	✓	✓	✓
	Pycnonotus tricolor	LC	Non-migrant	✓✓	✓	✓	✓✓	✓	✓✓	✓
Rallidae	*Fulica cristata*	LC	Non-migrant		✓					
	Gallinula chloropus	LC	Non-migrant		✓					
	Porphyrio poliocephalus	LC	Non-migrant		✓					
	Zapornia flavirostra	LC	Non-migrant		✓	✓		✓	✓	✓
Sarothruridae	*Sarothrura rufa*	LC	Non-migrant							✓
Scolopacidae	*Actitis hypoleucos*	LC	Non-migrant		✓	✓				
	Tringa glareola	LC	Non-migrant		✓					
	Tringa ochropus	LC	Non-migrant		✓					
Scopidae	*Scopus umbretta*	LC	Non-migrant		✓	✓		✓	✓	✓
Sturnidae	*Cinnyricinclus leucogaster*	LC	Non-migrant	✓						
	Lamprotornis chalybaeus	LC	Non-migrant						✓	
	Lamprotornis purpuroptera	LC	Non-migrant	✓	✓	✓			✓	✓
Threskiornithidae	*Bostrychia hagedash*	LC	Non-migrant	✓	✓	✓			✓	✓
	Threskiornis aethiopicus	LC	Non-migrant		✓				✓	✓
Turdidae	*Turdus olivaceus*	LC	Non-migrant						✓	
	Turdus pelios	LC	Non-migrant		✓	✓	✓		✓	✓
Tyrannidae	*Empidonax oberholseri*	LC	Non-migrant			✓				
Viduidae	*Vidua chalybeata*	LC	Non-migrant						✓	
	Vidua macroura	LC	Non-migrant	✓	✓✓	✓			✓	✓
Zosteropidae	*Zosterops senegalensis*	LC	Non-migrant		✓	✓			✓	✓

Annex 6. Team members for the biodiversity baseline survey in the Eastern Province, Rwanda

Tasks	**Role**	**Names**	**Email**	Phone
Overall lead for biodiversity surveys	PI, COMBIO project	Beth A. Kaplin	b.kaplin@ur.ac.rw bkaplin@antioch.edu	+250788664551
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Assistance with data analysis	Fulbright Fellow	Megan Sullivan	sullivanmks@gmail.com; megan.k.sullivan@yale.edu	