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

Biodiversity Baseline Inventory and Mapping of seven natural forests in the Eastern Province of Rwanda

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Executive Summary

There has been much attention on the Eastern Province of Rwanda which has been experiencing land use/land cover change, and effects of climate change, particularly reduced rainfall. This region of Rwanda has unique ecosystems, including remnant natural forests. Few systematic studies have been done on these remnant forests, and there is little information available about their biodiversity and threat status. The Government of Rwanda through its commitments to sustainable development, climate adaptation and biodiversity conservation, has partnered with the Swedish Development Agency (Sida) to establish and implement a project titled *Reducing vulnerability to climate change through enhanced community-based biodiversity conservation in the Eastern Province of Rwanda*. The project, commonly referred to as COMBIO, is implemented by the Ministry of Environment, the Rwanda Forestry Authority (RFA), the Belgian Development Agency Enabel, and the International Union for the Conservation of Nature (IUCN).

For effective restoration of the remnant natural forests of the Eastern Province, biodiversity baseline information is needed. This information will guide restoration interventions such as removal of exotic species, addressing threats, and will also provide a foundation for monitoring. With the support from the consortium, the Center of Excellence in Biodiversity and Natural Resource Management (CoEB), a UNESCO category 2 Center hosted at the University of Rwanda, undertook? the baseline biodiversity survey for seven remnant forests in the Eastern Province under the COMBIO project. Six taxon groups were selected for the survey: plants, herpetofauna (amphibians and reptiles), flying insects (e.g., pollinators), terrestrial arthropods, birds, and mammals. These taxon groups were selected because they have good indicator species of forest 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, there is expertise within the CoEB to complete 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 seven remnant forests all show signs of significant human activities, including wood cutting, waste dumping (many forests have a lot of plastic waste), presence of invasive plants and agroforestry trees inside the natural forest. The main threats and human activities observed in different forests are, in their order of frequency of occurrence, plastic material, livestock grazing, tree cutting, agriculture, waste dumping, groundcover clearing, charcoal making, beehive setting, human excreta, poaching, mining, burning, water channeling, dumping of hardware material, road creation, and human trails. The most common waste material found was plastic material, which is the main component of waste dumping sites found mainly at Ibanda-Makera forest and Muvumba forest. Livestock grazing, tree cutting, agriculture, and groundcover clearing reduces the natural vegetation and hampers ecological processes, while waste dumping, charcoal making, and human excreta contribute to pollution of the forest and neighboring watercourses, and disease transmission risks. The Muvumba forest is especially threatened by waste dumping with plastics and other garbage.

An important threat identified in the remnant forests in the presence of exotic species, which compete with the native species and can hinder restoration of native plants and wildlife. While native tree species >5cm diameter at breast height were found in some of the remnant forests, many parts of the native forest remnants are dominated by invasive species. Ibanda-Makera, Muvumba, and Mashoza Natural Forests all have dense areas of the invasive *Lantana camara* which inhibits regeneration of native species. Karushuga Natural Forest has *Eucalyptus* and *Grevillea* trees which should be removed for effective natural forest restoration. Some of these species are invasive, they may compete with the native trees in the forest remnant, and given that most of the forest remnants are small and are supposed to be under forest restoration, it is recommended to remove non-native or exotic trees which can compete with the native species in these remnant forests that are undergoing restoration. In addition, there are plenty of these exotic species in the surrounding landscape (agroforestry and woodlots) so there is really no reason to keep them in the natural forest remnants which are undergoing forest restoration.

Despite these pressures, the biodiversity survey found many important species of plants and animals which indicate the forests are valuable for conservation of the unique flora and fauna of the Eastern Province. The native plant species found in the forest include some Albertine Rift endemic species, species that are threatened or endangered in the IUCN Red List, and species of value to the surrounding communities. These include *Osyris lanceolata*, *Prunus africana*,

Euphorbia grantii and *Mimusops bagshawei.* There were also some species found that represent the first time these species have been recorded in Rwanda; the tentative scientific names are *Alchornea floribunda, Azima tragacantha, Diospyros abyssinica,* and *Anthocleista vogelii* and taxonomic confirmation is underway. These observations further emphasizes the value of these remnant forests for biodiversity conservation in Rwanda and the region. Other Albertine Rift endemics were found, notably the bird species *Sheppardia aequatorialis*. Seventeen migratory birds were observed in the remnant forests, which also represents an important biological value of the forests. Frog species were found in some forest remnants that are indicators of ecosystem health – these are noted in the annex and information presented in the report – and demonstrate that despite the heavy human pressures, some forested areas have maintained healthy habitats for different species.

Fifteen mammal species were found in the seven remnant forests and are distributed into five orders and 10 families: Artiodactyla (one family: Hippopotamidae; one species), Carnivora (four families: Canidae, Felidae, Herpestidae, and Viverridae; six species), Primates (one family Cercopithecidae; three species), Rodentia (three families: Muridae, Nesomydae, Spalacidae; four species), and Soricomorpha (one family: Soricidae; one species). Most of the species were recorded at Ibanda-Makera and Mashoza forest. No mammal or mammal sign was observed at Muvumba forest. The serval *Leptailurus serval* and dwarf mongoose *Helogale parvula* are among rare species which are indicators of healthy habitats. The vervet monkey *Chlorocebus pygerythrus*, the jackal *Canis adustus*, and the striped mouse *Lemniscomys striatus* are generalist species generally indicative of degraded habitats or ecosystems with human pressure. A remarkable diversity of mammals in the remnants forests is encouraging for the integrity of some the forest ecosystems and represents a valuable baseline for future monitoring.

The assessment of pollinators in the remnant forests provides valuable evidence for an ecosystem service often overlooked in mixed forest/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 forage into the remnant forests. Furthermore, other flying insects and terrestrial arthropods found in the remnant forests may provide services such as insect pest control and support to soil fertility through decomposition and soil aeration activities.

We developed a biodiversity status score to facilitate monitoring the remnant forests; the score is based on presence 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), and a threats score, with higher scores for forests with less presence of human activities and threats to the forest. This summary table of biodiversity status for each remnant forest is presented in a table format at the end of the report for easy interpretation. These tables can guide forest management, including restoration activities and follow up monitoring to track the trajectory of the forests over time, 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). In addition, the baseline survey provides up-to-date information on the area of each remnant forest, which serves as a foundation for monitoring changes in land cover of the remnant forests.

As recommendations, better monitoring and patrolling of these unique and valuable remnant forests is needed. Invasive plant species in the remnants should be removed. Further research

efforts can be put into studying their impacts but given that the remaining cover of native forest from Eastern Province is so limited, it is worthwhile to prioritize the native trees within the remnant boundaries. A lot of human activity has been observed in the forests; programs to sensitize the local communities, and activities with local schools and cooperatives could help draw attention to the value of these forests 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 forests. 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. Exploration of revenue generating activities in and around the forests (honey, birding tourism, etc.) would be valuable. Finally, buffer zones of planted trees would be valuable around each forest to demarcate the boundaries clearly, and these buffer zones would not only minimize negative edge effects, but could also be used by local communities for resources (e.g., wood, fruit trees, medicinal plants), if carefully managed and controlled by communities.

The baseline survey highlighted the fact that many species remain unevaluated in the IUCN Red List, and furthermore, the national threatened and endangered status of many of these species is not well understood. Thus, effort should be placed on advancing the Red List assessments for the major taxon groups (e.g., plants, birds, herpetofauna, pollinators) including the national status.

The work in this report represents an important step in the development and conservation of the biodiversity 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 forests. A further recommendation from this study is the need to establish national Red List criteria and a governance structure for this national Red List. There are also many species which have not been evaluated and it is recommended that these be evaluated, and threats be identified.

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1. 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 sancta that are being created by the COMBIO project.

In this report, we present the results of the biodiversity baseline survey for the seven natural forest remnants of the Eastern Province. This includes a desk review of state of information about each of the seven natural forest remnants located in Nyagatare, Bugesera, Ngoma, and Kirehe Districts. These reserves make up about 3,102 ha across these districts. In addition to the desk review, surveys in each of seven remnant forests 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 forests were scored in terms of biodiversity value, and this information is a tool to support restoration and monitoring. The forests were mapped, and all species observations and threats were recorded and georeferenced. The biodiversity and threats data and the forest maps will facilitate the management of the forests. The annex includes species checklists and photos.

1.1 Background

Rwanda's landscapes have gone through 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).

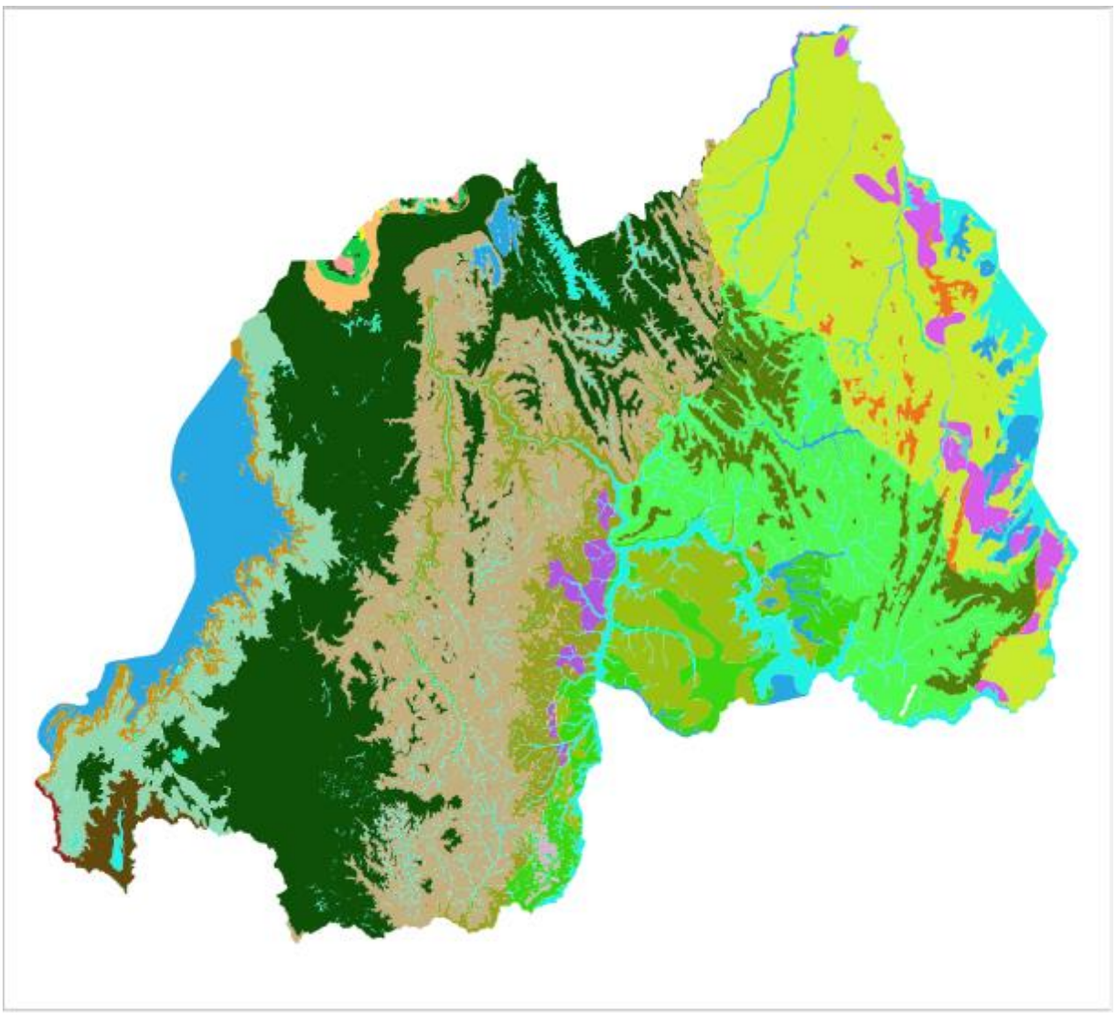


Figure 1. Map of the ecosystem types of Rwanda showing terrestrial and freshwater ecosystems. The legend for the map is shown below. Source: (SANBI, CoEB, & REMA, 2022).

1.2 Demographics of the Eastern Province

The Eastern Province has a population density of 433 people/km^2 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 (EICV), 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).

Examining the unweighted sample sizes at the provincial level for urban and rural domains in the EICV3 of 2011 and the EICV2 of 2005 provide insights into the distribution of the surveyed population. 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 remnant forests of the Eastern Province have been experiencing significant pressure from human activities including agriculture, tree cutting for wood, hunting, mining, and livestock grazing. However, despite these pressures, there are still representative ecosystems and some biodiversity remaining. The Eastern Province is has seven districts: Nyagatare, Kayonza, Gatsibo, Rwamagana, Bugesera, Kirehe and Ngoma and some of these districts have remnant forests.

1.3 General Information About the Remnant Forests of Eastern Province, Rwanda

Below we present background information for each of the seven remnant forests surveyed in this study based on a desk review that searched and reviewed published articles using Web of Science with keywords for each forest, and unpublished reports available on the internet using Google Scholar (Figure 2).

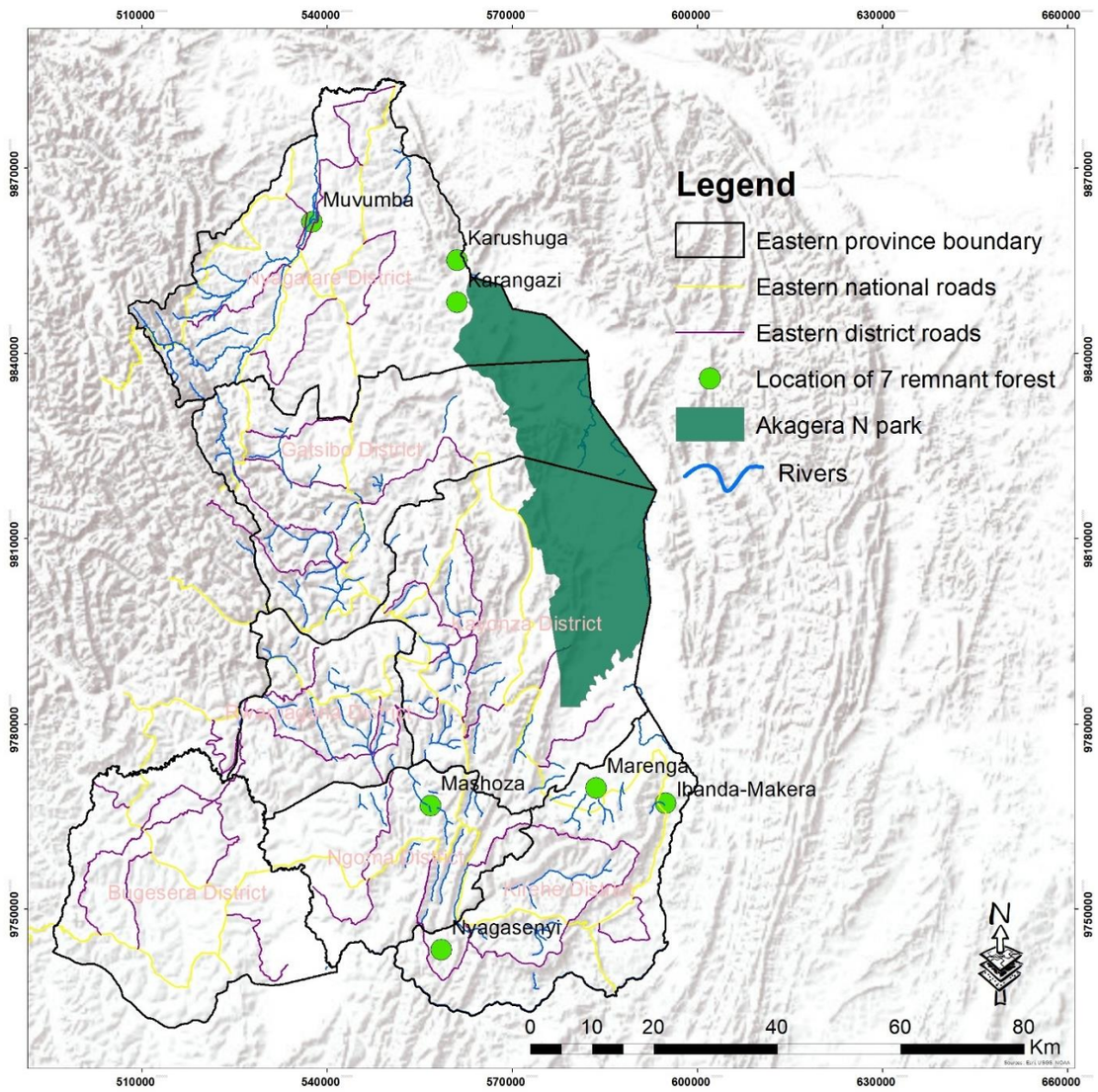


Figure 2. Map of the seven remnant forests located in the Eastern Province, Rwanda sampled in this study

1.3.1 Ibanda-Makera Natural Forest

Over the course of 31 years, from 1984 to 2015, the Ibanda-Makera Natural Forest in Rwanda's Eastern Province's Kirehe District suffered substantial land changes. The area of this forest has drastically decreased from 1425 hectares in 1984 to 169 hectares in 2015 and up to today, with concomitant losses of biodiversity and forest habitats. An 88% drop of this magnitude suggests serious ecological degradation of the forest environment (MINILAF, 2017). The loss of biodiversity, including plant and animal species unique to the limited forest cover of the Eastern Province, has led to habitat fragmentation, disturbance of ecological processes, and the loss of threats to the remaining ecosystems. In addition to posing serious threats to local wildlife populations recorded by the ACNR (2009), the shrinking forest area may also change ecosystem dynamics and result in a decline in species richness. The significant loss of Ibanda-Makera Natural Forest cover calls for urgent action (ACNR, 2009; REMA, 2015). The ACNR and Rwanda Environmental Management Authority reported some endangered and vulnerable species found in Ibanda-Makera Natural Forest, including 127 plant species dominated by the woody species *Phoenix reclinata Jacq, Ficus vallis-choudae Del,* and *Markhamia lutea (Benth) Schum*; 39 bush or shrub species such as *Teclea nobilis Delile, Dracaena afromontana Mildbr.,* and *Bridelia micrantha*; and 29 liana and herbaceous creeper species including *Lagenaria abyssinica (Hook) C. Jeffrey,* and *Basella alba L.* Intra-African migrant bird species like *Cuculus solitarius, Clamator levaillantii, Cuculus clamosus Merops apiaster* and *Acrocephalus scirpaeus* which are known as palearctic migrants, *Crinifer zonurus* which is endemic to Eastern Africa, and a vulnerable species *Balearica regulorum* according to the IUCN Red List, have also been observed. The mammals previously observed to inhabit Ibanda-Makera include *Cercopithecus mitis dogetti, Chlorocebus aethiops, Papio Anubis, Tragelaphus scriptus,* and *Felis serval* (ACNR, 2009). REMA reported other species such as *Panthera pardus, Syncerus caffer caffer* (Endangered*), Laptailurus serval, Numida meleagris,* and *Potamochoerus larvatus larvatus* (Vulnerable) (REMA, 2015)

1.3.2 Mashoza Natural Forest

Mashoza Natural Forest is a natural gallery forest in Ngoma District, Rurenge Sector. It is also referred to as Rujambara, Rugomero, and Parike. The forest is located on a hill in Mashoza (REMA, 2015). The ACNR report done in 2009 highlighted that Mashoza Natural Forest also known as Rugomero had a total area of 19.40 ha (ACNR, 2009) while the updated REMA report done in 2015 on the study to Establish a National List of Threatened Terrestrial Ecosystems and Species in Need of Protection in Rwanda mentioned that the total area of Mashoza was 17.00 ha with a perimeter length of 2,452 meters, situated in agro-bioclimatic zone 10, with an average slope of 12 degrees and altitude of 1,388 meters (RNRA, 2016). Based on the report from MINILAF (2017) on Forest investment for Rwanda, the forest has diminished from 36 hectares in 1984 to 18 hectares in 2015, a 51% habitat loss. The forest hosts both mountain plant species such as *Pittosporum spathicalyx* and other such as *Acacia polyacantha* and *Vangueria volkensii*, and a rare plant species known as *Pterygota mildbraedii*. *Blighia unjigata* a tree tropical forest ecosystems, has been recorded in this forest in 2009. *Chlorocebus aethiops*, the vervet monkey, have been reported in the forest (ACNR, 2009). The Vulnerable species *Numida meleagris* was found in Mashoza Natural Forest as reported by REMA (2018). Despite some remaining unique species, Mashoza forest ecosystem is severely damaged (REMA, 2015). According to the ACNR report, the invasive species that threaten Mashoza Natural Forest are *Lantana camara, Tithonia diversifolia,* and exotic species like *Grevillea* and *Eucalyptus* species (ACNR, 2009).

1.3.3 Marenga Natural Forest

Marenga Natural Forest is located in the Eastern Province of Rwanda in Nasho sector of Kirehe district. The Forest has an area of 25.56 hectares (reference?). A thorough search of available reports and publications shows there are no known surveys explicitly about biodiversity that have been carried out in Marenga Natural Forest. Future efforts should prioritize biodiversity surveys for this forest ecosystem since precise data is essential for conservation planning and sustainable management.

1.3.4 Karangazi Natural Forest

An assessment of forest cover conducted in Karangazi from 2015 to 2019 shows an absolute change in natural forest cover at the sector level, revealing a decrease of 321 hectares during these four years (Ly and Dia, 2023). The reduction in natural forest cover raises concerns regarding potential ecological impacts, including habitat fragmentation and biodiversity loss. Understanding the contributing factors behind this decline is crucial for implementing targeted conservation strategies and sustainable land management practices for the forest. There is little other available information about the biodiversity of this forest.

1.3.5 Karushuga Natural Forest

Karushuga Natural Forest, formally known as Nyagatare Natural Forest in the Rwimiyaga sector, is within the Eastern Province of Rwanda. The natural forest covers an area of 510.98 hectares with a perimeter of 24325 meters (MINILAF, 2014). There was no other available information about this forest.

1.3.6 Muvumba Natural Forest

Muvumba Natural Forest is 672.15 ha in the Eastern province of Rwanda, Nyagatare district. This forest is found in seven sectors: Karama, Nyagatare, Gatunda, Tabagwe, Musheri, Rwempasha and Matimba sector. The forest spans the Muvumba River. The main vegetation of this forest is dominated by the tree species *Vachellia kirkii* which is threatened in this region with extirpation due to human activities including the agriculture, firewood collection, and farming. In 2011, a report documented that the forest lost 46.5% of its original area over the past 30 years (REMA 2018). Measures to restore Muvumba Natural Forest include interventions by the local NGO called Association pour la Conservation de la Nature au Rwanda (ACNR) which started ecosystem restoration activities in Muvumba Natural Forest in collaboration with local communities to remove the exotic Eucalyptus species, prepare a *Vachellia kirkii* nursery, train local communities about agroforestry trees, distribute of *Grevillea robusta* in local communities, and plant *Vachellia kirkii* in restoration sites in the forest (ACNR 2010).

1.3.7 Nyagasenyi Natural Forest

Nyagasenyi Forest is located in Eastern province of Rwanda, Kirehe district, Gahara sector and is 19.00 ha. This forest is connected to Cyunuzi wetlands and Rwagitugusa wetland (also connected to Akagera wetland). Nyagasenyi forest is rich in fauna and flora. It has a rare and medicinal plant species including *Anthocleista grandiflora and Syzygium cordatum*. *Blighia unijugata, Trimeria grandiflora, Zanthophyllum chalybeum, Clausena anisata and Bridelia micrantha,* P*aulinia pinnata, Tacazzea floribunda, Ficus asperifolia, Rhoicissus tridentata and Neorautanenia mitis.* Other remnant species are represented by *Sapium ellipticum, Maesa lanceolata, Mitragyna rubrostipulata, Blighia unijugata and Albizia gummifera* are various plants of this forest. The fauna diversity that inhabits thi forest includes snakes such as *Naja melanoleuca* and *Naja nigricollis, Dendraoaspis jamesoni kimosae* (Mamba), and *Python sebae*. Other fauna reported in Nyagasenyi include *Cercopithecus mitis doggetii* and various bird species. In 2011, research indicated Nyagasenyi Natural Forest lost 58% of its original size in the past 30 years. The analysis predicted that it might lose more than 80% of its forest coverin the next 50 years due to high agriculture encroachment. However, there was no document found that discussed mitigation measures that are already started to promote and improve Nyagasenyi restoration and its biodiversity protection.

2. Methods

The biodiversity baseline survey methods were developed and approved with the team from the COMBIO partner organizations. Following approval of the methods, the seven remnant natural forests were sampled over two field campaigns, the first one from 24 September to12 October 2023, and the second one from 16 November to 6 December 2023. Each forest and its area are shown in Table 1. The eighth remnant natural forest in the Eastern Province, Karama Forest in Bugesera, was not accessible – the current managers of this forest would not provide permission to access it for the biodiversity sampling. For each of the seven remnant forests, biodiversity surveys were conducted that included plants, herpetofauna, flying insects, terrestrial arthropods,

birds, mammals and threats. The methods for each of these taxon groups and the threats survey are explained below. The forest remnants were mapped and the area determined for each forest (Table 1).

Table 1. Names and area for each remnant natural forest sampled in Eastern Province, Rwanda.

Remnant Natural Forest	**Area (ha)**
Ibanda-Makera	169.00
Nyagasenyi	19.00
Karushuga	262.69
Marenga	25.56
Muvumba	672.15
Karangazi	510.98
Mashoza	17.00

2.1 Plants

The purpose of the plant sampling was to obtain a baseline of indicators for each remnant, including plant diversity, density and size class distributions, which provide indications of biodiversity and carbon, and enable monitoring of change over time. The data also enables determination of plant communities within the remnant forest fragments. We used a stratified sampling approach to ensure that different vegetation types (e.g., closed canopy forest, open canopy forest, open areas of shrubland or grassland, wetlands) are sampled for representativeness. Within each of these strata, plots of 10m diameter (.01 ha) were randomly located to sample the vegetation. Circular plots were used because they are easier to establish than square or rectangular plots, they have fewer edge tree issues, and there is little sampling difference between circular and square or rectangular plots (Packalen et al. 2023). To stratify the vegetation types, we used Google Earth tools with site visits to identify the vegetation types. Effort was made to sample each stratum (homogeneous vegetation type), and where a stratum was present in several locations within the remnant, we have been attempting to sample within each replicate stratum. We aimed for at least 10% sampling in each vegetation type.

The plant survey team began from a defined starting point at the remnant which is within a homogenous vegetation type or stratum. Each starting point was georeferenced and direction of travel recorded to enable resampling for monitoring purposes. From the initial starting point in each stratum, the team moved 10 paces in a predetermined compass direction into the vegetation type to begin the sampling, with that point being the center of the circular plot. The area within the plot was examined to ensure it is homogeneous. If it is not, the plot center point has been shifted set distance to ensure the plot is within the intended vegetation type. Subsequent plots have been located by moving 250 paces in the same compass direction to set the next plot center point for sampling. The compass direction was modified to ensure that the sampling remains within the stratum. If the stratum can be identified with Earth Observation tools, the stratum was mapped and center points for each plot was randomly located on the map within each stratum, again for a coverage of ~10% of each stratum.

The following attributes were measured in each plot: tree density, woody plant (tree and shrub) species richness, and life form of enumerated woody plants (e.g., tree including classification as early or late successional, understory tree, shrub, sapling, liana). These measures provide an indication of the health and functioning of the forest fragments. To collect these data, within each plot, all trees with DBH >5cm were identified to species, DBH recorded, and height estimated. Trees with DBH<5cm and shrubs were counted (stems counts), identified to species and recorded, as well as lianas. 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 and geographical distributions were noted for each species identified. We consulted the Draft Report for the Survey and Mapping of Threatened Native Trees Species of Eastern Province produced by the Rwanda Forestry Authority (2024) for national threat status of native plants.

Analyses of the plant data were conducted in R (R Core Team, 2019). Species richness, evenness, Shannon diversity and evenness indices were calculated. Species rarity was calculated to provide a measure of local distribution of species and will be useful for monitoring over time. Rare species have a higher risk of local extinction (Rosenzweig 1995). Species rarity was calculated as the relative frequency of occurrence of each species in the plots (Van Gemerden 2003). Species were classified as rare (occurring in less than 10% of the plots), intermediate (10–60% plots) and common (>60% plots). 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 calculate an average rarity index of the plants found at each site (Leroy et al. 2012).

In order to define vegetation types in each natural forest, we quantified community composition by creating a distance matrix for the vegetation plots using a Euclidean distance index with the function vegdist() from the R package vegan (Oksanen et al., 2022). To visualize the clustering of plant plots into forest vegetation types or assemblages, we used non-metric multidimensional scaling (NMDS) (Kruskal, 1964) via the ordiplot() function in the vegan package. To visualize which species were most important in different plant plot clusters, we used the orditorp() function in the vegan package. Vegetation assemblages were identified for each of the seven remnant forests using this approach.

2.2 Herpetofauna

Amphibians and reptiles were surveyed using opportunistic visual encounter surveys (VES) during the day (Rödel & Ernst, 2004). This survey was not conducted during the night time and all observations took place after dawn and before dusk (6:00-18:00). Survey observations were recorded along set transects in each of the natural forests. Each observation period lasted 40 min to 3 hours, depending on the size of the transect. During direct observation, the location of each animal detected was noted (GPS coordinates and distance from road), habitat type (temporary pond and swamps), and water type (permanent running water, temporary running water, permanent pond) were also noted if present. If the animal was >10 m from one of these aquatic habitats, its position was noted as being “far from water”. The survey was exhaustive to ensure that all species present in each forest were detected. The species accumulation curve is against the time plateau. Statistical analysis was done using the PAST 4.03 software package (Paleontological Statistics) for Windows.

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 for use in identifying calling individuals. For reptiles, species encountered were photographed and identified in collaboration with of reptile experts in Rwanda, referencing the Field Guide to East African Reptiles (Spawls et al. 2006). 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 the University of Rwanda. We noted endemic status, recorded the IUCN Red List status, and categorized indicator status for each species that we observed. Checklists and distribution maps of the recorded species, with species statuses, were produced for each sampled forest (see appendices).

Herpetofauna as indicator species

Amphibians are renowned for their excellent use as biological indicators for ecosystem health among other services they provide worldwide (Pollet & Bendell-Young, 2000; Zaghloul et al. 2020). The taxa suggested for effective monitoring are described in Annex 6. The reason amphibians are important biological indicator species is due to their high sensitivity to pollutants, altered hydrology, and degradation of ecosystems (Hogan et al. 2008). Thus, amphibians can be used as ecosystems health indicators by analyzing their community structure, composition, and diversity (Ernst & Rödel, 2008; Hölting et al. 2016). Due to their particular mode of life (Wells, 2007), slight changes in environmental conditions expose amphibians to a high risk of decline which influences changes in their diversity (Roque et al. 2018). In Rwanda, 62 species are reported

to be distributed among all kinds of ecosystems, including both anthropogenically dominated and intact ecosystems (Dehling & Sinsch, 2023). For anthropogenically dominated systems, the study by Tumushimire et al. (2020) investigated the amphibian communities of altered wetlands of Rwanda, assessing the presence of anuran species in several types of microhabitats, to explain each species tolerance to different kinds of human disturbance, and use as indicators species in disturbed wetlands – such as those converted into farmlands and mines (Swanson et al. 2019). Other studies report species encountered in major natural forests (Dehling & Dehling, 2023; Dehling & Sinsch, 2023; Roelke & Smith, 2010) and wetlands (Dehling et al. 2011; Mindje et al. 2020).

Reptiles in Rwanda show a diversity of species of snakes, lizards, terrapins, and other reptiles and their distribution (Spawls et al. 2018). However, studies on their ecological importance such as potential for biological indicators are still poor, and thus we do not recommend using reptile species as indicator species for ecological heath. Further information on species distribution and respective diversity measurement of reptiles at particular sites is critically needed to better understand how reptiles can be used as indicator species to evaluate the status of ecosystems to generate science-based evidence to guide decisions and policy development for effective management and conservation of these ecosystems (Buschke et al. 2023).

2.3 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 & Ries, 2015; Kral et al., 2018a). During the field data collection, Pollard transects are established as a walking path; the size of the transects or path can vary depending on the habitat types. Along each transect, all butterflies were opportunistically recorded, captured, and identified; observed either flying, feeding on flowers, resting, or mud puddling along transects (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, honey bees, wasps, and flies were recorded while walking along the transects and the same procedure of capturing specimens, keeping the specimens in the entomological envelopes and transfer to the laboratory for further identification and confirmation were applied to the pollinators that were not able to be identified from the field. 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, 2017), 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 butterflies' distribution. The butterflies distributed in the 50 meters interval were grouped and assigned to single geographic location. The collected data were digitized into Microsoft Office (Microsoft Excell) and later processed and analyzed with the use of R programming software.

The plant-pollinators network graphs were built using the bipartite R packages and its functions within a ggplot2 R package (Dormann et al., 2014). The information about the pollinating insects diversity, their host plants, sites where these data were collected and the abundance number of pollinating insects that contacted the stigma were selected and then converted by frame2webs function of R into the matrix web that can used in bipartite analysis. Then the visweb function from bipartite package was used to draws the network graphs from the web. Under this survey, a web is a matrix representing the interactions observed between pollinating insects and their host

plants. These pollinator network interaction graphs provide insight into the ecological integrity of the pollinator community in each forest remnant.

2.4 Terrestrial Arthropods

Terrestrial arthropods were sampled using line transect methods (Naranjo, 2008). 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 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 $1m^2$ plot on the ground, removed the surface debris, and then searched for terrestrial arthropods moving on the ground by using manual aspirators and forceps, once arthropod is captured it was 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 15 minutes, transferring the captured insects into tubes as insects became captured in the net.

Once captured, regardless of method, specimens were transferred to plastic tubes containing concentrated alcohol of 96% for preservation. We archived 1,015 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, including the Field Guide to the Insects of South Africa (Picker et al. 2019), Kakamega forest book from Kenya and comparison to the reference species insect collections found at the Centre of Excellence in Biodiversity and Natural Resource Management. In this study, specimens were identified to family level.

We calculated Dominance, Simpson Index, and Shannon Diversity Index, and their combined analysis aims to provide insights into the overall health status of the natural forests. Data were analyzed using R programming software.

2.5 Birds

We used the point-count method to sample birds along the transects in the forest fragments, 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 of 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, and IUCN Red List status. The observed bird species were placed into nine different functional groups: 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), Scavenger (dead or decaying organic feeding) and Carnivorous (meat-feeding) species. The number of different functional groups is an indication of ecological integrity, and in this case, we see high functional diversity which suggests diversity of ecological interactions and niche specialization across all seven forests. Abundance data were utilized to calculate diversity using the Shannon-Weiner index of diversity (Magurran, 1988).

2.6 Mammals

Medium and large-sized mammals are surveyed in rapid assessments by recording direct observations and indirect signs of mammals along line transects (Larsen, 2016). Direct observations were based on occasional sightings of mammals such as primates and carnivores, and binoculars were used for observation and detection at large distances, while indirect signs of mammals included observations of fresh tracks, feces, burrows, and feeding signs. We noted and georeferenced the location of all direct observations and indirect signs of mammals that we observed during our sampling effort. Photos were taken where necessary to illustrate some observations and for further identification. We noted any direct observations or signs of mammals from within each site but outside the transect, for example while going to the transect or shifting from one transect to another. We also recorded the direct observations and GPS locations of mammals occasionally encountered by the members of other field teams. For each mammal species observed, we noted endemic status, indicator species status, IUCN Red List status, and noted species with particular conservation implications for each species that we observed.

Indicator species were identified based on the literature and the local contexts of the conservation of mammals. As most of the literature did not indicate many studies of indicator species among the mammals that we recorded, while some of the animals that have been used as indicator species such as the African otters were not recorded, we determined indicator species based on their occurrence and abundances and how they have been affected by anthropogenic impacts and their responses. Indicator species among mammals were described on their impacts and responses as indicator species and with the level of habitat status they indicate. We used RStudio to analyze all the qualitative presented in plots, including bar charts and boxplots (R Core Team, 2023). We calculated frequencies of occurrence for each species recorded to conduct comparisons between forests and within forests.

2.7 Threats and disturbances

To ensure effective outcomes of biodiversity monitoring, there is a need to identify the threats and disturbances that are present across our sampled sites (Lindenmayer et al. 2012). For this reason, we conducted a survey of the threats and disturbances alongside our biodiversity surveys to identify the currently existing threats and disturbances.

We walked along each transect and recorded all observed signs of threats and human disturbance (e.g. wood cutting, grazing, fires, trails, snares, garbage, mining) to quantify the abundance and frequency of these activities. We noted any threat that could be observed within two meters of either side of the transect (e.g. smaller threats, such as plastic waste), and we also considered any larger disturbances that could be directly observed by the observer (e.g. mining or tree cutting that could be seen from a distance). For any threat or disturbance more than two meters away from the transect, we estimated the offset distance from the transect in meters perpendicularly to the transect. We recorded the number of observations for each threat individually when it was feasible to do so (e.g. number of plastic bottles), and when a threat occurrence covered a large extent of a land surface (such as agriculture or wildfire) we estimated the area covered in square meters. Geographic coordinates were recorded for each observation of a threat or disturbance.

We classified threats and disturbances as something that was directly caused by humans; therefore, the threats that arise as long-term consequences of human impacts and are difficult to quantify or describe in the field (e.g., invasive plant species and climate change effects) were not considered as a threat or disturbance. Because plastic materials were the most frequently occurring threat, we counted individual occurrences of plastic waste if they were greater than five meters apart. When we observed more than 10 plastic materials in one place, or if plastic materials were mixed with other forms of garbage, we defined the threat as a waste dumping place. Therefore, a dumping site could contain a bulk of plastic materials or other types of glass bottles, mixed or not with other garbage. We also distinguished tree cutting from forest underground vegetation clearing as two distinct types of disturbances.

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 to be used in RStudio (R Core Team, 2023) where gglot2 and other operational tools were used to produce bar plots and box plots for a wide range of qualitative analyses for the occurrence of threats for all the forest sites and each individual forest.

3. Biodiversity & Threats General Survey Results

The seven remnant forests of the Eastern Province sampled in this baseline survey still harbor a number of important species of plants and animals including endemic and migratory species, and species listed as Vulnerable, Threatened or Endangered on the IUCN Red List, despite the presence of fairly heavy human disturbances. We first present general information about each taxon group across all remnant forests combined, then we present details of each forest remnant and the biodiversity and disturbances found in each.

3.1 Plants

From all seven remnant forests a total of 83 plant species from 36 families were recorded. Fabaceae was the most common family (15.72%), followed by Malvaceae family 11.94%, and Stilbaceae 0.62% which is the least (Figure 3). About 67% of the recorded plant species are considered as Least concern on the IUCN Red List, only 1% are considered Vulnerable, and almost 32% of the plant species are Not Evaluated (NE) by the IUCN Red List. Among the species observed, 80% are native to Rwanda and the region while 20% are introduced to Rwanda. Checklist of the plant species can be found in Annex 1.

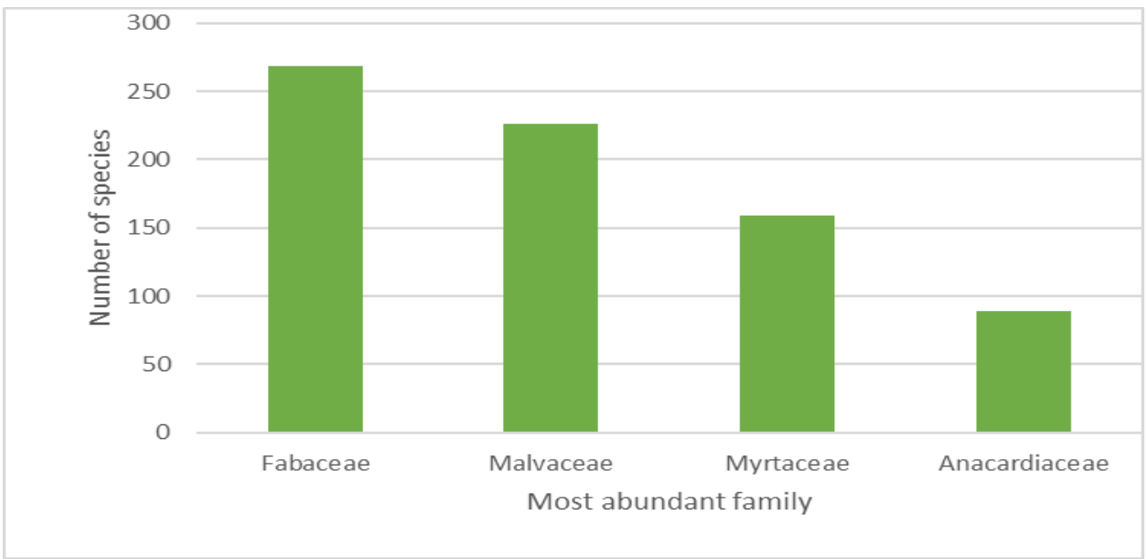


Figure 3. The top four most abundant plant families by number of species per family, across all seven forest remnants in the Eastern Province, Rwanda.

Figure 4 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 4a, Karushuga Natural Forest in green has the highest species richness, followed by Karangazi. 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 the curves reached the maximum 1.00 value, except for Marenga Natural Forest, which was very close to achieving sampling completeness.

Karushuga Natural Forest, with area of 269.69 hectares, stands out as having the highest species richness at 44 and a high Shannon diversity index of 3.21 (Table 2). Following closely is Karangazi

Natural Forest, with an area of 510.98 hectares, with species richness of 27 and a Shannon diversity index of 2.72. Muvumba Natural Forest, the largest among the seven remnant forests with an area of 672.15 hectares, exhibits lower species richness, with only seven species and a Shannon diversity index of 1.45. In addition to diversity, Table 2 also shows the mean dbh, native and exotic tree species stem density, mean wood density, and rarity index across the seven remnant forests.

Table 2. Species richness, diversity, mean DBH, native and exotic tree species stem density, mean wood density (WD) and rarity index across the seven remnant forests sampled in this study, Eastern Province, Rwanda.

	Site	Area (ha)	Spp richness	Shannon diversity	Mean DBH	Native spp stem density	Exotic spp stem density	Mean WD	Rarity index
1	Mashoza natural forest	17	17	1.45	0.53	353	397	0.63	0.01
2	Ibanda-Makera natural forest	169	13	1.71	6.10	257	187	0.55	0.01
3	Muvumba natural forest	672.15	7	1.45	2.40	65	155	0.63	0.01
4	Marenga natural forest	25.56	14	2.08	21.41	93	1	0.57	0.05
5	Nyagasenyi natural forest	19	14	2.23	3.28	81	28	0.56	0.05
6	Karangazi natural forest	510.98	27	2.72	0.70	922	114	0.55	0.01
7	Karushuga natural forest	262.69	44	3.21	1.35	773	110	0.56	0.02

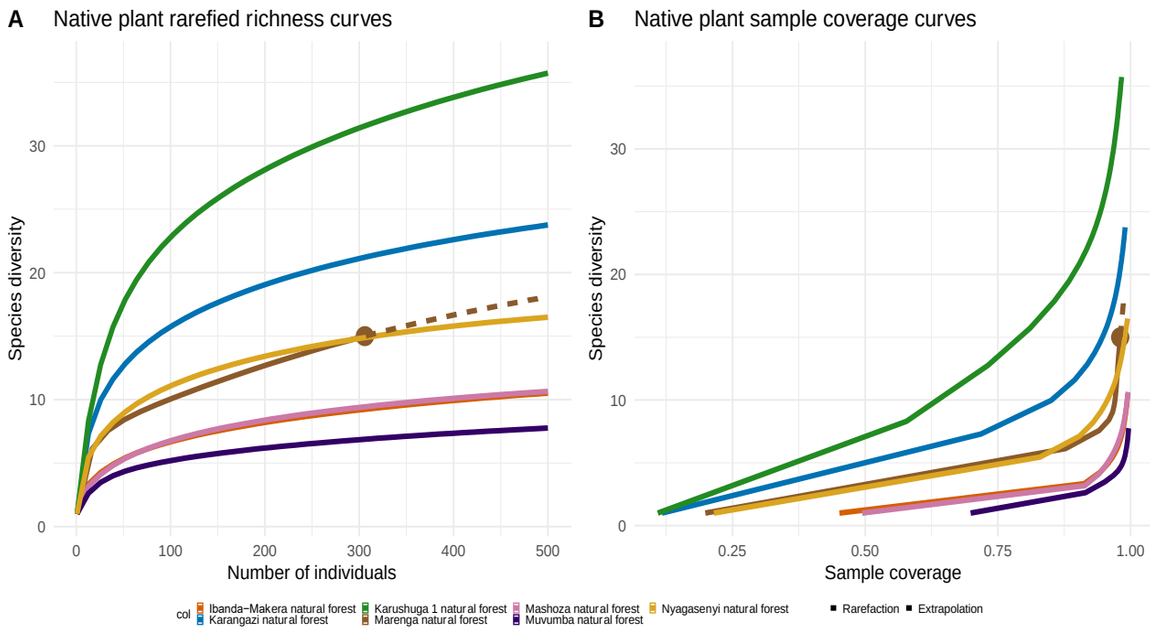


Figure 4. Sample-based (a) rarefaction and extrapolation curves and (b) sample coverage curves using introduced species richness (Hill numbers of order 0), comparing seven different sites. Solid lines represent curves based on sample data, while dashed lines represent extrapolations.

3.2 Herpetofauna

We observed a total of 14 amphibian species from five families, and eight reptile species from seven families, across the remnant forest sites (Annex 2). Hyperoliidae was the most common Family (43%), followed by Phrynobatrachidae (21%) and Ptychadenidae (21%), and Bufonidae and Pixycephalidae each had 7% of the species recorded. Most of the observed amphibian species are considered Least concern on the global IUCN Red List, but based on the National IUCN Red List category as published by Dehling and Sinsch (2023), *Hyperolius lateralis* is reported as Vulnerable to extinction.

We observed reptiles from seven families were recorded across the remnant forest sites (Annex 2). Each family had with one species except for the family Scinidae with two species. The reptile observations included two species of turtles, one species of chameleon, three species of lizards, and two species of snakes. Only one species, *Python sebae*, is listed as Near Threatened (Annex 2) on the IUCN Red List. Photos of some of the species observed during the sampling can be found in the Annex 7 and 8.

Figures 5 and 6 indicate 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 5, Ibanda-Makera Natural Forest has the highest species richness for amphibians, followed by Karushuga. Sample coverage curves help assess completeness of the biodiversity sampling. Curves that reach a plateau and come to vertical lines to the right of the graph represent sample coverage of 100%, indicating that sampling effort captured the entirety of the community. Almost all of our curves reached the maximum value for amphibians, but for reptiles there may be additional species found with targeted sampling.

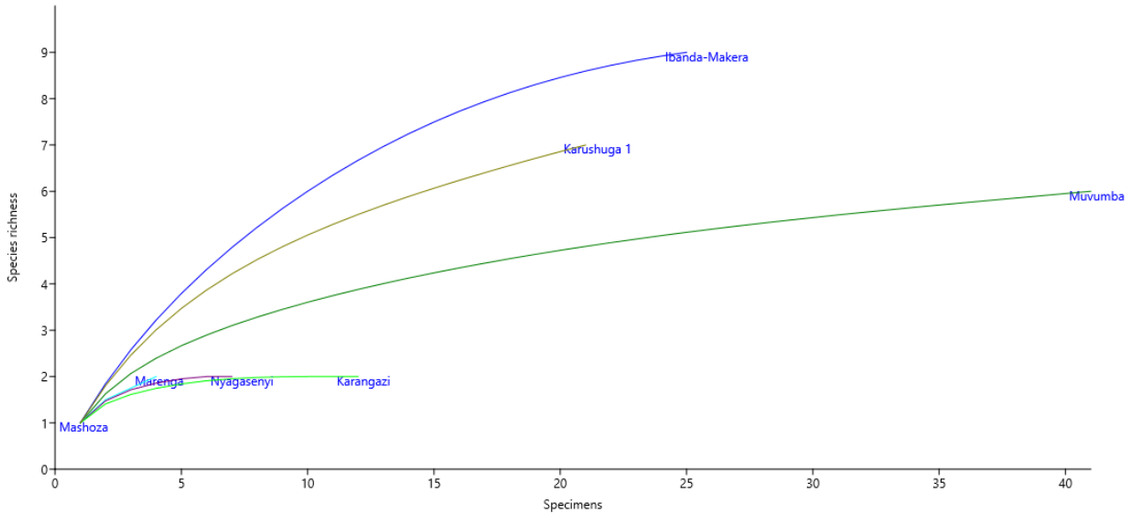


Figure 5. Species-based rarefaction curves of amphibian species richness for the sampled natural forests in Eastern Province, Rwanda.

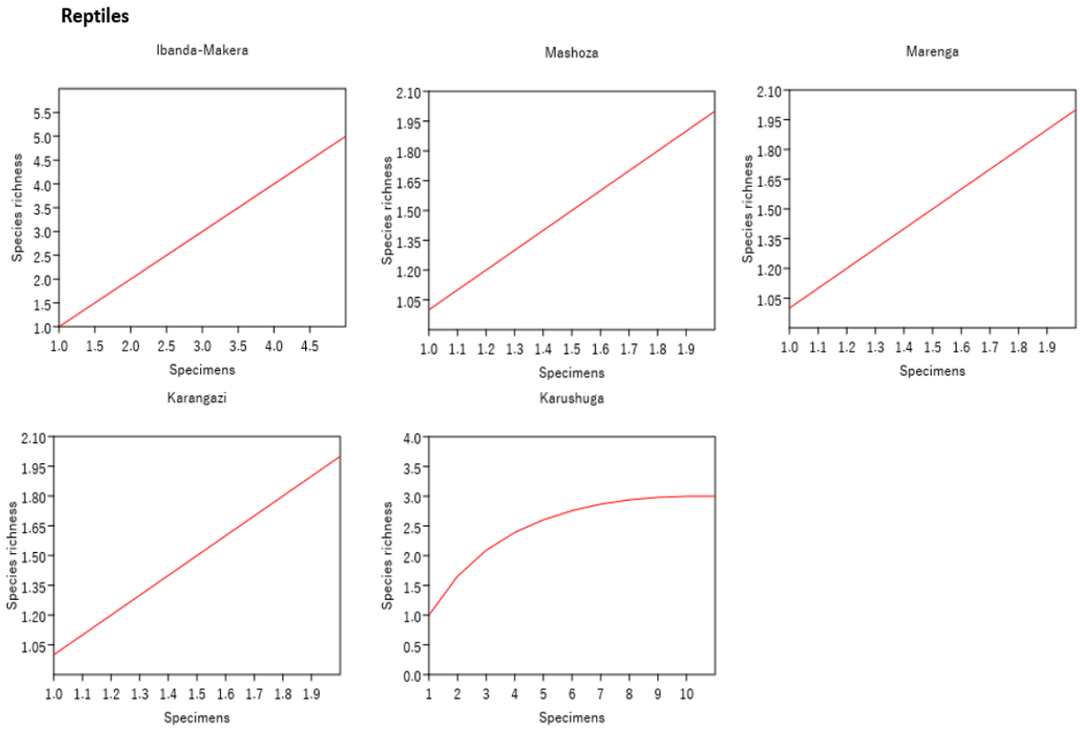


Figure 6. Species-based rarefaction curves for reptile sampled in the seven remnant forests sampled in Eastern Province, Rwanda.

3.3 Flying insects

A total of 86 butterfly species were recorded across the seven remnant forests (Annex 3). Butterfly observations were from five families. The most abundant butterfly family observed was Nymphalidae (46.28%), followed by Pieridae (37.75), Hesperiidae (5.99%), Papilionidae (5.63%) and the less abundant family was Lycaenidae (4.36%). Some of these butterflies are listed as Least Concern (51 species) by the IUCN Red List while others are listed as Evaluated (35 species).

The seven remnant forests are also rich in other kinds of pollinating insects. A total of 34 pollinating insects were found from 10 families, including honey bees and wild bees (Apidae), flies (Hesperiidae, Lycaenidae, Nymphalidae, Pieridae, and Chloropidae), wasps (Sphecidae), stingless bees (Halictidae), and hawk moths (Sphingidae, including *Cephonodes hylas*). The most abundant pollinator (honey bees) has an IUCN Red List status as Data Deficient (DD) (40.44%). Other pollinating insects are listed as Least Concern (LC) (20.70%), or Not Evaluated (NE) (38.86%).

Figure 7 shows the rarefaction curves which help understand the species richness while accounting for the sampling effort of flying insects. Curves that accumulate species at a more rapid rate (i.e., curves that are higher up on the graph) have higher species richness. Karushuga Natural Forest has the highest species richness and Marenga the lowest. 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. Sample coverage curves for butterflies (Figure 7B) indicate that additional sampling effort would add more species.

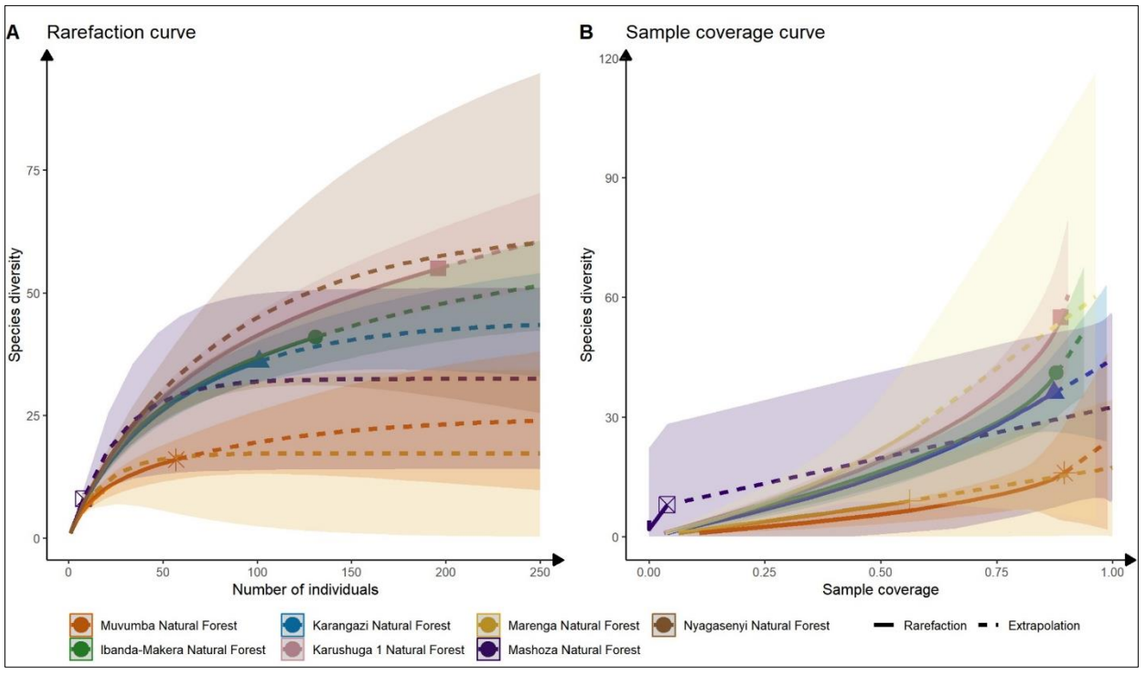


Figure 7. Butterfly rarefaction and extrapolation curves (A) and sample coverage curves (B) using butterfly species richness (Hill numbers of order 0) across the seven natural forest. Solid lines represent the curves based on sample data, and the dashed lines represent the extrapolations. Shaded areas represent the 95% confidence intervals surrounding the curves.

3.4 Terrestrial Arthropods

We sampled a total of 3,081 terrestrial arthropod individuals belonging to 79 families (Annex 4) across all seven natural forests sampled in the Eastern Province of Rwanda. In the Karushuga Natural Forest, we found a total of 52 families, followed by the Karangazi Natural Forest with 51 families, Ibanda-Makera with 46 families, Marenga Natural Forest with 41 families, Mashoza with 35 families and finally Nyagasenyi and Marenga with 31 families each (Figure 8)**.**

Figure 8 shows the amphibian species rarefaction curves, and indicates that more sampling could uncover additional species in Muvumba, Karushuga and Ibanda-Makera Natural Forests, while for

Mashoza, Marenga, Nyagasenyi and Karangazi, the curves indicate that the species richness for this taxon has been adequately sampled.

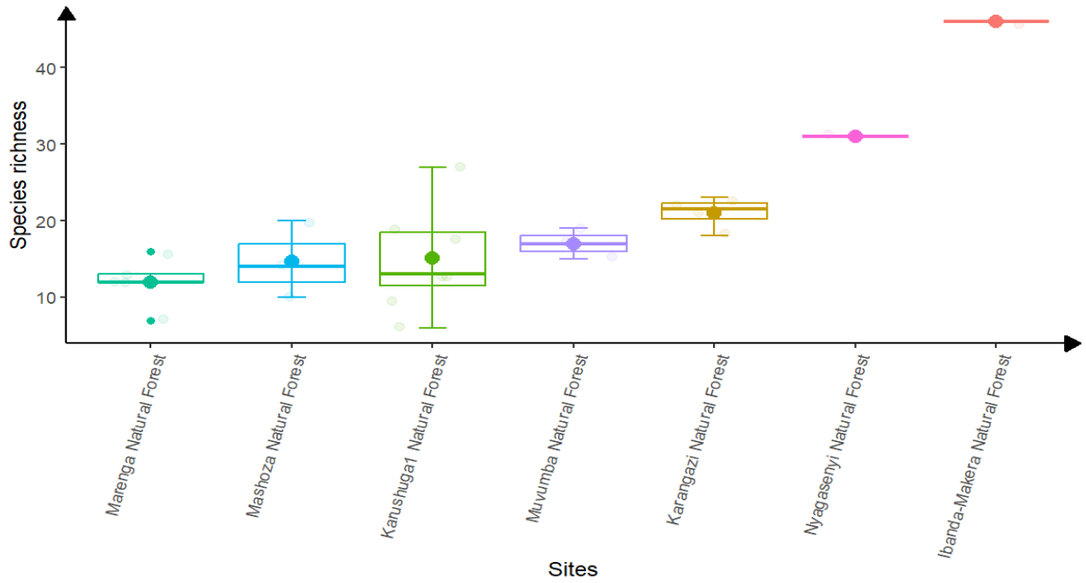


Figure 8. Terrestrial Arthropods richness distribution across all seven natural forests. Boxes are the interquartile ranges (IQR) and lines in boxes represent the median. Dots inside boxes represent average value. Whiskers correspond to largest or smallest value lesser/greater than the upper/lower quartile minus 1.5 times IQR.

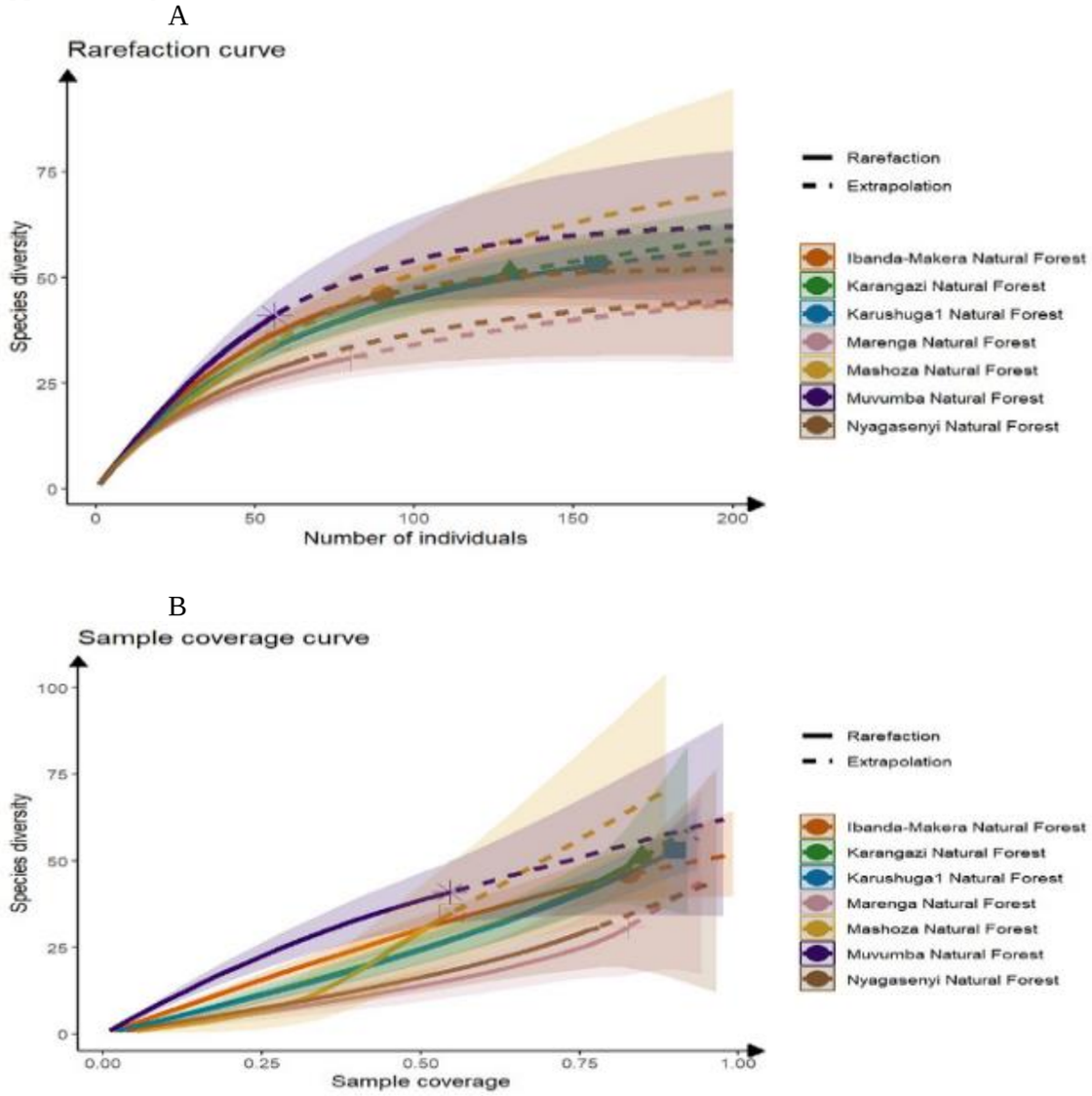


Figure 9. Terrestrial arthropod rarefaction curves (A) and sample coverage curve (B) indicating that sampling effort is proportional to species diversity for sampling of seven natural forest remnants in the Eastern Province, Rwanda

3.5 Birds

We found a total of 165 bird species in 53 families across the seven remnant forest sites (Figure 10). Among these bird communities, we observed 49 migratory species across all sites. We observed one endangered species, the Gray-crowned crane (*Balearica regulorum*) in Muvumba Natural Forest. Figure 11 shows the rarefaction curves which help understand the species richness while accounting for the sampling effort of birds. Curves that accumulate species at a more rapid rate (i.e., curves that are higher up on the graph) have higher species richness. Ibanda-Makera Natural Forest has the highest species richness as seen in Figure 11A. Sample coverage curves are used to assess the completeness of the biodiversity sampling, and from Figure 11B more sampling effort in birds would turn up more species of birds.

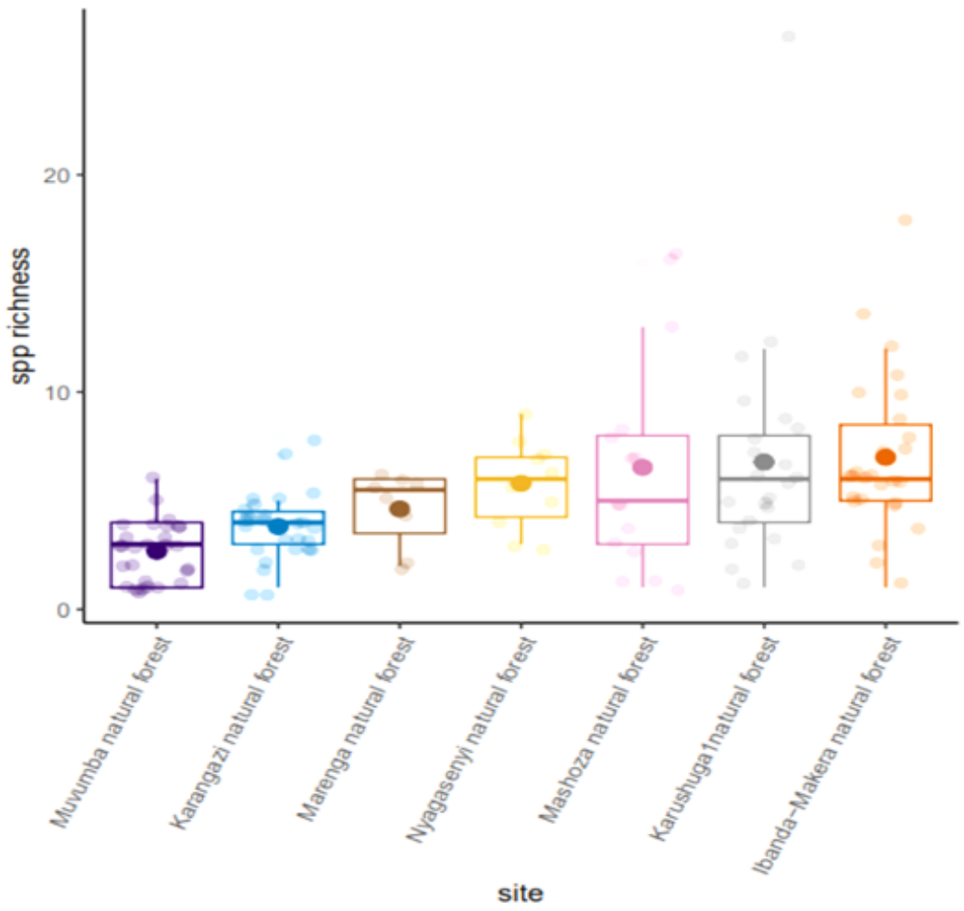


Figure 10. Bird species richness by site. Box and whisker plots compare species richness between the seven remnant forest sites; boxes represent the inter-quartile range (IQR), and lines in the center represent the median. Whiskers correspond to the largest/smallest value less/greater than the upper/lower quartile minus 1.5 times IQR. Points correspond to sampling units of point counts.

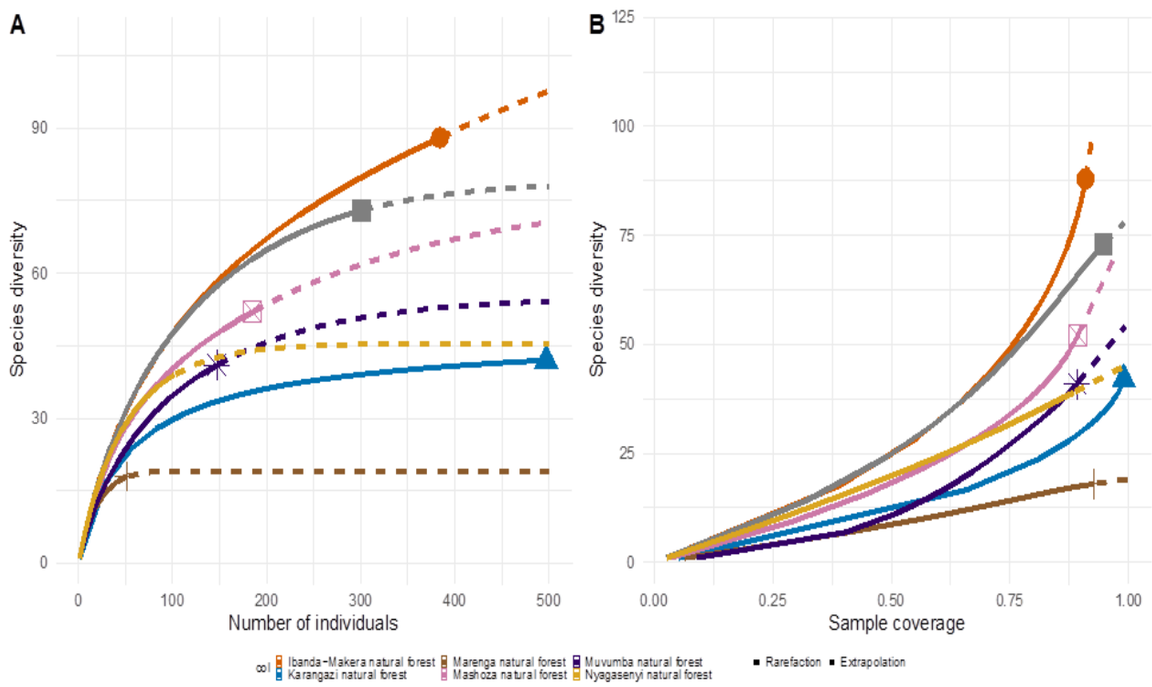


Figure 11. Sample-based (a) rarefaction and extrapolation curves and (b) sample coverage curves using introduced species richness (Hill numbers of order 0), comparing bird species richness across seven different sites. Solid lines represent curves based on sample data, while dashed lines represent extrapolations.

3.6 Mammals

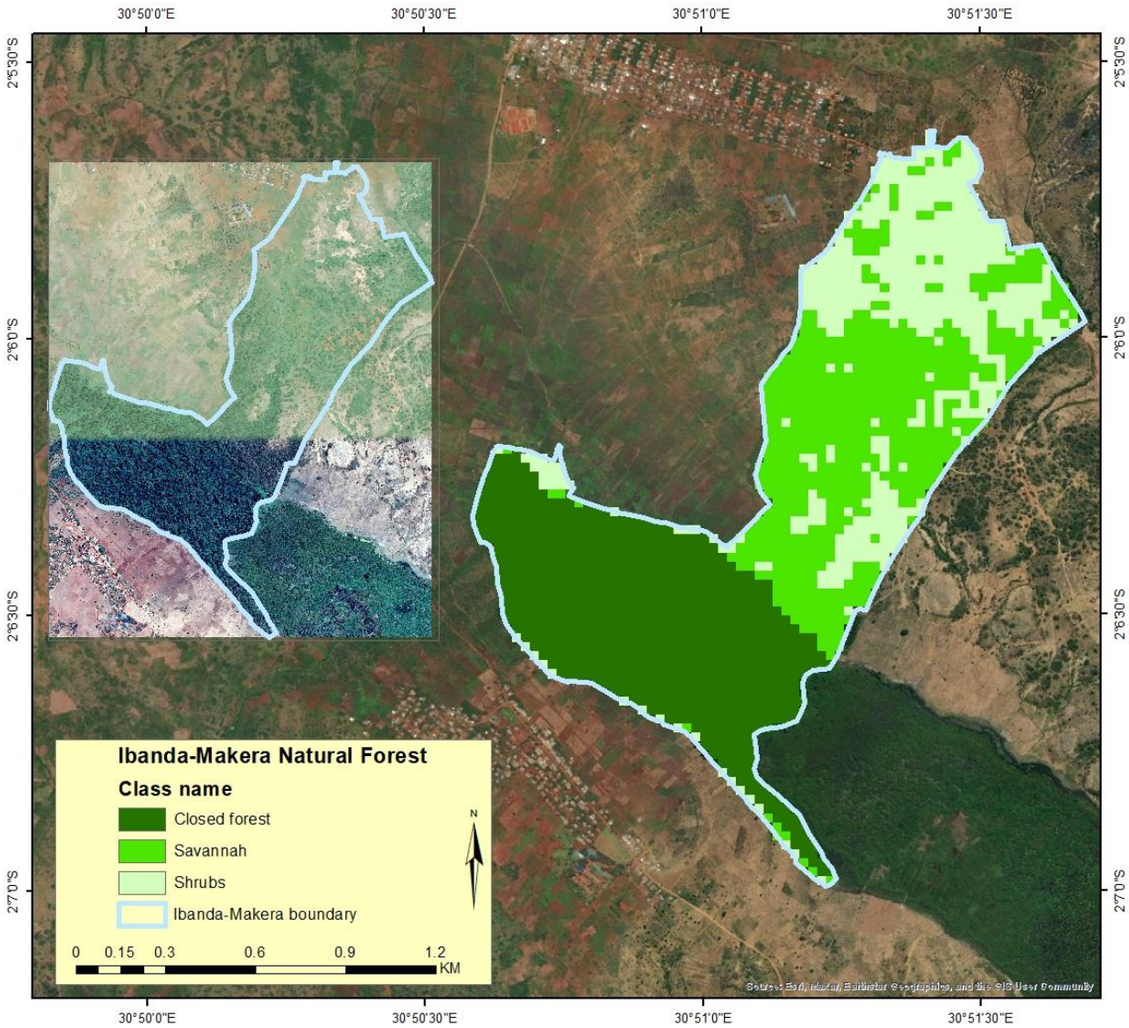
In the seven forests that were surveyed, a total of 15 mammal species were recorded, from 5 orders and 10 families, with 6 species of carnivores (order Carnivora, in four families), 4 species of rodents (order Rodentia), 3 species of primates (order Primates), one shrew (order Soricomorpha) and one ungulate (order Artiodactyla). Most of the species occurred at one site, few occurred at two sites, and the blue monkey occurred at three sites. The species in the IUCN category of threatened species is the hippopotamus which is Vulnerable. Two species are considered as rare records, namely the rufous-nosed *Oneomys hypoxanthus* recorded at Ibanda-Makera and the dwarf mongoose *Helogale parvula* recorded at Karangazi. No species among the ones recorded is endemic to Rwanda or the Albertine Rift.

4. Biodiversity Baseline Results for Each Remnant Forest in Eastern Province

Below are details of the biodiversity baseline survey conducted in the seven remnant forests sampled for this project. The order of forests presented below is: Ibanda-Makera, Karangazi, Karushuga, Marenga, Mashoza, Muvumba, and Nyagasenyi. For each remnant forest, the results for each taxon group are presented in the following order: plants, herpetofauna, flying insects, terrestrial insects, birds, mammals and then threats. Annex 1 is a table showing the area of

4.1 Ibanda-Makera Natural Forest

Ibanda-Makera Natural Forest was measured at 169.00 ha and includes large areas of open shrublands and savannah woodlands (Figure 12). Figure 13 shows the distribution of the biodiversity sampled in this forest, as well as the threats. Following are sections presenting the biodiversity details and threat assessment findings for this remnant forest.



Vegetation Class name	Area (ha)
Closed forest	65.96
Savannah	58.42
Shrubs	45.13

Figure 12. Map of Ibanda-Makera Natural Forest (16.90 ha) in Eastern Province with the current boundary and general vegetation categories and the areas of each.

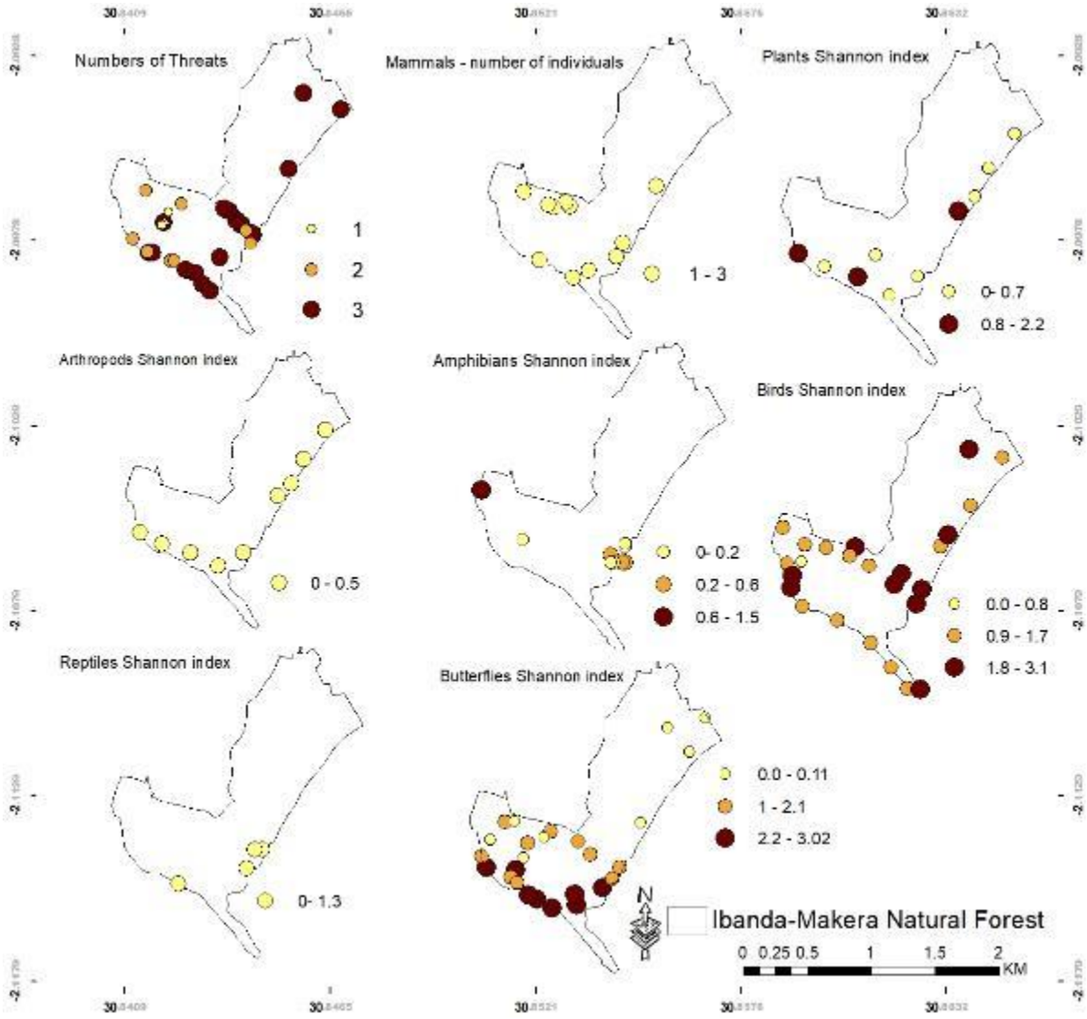


Figure 13. Figure Distribution of the biodiversity and threats observed in Ibanda-Makera Natural Forest. Values mapped are either frequency of occurrence (counts per distance surveyed) or diversity indices (Shannon Diversity Index).

4.1.1 Plants

A total of 17 species across 14 families was found in this forest (Table 3). Notably, the Fabaceae Family emerged as the predominant presence, constituting 17.64% of the recorded species, closely followed by the Moraceae family at 11.76%. About 77% of these species are indigenous to Rwanda and its surrounding region, while the remaining 23% are introduced species. Furthermore, a significant proportion of the identified species (76.47%), are listed as Least Concern according to the IUCN Red List. However, 23.52% of the species have yet to be evaluated and consequently are categorized as Not Evaluated on the IUCN Red List, highlighting the imperative for further research and conservation efforts to fully understand and safeguard the ecological integrity of this forest ecosystem.

Table 3. Plant species found in the Ibanda-Makera Natural Forest, Eastern Province, Rwanda

ID	Family	Scientific name	IUCN-Status	National status	Native or introduced	Life form
1	Anacardiaceae	*Lannea fulva*	NA	NA	Native	tree
2	Arecaceae	*Phoenix reclinata*	LC	NA	Native	Tree
3	Asparagaceae	*Dracaena steudneri*	LC	NA	Native	Tree
4	Asteraceae	*Laggera alata*	NA	NA	Native	N/A
5	Bignoniaceae	*Markhamia lutea*	LC	NA	Native	Tree
6	Celastraceae	*Gymnosporia heterophylla*	LC	NA	Introduced	Shrub

7	Fabaceae	*Biancaea decapetala*	LC	NA	Introduced	Shrub
		Senegalia polyacantha	NA	NA	Native	Tree
		Senna spectabilis	LC	NA	Introduced	tree
10	Moraceae	*Ficus sur*	LC	NA	Native	Tree
		Ficus thonningii	LC	NA	Native	Tree
12	Myrtaceae	*Syzygium guineense*	LC	NA	Native	Tree
13	Primulaceae	*Maesa lanceolata*	LC	NA	Native	Tree
14	Rutaceae	*Teclea nobilis*	LC	NA	Native	Tree
15	Sapindaceae	*Dodonaea viscosa*	LC	NA	Native	Shrub
16	Stilbaceae	*Nuxia floribunda*	LC	NA	Native	Tree
17	Verbenaceae	*Lantana camara*	NA	NA	Introduced	Shrub

The Nonmetric Multidimensional Scaling (NMDS) analysis identified six different vegetation assemblages in the Ibanda-Makera Natural Forest (Figure 14). The six vegetation assemblages are described below by the dominant canopy tree species and dominant understory species and other general characteristics and features related to the plants present and trends in human threats and disturbances.

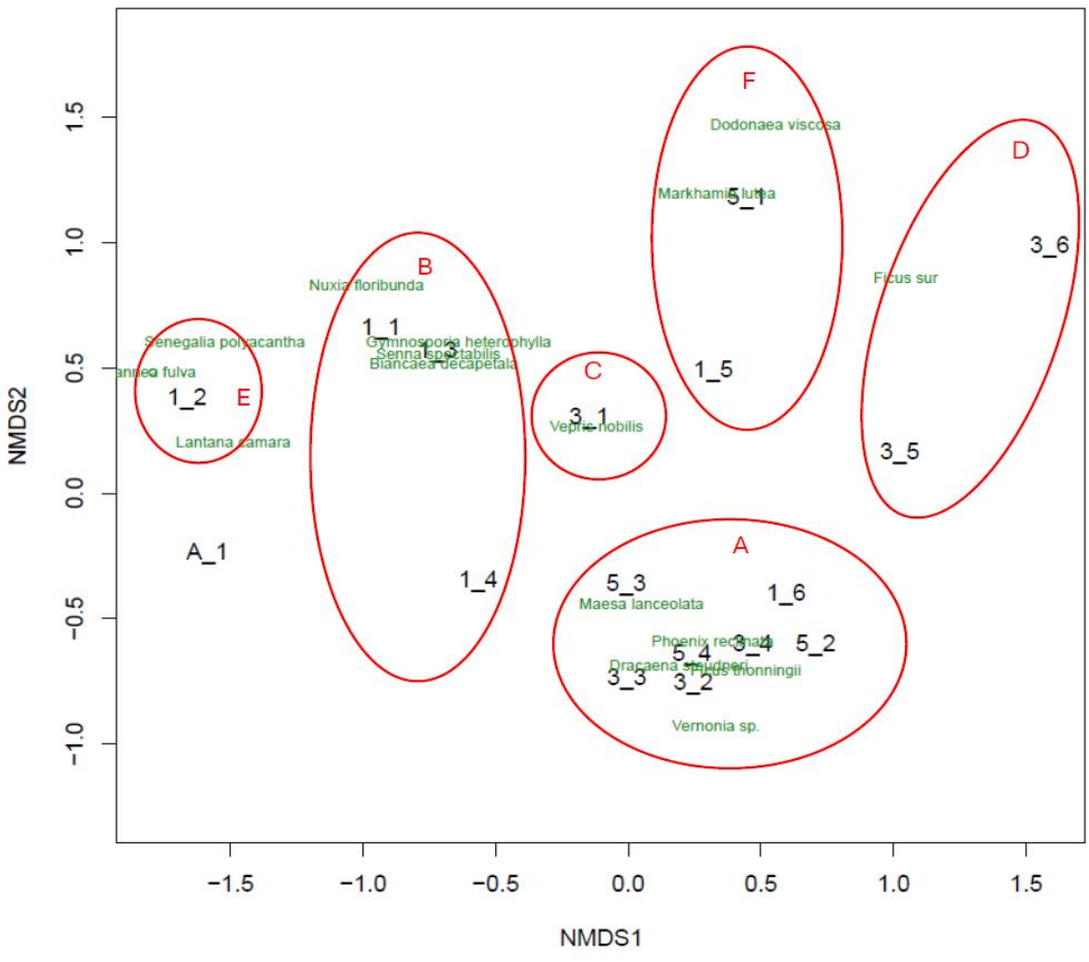


Figure 14. Nonmetric Multidimensional Scaling (NMDS) analysis of vegetation plots in Ibanda-Makera Natural Remnant Forest.

A. *Phoenix reclinata-Ficus thonningii* community**:** *Phoenix reclinata* and *Ficus thonningii* were the dominant species in this assemblage, with trees having relatively large diameter at breast height (DBH), averaging 29.61cm. These species were canopy trees, exerting influence on ecosystem structure and function, regulating microclimates and providing habitat. The understory was dominated by *Dracaena steudneri* and *Ficus sur*, with small DBH (<5cm). This assemblage was recorded from plots 3-3, 5-3, 3-2, 5-4, 3-4, 5-2, and 1-6

B. *Sersia natalensis-Lannea fulva-Lantana camara* community: This vegetation assemblage is defined by the dominance of *Searsia natalensis* which is an introduced shrub or small tree, along with either *Lannea fulva* (a native species) or *Lantana camara*, an introduced invasive species. All three of these dominant species are shrubby, small trees with average combined DBH of 8.25 cm, which is fairly small, and adapted to dry areas. Their emergence as dominant species within the remnant forest is observed in plots 1-4. There were no trees of these species <5cm DBH where *Lannea fulva* was dominant with *S. natalensis*, but where *L. camara* was dominant with *S. natalensis*, average DBH was 12.06 and average density of small trees (<5cm DBH) was 16.5. Both *Searsia natalensis* and *Lannea fulva* are characteristic species of drier savannah woodland. Remnant forests often exist within landscapes that have undergone significant ecological changes, such as deforestation or land conversion. The presence of *L. fulva* suggests a historical connection to savannah ecosystems, and reinforces the significance of their dominance in the remnant forest. This assemblage had recorded occurrences from plots 1-1 and 1-3 (*Lantana camara)* and 1-4 (*Lannea fulva)*.

C. *Dracaena steudneri-Lantana camara* community: This assemblage is characterised by shrubby vegetation dominated by the invasive *L. camara*. *L. camara*'s invasive nature exacerbates its dominance, outcompeting native species due to rapid growth and dense thicket formation. *Dracaena steudneri* is native to Rwanda and the region, and grows as a shrub or small tree. *Vepris nobilis* is part of this assemblage as a small tree. This assemblage was recorded in plots 3-1.

D. *Ficus sur-Phoenix reclinata* community: The dominance of *Ficus sur* characterized this vegetation assemblage; when another tree was dominant, it was *Phoenix reclinata*. There were few to no small trees in this assemblage. *Ficus sur* often created a closed canopy. This vegetation assemblage included plots 3-5 and 3-6.

E. *Senegalia polyacantha-Syzygium guineense* community: *Senegalia polyacantha* and *Syzygium guineense* characterize this vegetation assemblage with an average combined DBH of 13.27cm. The understory was dominated by *Lantana camara, Lannea fulva, and Markhamia lutea*. While the density of understory trees was high (average density of trees <5cm DBH was 105), this assemblage was recorded in plots 1-2.

F. *Markhamia lutea-Dodonaea viscosa* community: This assemblage is characterised by the dominance of the canopy tree *Markhamia lutea*, and *Dodonaea viscosa*, a shrub with pantropical distribution. *Dracaena steudneri* and *Lantana camara* are the common understory species in this assemblage. Recorded from plots 5-1 and 1-5.

4.1.2 Herpetofauna

Nine amphibian and five reptile species were recorded in the Ibanda-Makera Natural Forest (Table 4). As Figure 15 shows, Ibanda-Makera had the highest species richness for both amphibians and reptiles among the seven forests sampled. In Ibanda-Makera, the Hyperoliidae family had the most species observed (Table 4). The only amphibian species with an IUCN Red List status of concern - *Hyperolius lateralis* which is listed as Vulnerable to Extinction. Other amphibian species are considered Least Concerned by the IUCN Red List of threatened species. Among the reptiles, five families were recorded (Table 4). Only one species of reptile, *Python sebae*, is reported as Near Threatened per the IUCN Red List.

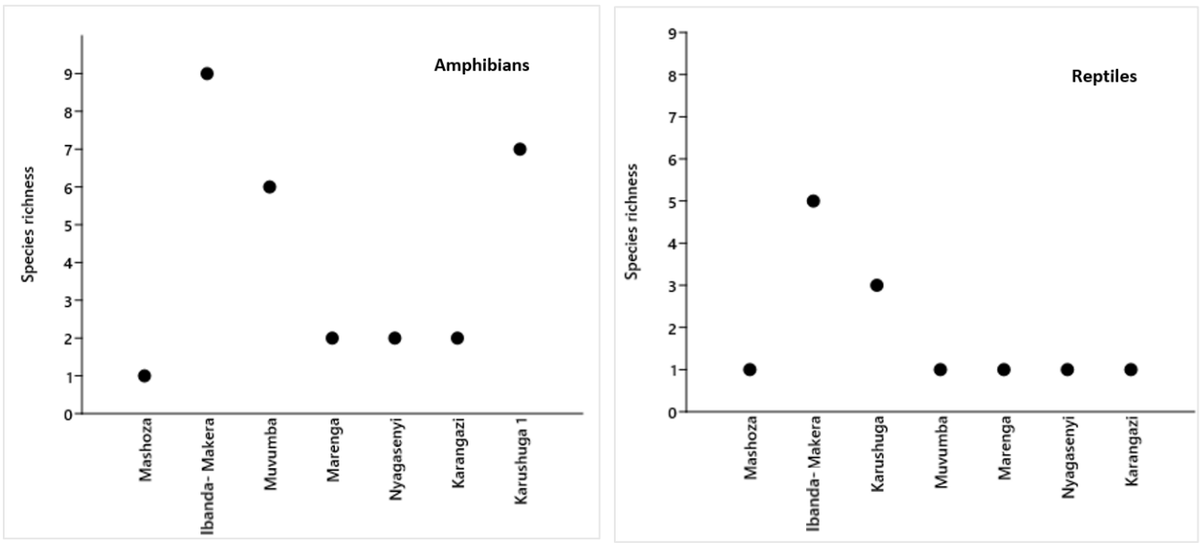


Figure 15. Amphibian and reptile species richness among the sampled natural forests. The dots represent the number of species per sampled natural forest. Dots represent the number of species per natural forest.

Table 4. Amphibian and reptile species recorded in the Ibanda-Makera Natural Forest with their global and local IUCN Red List status.

	Family	**Scientific name**	**Common name**	**Global IUCN status**	**National IUCN status**
AMPHIBIANS					
1	Hyperoliidae	*Hyperolius kivuensis* Ahl, 1931	Kivu Reed Frog	LC	LC
		Hyperolius lateralis Laurent, 1940	Mottle-sided Reed Frog	LC	VU
		Hyperolius rwandae Dehling, Sinsch, Rodel & Channing, 2013	Rwanda Long Reed Frog	LC	LC
		Hyperolius viridiflavus (Duméril & Bibron, 1841)	Common Reed Frog	LC	LC
2	Phrynobatrachidae	*Phrynobatrachus bequaerti* (Barbour & Loveridge, 1929)	Vissoke River Frog	LC	LC
		Phrynobatrachus kakamikro Schick, Zimkus, Channing, Köhler & Lötters, 2010	Kakamega Puddle Frog	DD	LC
3	Pixycephalidae	*Amietia nutti* (Boulenger, 1896)	Nutt's River 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	Chameleonidae	*Trioceros ellioti* (Günther, 1895)	Montane Side-striped Chameleon	LC	ND
2	Colubridae	*Philothamnus sp*	Tree Green snake	-	-
3	Pelomedusidae	*Pelomedusa sp*	Turtle	-	-

4	Pythonidae	*Python sebae* (Gmelin, 1789)	African (Rock) Python	NT	ND
5	Scincidae	*Trachylepis sp*	-	-	-

Hyperolius lateralis was only observed in Ibanda-Makera Natural Forest, and not in any of the other six remnant forests sampled in this study. This species is usually restricted to natural or near-natural habitats (Wagner & Böhme 2007; Sinsch et al. 2012; Mindje et al. 2020) The presence of this species in Ibanda-Makera suggests this forest is in a relatively healthy state in terms of vegetation cover. The other amphibian species recorded in Ibanda-Makera are mainly distributed in areas with human disturbances such as agriculture in the vicinity of the forest and human paths across the forest which are a pressing threat to this forest (Kalinda et al. 2023). Another interesting observation in Ibanda-Makera is *Hyperolius rwandae*, a species mostly found in savannah and open natural wetlands. This species also adds important information on the state of Ibanda-Makera Natural as a forest that still maintains patches of habitat integrity. Sinsch et al. (2012) reported *Hyperolius rwandae* species to be found in natural habitats, and it can co-occur with *Hyperolius lateralis* in undisturbed ecosystems.

4.1.3 Flying insects

A total of 41 butterfly species were recorded from Ibanda-Makera Natural Forest. These butterflies species are distributed into five families, and the most abundant family was Nymphalidae (51.91%) followed by Pieridae (28.24%), Papilionidae (9.16%), Hesperiidae (8.40%), and the last Lycaenidae (2.29%). The most abundant species found in Ibanda-Makera were *Tirumala petiverana*, followed by *Junonia terea* (Figure 16). Of these species, 22 are listed as Least Concern according to their IUCN Red List Status, and 19 remaining are Not Evaluated.

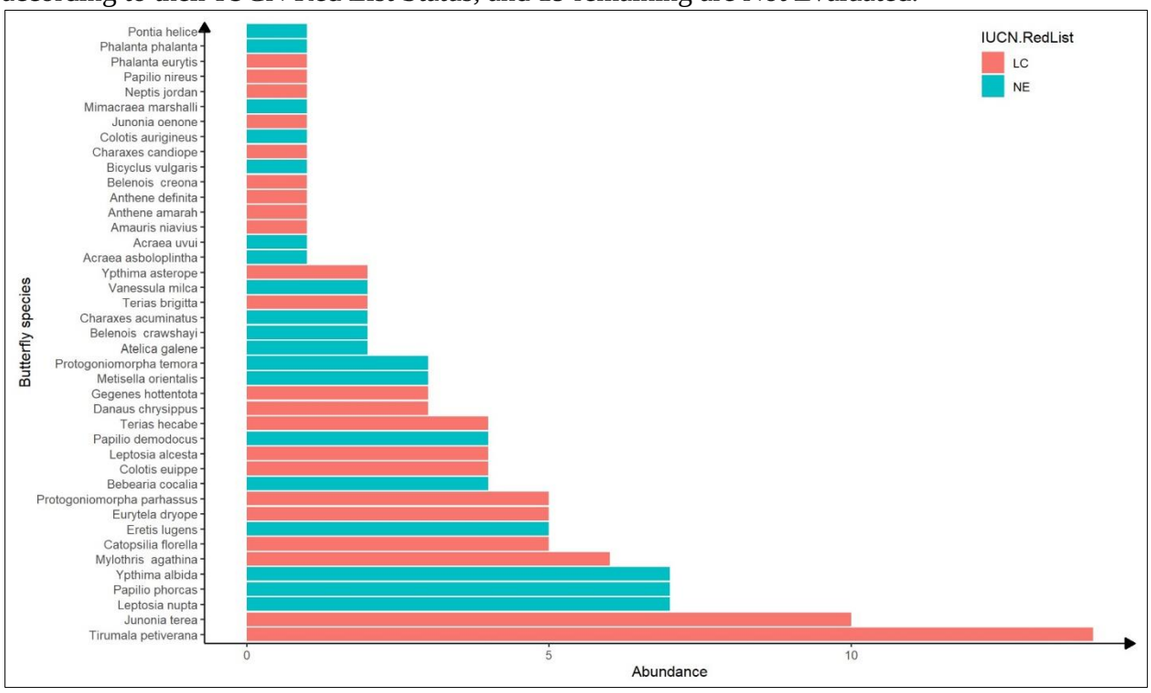


Figure 16. Diversity and abundance of butterfly species recorded from Ibanda-Makera Natural Forest. The orange box represents the species that are classified by the IUCN Red List as Least Concern while the turquoise box stands for the species that are not evaluated (NE).

We recorded two main plant-pollinator relationships in Ibanda-Makera (Figure 17). *Lantana camara*, an exotic invasive shrub species, is the main plant visited by the majority of pollinators in this forest. Pollinators of *Lantana camara* include *Amegilla sp*., *Apis mellifera*, *Cephonodes hylas*, *Tirumala petiverana*, *Catopsilia florerai*, *Danaus chrysippus*, *Junonia terea*, *Leptosia nupta*, *Papilio phorcas*, *Papilio demodocus* and *Phalanta phalanta*. Additionally, pollinators of *Thunbergia alata* included *Eristalinus sp*. and *Lasioglossum sp.* This pollinator network analysis highlights the fact that the invasive species *Lantana camara* is dominant in this forest system in terms of pollinator interactions, and promoting the diversity of plants in this forest would contribute to a more balanced pollinator network structure which could also benefit the surrounding agriculture land.

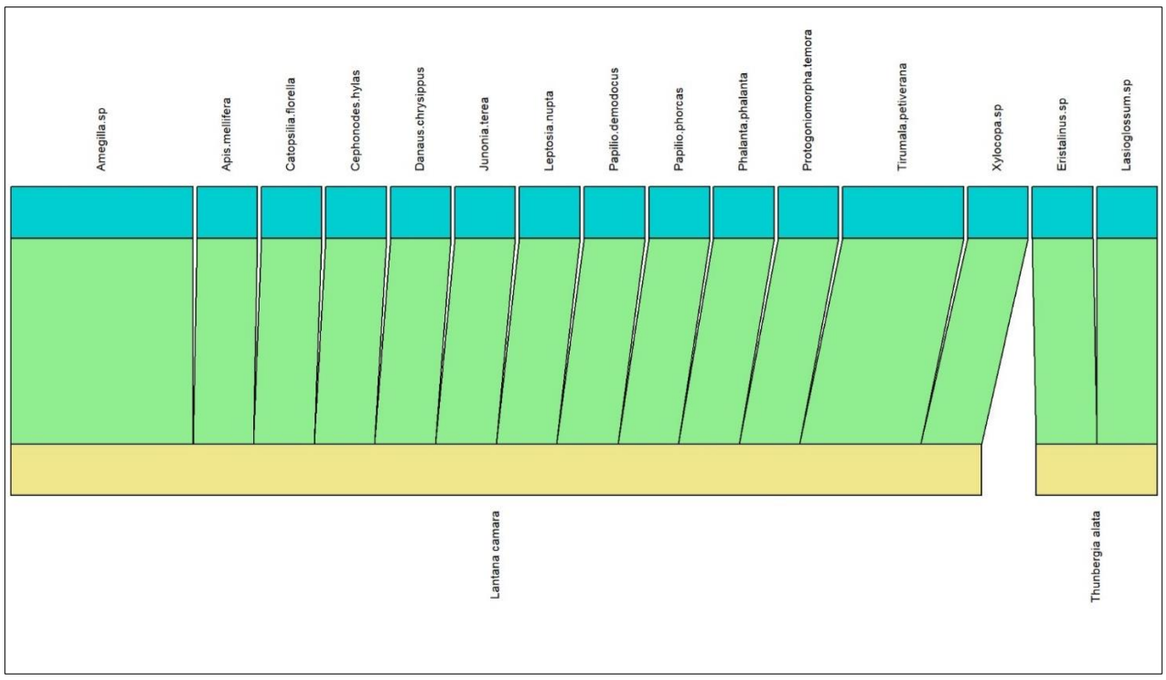


Figure 17. Network structure of plants and their pollinating insects recorded from Ibanda-Makera Natutal Forest. The upper band in turquoise color represent the flower visitor species while the lower part (bands in yellow color) represent plant diversity (host plant species). The middle part of the figure (in green color) represents the linkages (which plant was visited by which insect) between plants and their pollinating insects.

4.1.4 Terrestrial Arthropods

In Ibanda-Makera, we observed 360 individuals across 46 families, highlighting a rich and varied composition of terrestrial arthropods (see Annex 3 for checklist). The Hymenoptera Formicidae family, an omnivorous family, was the most commonly observed terrestrial arthropod, constituting 24% of the observed terrestrial insects. Pyrrchoridae, and herbivorous family, make up 10% of insects, while Lygaeidae, (herbivorous) and Cicadellidae (herbivorous) account for 6.39% and 5.8% of observations respectively (Table 5; Figure 18). The forest exhibits a Dominance index of 0.08 and a Shannon Weaver Diversity index of 3.05, reflecting a balanced distribution and high species diversity. The presence of the Apidae family is evidence of a pollination network within the Ibanda-Makera natural forest, emphasizing its ecological significance.

Table 5. The seven most common arthropods families recorded at Ibanda-Makera Natural Forest along with their functional groups

	Order	**Family**	**Common name**	**Functional Group**
1 2	Hymenoptera	Formicidae Ichneumonidae	Ants Ichneumon wasps (Rhorus Förster, 1869)	Omnivorous Parasitoids
3	Isoptera	Termitidae	Termites	Detritivorous
6 7 8	Hemiptera	Lygaeidae Cicadellidae Pyrrhocoridae	Seed bugs (Schilling, P.S. (1829) Leafhoppers Red bugs (Latreille, P.A. (1825a))	Herbivorous Herbivorous Herbivorous
9	Aranea	Salticidae	Jumping spiders	Predators

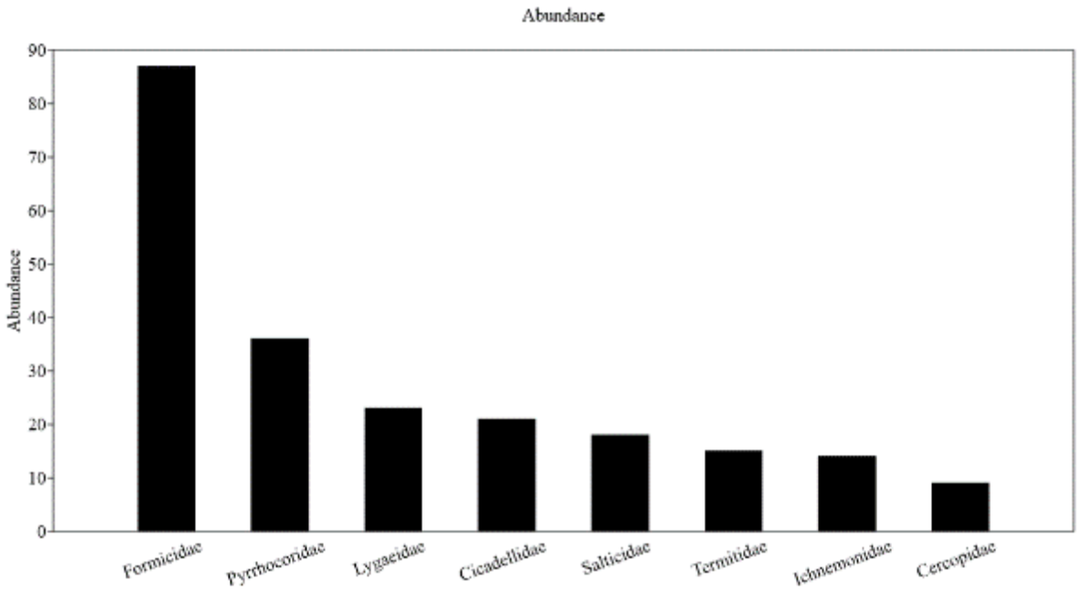


Figure 18. Most abundant arthropod families at Ibanda-Makera Natural Forest with greater than 10 individuals each.

The Ibanda-Makera Natural Forest was characterized by a high abundance of diverse arthropods such as Formicidae (omnivorous), Pyrrhocoridae (herbivorous), Lygaeidae (herbivorous), and Cicadellidae (herbivorous), reflects a balanced and complex trophic structure (Hompson et al. 2007). The presence of Formicidae, with their omnivorous nature, suggests a well-functioning ecosystem where these ants play vital roles in nutrient cycling, pest control, and seed dispersal. The abundance of herbivorous arthropods like Pyrrhocoridae, Lygaeidae, and Cicadellidae indicates a robust plant-animal interaction, contributing to overall biodiversity and ecological stability (Hompson et al. 2007).

4.1.5 Birds

During the bird survey conducted within the Ibanda-Makera Natural Forest, we documented a total of 88 bird species, representing 41 families. Our observations included six migratory bird species with varying migratory statuses: 4 full migrants 1 local migrant and 1 intra-African migrant.
In terms of functional groups, we identified eight categories 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. Notably, the most common functional group observed was insectivorous. Additionally, our survey revealed the presence of one Albertine Rift endemic bird species, the Albertine Rift Valley Equatorial Akalat (*Sheppardia aequatorialis*).

4.1.6 Mammals

At Ibanda-Makera, 7 species of mammals were recorded belonging to 3 orders (3 primates, 3 carnivores, and one rodent), and five families, three of which are carnivore families (Table 6). In general, the abundance of mammals is low. The table shows the occurrence of mammals and their endemic status and IUCN Red List Status. All species are in the IUCN Red List category of Least Concern (LC). Note that the subspecies of the blue monkey recorded is *C. mitis doggetti*, where the other subspecies occurring in natural forests in Rwanda is in Endangered (EN) category. The occurrence of mammals at Ibanda-Makera was also summarized with frequency of records (Figure 19). Two rare mammals found at Ibanda-Makera are the rusty-nosed rat, *Oenomys hypoxanthus,* spotted by direct sighting (Figure 20) and the serval, *Leptailurus serval*, noticed through scats.

Table 6. Summary of mammal occurrence at Ibanda-Makera forest, with indication of the means they were recorded, and endemism and IUCN Red List status

	Order	Family	Scientific name	Common name	AR endemic	IUCN status
1	Primates	Cercopithecidae	*Papio anubis*	Baboon	No	LC
2	Primates	Cercopithecidae	*Cercopithecus mitis doggetti*	Blue monkey	No	LC
3	Primates	Cercopithecidae	*Chlorocebus pygerythrus*	Vervet monkey	No	LC
4	Carnivora	Canidae	*Canis adustus*	Side-striped jackal	No	LC
5	Carnivora	Herpestidae	*Galerella sanguinea*	Slender mongoose	No	LC
6	Carnivora	Felidae	*Leptailurus serval*	Serval	No	LC
7	Rodentia	Muridae	*Oenomys hypoxanthus*	Rusty-nosed rat	No	LC

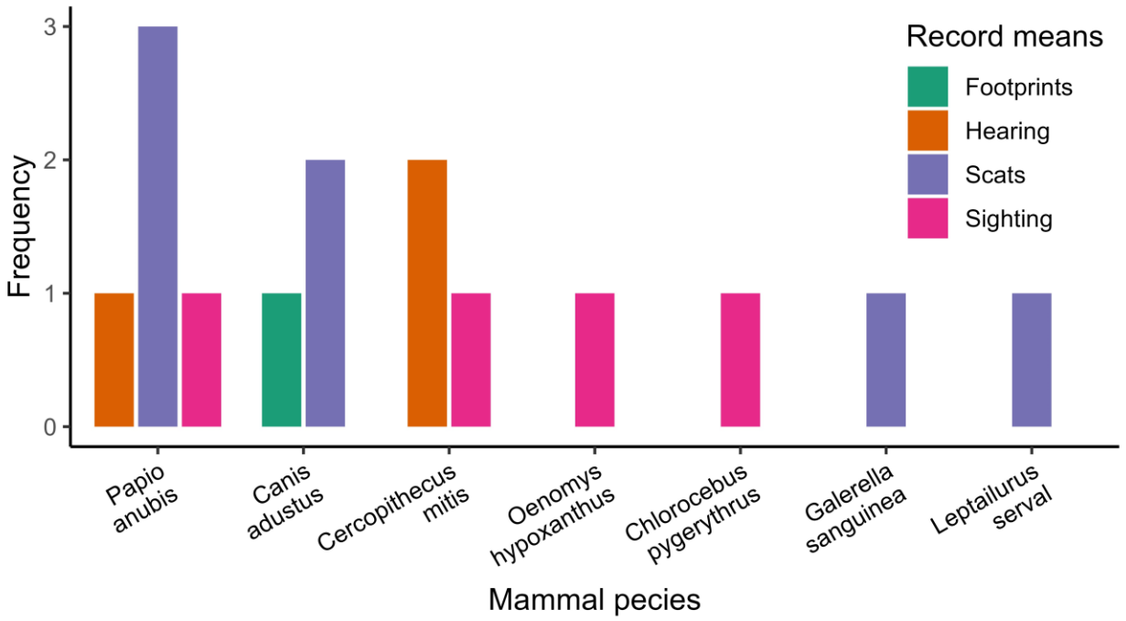


Figure 19. Mammal species occurrence at Ibanda-Makera forest with number of recorded occurrences with the means of recording

Figure 20. The rusty-nosed rat Oenomys hypoxanthus spotted at Ibanda-Makera Natural Forest.

4.1.7 Threats

The most prevalent threats found at Ibanda-Makera are plastic materials (52.5%) (Figure 21). More than 95% of individual counts of plastic materials are plastic bottles of water, juice, and other liquids that are discarded after being used. They are dispersed around and some of them may have been carried away by runoff. Waste dumping is a critical threat, and many different waste dumping places included plastic materials. Especially in Ibanda-Makera forest, most of the encountered waste dumping areas were made of glass bottles deposited at the edge of the forest (Figure 22). Nine records were identified as waste dumping places. In two places, we estimated between 200-250 bottles were deposited in one place. The other threats were tree cutting, livestock grazing, and human excreta in the forest or near pathways crossing the forest.

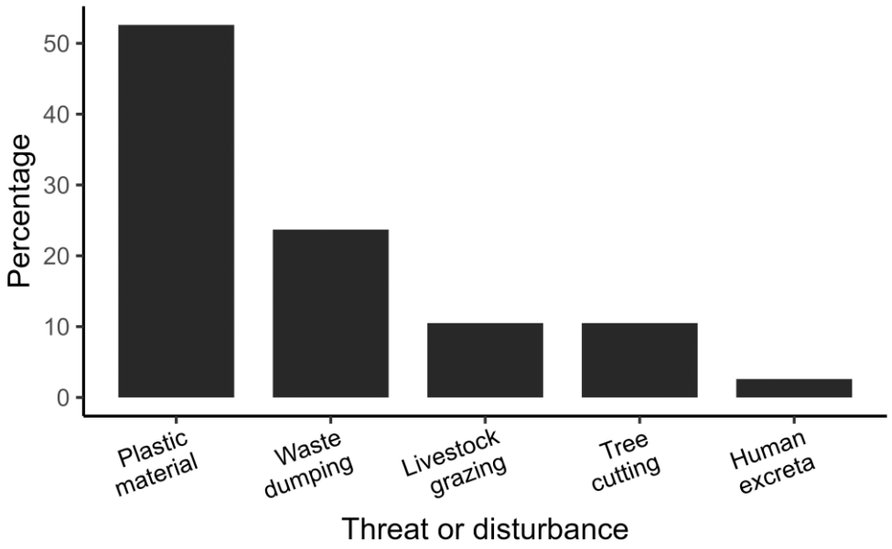
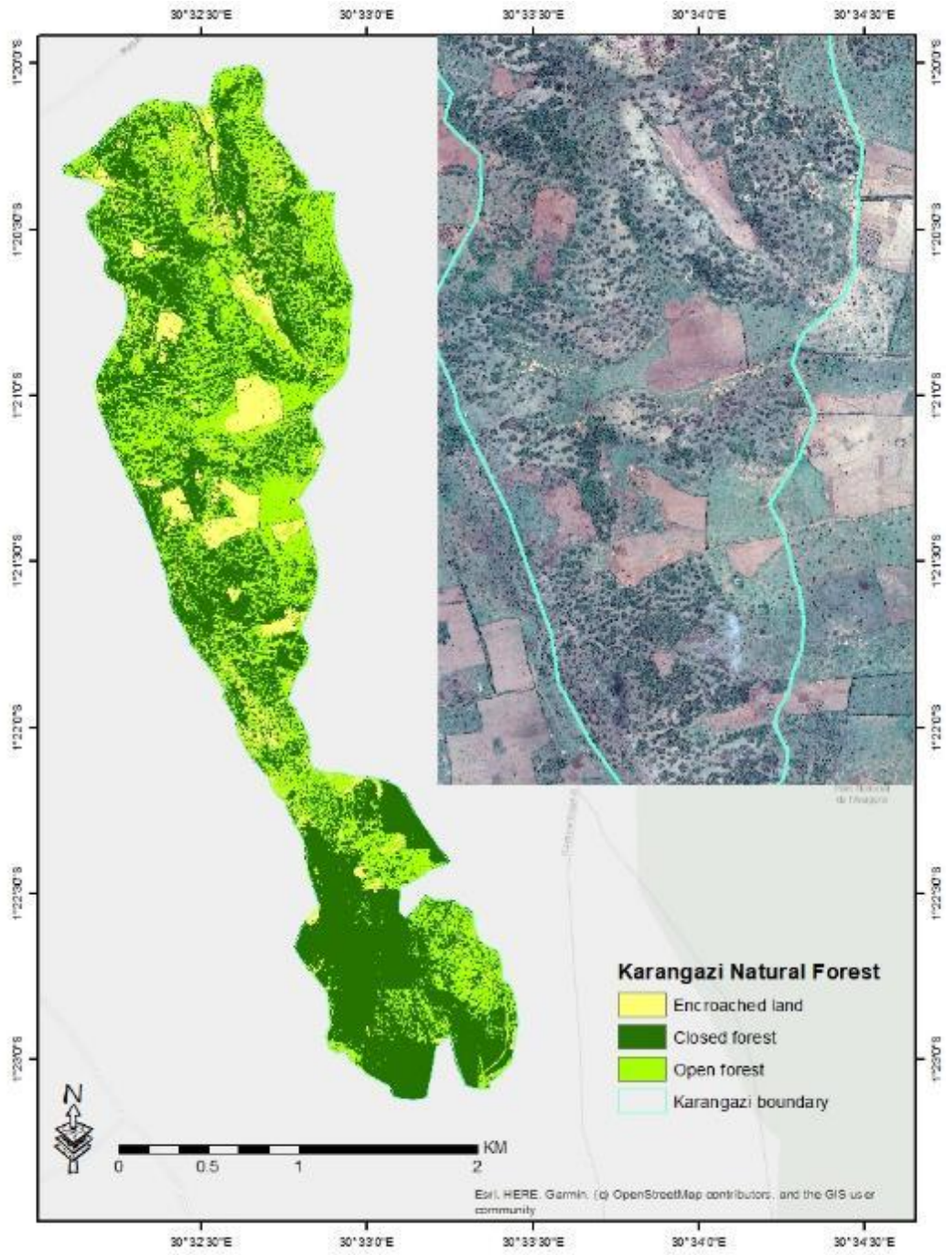


Figure 21. Threats occurrence and abundance at Ibanda-Makera Natural Forest

Figure 22. Waste dumping including glass bottles at Ibanda-Makera Natural Forest

4.2 Karangazi Natural Forest

Karangazi Natural Forest was measured at 510.98 ha and includes disturbed areas inside the forest boundary, as well as forested areas (Figure 23). Figure 24 shows the distribution of the biodiversity sampled in this forest, as well as the threats. Following are sections presenting the biodiversity details and threat assessment findings for this remnant forest.



Vegetation Class name	Area (ha)
Encroached land	55.62
Closed forest	269.11
Open forest	186.25

Figure 23. Map of Karangazi Natural Forest (510.98 ha) in Eastern Province with the current boundary and general vegetation categories and the areas of each category.

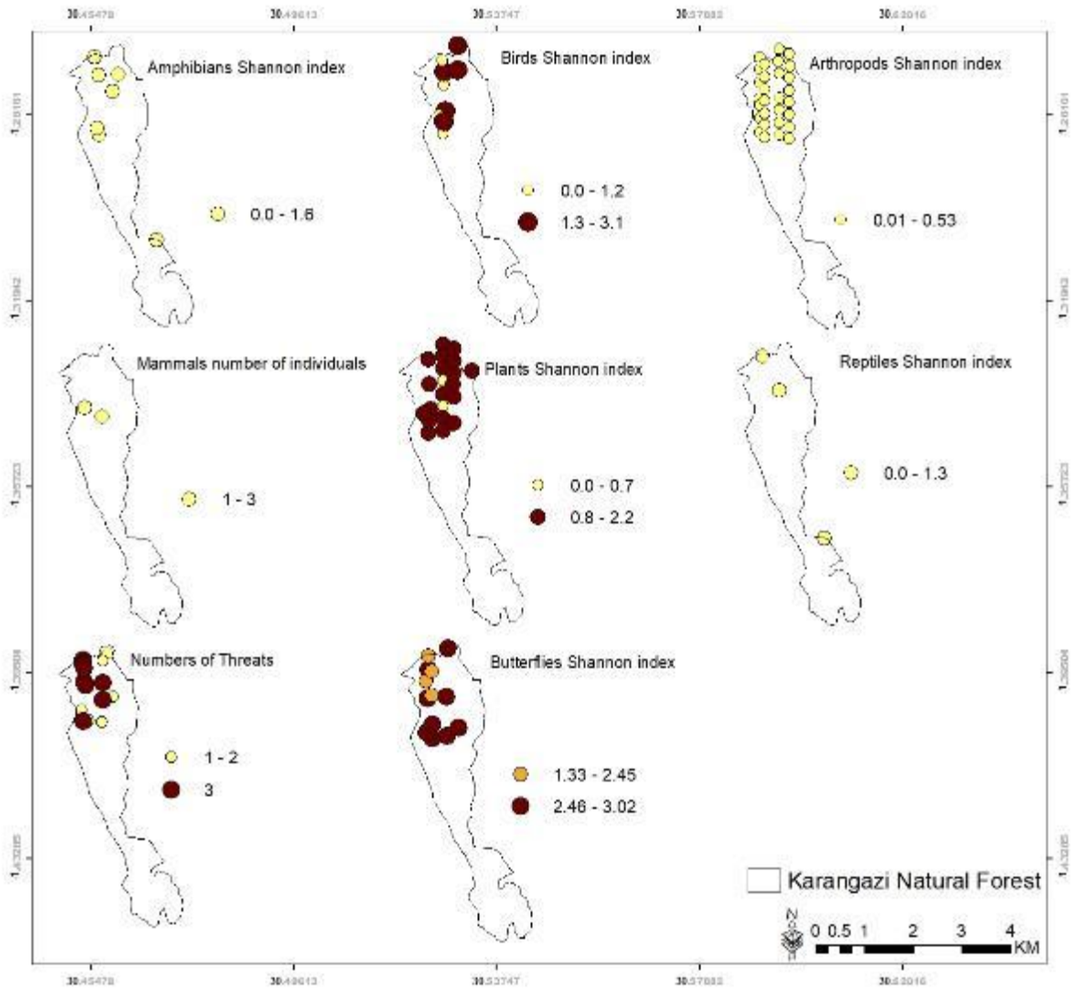


Figure 24. Distribution of the biodiversity and threats observed in Karangazi Natural Forest. Values mapped are either frequency of occurrence (counts per distance surveyed) or diversity indices (Shannon Diversity Index).

4.2.1 Plants

There were 35 plant species from 18 families found in Karangazi (Table 7). The Malvaceae Family comprised 20% of the recorded flora, followed by the Fabaceae Family at 11.42%. The majority, accounting for 80%, are indigenous to Rwanda and the surrounding region, underscoring the critical role of these forests in preserving native flora. However, 20% of the species recorded in this forest are of introduced origins, signaling potential challenges in maintaining ecosystem integrity. Furthermore, while 60% of the identified species are classified as Least Concern according to the IUCN, 11.42% remain unassessed and are categorized as Not Evaluated on the IUCN Red List, emphasizing the need for continued monitoring and conservation efforts to safeguard the biodiversity of Karangazi and similar forest ecosystems in the region.

Table 7. Families and species of plants found in the Karangazi Natural Forest, Eastern Province, Rwanda

ID	Family	Scientific name	IUCN Status	National status	Native or introduced	Life form
1	Anacardiaceae	*Lannea fulva*	NA	NA	Native	tree or shrub
		Ozoroa insignis subsp. reticulata	LC	NA	Native	tree or shrub
		Searsia natalensis	LC	NA	Introduced	tree or shrub

2	Apocynaceae	*Acokanthera schimperi*	LC	NA	Native	tree or shrub
		Carissa spinarum	LC	NA	Native	tree or shrub
3	Asparagaceae	*Asparagus flagellaris*	NA	NA	Native	Shrub
4	Asteraceae	*Microglossa densiflora*	NA	NA	Native	Shrub
		Laggera alata	LC	NA	Native	N/A
5	Burseraceae	*Commiphora africana*	LC	EN	Native	tree or shrub
6	Celastraceae	*Gymnosporia senegalensis*	LC	NA	Native	tree or shrub
7	Combretaceae	*Combretum molle*	LC	NA	Native	tree or shrub
8	Euphorbiaceae	*Croton dichogamus*	LC	NA	Native	tree or shrub
		Euphorbia tirucalli	LC	NA	Introduced	tree or shrub
9	Fabaceae	*Albizia adianthifolia*	LC	NA	Native	Tree
		Calliandra houstoniana var. calothyrsus	NA	NA	Introduced	tree or shrub
		Mimosa pigra	LC	NA	Introduced	Shrub
		Vachellia sieberiana	LC	NA	Native	Tree
10	Lamiaceae	*Ocimum gratissimum subsp. gratissimum*	NA	NA	Native	Shrub
11	Malvaceae	*Grewia similis*	NA	NA	Native	tree or shrub
		Grewia trichocarpa	NA	NA	Native	tree or shrub
		Hibiscus aponeurus	NA	NA	Native	Shrub
		Sida ovata	NA	NA	Native	Shrub
		Sida rhombifolia subsp. rhombifolia	NA	NA	Native	Shrub
		Triumfetta rhomboidea	NA	NA	Native	Shrub
		Hibiscus diversifolius	LC	NA	Native	Shrub
12	Myrtaceae	*Eucalyptus saligna*	LC	NA	Introduced	Tree
13	Phyllanthaceae	*Phyllanthus fischeri*	NA	NA	Native	tree
14	Rubiaceae	*Afrocanthium lactescens*	LC	EN	Native	Tree
15	Rutaceae	*Teclea nobilis*	LC	NA	Native	Tree
16	Santalaceae	*Osyris lanceolata*	LC	CR	Native	Shrub

17	Solanaceae	*Solanum aculeastrum*	LC	NA	Native	tree or shrub
		Solanum nigrum	LC	NA	Native	Shrub
18	Verbenaceae	*Lantana trifolia*	NA	NA	Introduced	Shrub
		Lantana camara	NA	NA	Introduced	Shrub

The Nonmetric Multidimensional Scaling (NMDS) analysis identified three different vegetation assemblages in the Karangazi Natural Forest (Figure 25).

A. *Phyllanthus fischeri-Triumfetta rhomboidei* vegetation community: This community is characterised by small trees and the absence of larger trees, with the dominant small tree being *Phyllanthus fischeri* together with the shrub *Triumfetta rhomboidei*, both indigenous to the region. Trees with a DBH >5cm are not common in this assemblage, and there is an open forest structure, characterized by a lack of mature canopy trees like *Croton dichogamus, Combretum molle, Searsia natalensis* which are common and an abundance of understory growth. The presence of native understory species, typically associated with savannah forest ecosystems is also characteristic. The assemblage included plots 1-2, 1-1, 1-7, 2-5, 1-4, 1-5, 2-6, 5-6, 2-7, 1-6, and 2-1.

B. *Croton dichogamus-Combretum molle* vegetation assemblage community: This assemblage is characterized by the two indigenous trees *Croton dichogamus* and *Combretum molle* which are typical to drier savannah woodland habitats. These trees were rarely larger than 5cm DBH, however. *Eucalyptus saligna*, an introduced tree, and *Grewia similis, Carissa spinarum, Osyris lanceolata, Afrocanthium lactescens* was found in this assemblage as common understories as well. In general the *Croton dichogamus-Combretum molle* assemblage is very open, due to the lack of large trees, and has abundant seedlings and understory shrubs. This assemblage is likely in a phase of regeneration or establishment within the forest ecosystem. The average density of small trees (<5cm DBH) was 25.46, suggesting the potential for future canopy development. The plots of 7-7, 2-3, 7-8, 5-8, 7-5, 7-2, 5-7, 1-3, 2-4, 5-5, 5-3, 2-2, 7-4, and 7-6 were in this assemblage.

C. *Solanum aculestrum-Asparagus flagellaris* vegetation community: This community is characterized by the lack of trees greater than 5cm DBH and an abundance of understory vegetation. *Solanum aculestrum*, a tall shrub, is dominant, and in the understory, *Asparagus flagellaris* dominates. *Solanum aculestrum* often indicates disturbed areas. *Asparagus flagellaris* is indicative of savannah woodland conditions. The absence of trees with a DBH >5cm implies historical disturbances. This assemblage was recorded in plots 5-1 and 5-4.

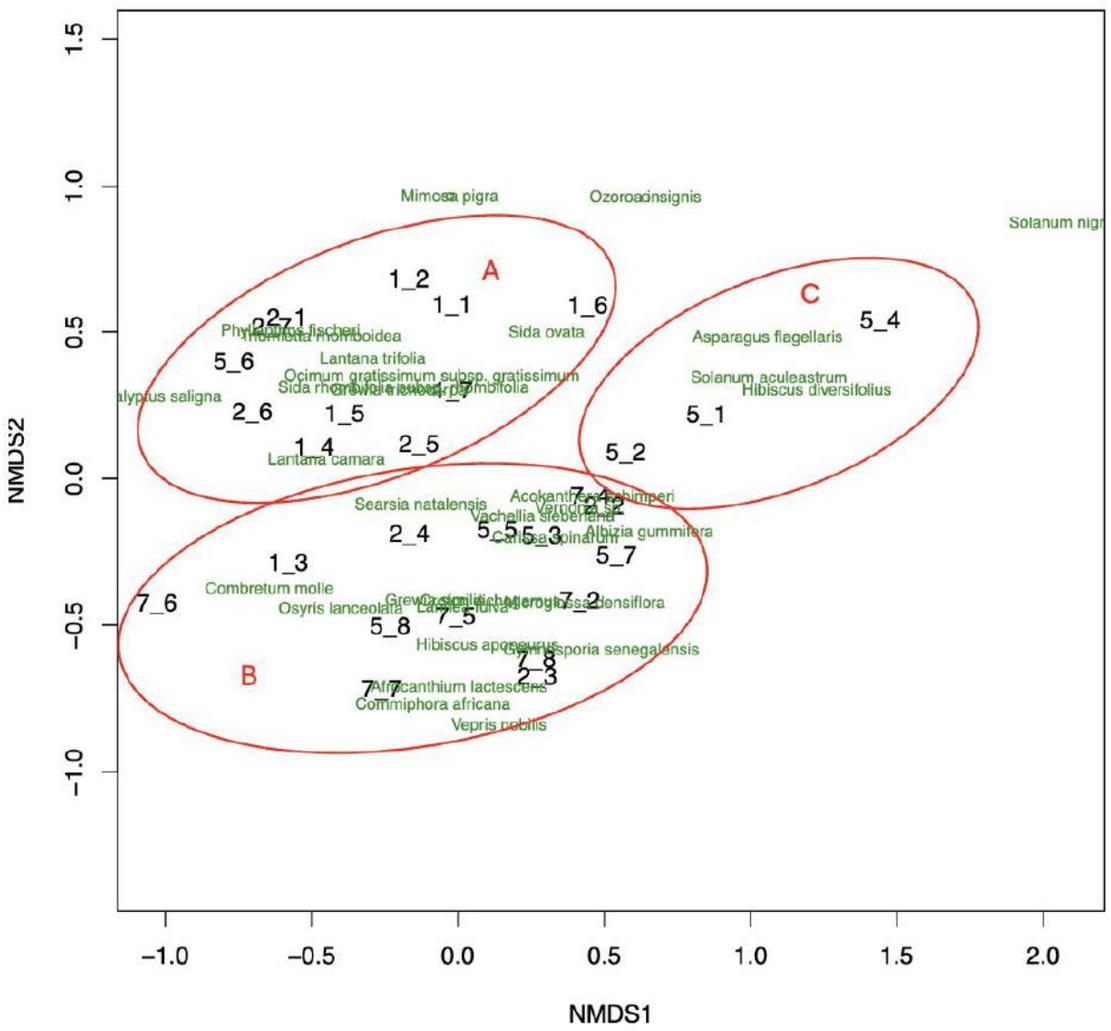


Figure 25. Nonmetric Multidimensional Scaling (NMDS) analysis of vegetation plots in Karangazi Natural Remnant Forest.

4.2.2. Herpetofauna

In Karangazi Natural Forest, we observed two families of amphibians and one reptile family were recorded with one species in each family (Table 8). All species recorded are listed as Least concerned under the IUCN Red List.

Table 8. Amphibian and reptile species recorded in the Karangazi Natural Forest with their global and local IUCN Red List status.

	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
REPTILES					
1	Lacertidae	*Adolfus jacksoni (Boulenger, 1899)*	Jackson's Forest Lizard	LC	ND

4.2.3 Flying insects

A total of 36 butterfly species from five families were recorded from Karangazi Natural Forest. The most common family was Pieridae (43.56%), followed by Nymphalidae (40.59%), Lycaenidae (8.91%), Papilionidae (3.96%), and Hesperiidae (2.97%). The most abundant species

were *Belenois creona*, followed by *Junonia oenone* (Figure 26). Of them, 25 butterflies are listed as Least Concern 11 remaining are Not Evaluated.

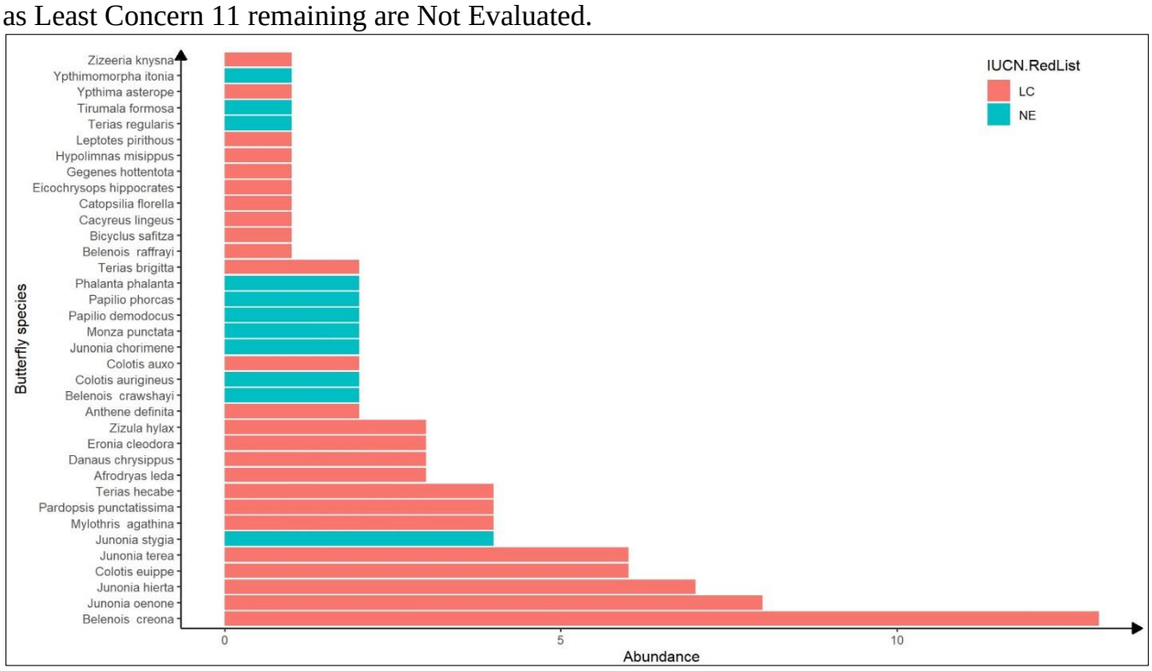


Figure 26. Diversity and abundance of butterfly species recorded from Karangazi Natural Forest. The orange box represents the species that are classified by the IUCN Red List as Least Concern while the turquoise box stands for the species that are not evaluated (NE).

Pollinator diversity recorded from Karangazi Natural Forest includes butterflies (*Belenois creona, Colotis euippe, Junonia oenone,* and *Eronia cleodora*), bees (*Apis mellifera* and *Amegilla sp.*), and flies from Syriphidae family. Their host plants are *Lantana camara, Emilia caespitosa, Barleria cristata, Clutia abyssinica, Asystasia gangetica, Guizotia scabra* and *Jasminum sp*. (Figure 27). The network structure is more diverse, with more flowering plants being visited by the pollinators, and *Lantana camara* played a lesser role in this pollinator network.

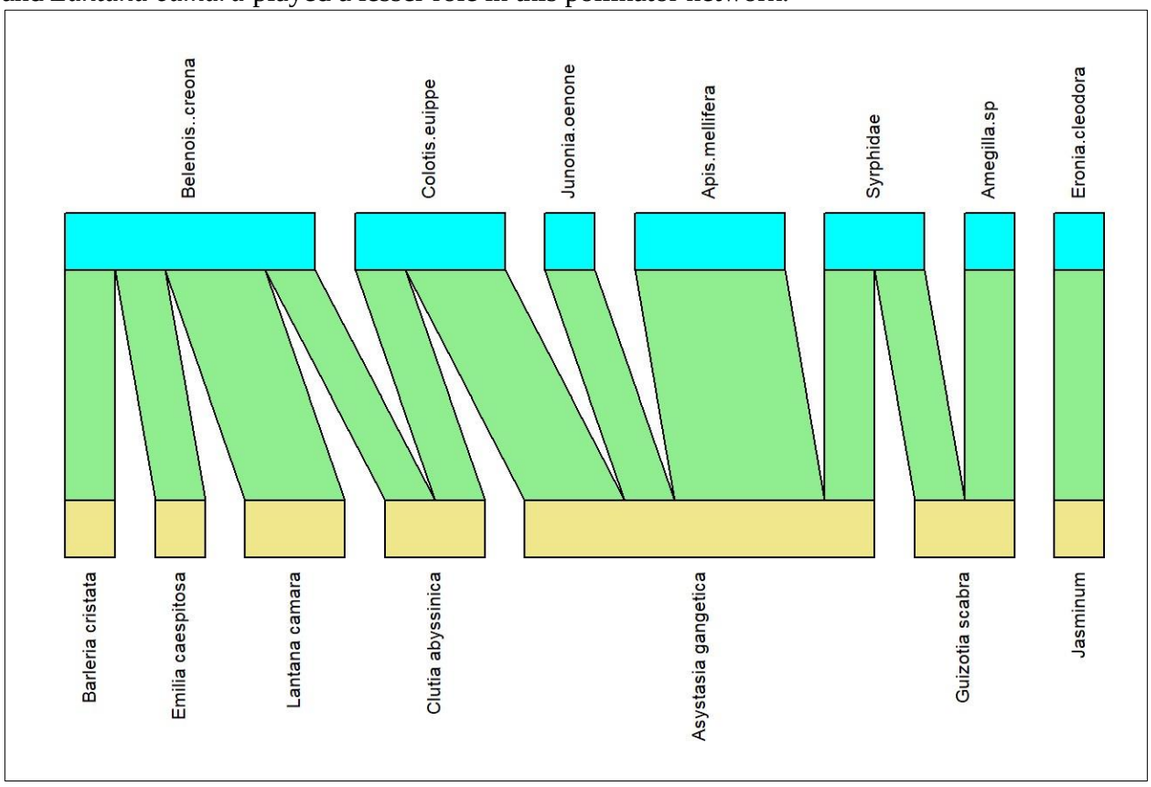


Figure 27. Network structure of plants and their pollinating insects recorded from Karangazi Natural Forest. The upper part (band in turquoise color) represents the flower visitors while the lower part (bands in yellow color) represents plant diversity (host plant species). The middle part of the figure (in green color) represents the linkage (which plant was visited by which insect species) between plants and their pollinating insects.

4.2.4 Terrestrial Arthropods

In the Natural Forest of Karangazi, 653 individuals of terrestrial arthropods belonging to 51 families were recorded. These arthropod assemblages were dominated by orthoptera (Acrididae family), Hymenoptera (Formicidae family) and heteroptera (Cercopidae family) (Table 9, Figure 28).

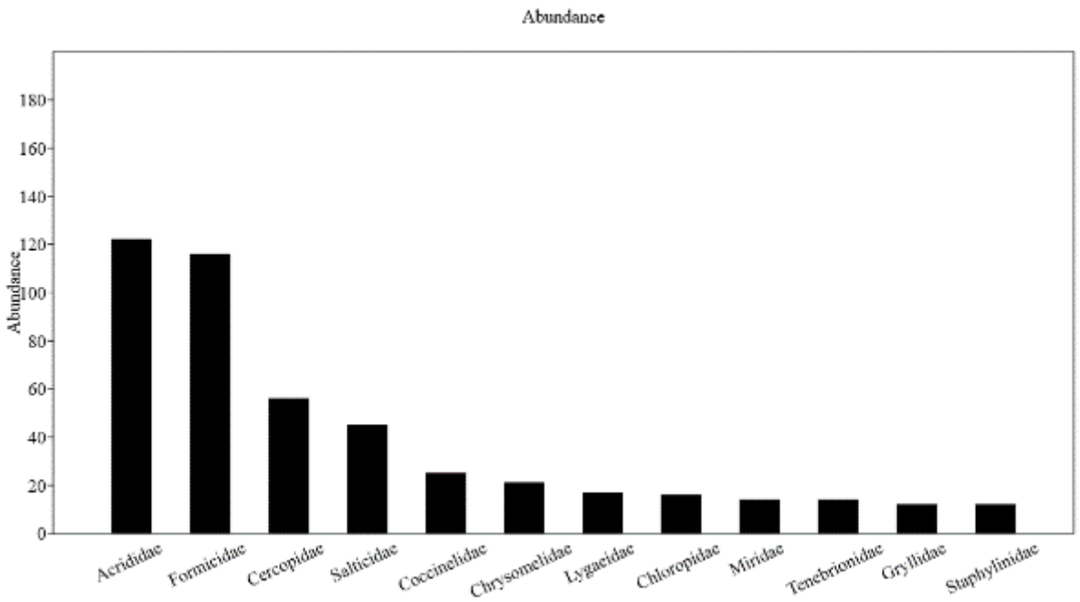


Figure 28. Most abundant arthropod families at Karangazi Natural Forest (those with greater than 10 individuals each).

Table 9. The 11 most common arthropod families recorded at Karangazi Natural Forest along with their functional groups

	Order	**Family**	**Common name**	**Functional Group**
1	Orthoptera	Gryllidae Acrididae	Cricket (Laicharting, J.N.E. (1781)) Grasshopper (MacLeay, W.S. (1821))	Omnivorous Herbivorous
2	Coleoptera	Staphylinidae Tenebrionidae Chrysomelidae Coccinellidae	Rove beetle (Iczn. (1959) Darkling beetle Leaf beetles (Latreille.1802) Lady bug (Latreille, 1807)	Predators Scavengers Herbivorous Carnivorous
3	Hymenoptera	Formicidae	Ants	Omnivorous
4	Hemiptera	Cercopidae Lygaeidae Miridae	Froghopper Seed bug Plant bug	Herbivorous Herbivorous Scavengers
5	Aranea	Salticidae	Jumping spider	Predators

4.2.5 Birds

The bird survey conducted in Karangazi Natural Forest revealed a diverse avian community comprising 41 bird species from 24 families. Among these, we documented seven migratory birds exhibiting different migratory statuses. We categorized the observed bird species into nine functional groups: 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), scavengers (dead matter-feeding), and carnivorous (meat-feeding). Only six of these functional groups were observed within Karangazi Natural Forest. Notably absent were herbivorous and scavenger bird species. Among the observed bird

species, the most common were those categorized as insect-feeders (insectivorous) within this forest.

4.2.6 Mammals

At Karangazi Natural Forest, we observed two species of mammals, the common dwarf mongoose and the vervet monkey, both of which were recorded once by direct observations of single individuals (Table 10). Neither species are endemic or have IUCN threatened category status. However, the dwarf mongoose indicated in the photo (Figure 29) is a rare record in Rwanda.

Table 10. Summary of the two recorded mammals at Karangazi forest

	Order	Family	Species name	Common name	Endemic species	IUCN status
1	Carnivora	Herpestidae	*Helogale parvula*	Dwarf mongoose	No	LC
2	Primates	Cercopithecidae	*Chlorocebus pygerythrus*	Baboon	No	LC

Figure 29. Dwarf mongoose at Karangazi Natural Forest during biodiversity baseline survey

4.2.7 Threats

The most encountered threat at Karangazi forest was livestock grazing (52.6%), which was recorded both from direct observations of grazing cows and goats, as well as signs of grazing (Figure 30). Other threats are agriculture, charcoal making, plastic material, and burning, each of which has a relative frequency of occurrence below 16%.

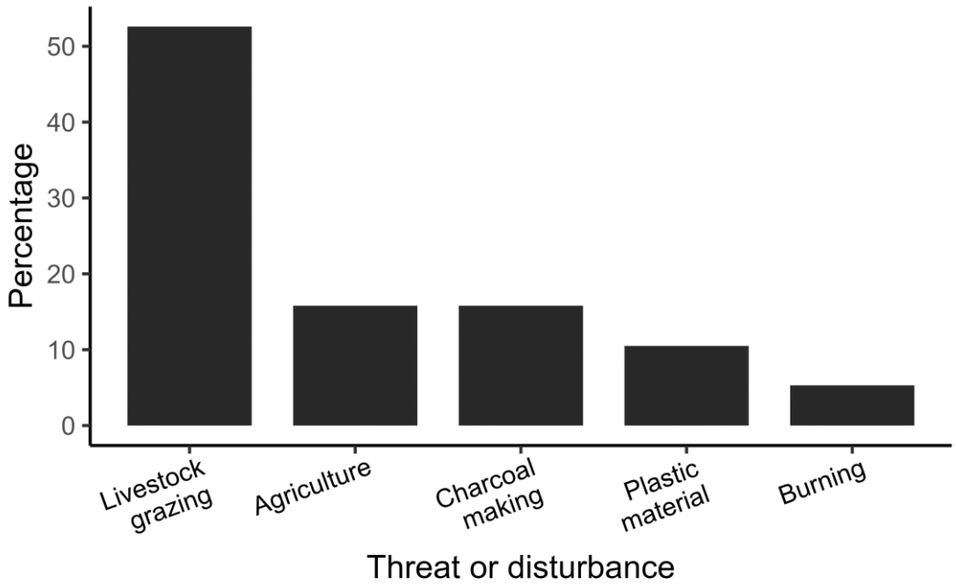
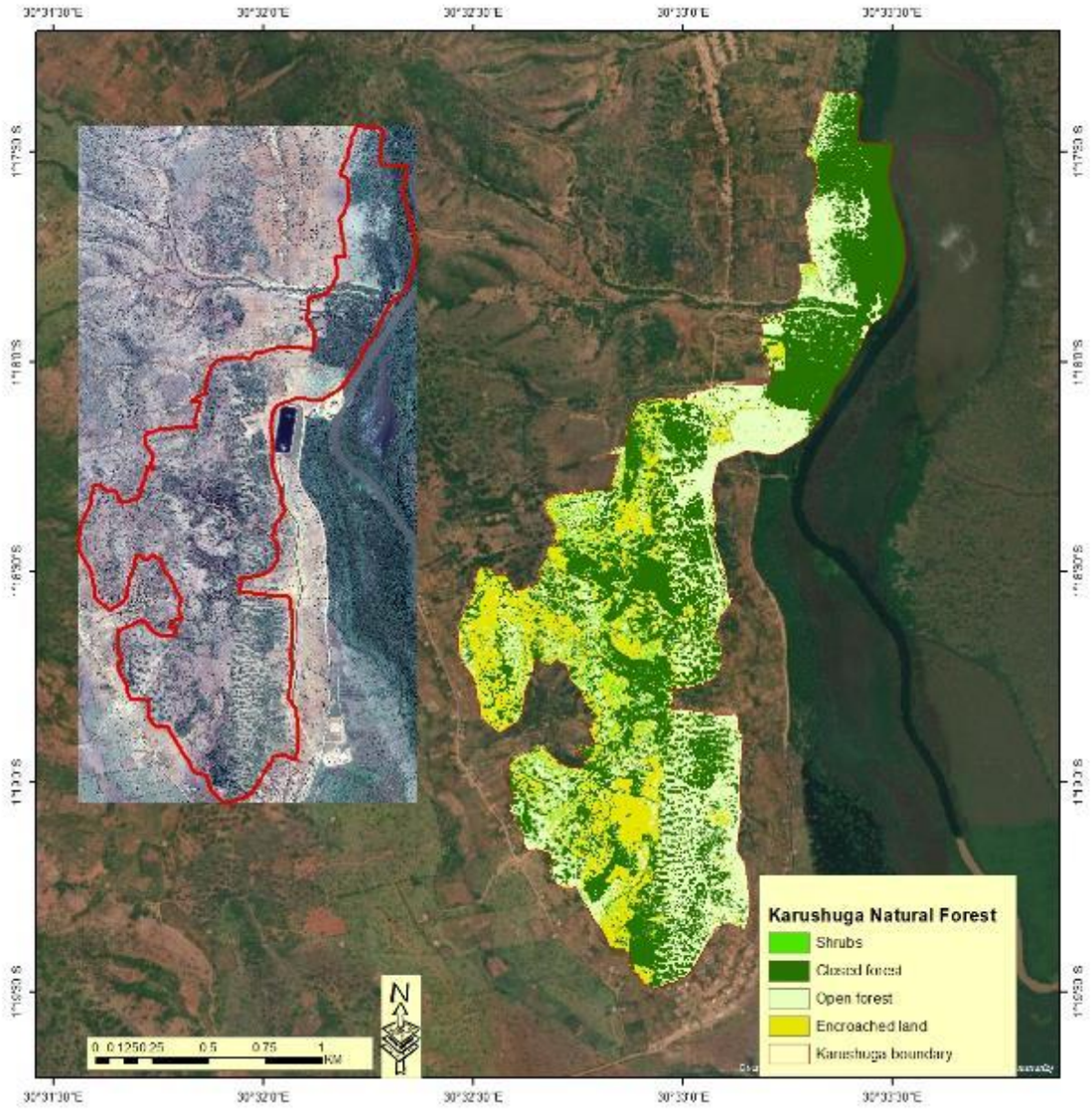


Figure 30. Threats occurrence and abundance at Karangazi Natural Forest

4.3 Karushuga Natural Forest

Karashugi Natural Forest was measured at 262.69 ha and includes disturbed areas inside the forest boundary, as well as shrubby and open forest areas areas (Figure 31). Figure 32 shows the distribution of the biodiversity sampled in this forest, as well as the threats. Following are sections presenting the biodiversity and threat assessment findings for this remnant forest.



Vegetation Class name	Area (ha)
Enchroached land	50.10
Open forest	80.18
Closed forest	114.13
Shrubs land	9.51

Figure 31. Map of Karashuga Natural Forest (262.69 ha) in Eastern Province with the current boundary and general vegetation categories.

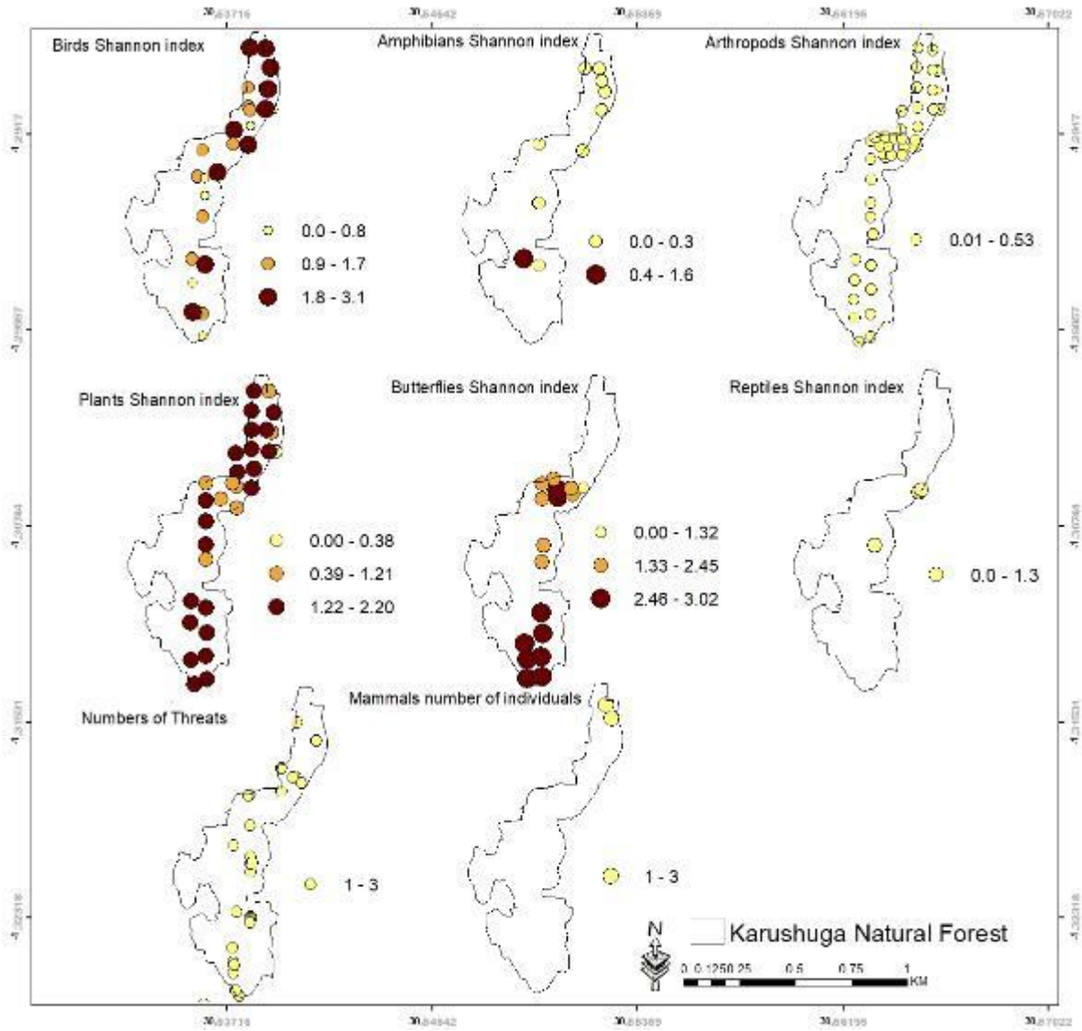


Figure 32. Distribution of the biodiversity and threats observed in Karashuga Natural Forest. Values mapped are either frequency of occurrence (counts per distance surveyed) or diversity indices (Shannon Diversity Index).

4.3.1 Plants

Among the sampled natural forests in the Eastern Province, Karushuga Natural Forest stands out as the forest with the highest species richness. Our survey documented a total of 49 plant species from 25 families (Table 11). The Fabaceae Family emerges as the most abundant, comprising 16.32% of the recorded species, followed by the Malvaceae family at 12.24%. Nearly 84% of these species are indigenous to Rwanda and its surrounding region, while 16% are introduced. Furthermore, 61.22% are classified as Least Concern according to IUCN status, although 4.08% are identified as Vulnerable. Strikingly, nearly 35% of the documented species remain unassessed on the IUCN Red List, underscoring the need for further evaluation and conservation efforts. This survey underscores the vital role of Karushuga Natural Forest in supporting biodiversity within the Eastern Province.

Table 11. Families and species of plants found in Karushuga Natural Forest, Eastern Province, Rwanda

ID	Family	Scientific name	IUCN Status	National status	Native or introduced	Life form
1	Anacardiaceae	*Lannea fulva*	NA	NA	Native	tree or shrub
		Searsia natalensis	LC	NA	Introduced	tree or shrub
2	Apocynaceae	*Acokanthera schimperi*	LC	NA	Native	tree or shrub

		Carissa spinarum	LC	NA	Native	tree or shrub
3	Asparagaceae	*Asparagus flagellaris*	NA	NA	Native	shrub
4	Asteraceae	*Microglossa densiflora*	NA	NA	Native	shrub
		Laggera alata	NA	NA	Native	shrub
5	Bignoniaceae	*Markhamia lutea*	LC	NA	Native	tree
6	Burseraceae	*Commiphora africana*	LC	EN	Native	tree or shrub
7	Celastraceae	*Gymnosporia heterophylla*	LC	NA	Introduced	shrub
8	Combretaceae	*Combretum molle*	LC	NA	Native	tree or shrub
9	Ebenaceae	*Euclea divinorum*	LC	NA	Native	tree or shrub
10	Euphorbiaceae	*Alchornea cordifolia*	LC	NA	Native	tree or shrub
		Croton dichogamus	LC	NA	Native	tree or shrub
		Euphorbia grantii	VU	NA	Native	tree or shrub
11	Fabaceae	*Albizia gummifera*	LC	NA	Native	tree
		Albizia petersiana	LC	NA	Native	tree or shrub
		Crotalaria laburnifolia	NA	NA	Native	shrub
		Crotalaria spinosa	LC	NA	Native	shrub
		Indigofera brevicalyx	NA	NA	Native	perennial
		Mimosa pigra	LC	NA	Introduced	shrub
		Senna didymobotrya	LC	NA	Native	tree or shrub
		Vachellia sieberiana	LC	NA	Native	tree
		Senna occidentalis	LC	NA	Introduced	subshrub
		Tephrosia vogelii	LC		Native	shrub
12	Lamiaceae	*Ocimum gratissimum subsp. gratissimum*	NA	NA	Native	shrub
13	Loganiaceae	*Strychnos usambarensis*	NA	NA	Native	tree or shrub

14	Malvaceae	*Grewia similis*	NA	NA	Native	tree or shrub
		Grewia trichocarpa	NA	NA	Native	tree or shrub
		Hibiscus aponeurus	NA	NA	Native	shrub
		Hibiscus surattensis	NA	NA	Native	shrub
		Sida rhombifolia subsp. rhombifolia	NA	NA	Native	shrub
		Triumfetta rhomboidea	NA	NA	Native	shrub
		Hibiscus diversifolius	LC	NA	Native	shrub
15	Moraceae	*Ficus thonningii*	LC	NA	Native	tree
16	Myrtaceae	*Eucalyptus saligna*	LC	NA	Introduced	tree
		Syzygium guineense	LC	NA	Native	tree
17	Phyllanthaceae	*Bridelia micrantha*	LC	NA	Native	tree
		Phyllanthus fischeri	NA	NA	Native	tree
18	Phytolaccaceae	*Phytolacca dodecandra*	NA	NA	Native	shrub
19	Proteaceae	*Grevillea robusta*	LC	NA	Introduced	tree
20	Rubiaceae	*Tarenna pavettoides*	LC	NA	Native	tree or shrub
		Afrocanthium lactescens	LC	EN	Native	tree
21	Rutaceae	*Teclea nobilis*	LC	NA	Native	tree
22	Santalaceae	*Osyris lanceolata*	LC	CR	Native	shrub
23	Sapotaceae	*Mimusops bagshawei*	VU	NA	Native	tree
24	Solanaceae	*Solanum aculeastrum*	LC	NA	Native	tree or shrub
25	Verbenaceae	*Lantana camara*	NA	NA	Introduced	shrub

The Nonmetric Multidimensional Scaling (NMDS) analysis identified three different vegetation assemblages in the Karashuga Natural Forest (Figure 33).

A. *Markhamia lutea-Sida rhombifolia* vegetation assemblage: This assemblage is characterized by the presence of the native tree *Markhamia lutea* and the understory shrub *Sida rhombifolia*. The average DBH of trees (8.6 cm) is relatively small, and the understory has small trees with a density of 19.33. Understory plants include *Hibiscus aponeurus*, *Hibiscus surattensis*, and sapling *Vachellia sieberiana.* Planted *M. lutea* trees are presented, indicating restoration activities have occurred in this forest. The assemblage included plots 6-3, 8-4, and 5-1.

B. *Vachellia sieberiana- Lannea fulva* vegetation assemblage: This assemblage is characterised by both mature trees of *Vachellia sieberiana* and *Lannea fulva and* seedlings of *Croton dichogamus, Croton dichogamus, Hibiscus diversifolius, Carissa spinarum, Albizia gummifera* as the *dominant* understories. With an average DBH of 9.71 cm for mature trees and a high density of small trees 20.19, there are signs of regeneration. The assemblage included plots 4-4,7-4,8-3,7-2,6-2,7-6,7-3,6-1,3-1,6-4,4-3,4-7,4-2,3-3,4-8,3-4,4-9,7-1,7-5, 3-2.

C. Grevillea robusta-Eucalyptus saligna vegetation assemblage: The dominance of invasive species like *Grevillea robusta* and *Eucalyptus saligna* characterise this assemblage. However, there are native species in the understory, including shrubs and saplings of *Alchornea cordifolia, Acacia mearnsii, Mimusops bagshawei,* and *Vachellia sieberiana* which are common alongside the invasive species, suggesting ongoing regeneration processes within the forest. The density of small trees is14.28 and the average diameter at breast height (DBH) of trees >5cm is 9.71 cm. The assemblage includes plots 9-3, 8-1, 8-2, 4-1, 9-2, 9-1, 5-2, and 4-5.

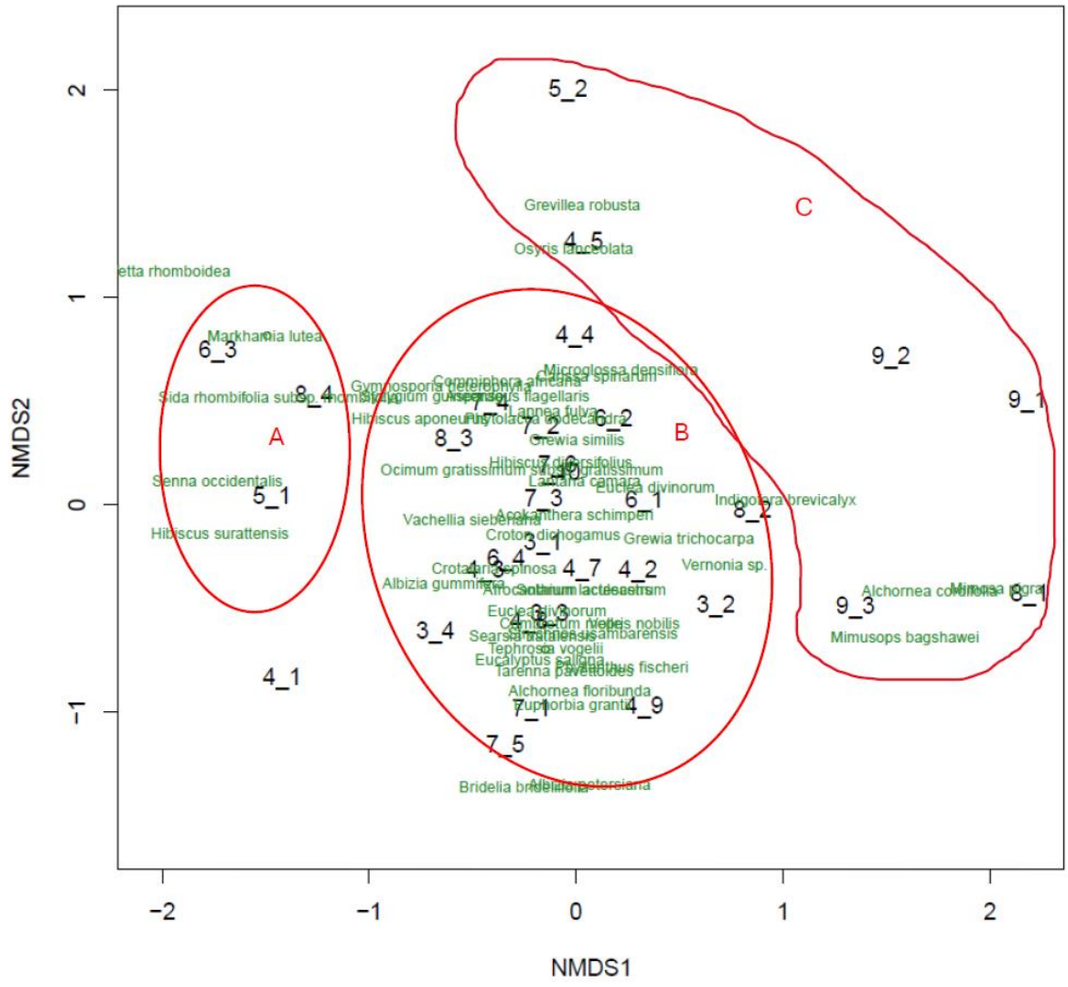


Figure 33. Nonmetric Multidimensional Scaling (NMDS) analysis of vegetation plots in Karashuga Natural Remnant Forest.

4.3.2 Herpetofauna

Four families were recorded in Karushuga Natural Forest (Table 12). Among the reptile species observed, two families were recorded including Lacertidae and Scinidae. Most of the observed species are listed as Least Concerned by the IUCN Red Lists except for those that have not been assessed.

Table 12. Amphibians and reptile species recorded in the Karushuga Natural Forest with their global and local IUCN Red List status.

	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
		Kassina senegalensis (Duméril & Bibron, 1841)	Bubbling Kassina	LC	LC
3	Phrynobatrachidae	*Phrynobatrachus natalensis (Smith, 1849)*	Common Toad-frog	LC	
4	Ptychadenidae	*Ptychadena anchietae (Bocage, 1868)*	Anchieta's Frog	LC	LC
		Ptychadena nilotica (Seetzen, 1855)	Nile grass frog	LC	LC
		Ptychadena porosissima (Steindachner, 1867)	Grassland Frog	LC	LC
REPTILES					
1	Lacertidae	*Adolfus jacksoni (Boulenger, 1899)*	Jackson's Forest Lizard	LC	ND
2	Scincidae	*Trachylepis striata (Peters, 1844)*	African Striped Mabuya	LC	ND
		Trachylepis sp	-	-	-

4.3.3 Flying insects

We recorded 55 butterfly species from five families from Karushuga Natural Forest. Of them, 39 butterflies are listed as Least Concern, and the remaining 16 are Not Evaluated. The most abundant species were *Tirumala petiverana*, followed by *Junonia terea* (Figure 34). The most common family was Pieridae (44.90%) followed by Nymphalidae (43.37%), Papilionidae (6.63%), Hesperiidae, (3.06%), and the last was Lycaenidae (2.04%).

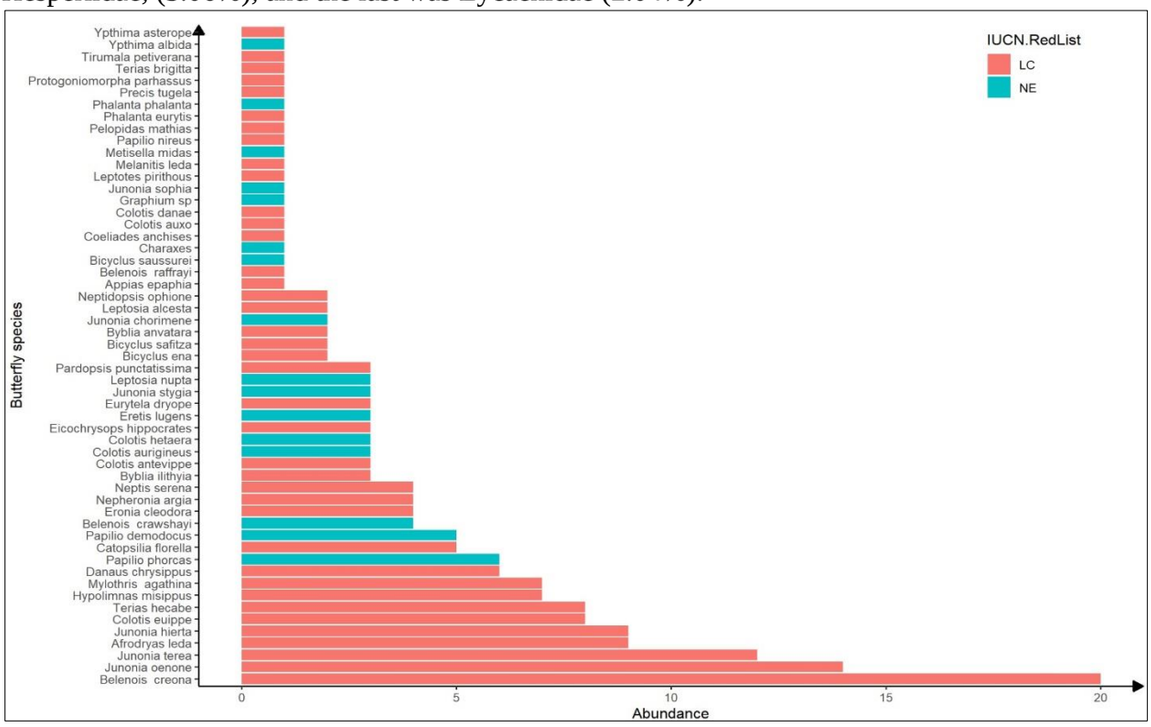


Figure 34. Diversity and abundance of butterfly species recorded from Karushuga Natural Forest. The orange box represents the species that are classified by the IUCN RedList as Least Concern while the turquoise box stands for the species that are not evaluated (NE). The Data analysis and visualization were carried out using the R platform (R version 4.3.2 Development Core Team, 2023) and suitable packages.

We recorded 18 pollinating insects in Karushuga Natural Forest. These insects included butterflies (*Junonia terea, Catopsilia florella, Colotis euippe, Junonia Sophia, Metisella midas, Belenois creona, Junonia oenone, Byblia anvatara, Afrodryas leda, Eronia cleodora, Eurema hecabe,* and *Mylothris agathina*), bees (*Lasioglossum sp.* and *Apis mellifera),* and flies (Syrphidae and Chloropidae) (Figure 35).

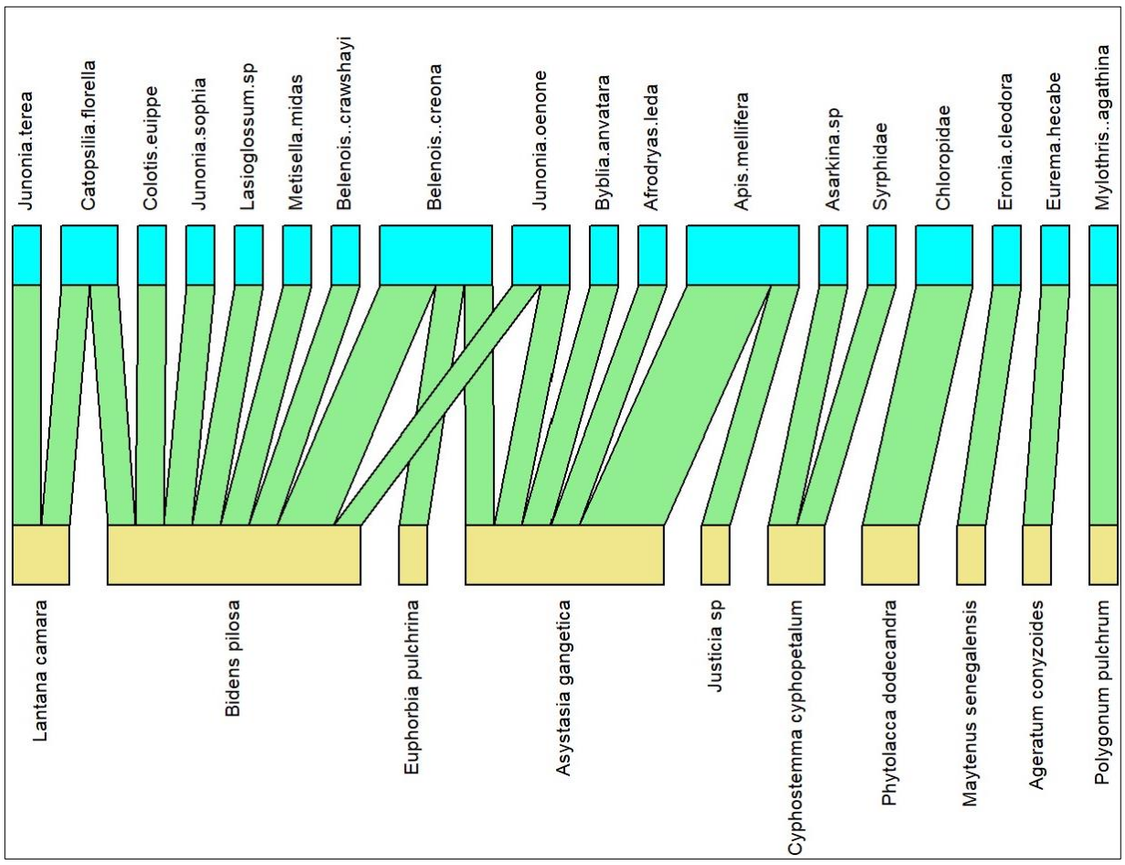


Figure 35. Network structure of plants and their pollinating insects from Karushuga Natural Forest. Upper part (turquoise band) represents flower visitors and lower band in yellow represents plant diversity (host plant species). Middle part in green represents linkage (which plant was visited by which insect species) between plants and their pollinating insects.

4.3.4 Terrestrial Arthropods

A total of 620 individuals belonging to 52 families were recorded in Karushuga Natural Forest. Three families – Formicidae, Salticidae, and Acrididae – have higher abundance compared to other families (Table 13, Figure 36). According to the IUCN Red List, all recorded families are not evaluated.

Table 13. Arthropods families recorded at Karushuga Natural Forest with their functional groups

	Order	**Family**	**Common name**	**Functional Group**
1	Hymenoptera	Formicidae	Ants	Omnivorous
2	Aranea	Salticidae	Jumping spider	Predators
3	Orthoptera	Acrididae Gryllidae	Grasshopper Cricket	Herbivorous Omnivorous
4	Coleoptera	Lycidae Staphylinidae Chrysomelidae	Net-winged beetle Rove beetle Leaf beetle	Detritivorous Predators Herbivorous
5	Hemiptera	Cercopidae	Froghopper	Herbivorous
7	Blattodea	Blattellidae	Wood cockroach	Detritivorous

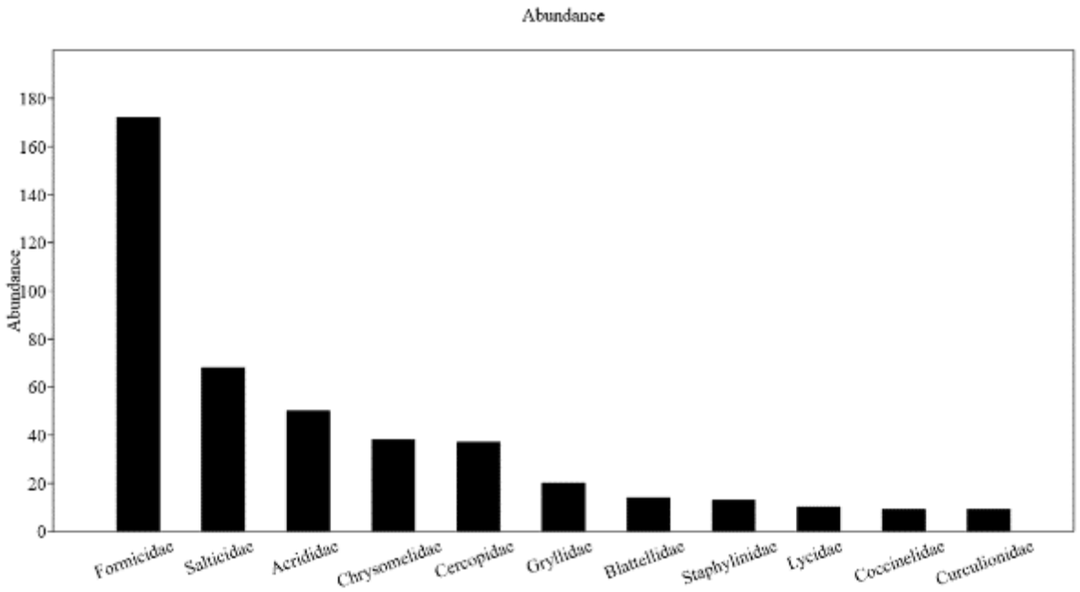


Figure 36. Most abundant arthropod families at Karushuga Natural Forest (those with greater than 10 individuals each).

4.3.5 Birds

We observed 74 bird species, grouped in 33 families, with 11 migrant birds of different migratory statuses, such as 6 full migrants, 1 partial migrant, 1 local migrant, and 3 intra-African migrants, in Karashuga Natural Forest. We identified one Endangered species on the IUCN Red List, the Gray-crowned Crane (*Balearica regulorum*).The study also revealed the presence of eight 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. In addition, 34 insect-eating bird species were recorded from 74 total species.

4.3.6 Mammals

Only one mammal was recorded at Karushuga Natural Forest, the hippopotamus *Hippopotamus amphibius* from footprints found around the Akagera River. It is classified as Vulnerable according to the IUCN Red List.

4.3.7 Threats

Many threats were recorded at Karushuga Natural Forest. The most prevalent threats were agriculture and groundcover clearing, each with 23.68% (Figure 37). Forest groundcover clearing at Karushuga is shown in Figure 38.

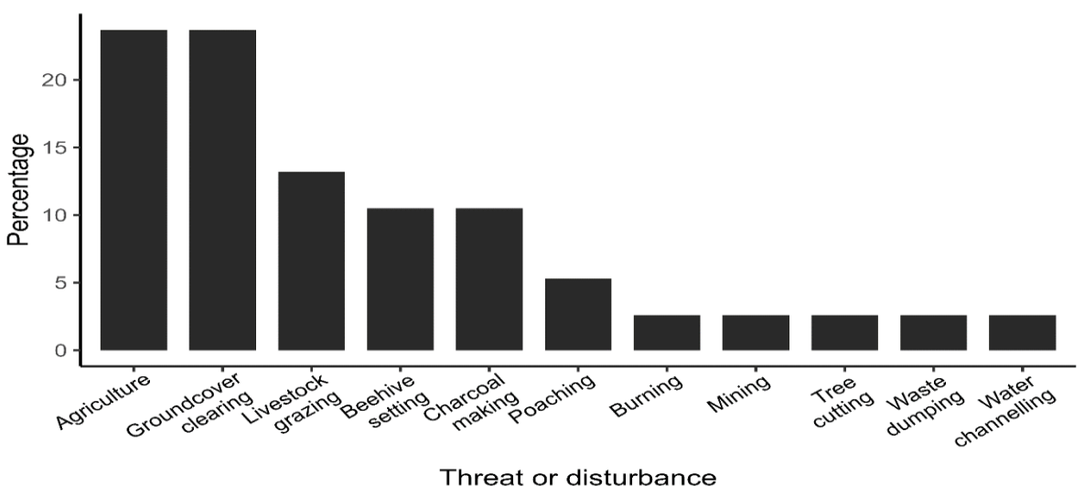
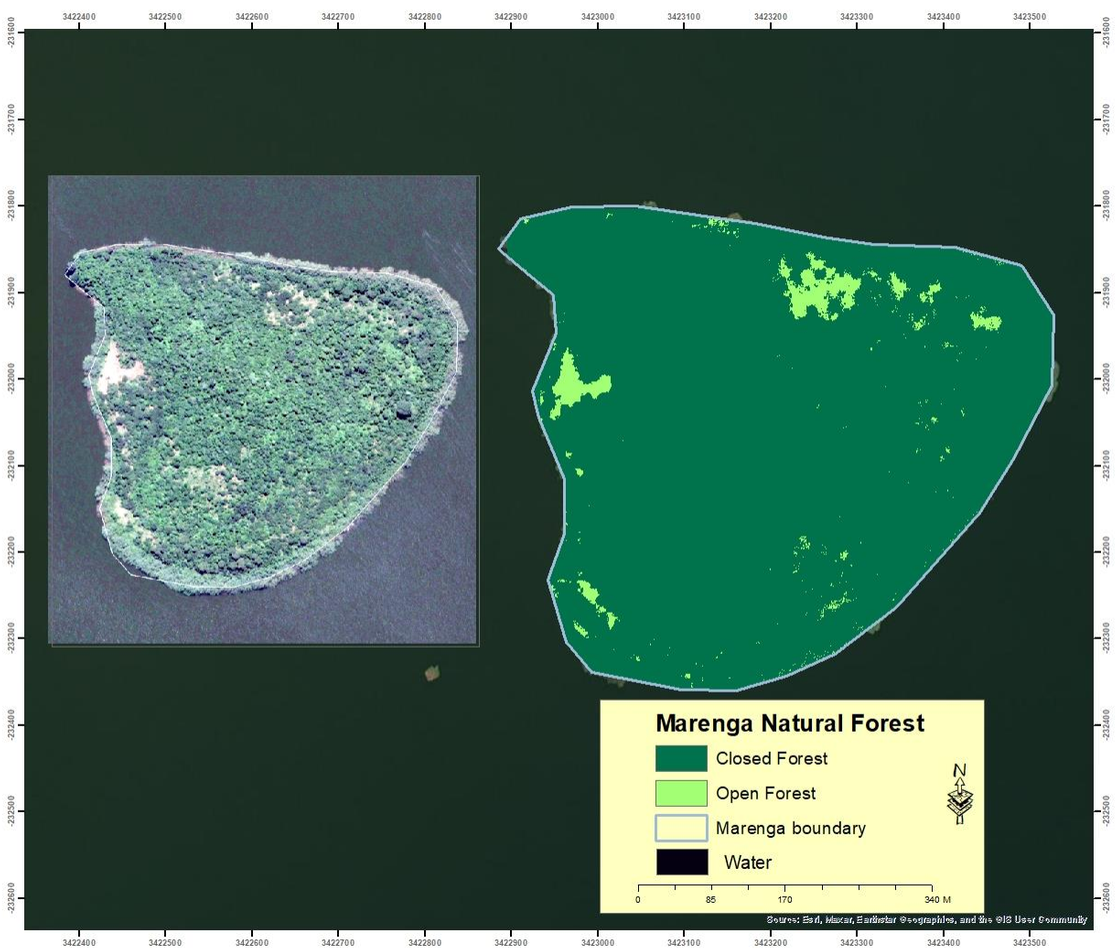


Figure 37. Threats occurrence and abundance at Karushuga Natural Forest

Figure 38. Natural forest clearing at Karushuga Natural Forest

4.5 Marenga Natural Forest

Marenga Natural Forest was measured at 25.56 ha and includes some small areas of open and disturbed forest inside the forest boundary (Figure 39). Figure 40 shows the distribution of the biodiversity sampled in this forest, as well as the threats. Following are sections presenting the biodiversity details and threat assessment findings for this remnant forest.



Vegetation Class name	Area (ha)
Closed forest	25.01
Open forest	0.83

Figure 39. Map of Marenga Natural Forest (25.56 ha) in Eastern Province with the current boundary and general vegetation categories.

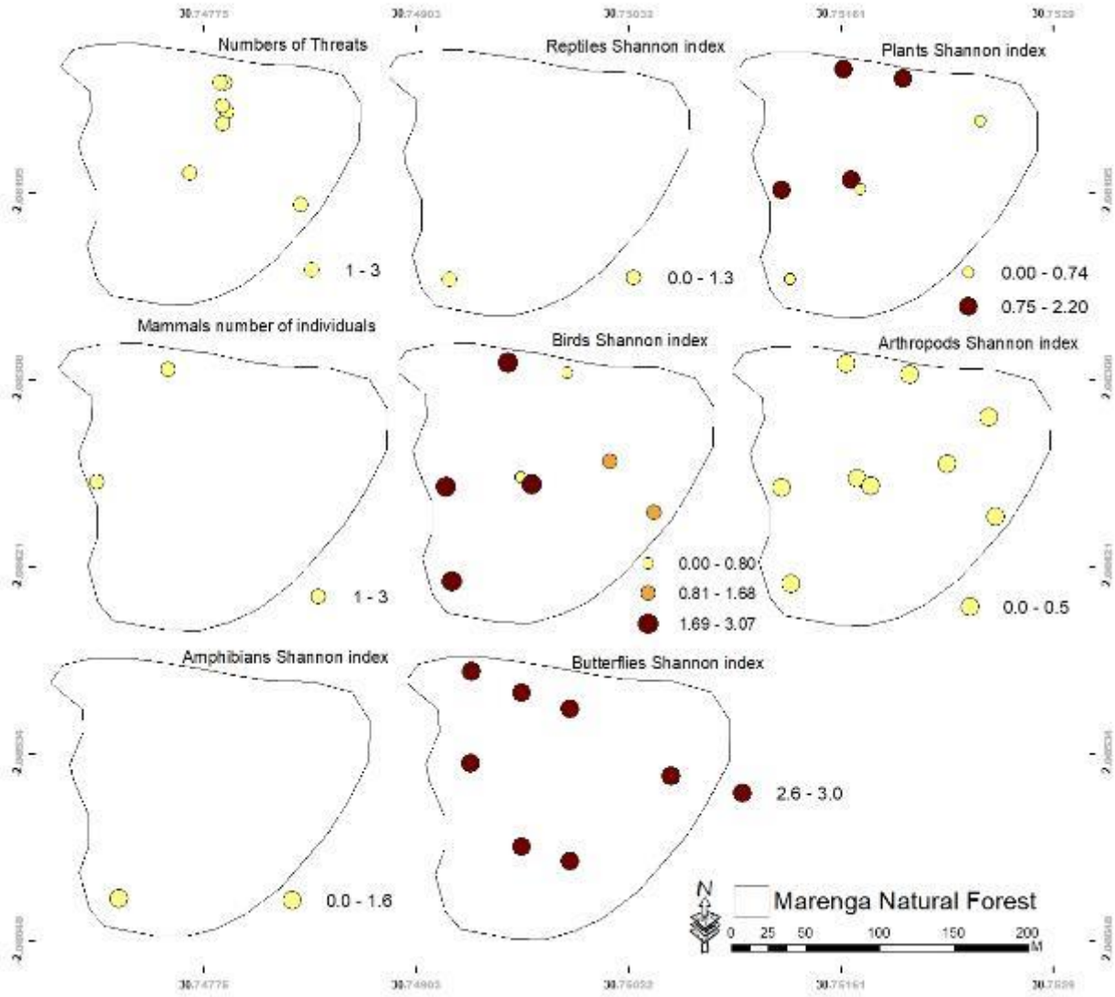


Figure 40. Distribution of the biodiversity and threats observed in Marenga Natural Forest. Values mapped are either frequency of occurrence (counts per distance surveyed) or diversity indices (Shannon Diversity Index).

4.5.1 Plants

In Marenga Natural Forest, the survey found 14 species from 7 families (Table 14). Among these families, the Malvaceae family emerged as the most common, with a substantial species richness of 28.57%, closely followed by the Euphorbaceae family at 21.42%. Notably, an overwhelming majority, accounting for 92.85%, of the recorded species are indigenous to Rwanda and its neighboring regions, while a smaller proportion, 7.14%, are introduced species. Encouragingly, the majority of the species (57.14%) are currently categorized as of Least Concern on the IUCN Red List. However, 7.14%, are classified as Vulnerable, warranting targeted conservation efforts. Regrettably, 35.71% of the species remain unassessed, necessitating further evaluation to ascertain their conservation status. This assessment sheds light on the value of Marenga Natural Forest for plant diversity and the pressing need for continued conservation initiatives.

Table 14. Families and species of plants found in the Marenga Natural Forest, Eastern Province, Rwanda

ID	**Family**	**Scientific name**	**IUCN Status**	**National status**	**Native or introduced**	**Life form**
1	Anacardiaceae	*Lannea fulva*	NA	NA	Native	tree or shrub
2	Arecaceae	*Phoenix reclinata*	LC	NA	Native	tree
3	Euphorbiaceae	*Euphorbia candelabrum*	LC	NA	Native	tree

		Euphorbia grantii	VU	NA	Native	shrub
		Euphorbia tirucalli	LC	NA	Introduced	tree or shrub
4	Fabaceae	*Albizia gummifera*	LC	NA	Native	tree
		Albizia petersiana	LC	NA	Native	tree or shrub
		Vachellia sieberiana	LC	NA	Native	tree
5	Malvaceae	*Dombeya rotundifolia*	LC	NA	Native	tree
		Grewia similis	NA	NA	Native	tree or shrub
		Grewia trichocarpa	NA	NA	Native	tree or shrub
		Sida rhombifolia subsp. rhombifolia	NA	NA	Native	shrub
6	Rutaceae	*Teclea nobilis*	LC	NA	Native	tree
7	Sapindaceae	*Haplocoelum foliolosum subsp. strongylocarpum*	NA	NA	Native	tree

The Nonmetric Multidimensional Scaling (NMDS) analysis identified two different vegetation assemblages in the Marenga Natural Forest (Figure 41).

A. Grewia trichocarpa-Phoenix reclinata community: *Grewia trichocarpa* is the dominant tree in this forest, which indicates a savannah woodland ecosystem, and this assemblage is also characterized by *Phoenix reclinata*. The average DBH is 41.38cm and the density of trees <5cm is 9.125. The understory was dominated by *Euphorbia grantii, Haplocoelum foliolosum subsp. Strongylocarpum, Teclea nobilis, Euphorbia candelabrum,* and *Vachellia sieberiana.* The assemblage included plots 2-1, 3-1, 3-2, 5-2, 5-1, 2-2, 4-1 and 1-2.

B. *Euphorbia tirucalli-Albizia gummifera* community: This assemblage is dominated by *Euphorbia tirucalli*, an introduced species, and *Albizia gummifera*. The average tree DBH of 45.46 is relatively large for this small remnant forest. *Vepris nobilis* was a dominant small tree, with a very low density of small trees (<5cm DBH).

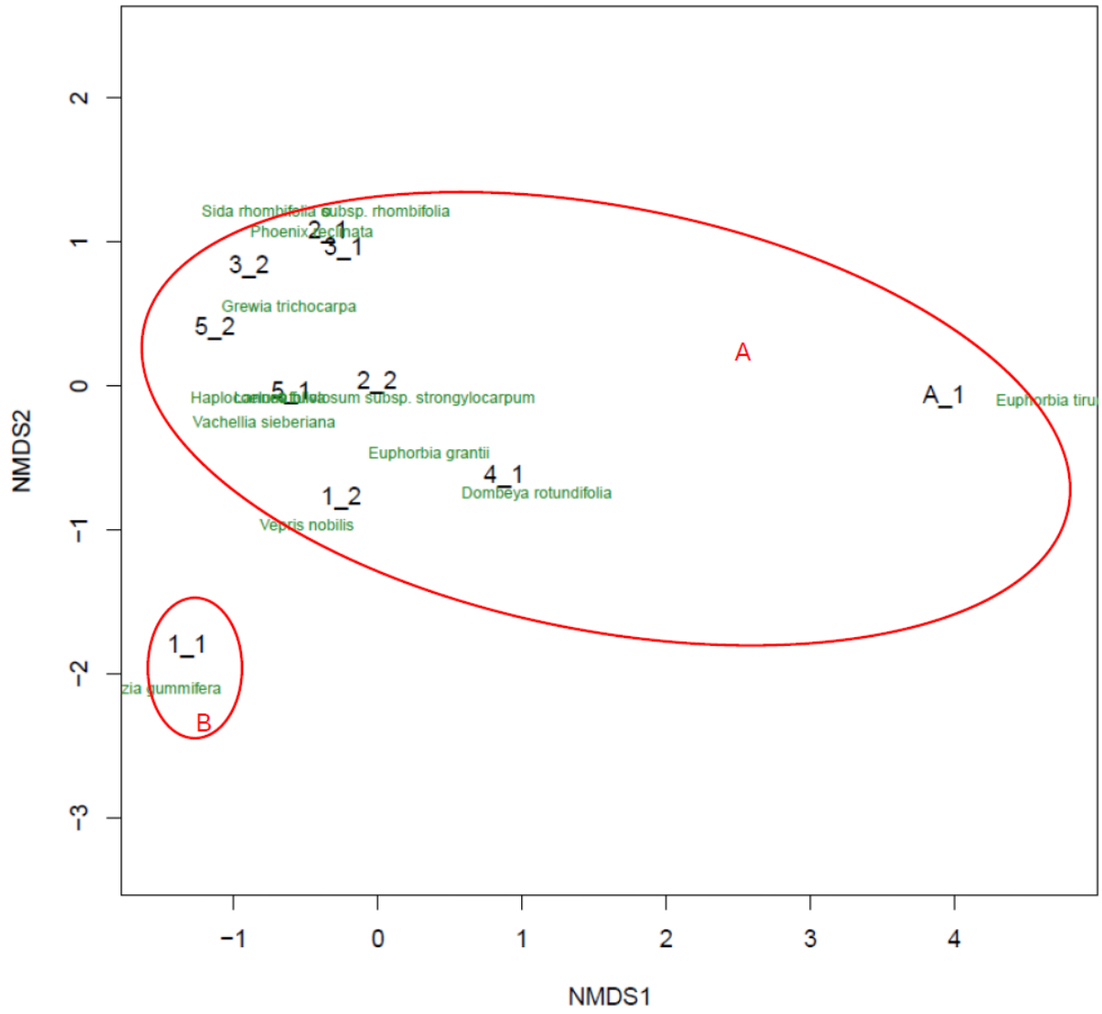


Figure 41. Nonmetric Multidimensional Scaling (NMDS) analysis of vegetation plots in Marenga Natural Remnant Forest.

4.5.2 Herpetofauna

We observed two amphibian and one reptile species from three separate families in Marenga Natural Forest (Table 15). Among the amphibian species, all species are listed as Least Concerned under the IUCN Red List. The turtle species observed has not been evaluated for the IUCN Red List.

Table 15. Amphibian and reptile species recorded in the Marenga Natural Forest with their global and local IUCN Red List status.

	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					
3	Testudinidae	*Kinixys spekii Gray, 1863*	Speke's Hinge-back Tortoise	NE	ND

4.5.3 Flying insects

Nine butterfly species were recorded from Marenga Natural Forest. The most abundant species was *Belenois creona*, followed by *Afrodryas leda* and *Leptosia nupta*. Of those nine species, seven are under the Least Concern (LC) category on the IUCN Red List, and the two remaining species are listed as Not Evaluated (NE) (Figure 42). These butterflies belong to three families. The most

abundant family was Pieridae (84.62%) while the least abundant families were Lycaenidae (7.69%) and Nymphalidae (7.69%). One pollinating insect (*Apis mellifera*) was spotted pollinating *Clutia myritina* and *Asystasia gangetica* plants.

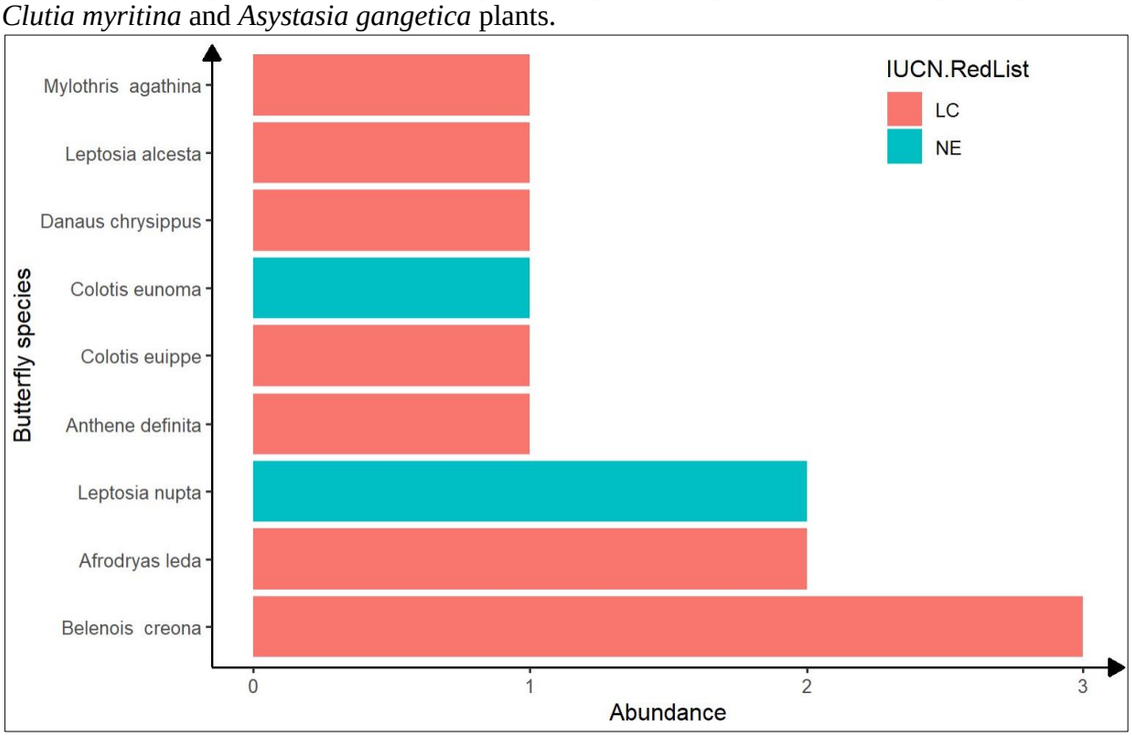


Figure 42. Diversity and abundance of butterfly species recorded from Marenga Natural Forest. The orange box represents the species that are classified by the IUCN Red List as Least Concern (LC) while the turquoise box stands for the species that are not evaluated (NE).

4.5.4 Terrestrial Arthropods

A total of 222 individuals belonging to 32 families were observed in this forest. Formicidae was the most abundant family (Table 16, Figure 43). None of the families have been evaluated according to the IUCN Red List.

Table 16. The five most abundant arthropods families recorded at Marenga Natural Forest along with their functional groups

	Order	**Family**	**Common name**	**Functional Group**
1	Hymenoptera	Formicidae	Ants	Omnivorous
2	Aranea	Salticidae	Jumping spider	Predators
3	Coleoptera	Chrysomelidae	Leaf beetle	Herbivorous
4	Blattodea	Blattellidae	Wood Cockroach	Detritivorous
5	Isoptera	Termitidae	Termite	Detritivorous

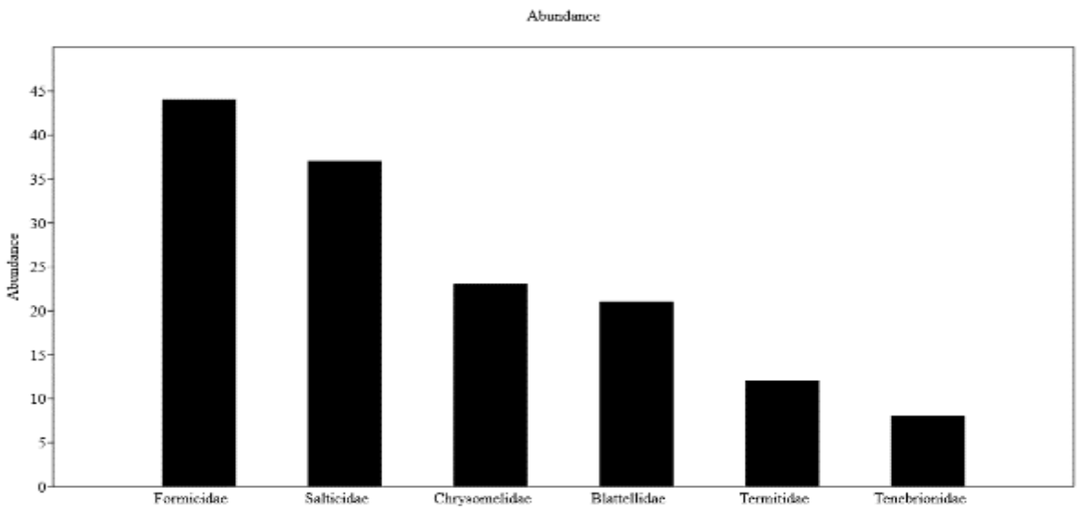


Figure 43. Most abundant arthropod families at Marenga Natural Forest with greater than ten individuals

4.5.5 Birds

In Marenga Natural Forest, we observed 19 bird species from14 families. Of these observed species, 5 were migratory species of different migratory statuses: 4 full migrants and 1 intra-African migrant. We identified six functional groups, including granivorous (seed-eating), omnivorous (eating both plant and animal matter), nectivorous (nectar-feeding), insectivorous (insect-eating), frugivorous (fruit-eating), piscivorous (fish-feeding) species. Notably, 8 of 19 of the bird species (42%) identified were insectivorous, feeding primarily on insects.

4.5.6 Mammals

At Marenga Natural Forest, the hippopotamus *Hippopotamus amphibius* is the only mammal recorded and many footprints were seen around the island. The species is classified as Vulnerable under the IUCN category, but it is not an endemic species.

4.5.7 Threats

The main threat recorded at Marenga Natural Forest was tree cutting. Few occurrences of threats and disturbances were observed, but there were 7 records of tree cutting (77.8% of threats), and we noted a single observation of beehive setting and plastic material at this site (Figure 44).

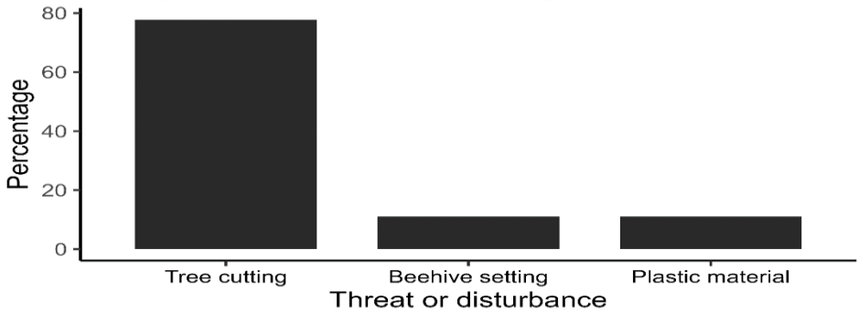
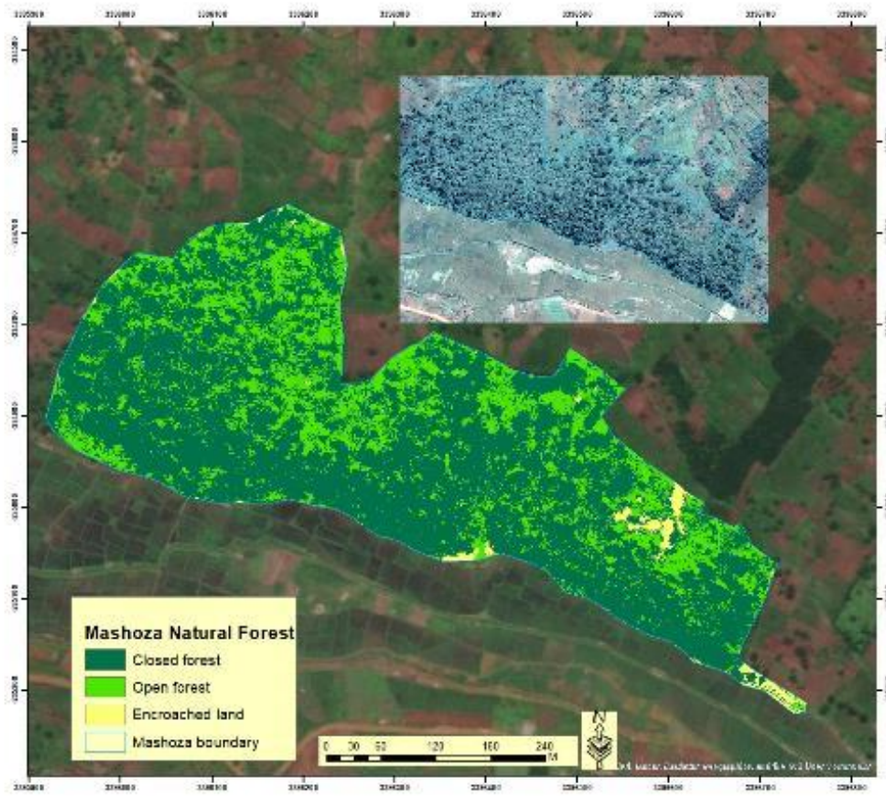


Figure 44. Threats occurrence and abundance at Marenga Natural Forest

4.5 Mashoza Natural Forest

Mashoza Natural Forest was measured at 17.00 ha and is a very small forest fragment with disturbed areas inside the forest boundary, as well as forested areas (Figure 45). Figure 46 shows the distribution of the biodiversity sampled in this forest, as well as the threats. Following are sections presenting the biodiversity details and threat assessment findings for this remnant forest.



Vegetation Class name	Area (ha)
Closed forest	12.46
Encroached land	0.37
Open forest	4.63

Figure 45. Map of Mashoza Natural Forest (17.00 ha) in Eastern Province with the current boundary and general vegetation categories.

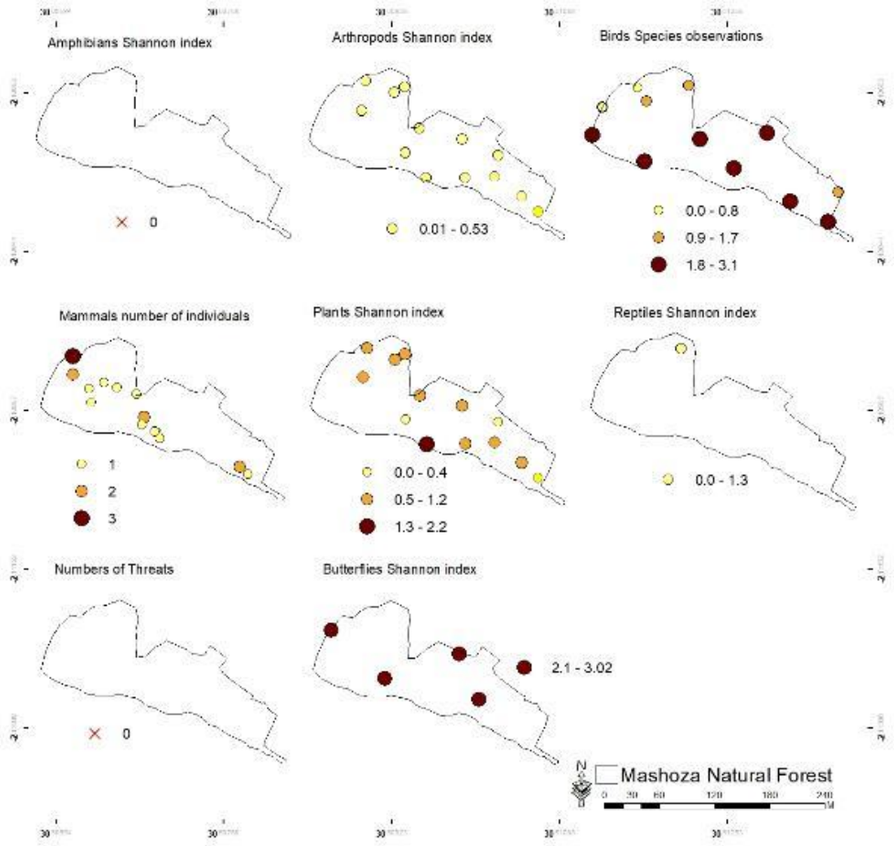


Figure 46. Distribution of the biodiversity and threats observed in Mashoza Natural Forest. Values mapped are either frequency of occurrence (counts per distance surveyed) or diversity indices (Shannon Diversity Index).

4.5.1 Plants

In the Mashoza Natural Forest, the survey found 21 species from 14 families (Table 17). The Fabaceae Family emerged as the most prominent contributor to species richness, comprising 28.57% of the recorded species, followed by the Asteraceae family at 14.28%. Of significant note is the overwhelming presence of native species, accounting for 81% of the total, while the remaining 19.04% were introduced species. Encouragingly, a substantial portion of the species, amounting to 61.9%, is classified as Least Concern according to the IUCN Red List. However, vigilance is warranted as 4.76% of the species are reported as Vulnerable, requiring immediate attention and conservation efforts. Additionally, 33.33% of the plant species remain unassessed, emphasizing the urgency for further evaluation to ascertain their conservation status.

Table 17. Families and species of plants found in Mashoza Natural Forest, Eastern Province, Rwanda

ID	**Family**	**Scientific name**	**IUCN Status**	**National status**	**Native or introduced**	**Life form**
1	Acanthaceae	*Acanthus polystachyus*	NA	NA	Native	tree or shrub
2	Asparagaceae	*Agave sisalana*	NA	NA	Introduced	shrub
3	Asteraceae	*Gymnanthemum amygdalinum*	NA	NA	Native	tree or shrub
		Microglossa densiflora	NA	NA	Native	shrub
		Laggera alata	NA	NA	Native	N/A
4	Bignoniaceae	*Markhamia lutea*	LC	NA	Native	tree
5	Celastraceae	*Gymnosporia heterophylla*	LC	NA	Introduced	shrub
6	Chrysobalanaceae	*Parinari excelsa*	LC	NA	Native	tree
7	Combretaceae	*Combretum molle*	LC	NA	Native	tree
8	Fabaceae	*Albizia adianthifolia*	LC	NA	Native	tree
		Albizia petersiana	LC	NA	Native	tree or shrub
		Biancaea decapetala	LC	NA	Introduced	shrub
		Erythrina abyssinica	LC	NA	Native	tree
		Senegalia polyacantha	NA	NA	Native	tree
		Senna didymobotrya	LC	NA	Native	tree or shrub
9	Lamiaceae	*Clerodendrum johnstonii*	LC	NA	Native	tree or shrub
10	Moraceae	*Ficus thonningii*	LC	NA	Native	tree
11	Rosaceae	*Prunus africana*	VU	EN	Native	tree
12	Rubiaceae	*Tarenna pavettoides*	LC	NA	Native	tree or shrub
13	Rutaceae	*Teclea nobilis*	LC	NA	Native	tree
14	Verbenaceae	*Lantana camara*	NA	NA	Introduced	shrub

The Nonmetric Multidimensional Scaling (NMDS) analysis identified two different vegetation assemblages in the Mashoza Natural Forest (Figure 47).

A. *Senegalia polyacantha-Lantana camara* community: *Senegalia polyacantha* is the dominant tree in this assemblage, which has significant levels of degradation. The invasive species *Lantana camara* is also dominant in the understory along with *Acanthus polystachyus, Gymnosporia heterophylla, Markhamia lutea, Teclea nobilis*, creating dense thickets, and there are several other non native species in this assemblage. *Senegalia polyacantha* average DBH was 11cm. Along with the relatively open canopy, there is a high density of small trees (<5cm DBH) in the understory, with an average density of 68.2. Vepris nobilis. This assemblage has also other dominant understories.The assemblage included plots 1-2, 1-7, 3-1, 3-3, and 2-1.

B. *Prunus africana-Teclea nobilis* community: *Prunus africana* is the dominant large tree in this assemblage with average DBH of 68.2, with the smaller tree *Teclea nobilis*. The understory was dominated by *Markhamia lutea* saplings, *Lantana camara*, *Gymnosporia heterophylla*, and *Erythrina abyssinica* with density of small trees (<5cm DBH) of 68.2. The community included plots 2-2, 2-3, 1-1, 1-4, 1-5, 1-6 and 1-3.

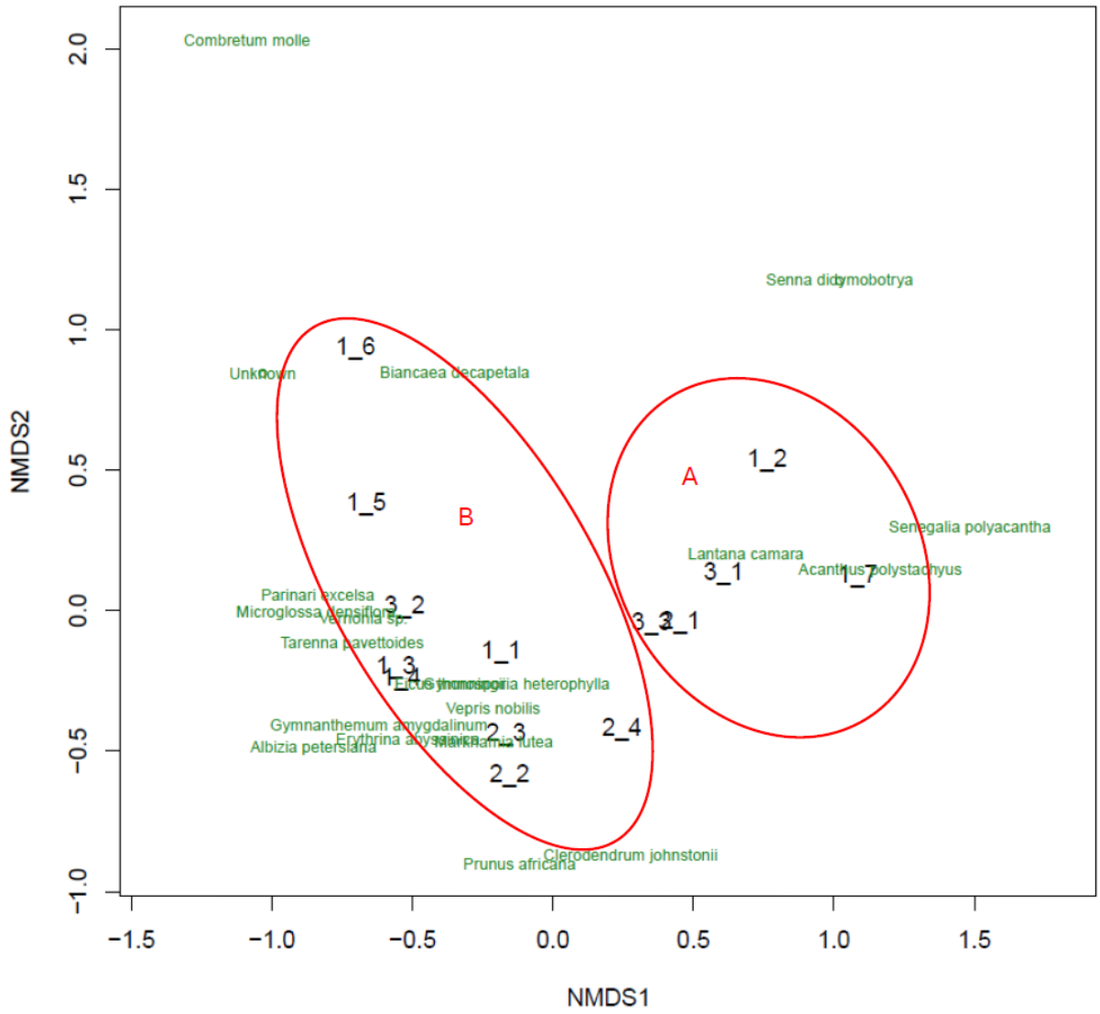


Figure 47. Nonmetric Multidimensional Scaling (NMDS) analysis of vegetation plots in Mashoza Natural Remnant Forest

4.5.2 Herpetafuna

The assessment of amphibians and reptiles in Mashoza Natural Forest resulted in only a single amphibian species (*Afrixalus quadrivittatus*) of the Family Hyperoliidae and one reptile species (*Trachylepis striata*) of the family Scinidae (Table 18).

Table 18. Amphibian and reptile species recorded in the Mashoza Natural Forest with their global and local IUCN Red List status.

	Family	Scientific name	Common name	Global IUCN status	National IUCN status
AMPHIBIANS					
1	Hyperoliidae	*Afrixalus quadrivittatus (Werner, 1908)*	Four-lined Spiny Reed Frog	LC	LC
REPTILES					
1	Scincidae	*Trachylepis striata (Peters, 1844)*	African Striped Mabuya	ND	LC

4.5.3 Flying insects

Eight butterfly species were sampled from Marenga Natural Forest (Table 19). The pollinating insects recorded from Mashoza Natural Forest are bees (*Xylocopa caffra*, *Xylocopa flavorufa*, and *Apis mellifera*) and flies from the Syrphidae family. All insects were pollinating a single plant species (*Lantana camara*), an invasive species.

Table 19. Butterfly species composition recorded from Mashoza Natural Forest.

	Family	Scientific name	Common name	IUCN status
1	Nymphalidae	Danaus chrysippus (Linnaeus 1758)	African queen butterfly	LC
2	Nymphalidae	Charaxes acuminatus Thurau, 1903	Mountain pearl charaxes	NE
3	Lycaenidae	Anthene definita (Butler, 1899)	Common hairtail	LC
4	Papilionidae	Papilio demodocus Esper (1798)	Citrus Gazer	NE
5	Papilionidae	Papilio phorcas Cramer (1775)	Apple-green Handkerchief	LC
6	Hesperiidae	Gegenes hottentota (Latreille, 1824)	Marsh Hottentot Skipper	LC
7	Pieridae	Leptosia nupta (Butler, 1873)	Immaculate spirit	NE
8	Pieridae	Terias brigitta (Stoll, [1780])	Broad-bordered Grass Yellow	LC

4.5.4 Terrestrial Arthropods

Mashoza Natural Forest had a total of 308 individuals across 35 families, dominated by Hymenoptera (Formicidae), which is a multi-functional group, Diptera (Agromyzidae) known for herbivory, Diptera (Culicidae) which are hematophagous and Aranea (Salticidae) which are predators (Table 20, Figure 48). IUCN Red List status for these insects is not evaluated**.**

Table 20. Arthropods families and their functional groups at Mashoza Natural Forest

	Order	Family	Common name	Functional group
1	Hymenoptera	Formicidae Ichneumonidae Scoliidae	Ants Ichneumon wasp Scoliid wasp	Omnivorous Parasitoids Parasitoids
2	Aranea	Salticidae	Jumping spider	Predators
3	Blattodea	Blattidae	Wood cockroach	Detritivorous

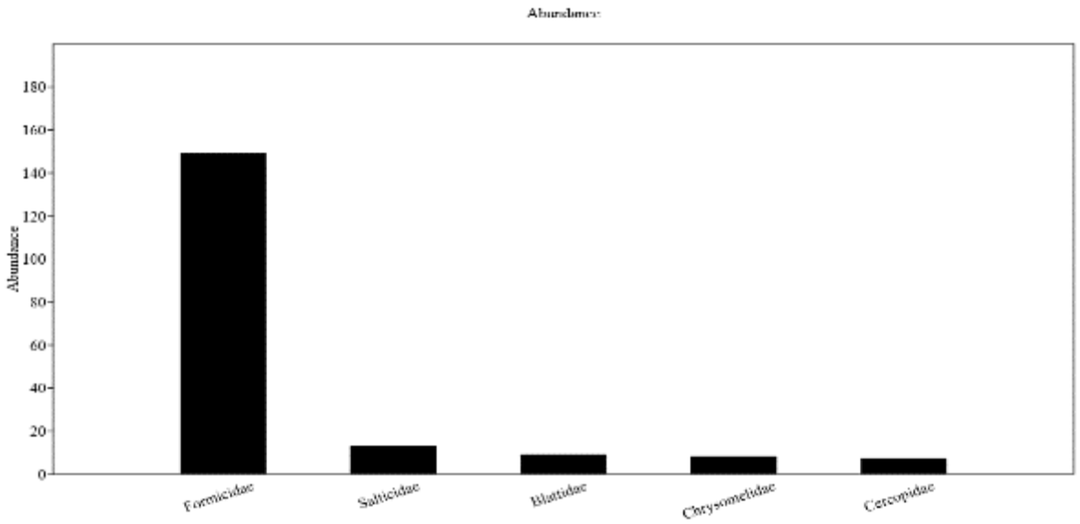


Figure 48. Most abundant arthropods families at Mashoza Natural Forest with greater than 10 individuals.

4.5.5 Birds

We observed 54 diverse bird species in Mashoza Natural Forest, with six migratory birds of different migratory statuses: 3 full migrants, 1 local migrant, and 2 intra-African migrants. For functional groups, we observed six among nine categorized functional groups, including granivorous (seed-eating), omnivorous (eating both plant and animal matter), nectivorous (nectar-feeding), insectivorous (insect-eating), frugivorous (fruit-eating, and carnivorous (meat-feeding) species. The insectivorous birds were the most common functional group (23 bird species) observed, followed by nectivorous (7 bird species) in 54 species documented.

4.5.6 Mammals

Seven species of mammals were recorded, belonging to four orders, and seven families. The order Carnivora includes three species (Table 21). Remarkably, each of the seven species belongs to its own family, which indicates another level of diversity. All the recorded species are in the LC category of IUCN Red List and there is no endemic species. Apart from two species that are generally rare in Rwanda, the African civet (*Civettictis civetta)* and the serval (*Leptailurus serval*), the other species are common in moderately and highly disturbed natural habitats. The serval is classified globally as LC. The next figure shows the occurrence of the mammals in terms of abundance that was low in general (Figure 49).

Table 21. Summary of the mammals recorded at Mashoza Natural Forest including information on endemic and IUCN status

	Order	Family	Scientific name	Common name	AR endemic	IUCN status
1	Carnivora	Viverridae	*Civettictis civetta*	African civet	No	LC
2	Carnivora	Canidae	*Canis adustus*	Side-striped jackal	No	LC
3	Carnivora	Felidae	*Leptailurus serval*	Serval	No	LC
4	Primates	Cercopithecidae	*Chlorocebus pygerythrus*	Vervet monkey	No	LC
5	Rodentia	Nesomyidae	*Cricetomys sp.*	Forest pouched rat	No	LC
6	Rodentia	Muridae	*Lemniscomys striatus*	Grass striped mouse	No	LC
7	Soricomorpha	Soricidae	*Crocidura sp. 1*	White-toothed shrew	No	LC

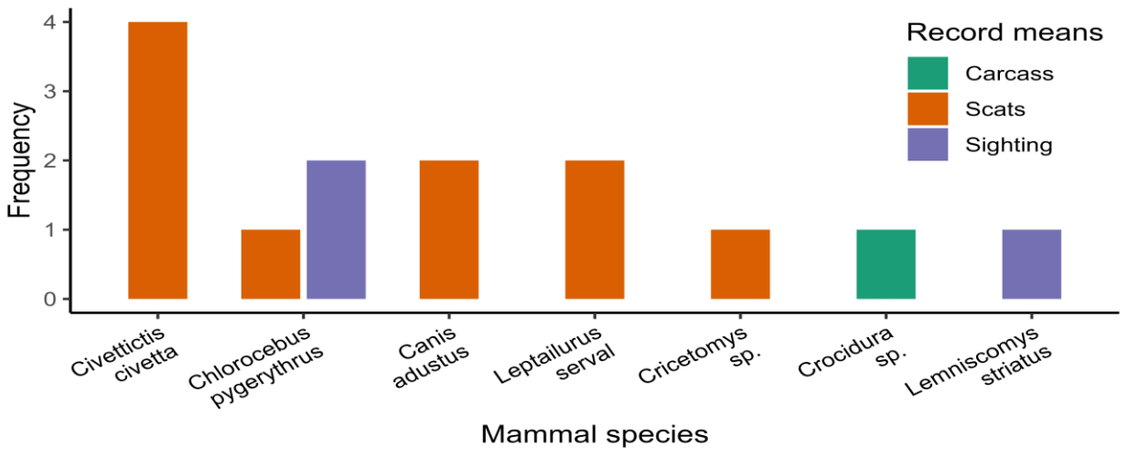


Figure 49. Occurrence of mammals at Mashoza forest with number of individuals and means by which they were recorded.

4.5.7 Threats

At Mashoza Natural Forest, the main threats are beehive settings and human excreta (both accounting for 50% of records), but the occurrence of threats is low in general since two threats were covered in 4 records (Figure 50). Mashoza forest, has been found not easily accessible for many places, along the transect, which could more easily be possible through a few existing trails. We realized the occurrence of beehives setting at Mashoza but near the edge (at least 8 beehives counted). We also witnessed the occurrence of hunting with dogs during the surveying time. The shrubs that exist at Mashoza are highly entangled and many are thorny, which limits access to many places. The main occurring issue at Mashoza is the invasive plant *Lantana camara* (figure in Appendix) which was not mentioned because it is not easily quantifiable. A large proportion of the forest may have been affected by that plant.

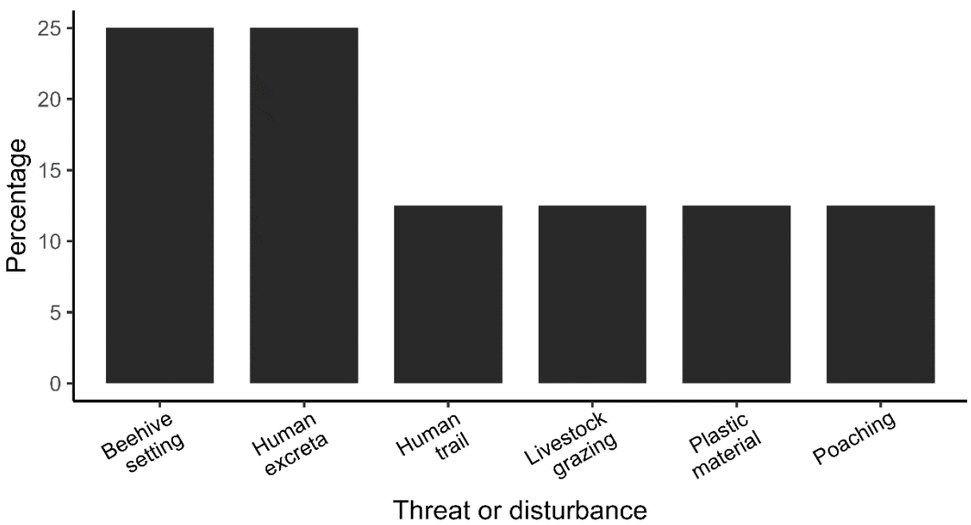
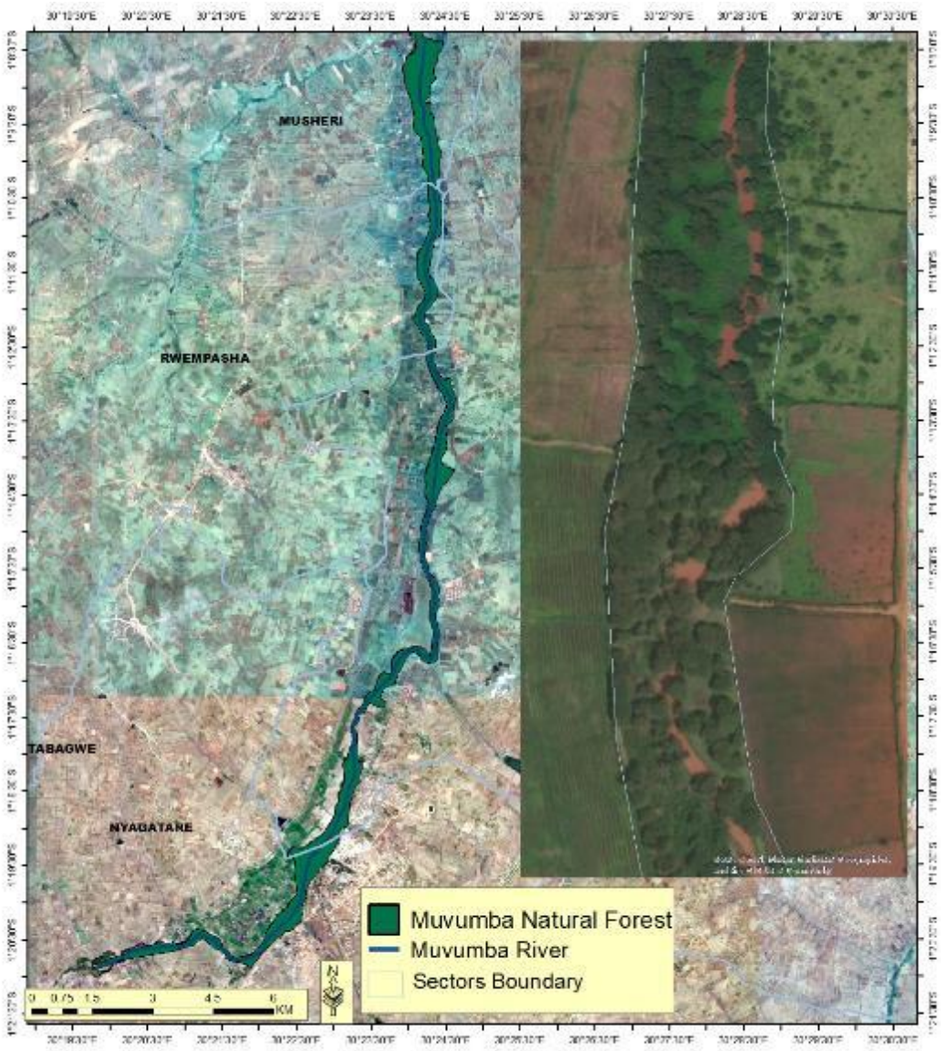


Figure 50. Threats occurrence and abundance at Mashoza Natural Forest

4.6 Muvumba Natural Forest

Muvumba Natural Forest was measured at 672.15 ha. It is a long narrow gallery forest along the Muvumba River (Figure 51). Figure 52 shows the distribution of the biodiversity sampled in this forest, as well as the threats. Following are sections presenting the biodiversity details and threat assessment findings for this remnant forest.



Vegetation Class name	Area (ha)
Muvumba forest	502.07
River	170.08

Figure 51. Map of Muvumba Natural Forest (672.15 ha) in Eastern Province with the current boundary and general vegetation categories.

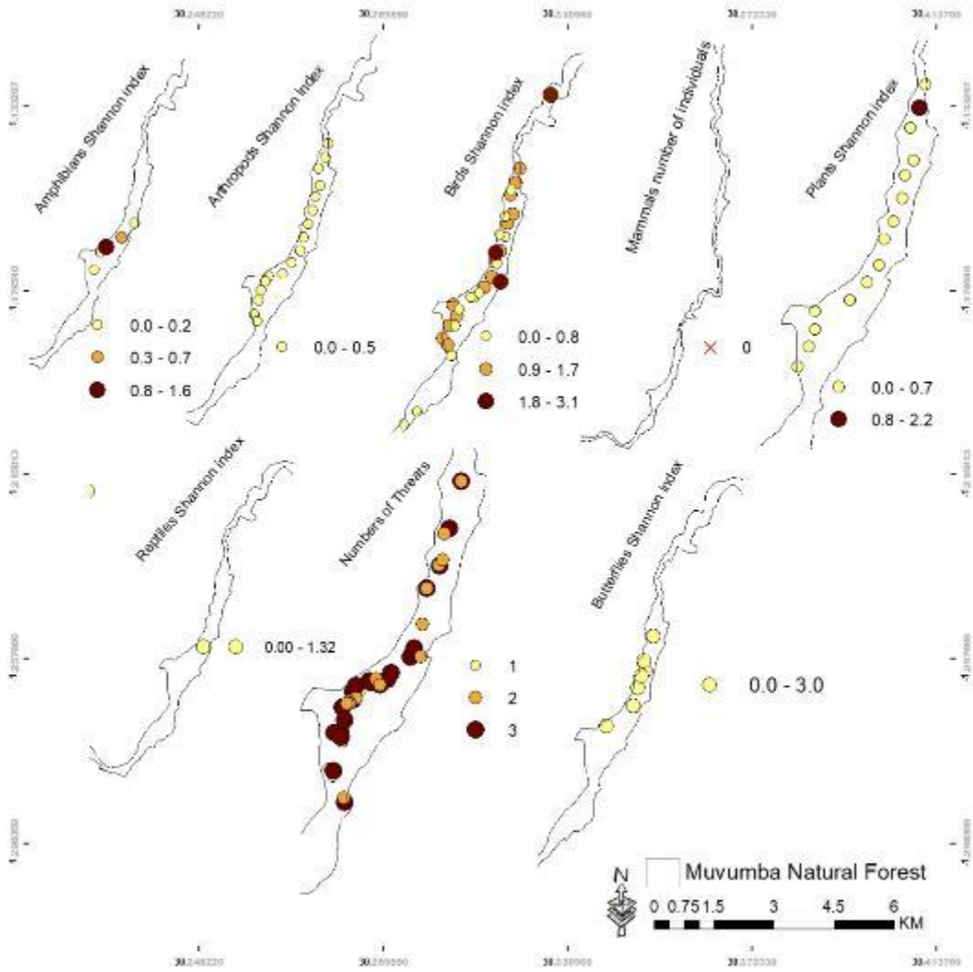


Figure 52. Distribution of the biodiversity and threats observed in Muvumba Natural Forest. Values mapped are either frequency of occurrence (counts per distance surveyed) or diversity indices (Shannon Diversity Index).

4.6.1 Plants

Muvumba Natural Forest had the lowest species richness among the seven remnants. Within Muvumba, a total of 13 species spanning 8 families were documented (Table 22). The Fabaceae Family is the most common with the highest species richness at 30.76%, followed by Malvaceae and Lamiaceae families at 15.38% each. Of the recorded species, 61.54% were identified as native to Rwanda and the region, while 38.46% were introduced. Furthermore, 53.84% of the species were classified as Least Concern according to the IUCN status, with 46.25% listed as Not Evaluated on the IUCN Red List.

Table 22. Families and species of plants found in Muvumba Natural Forest, Eastern Province, Rwanda

ID	**Family**	**Scientific name**	**IUCN Status**	**National Status**	**Native or introduced**	**Life form**
1	Asteraceae	*Gymnanthemum amygdalinum*	NA	NA	Introduced	shrub
2	Celastraceae	*Gymnosporia heterophylla*	LC	NA	Introduced	shrub
3	Fabaceae	*Biancaea decapetala*	LC	NA	Native	tree or shrub
		Senna spectabilis	NA	NA	Introduced	tree or shrub

		Vachellia sieberiana	LC	NA	Native	Tree
		Vachellia kirkii	NA	NA	Native	Tree
4	Lamiaceae	*Clerodendrum johnstonii*	NA	NA	Native	shrub
		Ocimum gratissimum subsp. gratissimum	NA	NA	Native	shrub
5	Malvaceae	*Pavonia urens var. irakuensis*	LC	NA	Native	Tree
		Triumfetta rhomboidea	LC	NA	Native	tree or shrub
6	Poaceae	*Bambusa balcooa*	NA	NA	Introduced	shrub
7	Rubiaceae	*Rytigynia kigeziensis*	LC	NA	Native	Tree
8	Verbenaceae	*Lantana camara*	LC	NA	Introduced	Tree

The Nonmetric Multidimensional Scaling (NMDS) analysis identified two different vegetation assemblages in the Muvumba Natural Forest (Figure 53).

A. *Vachellia sieberiana-Lantana camara* vegetation community: Shrubs and small trees characterize this assemblage, with *Vachellia sieberiana* trees and dense thickets of the invasive *Lantana camara*. The average DBH is 17.75cm and small understory trees have an average density of 6.75. The understory is comprised of *Gymnosporia heterophylla* and *Triumfetta rhomboidea.* The assemblage included plots 1-11, 1-7, and 1-12.

B. *Vachellia sieberiana-Vachellia kirkii* vegetation community: This assemblage is characterized by trees typical of open woodland savannah with DBH of 58.77cm, with some understory species including *Gymnosporia heterophylla, Triumfetta rhomboidei, Ocimum gratissimum subsp. Gratissimum* which has the average density of 13.44 .The assemblage was made in 2-2, 1-8, 1-10,1-9,2-1,1-3,1-6,2-4,1-5,2-3,1-1,1-4, and 2-5.

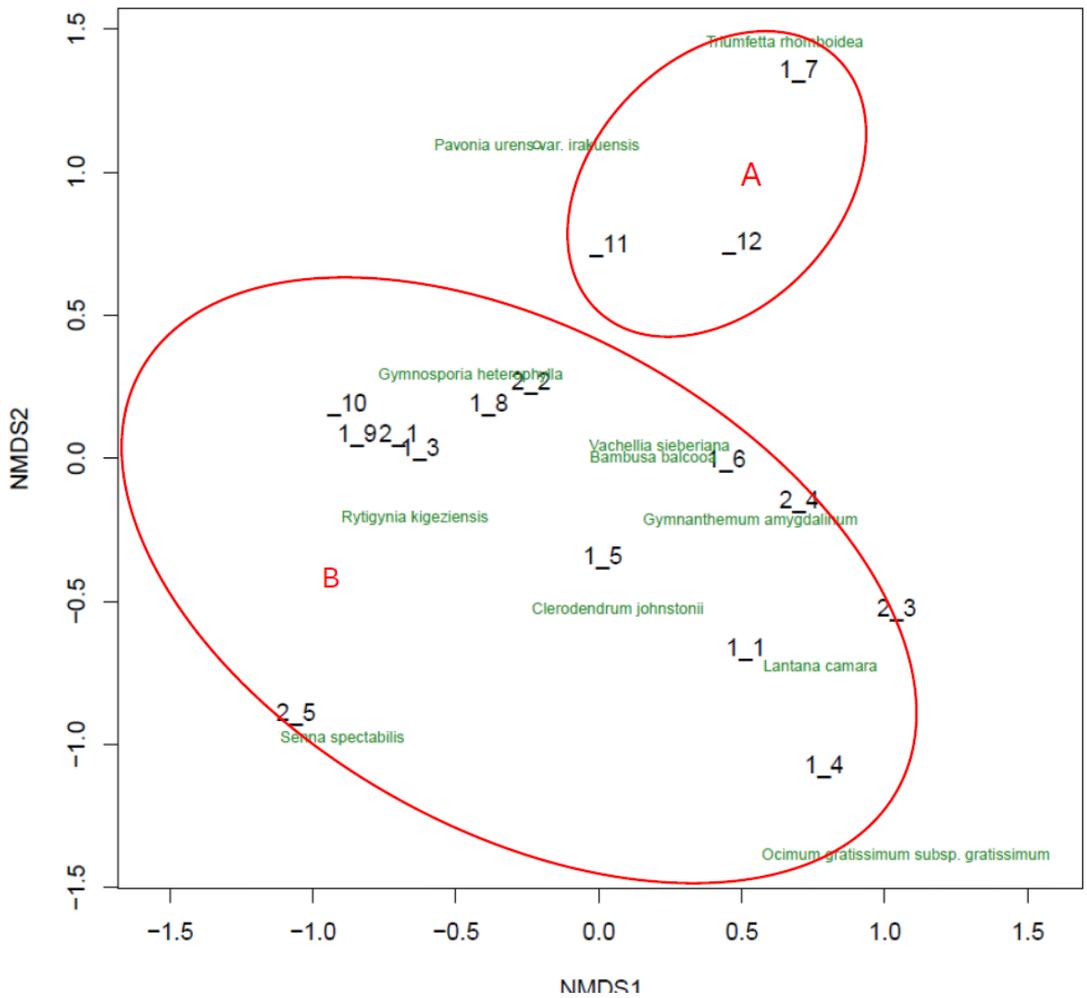


Figure 53. Nonmetric Multidimensional Scaling (NMDS) analysis of vegetation plots in Muvumba Natural Remnant Forest.

4.6.2 Herpetofauna

Three families of amphibian species were recorded in the Muvumba Natural Forest including Phrynobatrachidae with the majority of species (3 in total) (Table 23). During this survey, there were no species of reptiles recorded in this forest.

Table 23. Amphibians species recorded in the Muvumba Natural Forest with their global and local IUCN Red List status.

	Family	**Scientific name**	**Common name**	**Global IUCN status**	**National IUCN status**
AMPHIBIANS					
1	Hyperoliidae	*Hyperolius kivuensis Ahl, 1931*	Kivu Reed Frog	LC	LC
2	Phrynobatra-chidae	*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
3	Ptychadenidae	*Ptychadena anchietae (Bocage, 1868)*	Anchieta's Frog	LC	LC
		Ptychadena nilotica (Seetzen, 1855)	Nile grass frog	LC	LC

4.6.3 Flying insects

A total of 16 butterfly species were recorded from the Muvumba Natural Forest. Among those species, 10 species are categorized as Least Concern and the remaining six species are under the Not Evaluated category of the IUCN Red List (Figure 54). These species are distributed into three families where the most abundant family was Nymphalidae (59.65%) followed by Pieridae (29.82%) and the last was Hesperiidae (10.53%). Only single pollinating insect (*Apis mellifera*) was spotted visiting the *Asystasia gangetica.*

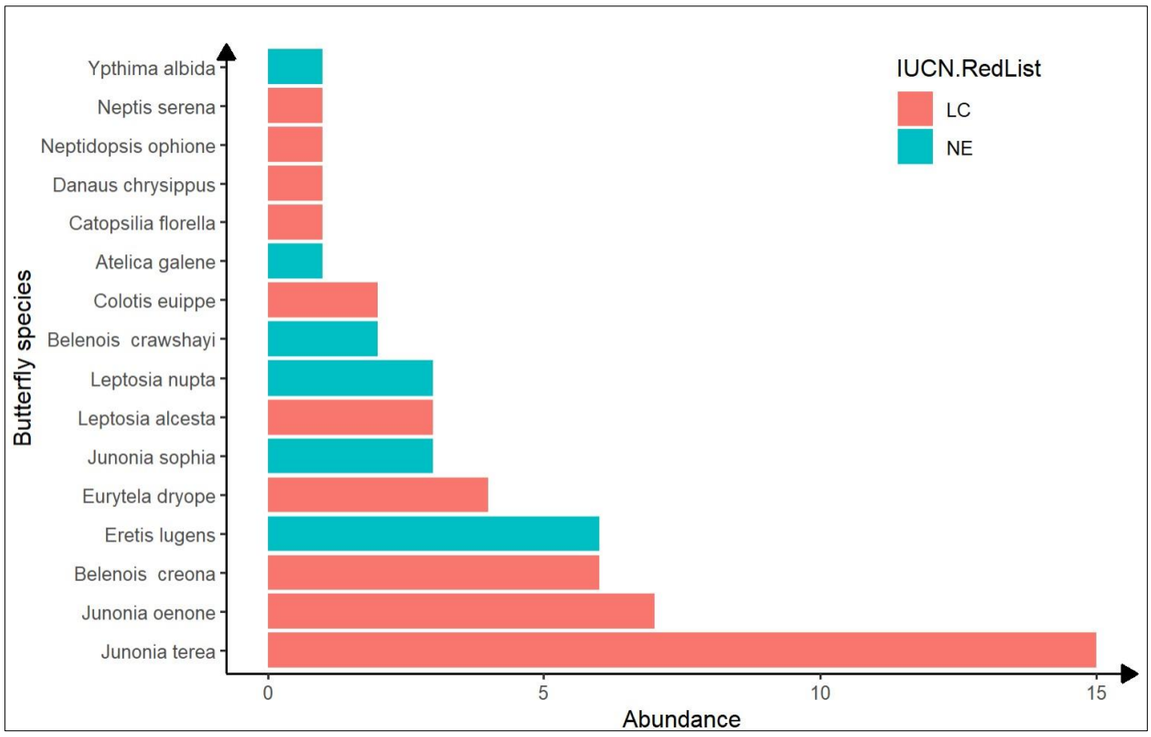


Figure 54. Diversity and abundance of butterfly species recorded from Muvumba Natural Forest. The orange box represents the species that are classified by the IUCN Red List as Least Concern while the turquoise box stands for the species that are not evaluated (NE).

4.6.4 Terrestrial Arthropods

In Muvumba Natural Forest, we collected a total of 397 individual specimens belonging to 41 families. The most common families, in descending order, are Formicidae, Salticidae, Carabidae (Table 24, Figure 55).

Table 24. The eight most abundant arthropod families and their functional groups recorded at Muvumba Natural Forest.

	Order	**Family**	**Common name**	**Functional group**
1	Hymenoptera	Formicidae	Ants	Omnivorous
2	Coleoptera	Carabidae Chrysomelidae Staphylinidae	Ground beetle Leaf beetle Rove beetle	Predators Herbivorous Predators
3	Orthoptera	Acrididae	Grasshopper	Herbivorous
4	Aranea	Salticidae Araneidae	Jumping spider Orb-weaver spider (Clerck, C. 1757)	Predators Predators
5	Hemiptera	Miridae Alydidae	Plant, Leaf Bug (Fallen, 1807) Broad-headed bug (Herrich-Schäffer, G.A.W. (1847)	Herbivorous Herbivorous

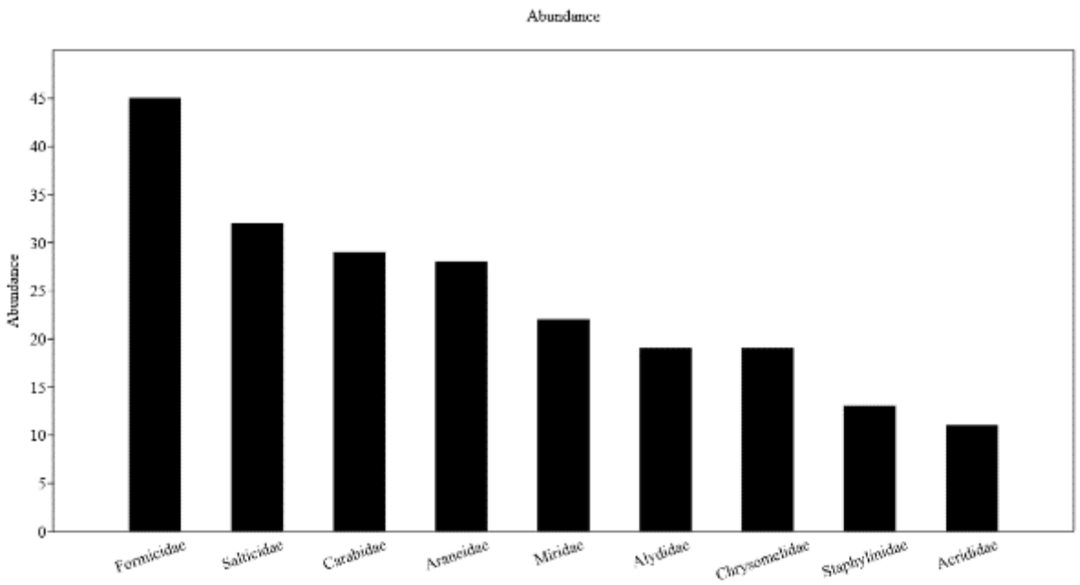


Figure 55. Most abundant arthropods families at Muvumba Natural Forest (those with greater than 10 individuals)

4.6.5 Birds

We observed 41 bird species from 24 families. Of these observed bird species, we observed five species of migratory birds with different migratory statuses: 4 full migrants, 2 partial migrants, and 3 intra-African migrants. We observed one endangered species on the IUCN Red List, the Gray-Crowned Crane (*Balearica regulorum*). Almost all functional groups were observed within this remnant forest, including granivorous (seed-eating), omnivorous (eating both plant and animal matter), nectivorous (nectar-feeding), insectivorous (insect-eating), scavenger (dead or decaying matter-eating), herbivorous (plant-feeding), piscivorous (fish-feeding), and carnivorous (meat-feeding) species, except frugivorous (fruit-eating) birds.

4.6.6 Mammals

At Muvumba, we observed no mammals. This may be due to the high abundance and diversity of threats at this site, please see the section on threats below.

4.6.7 Threats

Several threats and disturbance types were encountered at Muvumba Natural Forest (Figure 56). The main threats recorded are plastic materials (44%). Plastic materials, especially plastic bottles for juice and water mixed with various garbage are the main component of the waste dumping zones (14%). Two dumping sites are just close behind a school built just adjacent to the forest. Tree cutting is also frequent (14%). There are many places where cut trees were found (Figure 57) and large spaces where tree clearing was noticed. In general, many threats are occurring at Muvumba Natural Forest that lead to pollution, which will end up in the Muvumba River. Mining for sand materials was observed, and a road was created for mine access. Besides dumping sites, frequent human excreta make the place less hygienic and lead to more pollution hazards at the site.

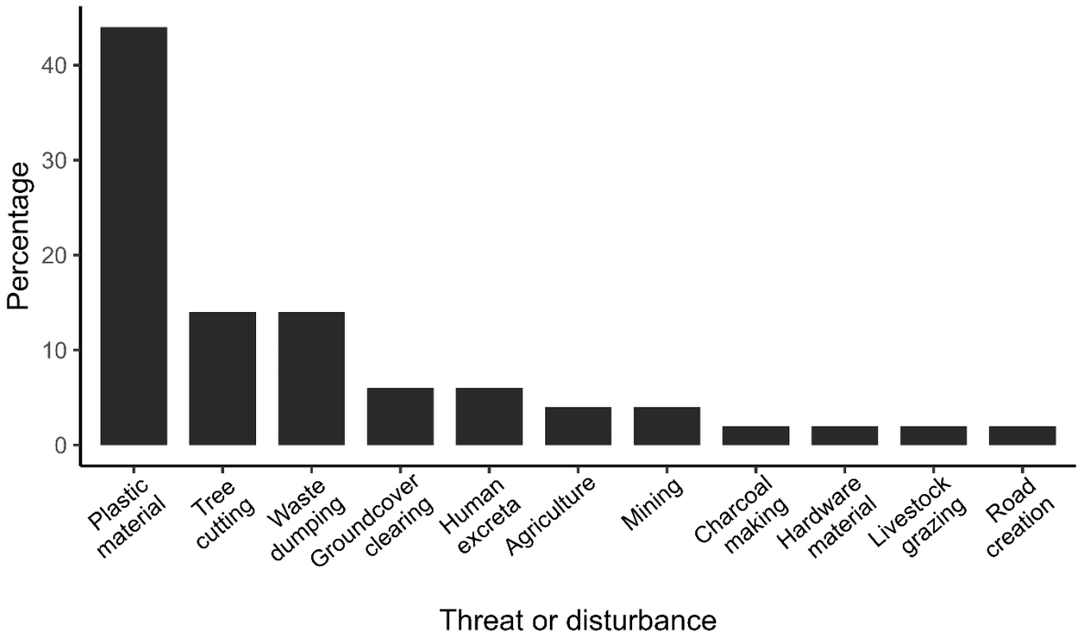
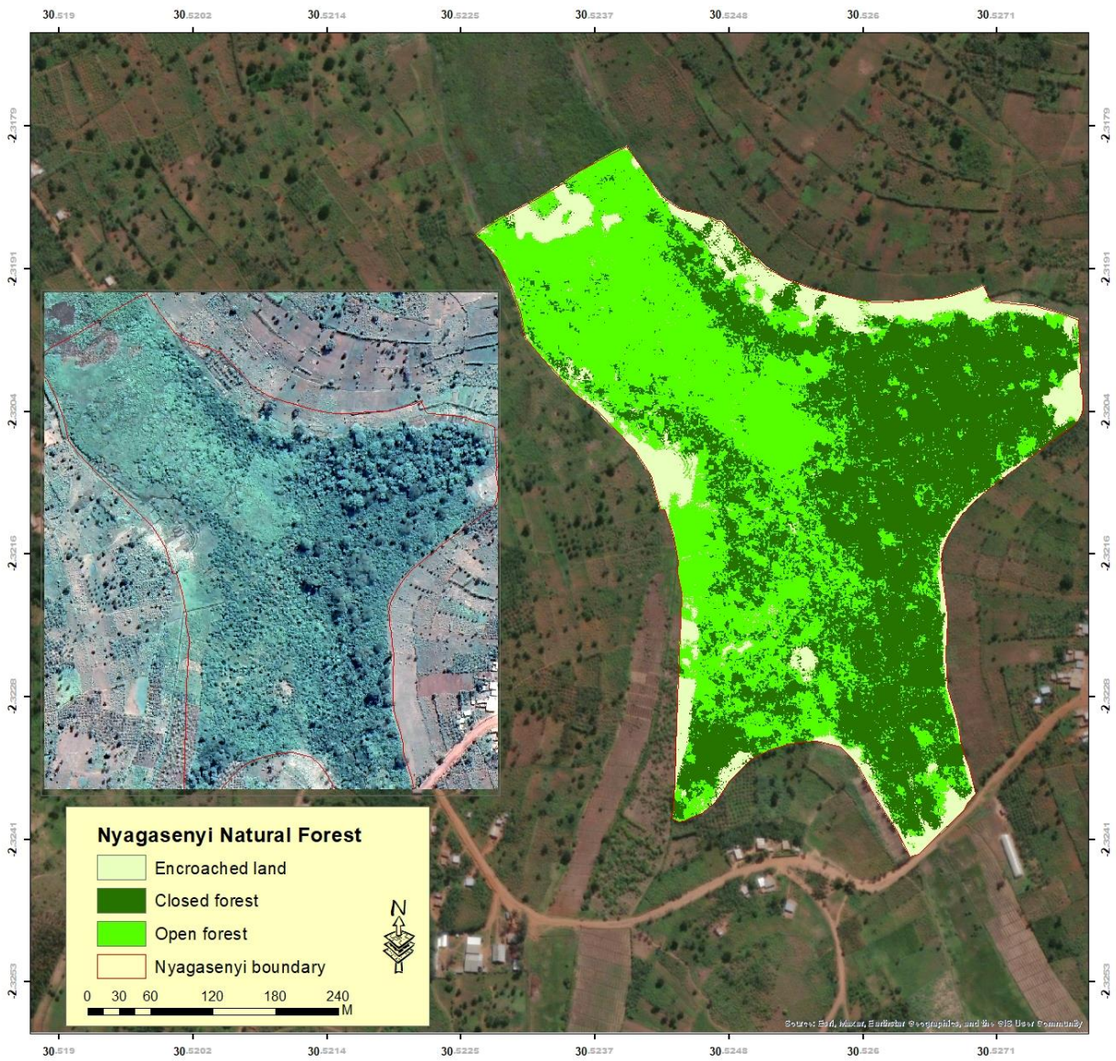


Figure 56. Threats occurrence and abundance at Muvumba Natural Forest

Figure 57. Waste dumping place (left) and tree cutting (right) at Muvumba Natural Forest

4.7 Nyagasenyi Natural Forest

Nyagasenyi Natural Forest was measured at 19.00 ha and includes disturbed areas inside the forest boundary, as well as forested areas (Figure 58). Figure 59 shows the distribution of the biodiversity sampled in this forest, as well as the threats. Following are sections presenting the biodiversity details and threat assessment findings for this remnant forest.



Vegetation Class name	Area (ha)
Encroached land	2.16
Closed forest	8.41
Shrubs	7.99

Figure 58. Map of Nyagasenyi Natural Forest (19.00 ha) in Eastern Province with the current boundary and general vegetation categories.

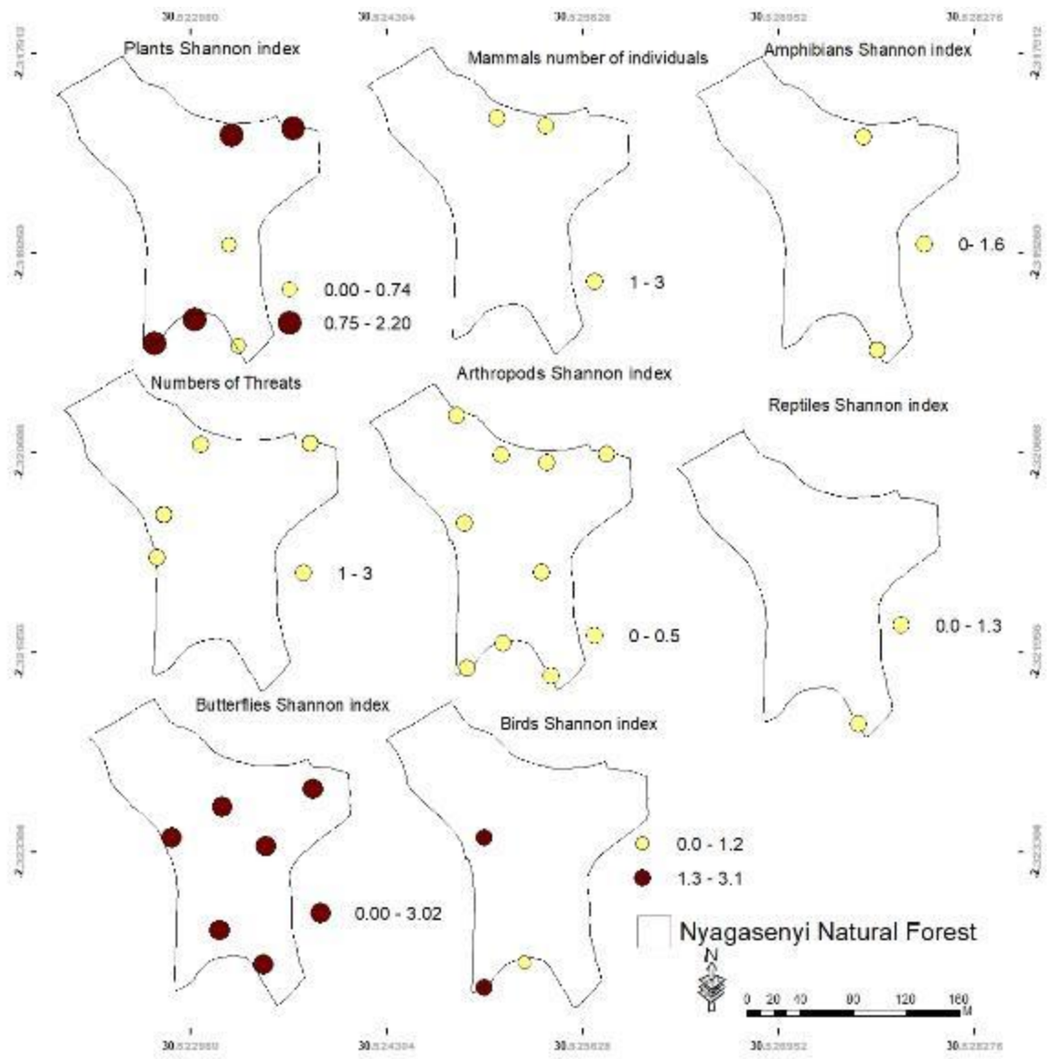


Figure 59. Distribution of the biodiversity and threats observed in Nyagasenyi Natural Forest. Values mapped are either frequency of occurrence (counts per distance surveyed) or diversity indices (Shannon Diversity Index).

4.7.1 Plants

Nyagasenyi Natural Forest has 17 plant species across 17 families (Table 25). Notably, each family represents approximately 5.88% of the total species richness. A majority of these species (82.36%) are indigenous to Rwanda and the region, underscoring the forest's ecological significance for plant conservation. Introduced species comprised 17.64% of the total species recorded. In terms of conservation status, a considerable portion (64.70%) of the species are categorized as Least Concern according to the IUCN Red List. About 35.30% remain unassessed, warranting further evaluation to better understand and mitigate potential risks to biodiversity.

Table 25. Families and species of plants found in Nyagasenyi Natural Forest, Eastern Province, Rwanda

ID	Family	Scientific name	IUCN Status	National Status	Native or introduced	Life form
1	Acanthaceae	*Acanthus polystachyus*	NA	NA	Native	Shrub
2	Arecaceae	*Phoenix reclinata*	LC	NA	Native	Tree
3	Asparagaceae	*Dracaena afromontana*	LC	NA	Native	Shrub
4	Asteraceae	*Gymnanthemum amygdalinum*	NA	NA	Native	Tree or shrub
5	Bignoniaceae	*Markhamia lutea*	LC	NA	Native	tree

6	Celastraceae	*Gymnosporia heterophylla*	LC	NA	Introduced	Shrub
7	Fabaceae	*Albizia petersiana*	LC	NA	Native	Tree or shrub
8	Gentianaceae	*Anthocleista schweinfurthii*	LC	NA	Native	Tree
9	Lamiaceae	*Tetradenia riparia*	LC	NA	Native	Shrub
10	Malvaceae	*Triumfetta rhomboidea*	NA	NA	Native	Shrub
11	Phyllanthaceae	*Bridelia micrantha*	LC	NA	Native	Tree
12	Primulaceae	*Maesa lanceolata*	LC	NA	Native	Tree
13	Proteaceae	*Grevillea robusta*	LC	NA	Introduced	Tree
14	Rosaceae	*Rubus rigidus*	NA	NA	Native	Shrub
15	Rubiaceae	*Mitragyna rubrostipulata*	NA	NA	Native	Tree
16	Rutaceae	*Teclea nobilis*	LC	NA	Native	Tree
17	Verbenaceae	*Lantana camara*	NA	NA	Introduced	shrub

The Nonmetric Multidimensional Scaling (NMDS) analysis identified two different vegetation assemblages in the Nyagasenyi Natural Forest (Figure 60).

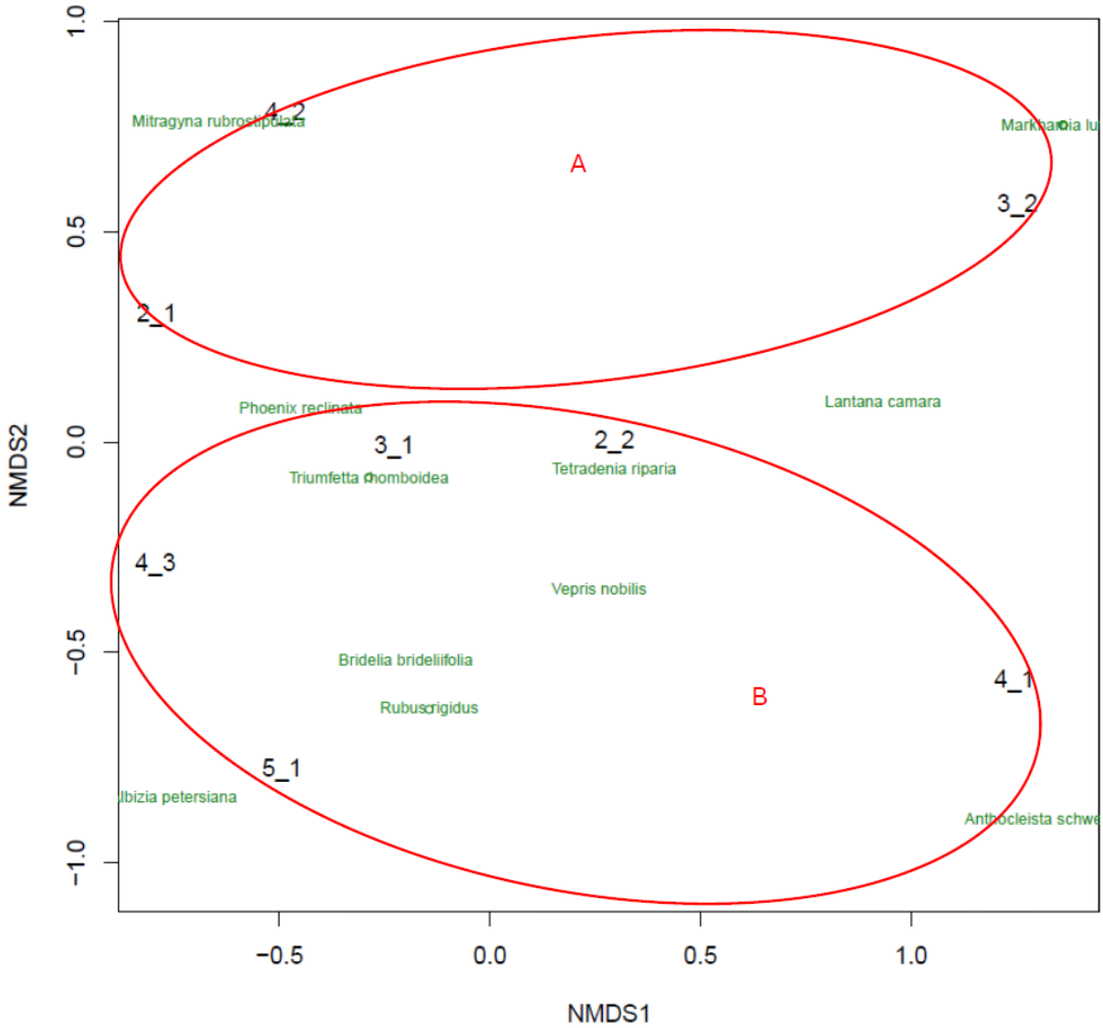


Figure 60. Nonmetric Multidimensional Scaling (NMDS) analysis of vegetation plots in Nyagasenyi Natural Remnant Forest.

A. *Grevillea robusta-Phoenix reclinata* vegetation community: This assemblage is dominated by the introduced *Grevillea robusta* tree which is commonly associated with agroforestry systems. In addition to this dominant tree, there is a mix of other mature tree species, and the average DBH across all species is 22.8 cm, with few small trees in the understory including *Mitragyna rubrostipulata, Phoenix reclinate, Dracaena afromontana,* and *Bridelia brideliifolia*. This assemblage includes plots 4-2, 2-1 and 3-2.

B. *Anthocleista schweinfurthii-Bridelia brideliifolia* vegetation community: This assemblage is dominated by small trees or treelets, *Anthocleista schweinfurthii* and *Bridelia brideliifolia,* which is a shrub or small tree. There are other native species present including *Phoenix reclinata* and *Maesa lanceolata*. The trees in this assemblage that are greater than 5cm DBH are quite large, with an average DBH for all large trees of 82.11cm. There are seedlings of native species in the understory including *Lantana camara, Mitragyna rubrostipulata,* and *Albizia petersiana.* The density of trees <5cm is 9.125. This assemblage includes plots 3-1, 2-2, 4-3, 4-1 and 5-1.

4.7.2 Herpetofauna

Only two species of amphibians in the family Ptychadenidae and Phrynobatrachidae were recorded (Table 26). There were no reptile species observed during this survey in this natural forest. All recorded species are listed as Least Concerned under the IUCN Red List.

Table 26. Amphibian species recorded in Nyagasenyi Natural Forest, Rwanda

	Family	**Scientific name**	**Common name**	**Global IUCN status**	**National IUCN status**
AMPHIBIANS					
1	Phrynobatrachidae	*Phrynobatrachus natalensis (Smith, 1849)*	Common Toad-frog	LC	LC
2	Ptychadenidae	*Ptychadena nilotica (Seetzen, 1855)*	Nile grass frog	LC	LC

4.7.3 Flying insects

A total of 28 butterfly species from four families were recorded from the Nyagasenyi Natural Forest. The most abundantly observed family was Nymphalidae (53.33%) followed by Pieridae (20.00%), and the least common were Hesperiidae (13.33%) and Lycaenidae (13.33%). Among the 28 butterfly species, 15 species are categorized as Least Concern, and the remaining 13 species are under the Not Evaluated category of the IUCN Red List (Figure 61).

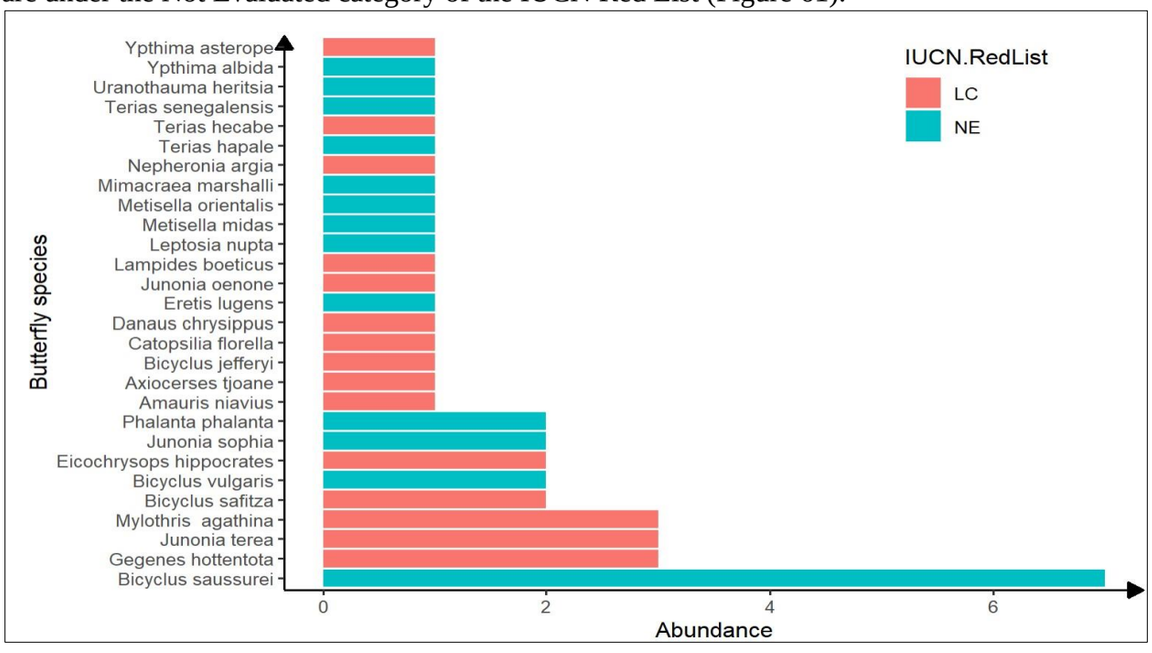


Figure 61. Diversity and abundance of butterfly speciesnfrom Nyagasenyi Natural Forest. Orange represents species classified by IUCN Red List as Least Concern while turquoise shows species that are not evaluated (NE).

A total of seven pollinating insects were recorded in the Nyagasenyi Natural Forest during the survey. These include bees (*Apis mellifera* and *Xylocopa flavorufa*), wasp (Sphecidae), flies (Chloropidae) and butterflies (*Gegenes hottentota*, *Junonia terea*, and *Lampides boeticus*). We observed *Lantana camara* to be the most visited species by pollinators, followed by *Lantana trifolia* (Figure 62). The most abundant pollinator was bees (*Apis mellifera*).

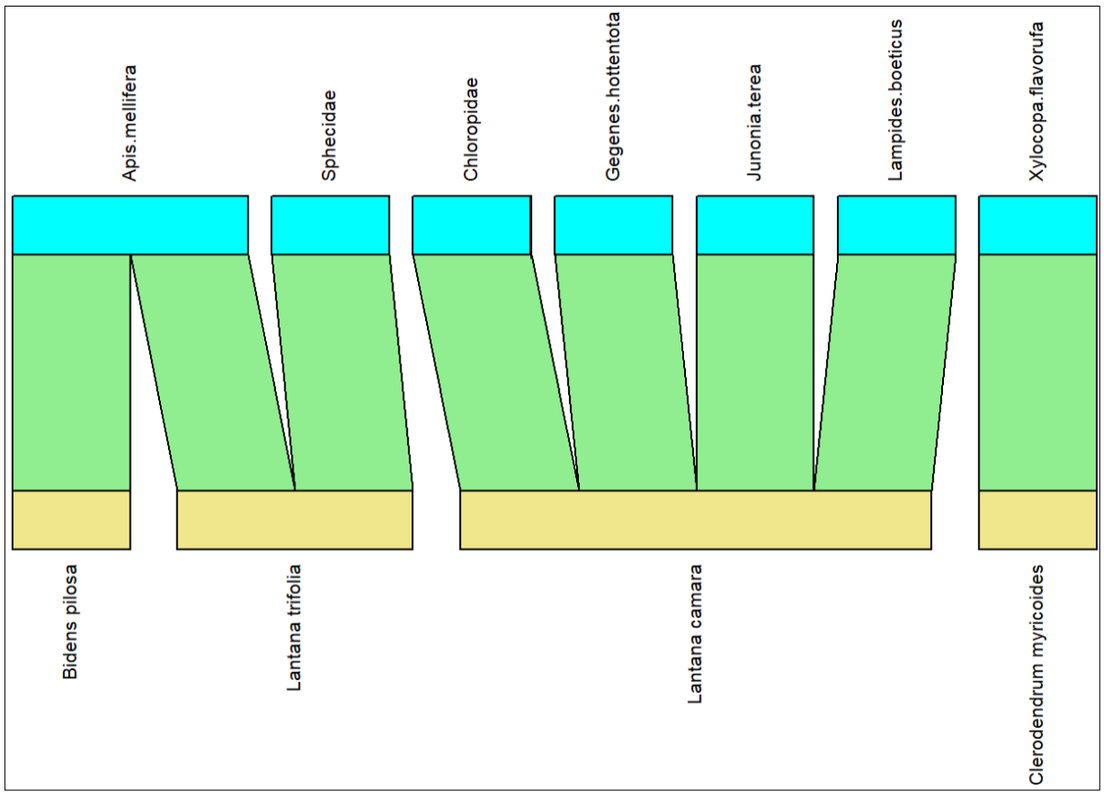


Figure 62. Network structure of Plants and their pollinating insects recorded from Nyagasenyi Natural Forest. The upper part (band in turquoise color) represents the flower visitors while the lower part (bands in yellow color) represent plant diversity (host plants). The middle part of the figure (green color) represents the linkage (which plant was visited by which insect) between plants and their pollinating insects.

4.7.4 Terrestrial Arthropods

In the Nyagasenyi Natural Forest, a comprehensive survey of terrestrial arthropods revealed a total of 521 individuals belonging to 31 families. Notably, the forest demonstrated an abundance of Formicidae, Salticidae, Blattellidae, and Acrididae (Table 27, Figure 63).

Table 27. The most abundant arthropod families and their functional groups recorded at Nyagasenyi Natural Forest.

	Order	**Family**	**Common name**	**Functional group**
1	Hymenoptera	Formicidae	Ants	Omnivorous
2	Aranea	Salticidae	Jumping spider	Predators
3	Coleoptera	Chrysomelidae	Leaf beetle	Herbivorous
4	Orthoptera	Acrididae	Grasshopper	Herbivorous
5	Blattodea	Blattellidae	Wood Cockroach	Detritivorous

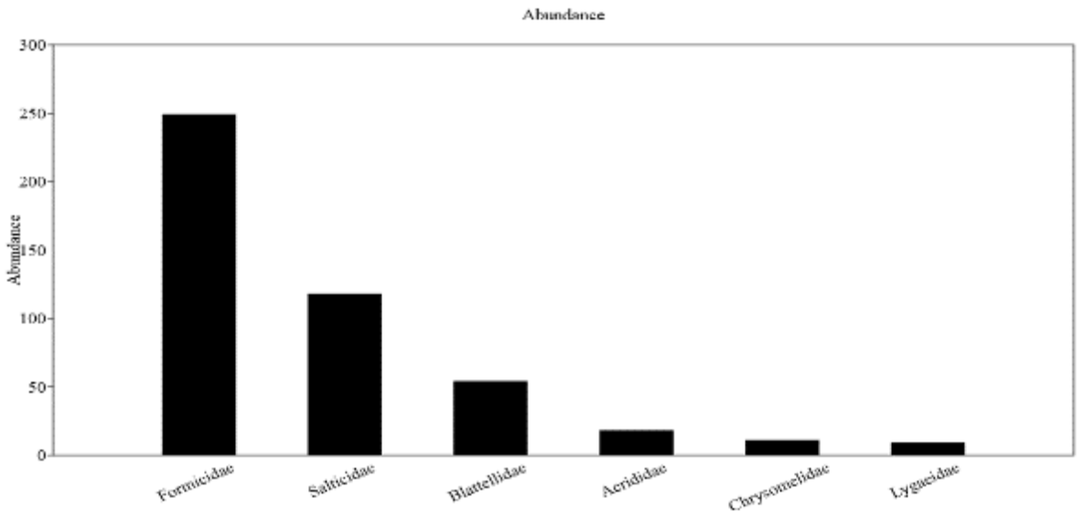


Figure 63. Most abundant arthropods families at Nyagasenyi Natural Forest (those with greater than 10 individuals)

4.7.5 Birds

We observed 39 bird species, from 23 families in Nyagasenyi Natural Forest. Of these observed bird species, we found that 4 of these were migratory birds of different migratory statuses: 3 full migrants and 1 intra-African migrant. In this forest, we observed six functional groups, including granivorous (seed-eating), omnivorous (eating both plant and animal matter), nectivorous (nectar-feeding), insectivorous (insect-eating), frugivorous (fruit-eating, and herbivorous (plant-feeding) species. Insect-eating birds (insectivorous) were the most common functional group, accounting for 18 of the 39 bird species.

4.7.6 Mammals

Two mammal species were recorded at Nyagasenyi Natural Forest, a mongoose and mole rat (Table 28). They were identified through their scat, and each was recorded once. Because we did not directly observe the mongoose, it was not possible to identify to the species level.

Table 28. Occurrence of mammals at Nyagasenyi Natural Forest

	Order	Family	Species name	Common name	Endemic species	IUCN status
1	Carnivora	Herpestidae	*Herpestes sp.*	Mongoose	No	LC
2	Rodentia	Spalacidae	*Tachyoryctes splendens*	East African mole rat	No	LC

4.7.7 Threats

While few threats were recorded at Nyagasenyi Natural Forest, the most occurring threat was the agriculture (55.56%) (Figure 64). Other activities with lower levels of occurrence were poaching, livestock grazing, and groundcover clearing.

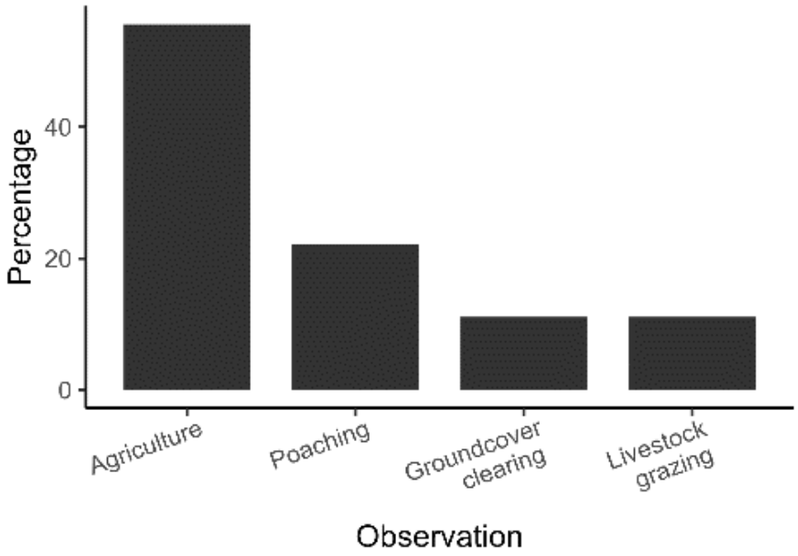


Figure 64. Threats occurrence and abundance at Nyagasenyi Natural Forest

5. A Synthesis of Biodiversity Information from the Remnant Natural Forests

5.1 Plants

Among the seven remnant forests sampled, Karushuga was found to have the highest native species richness, followed by Karangazi natural forest, and Muvumba had the least species richness (Figure 65). All the forest remnants have non native invasive species in them which will have a serious negative effect on ecosystem integrity and forest restoration efforts. The specific invasive species are indicated in the section describing the plant diversity of each forest remnant, and summarized in the table in Conclusion section.

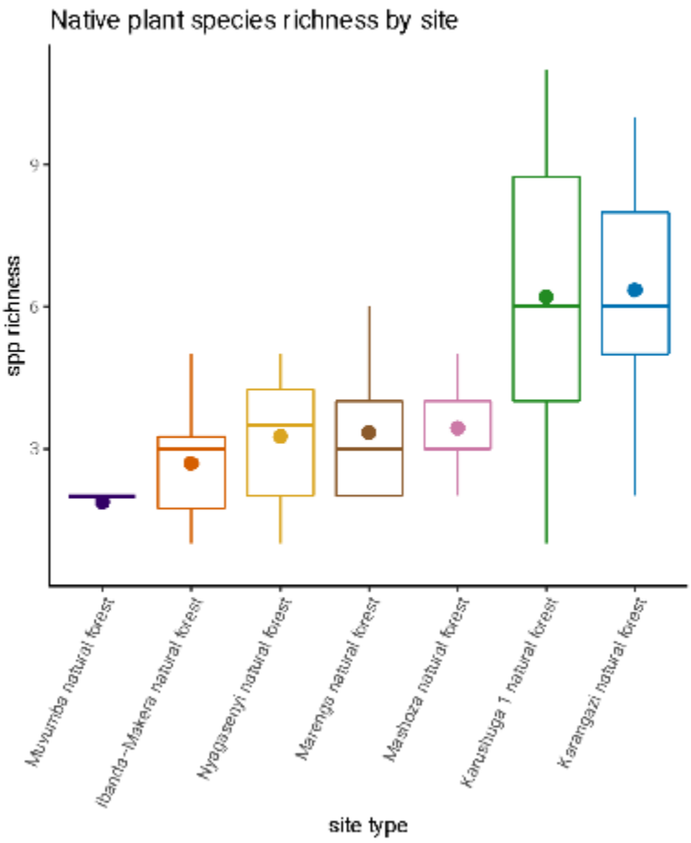


Figure 65. Native species richness by forest site. Figures compare species richness between the seven different sites. Boxes represent inter-quartile range (IQR), lines in the center represent the median. Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. Points correspond to each 10×10 m forest sampling plot.

5.2 Herpetofauna

The current survey develops for the first time information on the herpetofauna in the seven natural forests of the eastern province of Rwanda. There has so far been no comprehensive list published on the herpetofauna in the selected natural forests except a few reports developed for management. Based on the findings of this study, the survey has shown that these seven natural forests, despite the presence of human disturbance, substantiated by the presence of species that are indicators of disturbance, and are important natural ecosystems for biodiversity (Figure 66).

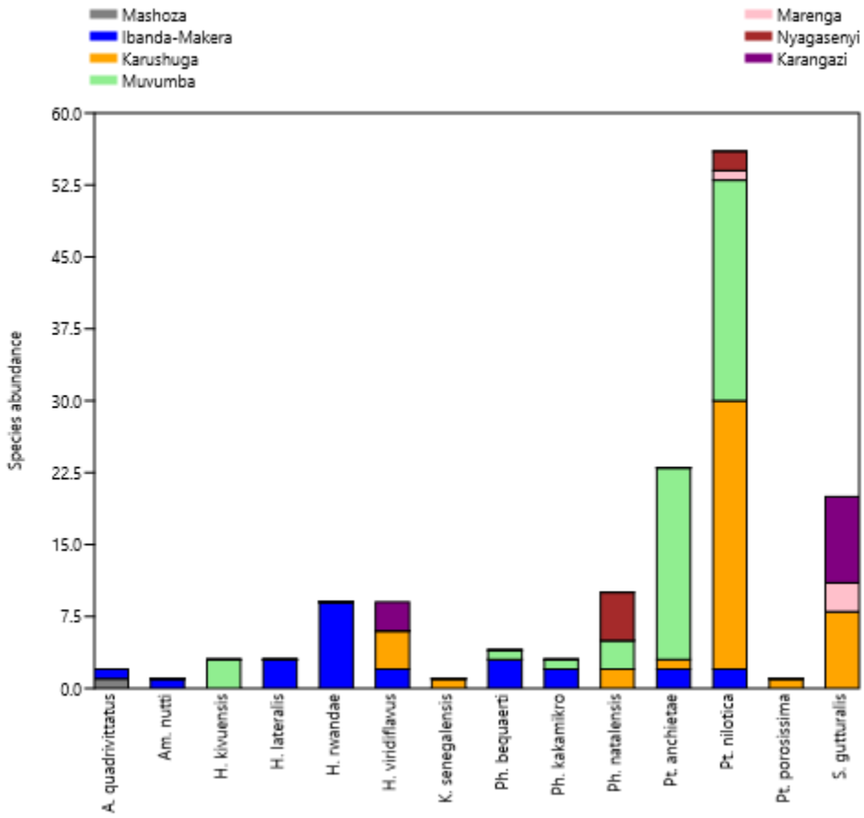


Figure 66. Species occurrence in each sampled remnant forest.

While amphibian diversity was found to be high in Ibanda-Makera followed by Karushuga and Muvumba Natural Forest, the reptile populations remain poorly recorded. We observed a high number of reptile species in Ibanda-Makera and Karushuga Natural Forests but the relative abundance for each species was low. This calls for the need for further in depth surveys to determine abundance and richness of reptile species in the remnant natural forests. Amphibian and reptile distribution and occurrence in an area depends on multiple factors that enable their survival and maintenance of their population (Gibbons et al. 2000). These factors include the presence of favorable habitats such as forests and wetlands, hide outs for predators, conspecifics and availability and accessibility to food (Cunningham et al. 2016; Qian et al. 2007).

Currently, 62 species of amphibians are known to occur in Rwanda and no comprehensive data exist to account for reptiles in Rwanda. A good number of studies have been carried out in protected areas and other important ecosystems mainly located in the North, west and southern province of Rwanda. There are few studies that reported the biodiversity of the natural forests of the eastern province where amphibian and reptile information remains poor (Bizuru et al. 2011; Joram et al. 2010). This limits the capacity to have a comparative understanding of the findings of this study and previous studies to develop a comprehensive list of species of the surveyed natural forests. However, the current study provides a baseline for the species in these forests and could be important to continuously survey the forests to maximize the species of amphibians and reptiles in the areas.

Among the recorded species of amphibian and reptiles, species of conservation importance include *Hyperolius lateralis* which is vulnerable to extinction in Rwanda though reported as Least Concern by the Global IUCN Red List (Dehling & Sinsch, 2023). Among reptiles, only *Python sebae* is reported Near threatened. However, both species of reptile and amphibian ranked important for conservation were observed in Ibanda-Makera Natural Forest which draws the attention to

strengthen the conservation of this forest. Hence, Ibanda-Makera could be ranked as of high biodiversity value based on herpetofauna presence, followed by Karushuga and Muvumba forests. Other forests including Karangazi, Mashoza, Nyagasenyi and Marenga Natural Forests, despite their low diversity of species of amphibians and reptiles, are ecosystems that need urgent conservation and management efforts to regain their natural status and functionality.

5.3 Flying Insects

A total of 86 butterfly species were recorded from seven natural forests and their species richness (Figure 67). Of those, 55 butterflies were recorded from Karushuga Natural Forest had the most number of species (55) followed by Ibanda-Makera Natural Forest (44) and Karangazi Natural Forest (36). Mashoza Natural Forest had the least with eight species. These 86 recorded butterflies were distributed into five families and the most abundant butterfly family was Nymphalidae (46.28%), followed by the butterflies from Pieridae family (37.75); Hesperiidae (5.99%); Papilionidae (5.63%) and the least abundant family was Lycaenidae (4.36%). Almost 80% of those butterflies recorded from the natural forest are listed by the IUCN Red List as Least Concern (LC) and about 21% of the remaining butterflies are Not Evaluated (NE) by the IUCN Red List.

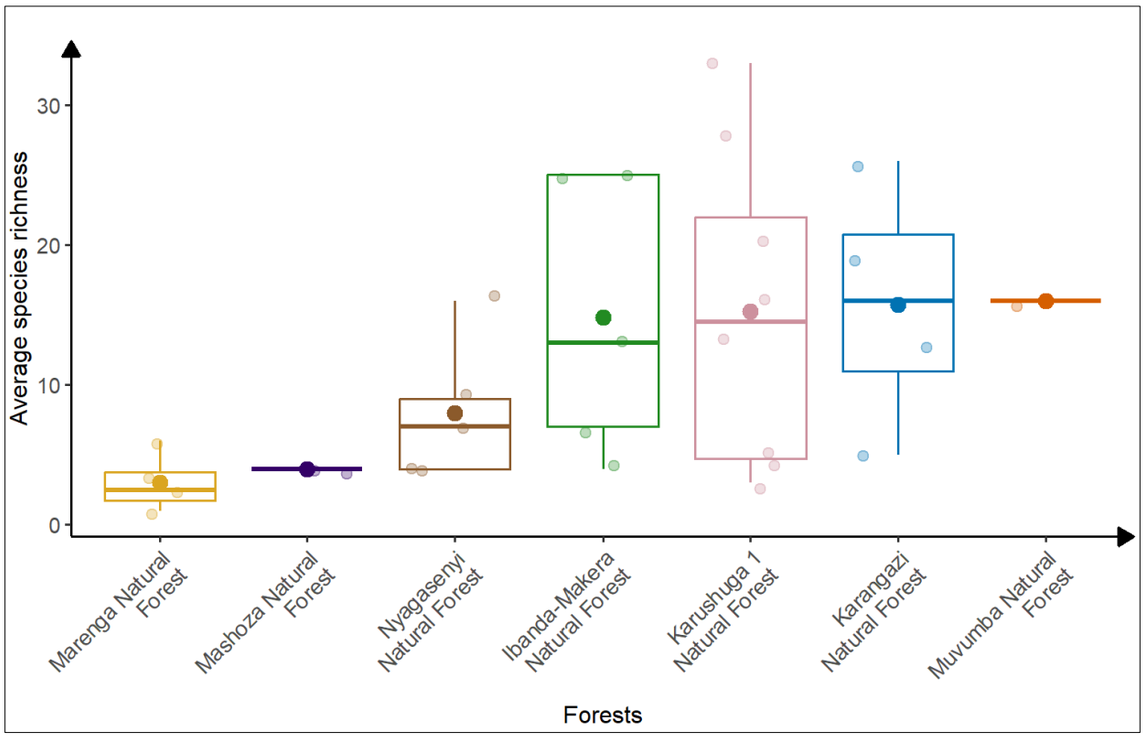


Figure 67. Butterfly richness distribution across the selected seven natural forest. The boxes are the inter-quartile ranges (IQR) and the line in the boxes represent the median. The solid points inside the boxes represent the average (mean). Whiskers correspond to the largest/smallest value less/greater than upper/lower quartile minus 1.5 times IQR. The Data analysis and visualization were carried out using the R platform (R version 4.3.2 Development Core Team, 2023) and suitable packages.

A total of 34 pollinating insects including honey bees, wild bees, butterflies, flies and wasps were recorded from natural forests namely and their species richness distribution were the following: Ibanda-Makera Natural Forest (n=15), Karangazi Natural Forest (n=7), Karushuga 1 Natural Forest(n=18), Marenga Natural Forest (n=1), Mashoza Natural Forest (n=4), Muvumba Natural Forest (n=1), and Nyagasenyi Natural Forest(n=7). Some of the pollinators were identified to the family level, genus and species level, and their composition distribution across these taxonomic classification ranks are 36 identified species to the species level, four identified species to the genus level and six species identified to the family level.

Of those pollinating insects, some of them shared host plants while others were recorded visiting only one plant species (Figure 68), but this could be due to the season and short time period of the sampling. The larger band (upper side) on Figure 68 indicates the pollinators that were the most abundant across all the seven remnant forests sampled, and the larger band (in yellow color at the bottom part of the figure) indicates the plant species that received many pollinating insects. So, the highest pollinator abundance was *Apis mellifera* (from Apidae family), followed by the

butterfly *Belenois creona* (from Pieridae family). The plant species that received many pollinators was *Lantana camara* followed by the *Asystasia gangetica* (Figure 68). This information serves as a valuable baseline for monitoring progress on restoring these forest remnants and their ecosystem services.

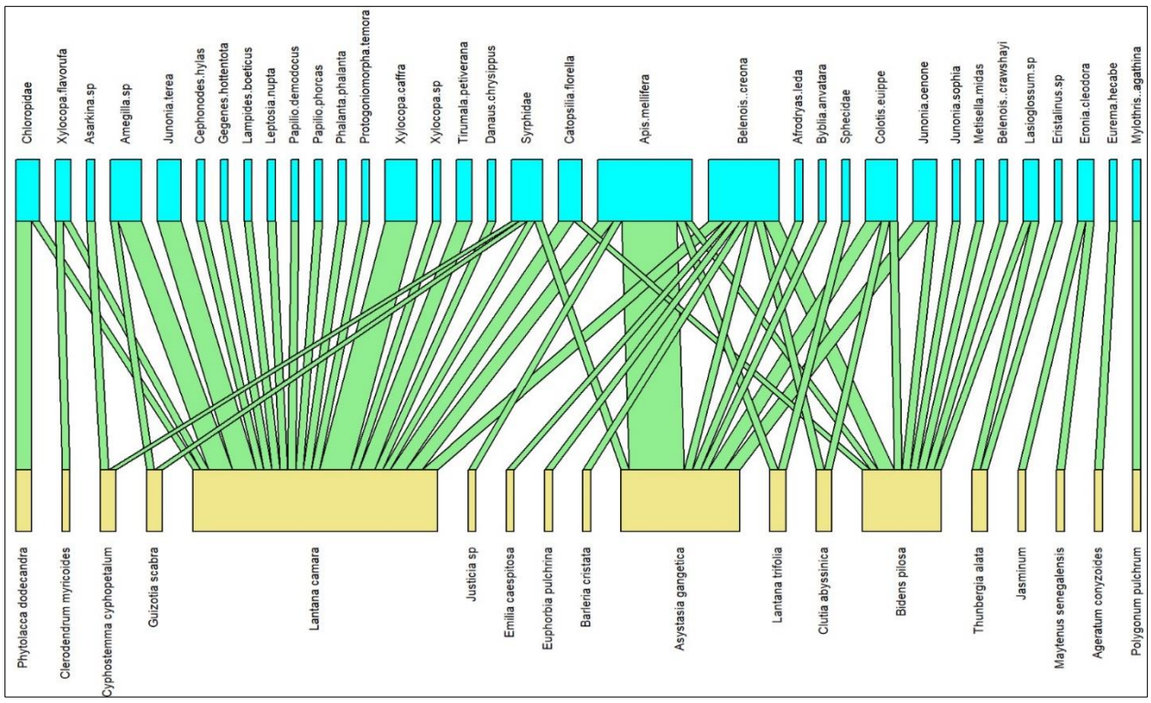


Figure 68. Network structure of Plants and their pollinating insects recorded from seven natural forest. The upper part (band in dark turquoise color) represent the flower visitors while the lower part (bands in yellow color) represent plant diversity (host plants). The middle part of the figure (inn green color) represent the linkage (which plant was visited by which insect) between plants and their pollinating insects.

5.4 Terrestrial arthropods

This survey develops baseline data of terrestrial arthropods across all seven natural forests in the Eastern province of Rwanda. A notable gap exists in the monitoring of terrestrial arthropods, with no published literature available on this subject in these forests, except for the ongoing research conducted by C Iradukunda on Formicidae (ants), which is yet to be published. Despite the existence of disturbance, all natural forests sampled show a relatively high species diversity which is an encouraging indicator for biodiversity. The prevalent dominance of the Formicidae family in all the forests is noteworthy, given its omnivorous nature (Table 29).

Table 29. Comparison of species diversity across all Natural Forests.

Natural Forest	**Dominance index**	**Simpson Index**	**Shannon Weaver Diversity Index**
Ibanda-Makera Natural Forest	0.088	0.91	3.05
Karangazi Natural Forest	0.088	0.91	2.99
Karushuga Natural Forest	0.1088	0.891	2.97
Marenga Natural Forest	0.1015	0.8985	2.698
Mashoza Natural Forest	0.2605	0.7395	2.187
Muvumba Natural Forest	0.06028	0.9397	3.117
Nyagasenyi Natural Forest	0.2932	0.7068	1.805

Notably, the Nyagasenyi and Mashoza Natural Forest stand out with relatively high Dominance Indices, indicating a concentration of certain species (Table 29). However, this forest records a comparatively lower Simpson Index and Shannon Weaver Diversity Index, suggesting a less diverse and more specialized arthropod community dominated by a few species. In contrast, Muvumba Natural Forest displays a low Dominance Index coupled with a high Simpson Index and Shannon Weaver Diversity Index, indicative of a more evenly distributed and diverse arthropod community. These variations underscore the importance of considering multiple

ecological indices for a comprehensive understanding of biodiversity within different natural forest ecosystems.

Muvumba and Ibanda-Makera forests have the highest Shannon Weaver Diversity Index values, indicating greater species richness and evenness. Conversely, Nyagasenyi Natural Forests displays the lowest diversity index, suggesting a less diverse ecosystem. Overall, while some forests exhibit balanced distribution and higher taxon diversity, others display higher dominance and lower diversity, underscoring the varied ecological dynamics across these natural habitats.
This survey develops baseline data of terrestrial arthropods across all seven natural forests in the Eastern province of Rwanda. A notable gap exists in the monitoring of terrestrial arthropods. So far there is no published literature available on this subject in these forests, except for the ongoing research conducted by C. Iradukunda on Formicidae (ants), which is yet to be published.

5.5 Birds

The avian baseline study conducted in the Eastern Province of Rwanda provided valuable insights into avian diversity across the seven remnant forests. Our findings highlight the richness of avian communities in this region, with a total of 165 bird species identified, representing 53 families (Annex 5). One significant aspect of our study is the documentation of 17 migratory species. Migratory birds play a crucial role in ecosystem dynamics, connecting different habitats and often serving as indicators of environmental health (Gregory & Strien, 2010), as of now, migration is under threat everywhere due to global shifts (Bauer & Hoye, 2015; Xu et al., 2022). Discovering their presence and behavior in these forests is essential for effective conservation management (Marini, 2017; Shuter et al., 2010).

Of particular note are several important bird species observed during the surveys. This includes the endangered Gray-crowned crane (*Balearica regulorum*) within Muvumba Natural Forest. This finding underscores the importance of preserving these forests as critical habitats for threatened species (REMA, 2018). The presence of such iconic and endangered species emphasizes the need for conservation efforts aimed at protecting their habitats and ensuring their survival (Pollock, 2018). Another important species observed during the surveys was *Sheppardia aequatorialis* the Equatorial Akalat, an Albertine Rift endemic, *Laniarius mufumbiri* the Papyrus Gonolek listed as Near Threatened on the IUCN Red List, and *Microparra capensis* the Lesser Jacana which is listed as Least Concern but is not in the region of these forest remnants.

Furthermore, our study reveals the presence of nine diverse functional groups within the sampled bird families across all remnant forests. Birds serve as important ecological indicators by performing crucial tasks like pollination, seed dispersal, and predation (Batisteli, 2018). This diversity of functional groups indicates a complex web of ecological interactions and niche specialization within these ecosystems (Batisteli, 2018; Pigot et al., 2016). This complexity highlights how crucial it is to safeguard habitat integrity to support the various ecological functions that different species of birds play (Bregman et al., 2016; Maas et al., 2016; Wenny et al., 2011).
In conclusion, the baseline study provided a comprehensive overview of avian diversity in the Eastern Province of Rwanda, highlighting the richness of species, the significance of migratory patterns, the presence of endangered species, and the complexity of ecological interactions within these remnant forests. These findings are crucial for informing conservation strategies aimed at preserving avian biodiversity and maintaining the ecological integrity of these important ecosystems.

5.6 Mammals

Fifteen species of mammals were recorded in the seven forests that were surveyed (Figure 69) including six carnivores *Canis adustus, Civettictis civetta, Galerella sanguinea, Helogale parvula, Herpestes sp., Leptailurus serval,* four primates *Chlorocebus pygerythrus, Lemniscomys striatus, Cercopithecus mitis, Papio anubis*, three rodents *Cricetomys sp., Oenomys hypoxanthus, Tachyoryctes splendens,* the hippopotamus *Hippopotamus amphibius* and a shrew *Crocidura sp*; most species were found at Ibanda-Makera and Mashoza Natural Forests, with six species for each (Figure 68). Based on existing information on mammal surveys in Rwanda, four among the 15 species are rare species: *Oenomys hypoxanthus, Helogale parvula, Leptailurus serval,* and *Civettictis civetta.*

The mammals that are selected as indicators during the restoration practice include indicators of healthy ecosystems such as the serval cat and *Leptailurus serval*, the hippopotamus, and the dwarf mongoose *Helgale parvula*. The vervet monkey *Chlorocebus pygerythrus* and the grass striped mouse *Lemniscomys striatus* will be indicators of degraded ecosystems. We also recommend more effort in the two forest where many mammals were for more potential records of additional species. Especially since mammals require a wide range and healthy habitats, we recommend immediate efforts in prevention of human encroachment with law enforcement and community support in the forests while removing existing threats as possible.

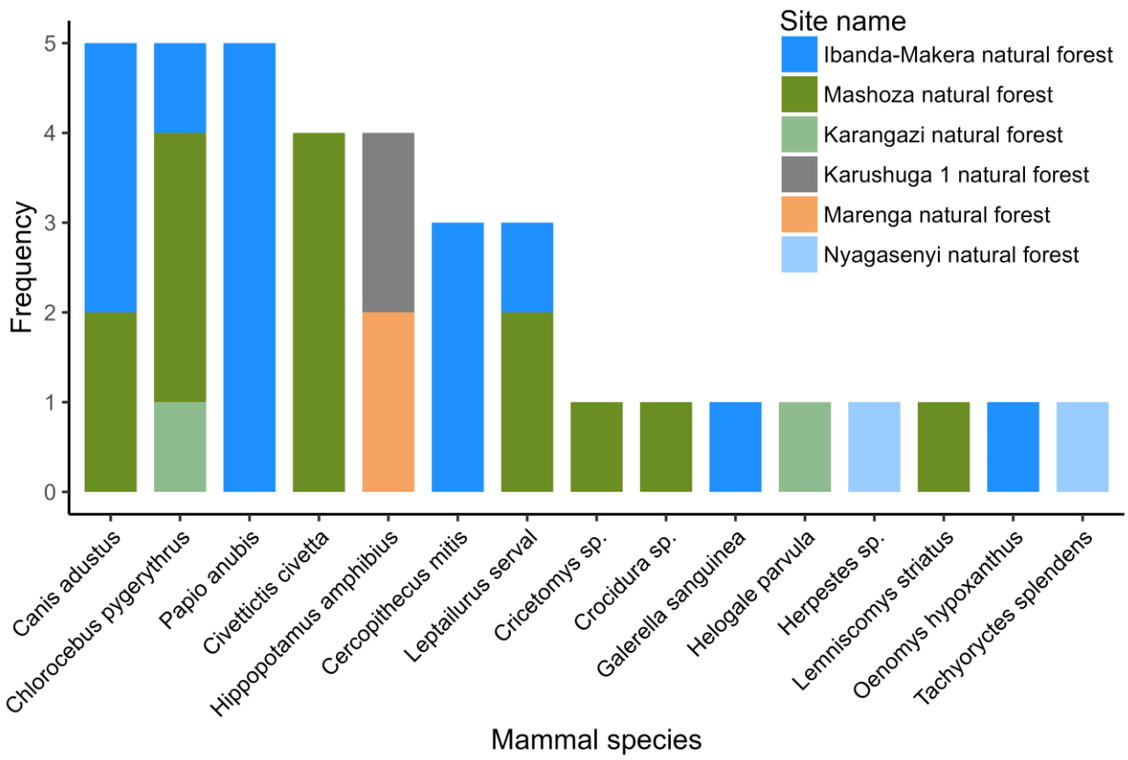


Figure 69. Summary of mammal occurrence for the remnant forests

The frequency of mammals was compared across the seven forests. The frequency of occurrence of mammals was evaluated as the number of recorded occurrences of species by each of the six forest sites where mammals were recorded (A) and sites were compared on their occurrences of mammals using a Kruskal-Wallis test; there was no significant difference between forests (p=0.59) (Figure 70). At Muvumba Natural Forest, no mammals were detected; therefore, it does not appear in Figure 69 and 70.

Bats as a group of mammals were not surveyed due to the challenging logistics associated with them, while for terrestrial small mammals, proper sampling efforts could not be applied within a limited time. One of the surprising results was the lack of records of mammals at Muvumba Natural Forest. From background information, of the eights surveyed wetland complexes with birds, not only Muvumba wetland complex presented the lowest species richness, but also no mammal was recorded at Muvumba in rapid assessments (ARCOS, 2021).

Hippopotamus can be good indicators of climate change among large mammals, mainly due to their requirement for wetlands and heat tolerance, which will likely be adversely affected by climate change (Shilla, 2014). Otters can be used as indicator for freshwater ecosystem quality as found in earlier study (Lee & Rudd, 2003; Schneider, 2010); therefore, future monitoring efforts should also evaluate their occurrence.

Terrestrial small mammals have been shown to be good indicator species for habitat quality and suitability (Avenant, 2000; Horváth et al. 2011; Leis et al. 2008; Root-Bernstein et al. 2014). Transect surveys and indirect surveys are not very effective for terrestrial small mammals (rodents and shrews) unlike medium and large-sized mammals, while we should be expecting more species than we found. It is recommended to target small mammals (rodents mainly) in future work on defining local indicator species of ecological integrity along restoration practice. Recording of small mammals can rely on both direct and indirect methods, including sightings (live animals, carcasses), different signs (digging, feeding, tracks), sounds (e.g. bats), and non-invasive trapping

(camera traps, Sherman and pitfall traps, for terrestrial small mammals, mist nets and acoustics for bats). Monitoring indicator species may not focus only on single species, but a variation of species (Chase et al. 2000), many species representing various taxa and life histories (Carignan & Villard, 2002), large mammal assemblages and their community responses (Cheyne et al. 2016), or follow response-guild approaches (Croonquist & Brooks, 1991). However, there are not yet local studies that show indicator species among small mammals in the East African region and the Albertine Rift.

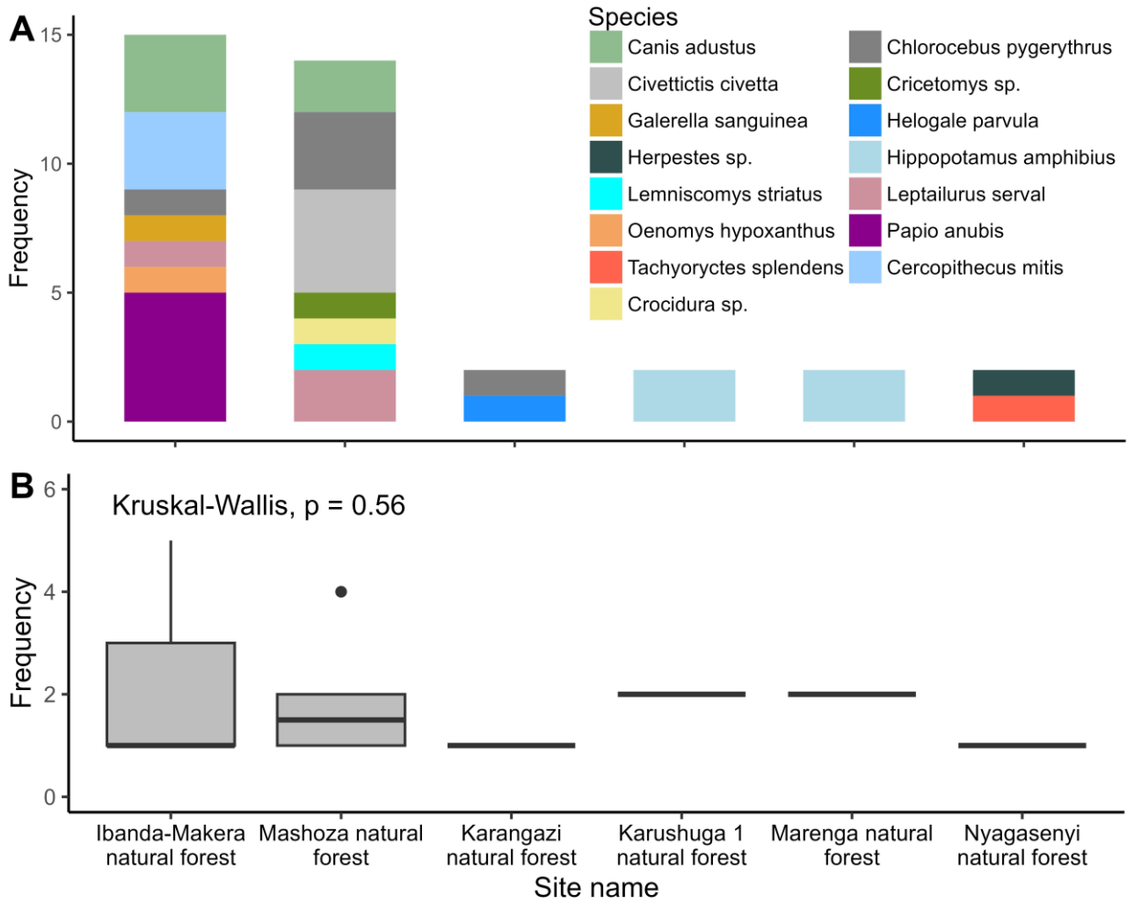


Figure 70. Frequency of mammals recorded in 7 natural forests surveyed in the Eastern Province of Rwanda. Figure A shows the accumulated abundance of species and B shows the frequency by forest in box plots, where the thick line shows the median value.

5.7 Threats

Sixteen types of threats and human disturbances were recorded in the seven forests that were surveyed. Four out of the 16 threats were represented each by single occurrence (Figure 71). Overall, the most prevalent and pervasive threat is the occurrence of plastic materials. The sites that recorded the most types of threats are Muvumba and Karushuga Natural Forests.

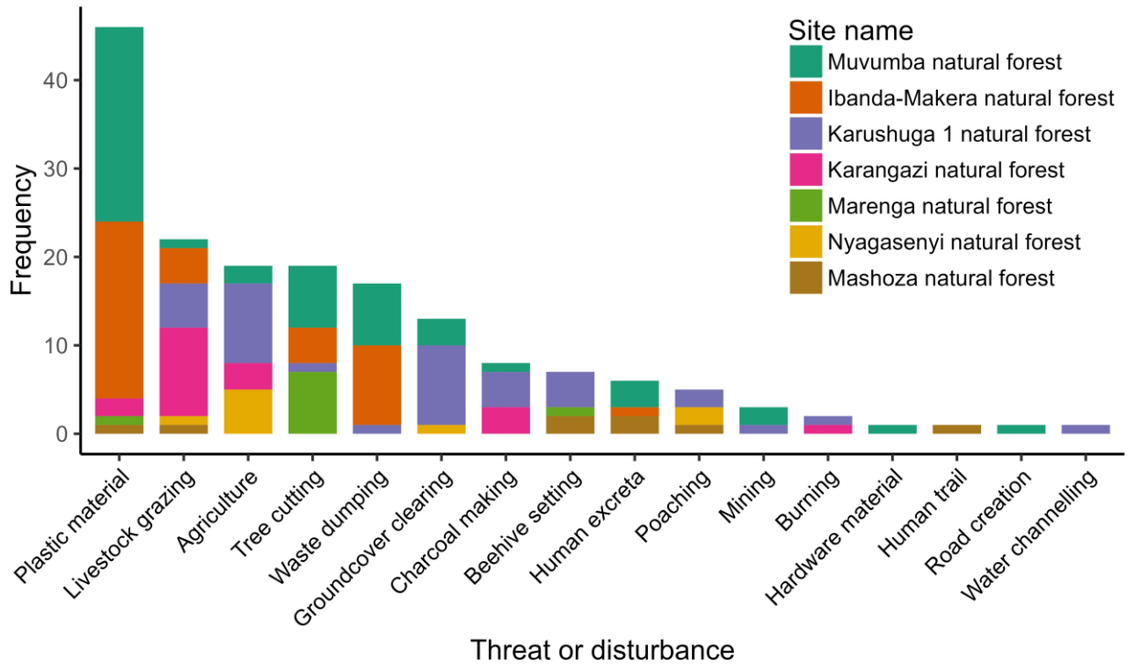


Figure 71. Summary of threats occurrence for the forests

The threats were evaluated by their relative frequencies of occurrence in the seven remnant forests (Figure 72). There was no significant difference between forests (p=0.39).

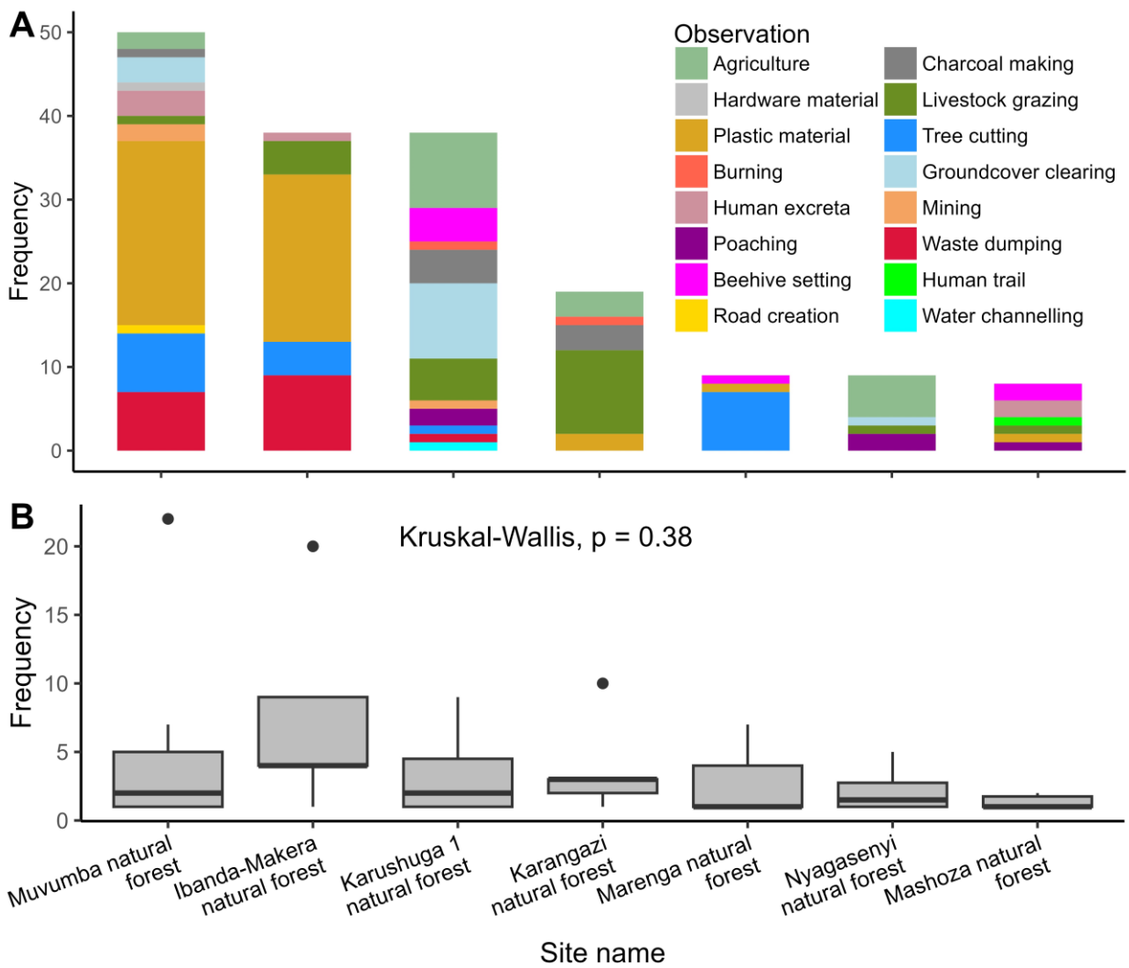


Figure 72. Frequency of the threats and human disturbances recorded in seven natural forests surveyed in the Eastern Province of Rwanda. Figure A shows accumulated abundance by threat categories and B shows frequencies by forest as box plots; lines in boxes show the median value.

The most common threats by the frequency of occurrence was the plastic materials. Overall, the other threats were prevalent and the five following threats - livestock grazing agriculture, tree cutting, waste dumping, and ground cover clearing - were slightly different in their rates occurrence. However, those other threats except waste dumping often cover a larger space, which

was defined in threat description as extent or scope of the threat. There was unequal distribution of most of the threats, with each of them most prevalent at less than a half of the sites, mostly at two or three sites. For example, plastic materials and waste dumping areas were mostly recorded at Ibanda-Makera and Muvumba Natural Forests, while insignificant at other sites.

Plastic materials and dumpsites especially, as well as presence of human excreta, have direct negative consequences on the health of animal wildlife. The findings from this survey leads to some important recommendations, among others: to plan restoration along with removal of the plastic materials and waste dumping sites, to mobilize and educate the community about the health of ecosystems and the proper behaviors to keep them safe, and to increase law enforcement measures where necessary. Measures should be taken as possible to halt the group of threats that have cascading and cumulative effects on forest cover clearance, namely the tree cutting, ground cover clearing, agriculture and livestock grazing, since their occurrence during restoration and ecosystem protection will hamper the outcomes of intervention efforts. In general, there is a need not only to remove direct and cascading factors that bring plastics into ecosystems that are concerned by restoration interventions, but also prevent any further disposal of plastics into the sites. All those efforts need to be supported by community engagement and education which should lead to pragmatic actions and shared benefits.

6. Conclusions and Recommendations

We have summarized the taxon and threats information into table format to enable users of this report to capture the status of each forest based on the status of key biodiversity elements in the forests (Table 30). 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 forests with less presence of human activities and threats to the forest.

Scores were summed for each forest to give an indication of the overall ‘biodiversity score’ for each of the seven forest remnants. 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 forests and can help to track the trajectory of the forests over time with follow up monitoring. The monitoring could target all or a subset of the taxon groups surveyed in this report. Table 30 also includes recommendations for interventions for each forest remnant based on the findings. Table 31 presents specific species across all taxon groups sampled that can be used to help monitor forest 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.

The size of the forest remnants is a factor in the biodiversity status of each forest – smaller remnants simply have fewer habitats and are affected by edge effects which reduce biodiversity and bring in negative impacts. Overall, if possible, the area of each forest, especially the smaller forests, should be expanded with restoration, and buffer zones around the forests composed of trees that would buffer edge effects and delineate the forest boundaries, would be valuable. These buffer zones could include plant species of value to the surrounding community and could be used and managed in a community forest arrangement. Some of the vegetation assemblages in some of the remnant forests were completely dominated by invasive introduced plant species such as *Lantana camara.* This species and the other invasive species should be prioritized for removal to facilitate restoration of these forests.

The Center of Excellence in Biodiversity and Natural Resource Management team that completed this work is shown in Annex 9. These individuals may be contacted regarding taxonomy or other aspects of their respective taxon groups.

Table 30. Status of the seven remnant forests based on the biodiversity baseline sampling (high score means healthier forest in better condition)

	Ibanda-Makera	**Karangazi**	**Karushuga**	**Marenga**	**Mashoza**	**Muvumba**	**Nyagasenyi**
Plant invasive spp score (0-5)	4	4	4	5	3	3	4
Plant late successional status score (0-3)	2	1	1	1	2	1	1
Amphibian tolerance score (0-4)	4	0	0	0	0	0	0
Herp Threatened or Endangered spp	2	0	0	0	0	0	0
Butterflies functional group score (0-4)	4	4	4	1	3	4	3
Terrestrial Arthropod functional group score (1-3)	1	2	2	3	3	2	2
Birds migratory spp score (0=0, 1-3 migratory spp=1, 4 or more = 2; >4= 3)	0	0	3	2	2	0	0
Birds Endemic, Threatened or Endangered spp (0=1, at least 1)	1	0	0	0	0	0	0
Mammals encounter rate score (0-5)	5	1	1	1	5	0	1

Mammals indicator score (0-3)	3	1	1	1	1	0	0
Threats encounter rate score (0-5)	2	3	2	4	4	1	4
Biodiversity status score	**28**	**16**	**18**	**18**	**23**	**11**	**15**
Comments	The forest is still composed of natural vegetation and some species adapted to specific habitats still occur in the forest. Invasive plants (*Senna* and *Lantana*) are thick in some areas. Urgent activities to control resource use and pollution in the forest is needed; agriculture and logging need to be ended.	The forest is threatened by human activities, including agriculture, livestock grazing, and dumping of plastic waste	Human activities such as agriculture and livestock grazing are threats to the forest. There are invasive plant species that should be attended to.	The forest faces minimal threats; the only noticeable threat to this forest is logging of trees.	The forest is threatened by invasive species such as *Lantana camara* and consists of human paths that disturb the forest's integrity.	The forest is encroached by humans: waste disposal, fishing, charcoal making and tree logging	Human activities such as agriculture threaten the forest
Recommendations	Halt human use of the forest is important to	Implement sustainable land mgmt	Adopt sustainable land	Control access to the forest to end	Remove invasive species, stop	Control access to the forest,	Adopt sustainable agricultural

	allow natural regeneration of disturbed habitats and recovery of populations of species specific to the forest. Remove the invasive plants especially *Senna* and *Lantana*.	practices, reduce plastic pollution. Remove the *Eucalyptus*, *Calliandra* and *Lantana camara* in this forest.	management practices is important to reduce threats to the forest. Remove the invasive plants *Eucalyptus, Calliandra, Grevillea,* and *Lantana camara.*	illegal logging; implement community projects that give access to woodlots for wood needs.	human passage in the forest and carry out restoration. Remove the *Agave* and *Lantana camara* in this forest.	and reduce unsustainable resource use in the forest. Remove the *Lantana camara* and *Senna spectabilis.*	practices and conservation measures to reduce these risks and maintain the long-term well being of the forest ecosystem. Remove the *Lantana* and *Grevillea* in this forest.

Table 31. Species to pay attention to in future monitoring activities

Taxon group	**Category (invasive, threatened or endangered)**	**Indicator species (write in what it indicates: disturbed or undisturbed)**	**Indicator attribute**
Plants	Invasives	*Lantana camara,* *Biancaea decapetala,* *Mimosa pigra* *Searsia natalensis (Rhus natalensis)* *Gymnosporia heterophylla,* *Senna spectabilis* *Eucalyptus saligna*	Disturbed ecosystem
	Endangered or threatened	*Osyris lanceolata,* *Prunus africana* *Euphorbia grantii,* *Mimusops bagshawei*	Healthy ecosystems; priority ecosystem for protection due to economic value
Herps		*Hyperolius lateralis* *Hyperolius cinnamomeoventris*	Healthy ecosystems
		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*	Disturbed ecosystems
Flying insects		*Acraea asboloplintha, Acraea uvui, Appias epaphia, Atelica galene, Axiocerses tjoane, Bebearia cocalia, Charaxes, Charaxes acuminatus, Charaxes candiope, Coeliades anchises, Colotis auxo, Colotis danae, Colotis*	Pollinators, fruit-feeders and generally flagship for insect conservation as they indicate the health of the

		euippe, Colotis eunoma, Colotis hetaera, Danaus chrysippus, Eicochrysops Hippocrates, Junonia chorimene, Junonia stygia, Junonia terea, Metisella midas, Metisella orientalis, Mimacraea marshalli, Monza punctata, Nepheronia argia, Neptidopsis ophione, Papilio demodocus, Papilio nireus, Papilio phorcas, Pardopsis punctatissima Uranothauma heritsia, Vanessula milca, Ypthima albida, Ypthimomorpha itonia, Apis mellifera, Xylocopa caffra, Lasioglossum sp, Sphecidae, Amegilla sp, Xylocopa flavorufa	environment (Barrios et al., 2016; Hayet et al., 2021).
Terrestrial Arthropods		Coccinelidae family (Lady bugs) Hymenoptera family (wasps) Culculionida family (weevil)	Predators, play a crucial role in pest control. Disturbed ecosystems
	Invasive	Cerambycidae Family (Asian longhorned beetle) Bupresidae Family (Jewel beetle)	Some species of 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. These species are not yet studied nor widely reported in Rwanda (Walther et al., 2009). Disturbed ecosystems
Birds	Endangered	*Balearica regulorum* Grey crowned crane	Healthy ecosystem

	Near Threatened	*Laniarius mufumbiri* Papyrus Gonolek	
	Albertine Rift endemic	*Sheppardia aequatorialis* Equatorial Akalat	Healthy ecosystem
	Forest interior species	Bird species found mainly in forest interior, not edge or open fields/human dominated landscapes	Healthy ecosystem
Mammals	Least Concern	*Helogale parvula* Widespread but rare species in Rwanda that needs grassy vegetation for hiding and as shelter; indicator of open woodland or woodland savannah	Healthy savannah 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 (either savannah, forest, or wetland)
	Least Concern	*Galerella sanguinea* Often attracted to any place, even with high disturbances, providing shelter depending on availability of smaller of small mammals	Disturbed ecosystem, often at high level
	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, often at high level
	Least Concern	*Chlorocebus pygerythrus* Often attracted to non-natural environment where people's belongings are preferred, whether crops or other feeding stuff, except for the shelter	Disturbed ecosystem, often at high level
	Least Concern	*Lemniscomys striatus*	Disturbed ecosystem

		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	
	Least Concern	*Oenomys hypoxanthus* Can adapt to the interior part of disturbed ecosystems where there is thick and tall herbaceous or shrubby vegetation cover, often with shrubs it spends some time standing above ground level; indicator of interior undisturbed habitat	Moderate ecosystem
	Least Concern	*Cercopithecus mitis* Often occurring in small populations with slow population dynamics, they are either indicative of healthy forest with fruiting trees or wetland to keep distance from humans; interference with humans and their assets is accidental	Healthy ecosystem, with possible edge disturbance
	Least Concern	*Civettictis civetta* Can adapt to the interior part of disturbed ecosystems; mostly in need of shelter away from disturbance; open entangled shrubs often necessary; indicator of interior undisturbed habitat	Moderate ecosystem
	Least Concern	*Cricetomys sp.* Mostly attracted by seeds that they eat as food; indicator of forest floor functions	Moderately disturbed ecosystem
	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

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8. Annexes

Annex 1. Native plant species checklist of seven remnant forest in Eastern Province, Rwanda. None have been found to be endemic to Rwanda but some may be Albertine Rift endemics

Id	Family	Scientific Name	Distribution
1	Acanthaceae	*Acanthus polystachyus*	Ethiopia to NW. Tanzania
		Asystasia mysorensis	Ethiopia to S. Africa, Yemen, India
		Dicliptera colorata	Rwanda to N. Malawi
		Hygrophila auriculata	Tropical & S. Africa, Indian Subcontinent to Indo-China
		Thunbergia alata	Tropical & S. Africa, Madagascar
2	Amaranthaceae	*Achyranthes aspera*	Tropical & Subtropical Old World
		Psilotrichum patulum	Ethiopia to E. DR Congo and Tanzania, S. India, Sri Lanka
3	Anacardiaceae	*Searsia longipes*	Tropical Africa
4	Apiaceae	*Centella asiatica*	Tropical & Subtropical Old World to E. Australia and W. Pacific.
5	Apocynaceae	*Carissa spinarum*	Africa to Indo-China, Australia to New Caledonia
6	Araliaceae	*Hydrocotyle mannii*	Tropical Africa, Madagascar
7	Asparagaceae	*Asparagus africanus*	Tropical & S. Africa, Arabian Peninsula, W. India
		Dracaena fragrans	Tropical Africa
8	Asteraceae	*Aspilia africana*	Tropical Africa
		Bothriocline longipes	Gabon to Kenya and S. Tropical Africa
		Conyza pallidiflora	
		Crassocephalum vitellinum	Nigeria to South Sudan and Zambia
		Distephanus biafrae	Tropical Africa
		Gymnanthemum amygdalinum	E. Bolivia to Brazil, Tropical Africa, W. Yemen
		Lipotriche scandens	Tropical & S. Africa, Madagascar
		Microglossa densiflora	Tropical Africa
		Solanecio mannii	Nigeria to Ethiopia and S. Tropical Africa
9	Bignoniaceae	*Markhamia lutea*	Ghana to South Sudan and Tanzania
10	Commelinaceae	*Commelina africana*	Africa, Arabian Peninsula
11	Convolvulaceae	*Ipomoea cairica*	Tropical & S. Africa, W. Indian Ocean, Israel to Arabian Peninsula, India to Taiwan
		Ipomoea pileata	Tropical & Subtropical Old World
12	Cucurbitaceae	*Momordica foetida*	Tropical & S. Africa
13	Euphorbiaceae	*Acalypha volkensii*	Ethiopia to Burundi
		Ricinus communis	NE. Tropical Africa
		Tragia brevipes	Cameroon to Somalia and Zimbabwe

14	Fabaceae	*Albizia adianthifolia*	Tropical & S. Africa, E. & E. Central Madagascar
		Albizia petersiana	S. Somalia to S. Africa
		Chamaecrista usambarensis	E. Tropical Africa
		Crotalaria spinosa	Tropical Africa, Arabian Peninsula
		Erythrina abyssinica	Central African Republic to Eritrea and Botswana
		Indigofera brevicalyx	Eritrea to E. Central & E. Tropical Africa, SW. Arabian Peninsula
		Senegalia polyacantha	Tropical & S. Africa, Indian Subcontinent
		Senna didymobotrya	Ethiopia to S. Tropical Africa
		Vachellia sieberiana	Tropical & S. Africa
		Vigna parkeri	Tropical Africa, Madagascar
15	Lamiaceae	*Clerodendrum johnstonii*	SW. Ethiopia to Zambia
		Coleus melleri	Tropical Africa, E. Madagascar
		Leonotis ocymifolia	Eritrea to S. Africa
		Ocimum gratissimum subsp. gratissimum	Tropical & Subtropical Old World
		Ocimum lamiifolium	Cameroon to Eritrea and Zambia
16	Linderniaceae	*Craterostigma plantagineum*	Tropical & Northern Prov., SW. Arabian Peninsula, India
17	Malvaceae	*Hibiscus calyphyllus*	Eritrea to S. Africa, W. Indian Ocean, Arabian Peninsula
		Pavonia urens var. irakuensis	E. Central & E. Tropical Africa
		Sida rhombifolia	Tropical & Subtropical Old World
		Sida tenuicarpa	Ethiopia to E. Central & E. Tropical Africa
		Triumfetta rotundifolia	Indian Subcontinent to Indo-China
18	Menispermaceae	*Hyalosepalum caffrum*	Ethiopia to S. Africa
19	Oleaceae	*Jasminum schimperi*	Congo to Ethiopia and Tanzania
20	Onagraceae	*Ludwigia abyssinica*	Tropical & S. Africa, Comoros, Madagascar
21	Oxalidaceae	*Oxalis corniculata*	Indian Subcontinent to Japan and Philippines
		Oxalis obliquifolia	Eritrea to S. Africa
22	Phyllanthaceae	*Flueggea virosa*	Africa to Australia.
		Phyllanthus fischeri	Eritrea to E. Central & E. Tropical Africa
23	Phytolacca dodecandra	*Phytolacca dodecandra*	Tropical & S. Africa, Madagascar
24	Polygonaceae	*Persicaria decipiens*	Tropical & Subtropical Old World to Australasia
		Rumex abyssinicus	Nigeria to Eritrea and S. Tropical Africa, Madagascar

25	Rubiaceae	*Tarenna pavettoides*	Tropical & S. Africa
26	Santalaceae	*Osyris lanceolata*	Canary Islands, S. Iberian Peninsula Baleares, Sahara to S. Africa, Socotra, Indian Subcontinent to S. China and Indo-China
27	Solanaceae	*Solanum mauense*	Kenya to Tanzania
		Solanum nigrum	Temp. Eurasia, Macaronesia, N. & NE. Tropical Africa
		Solanum tettense	Ethiopia to N. Namibia
28	Vitaceae	*Cyphostemma maranguense*	Central & S. Kenya to N. Tanzania

Annex 2. Amphibians and reptiles recorded among the seven sampled natural forests. Among the reptiles, we recorded two species of turtles, one chameleon, two snake species, and three lizards. LC: Least Concern, VU: Vulnerable, NT: Near Threatened, DD: Data Deficiency, NE: Not Evaluated, 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	*Afrixalus quadrivittatus (Werner, 1908)*	Four-lined Spiny Reed Frog	LC	LC
		Hyperolius kivuensis Ahl, 1931	Kivu Reed Frog	LC	LC
		Hyperolius lateralis Laurent, 1940	Mottle-sided Reed Frog	LC	VU
		Hyperolius rwandae Dehling, Sinsch, Rodel & Channing, 2013	Rwanda Long 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	Pixycephalidae	*Amietia nutti (Boulenger, 1896)*	Nutt's River Frog	LC	LC
5	Ptychadenidae	*Ptychadena anchietae (Bocage, 1868)*	Anchieta's Frog	LC	LC
		Ptychadena nilotica (Seetzen, 1855)	Nile grass frog	LC	LC
		Ptychadena porosissima (Steindachner, 1867)	Grassland Frog	LC	LC
REPTILES					
1	Chameleonidae	*Trioceros ellioti (Günther, 1895)*	Montane Side-striped Chameleon	LC	ND
2	Colubridae	*Philothamnus sp*	Tree Green snake	-	-
3	Lacertidae	*Adolfus jacksoni (Boulenger, 1899)*	Jackson's Forest Lizard	LC	ND
4	Pelomedusidae	*Pelomedusa sp*	Turtle	-	-
5	Pythonidae	*Python sebae (Gmelin, 1789)*	African (Rock) Python	NT	ND
6	Scincidae	*Trachylepis sp*	-	-	-
		Trachylepis striata (Peters, 1844)	African Striped Mabuya	LC	ND
7	Testudinidae	*Kinixys spekii Gray, 1863*	Speke's Hinge-back Tortoise	NE	ND

Annex 3. Butterfly species recorded from seven natural forests. The sign tick (✓) represents the presence of the species; empty cells are absence. LC stands for the Least Concern of the IUCN categories while the NE stands for the Not Evaluated. IM= Ibanda-Makera; Kz=Karangazi; Kg=Karashuga; Mg=Marenga; Mz=Mashoza; Mv=Muvumba; Ny=Nyagansenyi

#	Family	Scientific names	English name	IUCN	IM	Kz	Kg	Mg	Mz	Mv	Ny
1	**Hesperiidae**	*Coeliades anchises*	One-pip Policeman	LC			✓				
		Eretis lugens	Savanna elf	NE	✓		✓			✓	✓
		Gegenes hottentota	Marsh Hottentot Skipper	LC	✓	✓			✓		✓
		Metisella midas		NE			✓				✓
		Metisella orientalis	Eastern sylph	NE	✓						✓
		Monza punctata		NE		✓					
		Pelopidas mathias		LC			✓				
2	**Lycaenidae**	*Anthene amarah*	Black-striped Hairtail	LC	✓						
		Anthene definita	Common hairtail	LC	✓	✓		✓	✓		
		Axiocerses tjoane	Eastern Scarlet	LC							✓
		Cacyreus lingeus	Bush Bronze	LC		✓					
		Eicochrysops hippocrates	White pipped blue	LC		✓	✓				✓
		Lampides boeticus	Long-tailed Blue	LC							✓
		Leptotes pirithous	Common zebra blue	LC		✓	✓				
		Mimacraea marshalli	Marshall's acraea mimic	NE	✓						✓
		Uranothauma heritsia		NE							✓
		Zizeeria knysna	African Grass Blue	LC		✓					
		Zizula hylax	Gaika Blue	LC		✓					
3	**Nymphalidae**	*Acraea asboloplintha*	Black-winged accraea	NE	✓						
		Acraea uvui	Tiny acraea	NE	✓						
		Amauris niavius	The friar	LC	✓						✓
		Atelica galene	The Forest glade nymph	NE	✓					✓	

		Bebearia cocalia	Common palm Forester	NE	✓						
		Bicyclus ena	Grizzled Bush Brown	LC			✓				
		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	✓						✓
		Byblia anvatara	African Joker	LC			✓				
		Byblia ilithyia	Spotted Joker	LC			✓				
		Charaxes	Charaxes	NE			✓				
		Charaxes acuminatus	Mountain pearl charaxes	NE	✓				✓		
		Charaxes candiope	Green-veined Charaxes	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			✓				
		Neptidopsis ophione	Neptidopsis ophione	LC			✓			✓	
		Neptis jordan	Jordan's Sailor	LC	✓						
		Neptis serena	Serena sailor	LC			✓			✓	
		Pardopsis punctatissima	Pardopsis punctatissima	LC		✓	✓				
		Phalanta eurytis	Forest leopard	LC	✓		✓				
		Phalanta phalanta	Common leopard	NE	✓	✓	✓				✓
		Precis tugela	Precis tugela	LC			✓				
		Protogoniomorpha parhassus	Mother-of-pearl	LC	✓		✓				

		Protogoniomorpha temora	Blue mother-of-pearl	NE	✓						
		Tirumala formosa	Tirumala formosa	NE		✓					
		Tirumala petiverana	Blue Monarch	LC	✓✓		✓				
		Vanessula milca	Lady's maid	NE	✓						
		Ypthima albida	Silver ringlet	NE	✓		✓			✓	✓
		Ypthima asterope	African ringlet	LC	✓	✓	✓				✓
		Ypthimomorpha itonia	Ypthimomorpha itonia	NE		✓					
4	**Papilionidae**	*Graphium sp*	Swallowtails	NE			✓				
		Papilio demodocus	Citrus Swallowtail	NE	✓	✓	✓		✓		
		Papilio nireus	Narrow Green-banded Swallowtail	LC	✓		✓				
		Papilio phorcas	Green-banded swallowtail	NE	✓	✓	✓		✓		
5	**Pieridae**	*Afrodryas leda*	Autumn-leaf Vagrant	LC		✓	✓	✓			
		Appias epaphia	Diverse Albatross White	LC			✓				
		Belenois crawshayi	Black-spotted Caper White	NE	✓	✓	✓			✓	
		Belenois creona	African Caper White	LC	✓	✓✓	✓	✓		✓	
		Belenois raffrayi	Raffrayi's caper	LC		✓	✓				
		Catopsilia florella	African Migrant	LC	✓	✓	✓			✓	✓
		Colotis antevippe	Southern Red Tip	LC			✓				
		Colotis aurigineus	African Arab Tip	NE	✓	✓	✓				
		Colotis auxo	Sulphur Orange Tip	LC		✓	✓				
		Colotis danae	Scarlet tip	LC			✓				
		Colotis euippe	Round-winged Orange Tip	LC	✓	✓	✓	✓		✓	
		Colotis eunoma	Three spot crimson tip	NE				✓			
		Colotis hetaera	Eastern purple tip	NE			✓				
		Eronia cleodora	Vine-leaf Vagrant	LC		✓	✓				
		Leptosia alcesta	African Wood White	LC	✓		✓	✓		✓	
		Leptosia nupta	Immaculate spirit	NE	✓		✓	✓	✓	✓	✓
		Mylothris agathina	Eastern Dotted Border	LC	✓	✓	✓	✓			✓

		Nepheronia argia	Large Vagrant	LC			✓				✓
		Pontia helice	Meadow white	NE	✓						
		Terias brigitta	Broad-bordered Grass Yellow	LC	✓	✓	✓		✓		
		Terias hapale	Pale grass yellow	NE							✓
		Terias hecabe	Grass yellow	LC	✓	✓	✓				✓
		Terias regularis	Terias regularis	NE		✓					
		Terias senegalensis	Terias senegalensis	NE							✓

Annex 4. Terrestrial arthropods recorded from seven natural forests. IM= Ibanda-Makera; Kz=Karangazi; Kg=Karashuga; Mg=Marenga; Mz=Mashoza; Mv=Muvumba; Ny=Nyagansenyi

Order	Family	IM	Kz	Kg	Mg	Mz	Mv	Ny
Acarina	Ixodidae		✓					
Aranea	Araneidae	✓		✓			✓	✓
	Oniscidae				✓			
	Pholcidae	✓	✓	✓	✓		✓	
	Salticidae	✓	✓	✓	✓	✓	✓	✓
	Trombididae	✓	✓			✓		
Blattodea	Blaberidae	✓	✓	✓	✓			✓
	Blattellidae	✓	✓	✓	✓			✓
	Blattidae	✓	✓	✓		✓	✓	✓
Callipodida	Callipodidea				✓	✓	✓	
Coleoptera	Buprestidae				✓			✓
	Carabidae		✓	✓	✓	✓	✓	✓
	Chrysomelidae	✓	✓	✓	✓	✓	✓	✓
	Clusiidae		✓					
	Coccinelidae		✓	✓		✓	✓	✓
	Curculionidae	✓	✓	✓	✓	✓	✓	✓
	Dermistidae	✓						
	Elateridae	✓	✓				✓	
	Histeridae		✓					
	Hydrophilidae			✓				
	Lycidae		✓	✓	✓			
	Meloidae		✓	✓				✓
	Scarabaeidae		✓	✓	✓			
	Scydmaenidae			✓				
	Staphylinidae		✓	✓	✓	✓	✓	✓
	Tenebrionidae	✓	✓	✓	✓	✓	✓	✓

Hemiptera	Alydidae	✓	✓			✓	✓	
	Aphididae	✓	✓					
	Bradyporinae	✓						
	Cerambycidae	✓						
	Cercopidae	✓	✓	✓	✓	✓	✓	✓
	Cicadellidae	✓	✓			✓	✓	
	Cicadidae		✓	✓		✓		
	Coreidae						✓	
	Dictyopharidae		✓	✓				
	Lygaeidae	✓	✓	✓	✓	✓	✓	✓
	Membracidae			✓				
	Miridae	✓	✓	✓		✓	✓	✓
	Pentatomidae	✓	✓	✓	✓			✓
	Pyrrhocoridae	✓	✓	✓				
	Reduviidae	✓	✓	✓	✓			
	Scutelleridae			✓			✓	
	Tingidae			✓				✓
	Coreidae			✓				
Hymenoptera	Apidae	✓		✓				✓
	Braconidae					✓		
	Drynindae		✓					
	Eumenidae		✓	✓			✓	
	Formicidae	✓	✓	✓	✓	✓	✓	✓
	Ichnemonidae	✓		✓	✓	✓	✓	✓
	Scoliidae					✓		
	Vespidae	✓	✓	✓			✓	
Isopoda	Oniscidae	✓	✓	✓	✓	✓	✓	✓
Isoptera	Termitidae	✓		✓	✓	✓	✓	
Mantodea	Mantidae	✓						
	Thespidae	✓					✓	
Odonata	Coenagrionidae			✓				
	Lestidae						✓	
	Libellulidae			✓	✓		✓	
Orthoptera	Acrididae	✓	✓	✓	✓		✓	✓
	Gryllidae	✓	✓	✓	✓	✓	✓	✓
	Pyrgomorphidae	✓						
	Tetrigidae		✓	✓		✓	✓	
	Tettigoniidae	✓	✓	✓	✓	✓	✓	✓

Annex 5. Bird checklist for the seven remnant forests in Eastern Province. IM= Ibanda-Makera; Kz=Karangazi; Kg=Karashuga; Mg=Marenga; Mz=Mashoza; Mv=Muvumba; Ny=Nyagansenyi; pm=partial migrant; Albertine Rift endemic marked with *

Families	***Scientific names***	IUCN	Migra-tory	IM	Kz	Kg	Mg	Mz	Mv	Ny
Accipitridae	*Accipiter tachiro*	LC	Non-migrant	✓					✓	
Acrocephalidae	*Acrocephalus gracilirostris*	LC	Non-migrant			✓				
Scolopacidae	*Actitis hypoleucos*	LC	Non-migrant						✓	
Ploceidae	*Amblyospiza albifrons*	LC	Non-migrant							✓
Ploceidae	*Anaplectes rubriceps*	LC	Non-migrant		✓					
Ciconiidae	*Anastomus oscitans*	LC	Non-migrant	✓				✓		
Cisticolidae	*Apalis cinerea*	LC	Non-migrant					✓		
Cisticolidae	*Apalis flavida*	LC	Non-migrant		✓	✓				
Trogonidae	*Apaloderma narina*	LC	Non-migrant	✓						
Apodidae	*Apus caffer*	LC	Non-migrant						✓	
Accipitridae	*Aquila spilogaster*	LC	Non-migrant	✓						
Ardeidae	*Ardea intermedia*	LC	Non-migrant	✓						
Ardeidae	*Ardea melanocephala*	LC	Non-migrant						✓	
Pycnonotidae	*Atimastillas flavicollis*	LC	Non-migrant	✓			✓	✓	✓	
Accipitridae	*Aviceda cuculoides*	LC	Non-migrant	✓						
Gruidae	*Balearica regulorum*	EN	Partial migrant			✓			✓	
Platysteiridae	*Batis molitor*	LC	Non-migrant		✓	✓		✓		
Threskiornithidae	*Bostrychia hagedash*	LC	Non-migrant				✓	✓	✓	✓
Muscicapidae	*Bradornis pallidus*	LC	Non-migrant					✓		

Locustellidae	*Bradypterus carpalis*	LC	Non-migrant	✓						
Ardeidae	*Bubulcus ibis*	LC	Non-migrant	✓					✓	
Accipitridae	*Buteo augur*	LC	Non-migrant			✓		✓		
Accipitridae	*Buteo buteo*	LC	Non-migrant	✓						
Cisticolidae	*Camaroptera brachyura*	LC	Non-migrant			✓	✓			
Cisticolidae	*Camaroptera brevicaudata*	LC	Non-migrant	✓	✓ ✓	✓ ✓		✓	✓	
Campephagidae	*Campephaga flava*	LC	Non-migrant	✓				✓	✓	
Cuculidae	*Centropus monachus*	LC	Non-migrant							✓
Cuculidae	*Centropus superciliosus*	LC	Non-migrant	✓	✓	✓			✓	✓
Muscicapidae	*Cercotrichas hartlaubi*	LC	Non-migrant		✓	✓		✓		
Alcedinidae	*Ceryle rudis*	LC	Non-migrant			✓				
Nectariniidae	*Chalcomitra senegalensis*	LC	Non-migrant			✓				
Nectariniidae	*Charcomitra senegalensis*	LC	Non-migrant	✓				✓		
Cuculidae	*Chrysococcyx klaas*	LC	Migrant	✓						
Sturnidae	*Cinnyricinclus leucogaster*	LC	Non-migrant	✓						
Nectariniidae	*Cinnyris chloropygius*	LC	Non-migrant						✓	
Nectariniidae	*Cinnyris cupreus*	LC	Non-migrant							✓
Nectariniidae	*Cinnyris erythrocercus*	LC	Non-migrant			✓	✓	✓	✓	✓
Nectariniidae	*Cinnyris mariquensis*	LC	Non-migrant		✓	✓		✓		
Nectariniidae	*Cinnyris reichenowi*	LC	Non-migrant					✓		
Accipitridae	*Circus ranivorus*	LC	Non-migrant			✓				
Cisticolidae	*Cisticola cantans*	LC	Non-migrant			✓				

Cisticolidae	*Cisticola chubbi*	LC	Non-migrant					✓	✓	✓
Cisticolidae	*Cisticola galactotes*	LC	Non-migrant							✓
Cisticolidae	*Cisticola woosnami*	LC	Non-migrant	✓	✓	✓				
Coliidae	*Colius striatus*	LC	Non-migrant	✓		✓	✓	✓		✓
Coraciidae	*Coracias caudatus*	LC	Non-migrant			✓				
Alcedinidae	*Corythornis cristatus*	LC	Non-migrant	✓				✓	✓	✓
Muscicapidae	*Cossypha heuglini*	LC	Non-migrant	✓		✓	✓	✓	✓	✓
Muscicapidae	*Cossypha natalensis*	LC	Non-migrant	✓						
Musophagidae	*Crinifer personatus*	LC	Non-migrant	✓	✓	✓				
Musophagidae	*Crinifer zonurus*	LC	Non-migrant			✓				✓
Fringillidae	*Crithagra frontalis*	LC	Non-migrant			✓				
Fringillidae	*Crithagra mozambica*	LC	Non-migrant		✓	✓		✓		
Cuculidae	*Cuculus solitarius*	LC	Intra-Africa migrant		✓	✓			✓	
Nectariniidae	*Cyanomitra verticalis*	LC	Non-migrant	✓						
Nectariniidae	*Cynnyris venustus*	LC	Non-migrant	✓	✓			✓		✓
Anatidae	*Dendrocygna viduata*	LC	Non-migrant						✓	✓
Picidae	*Dendropicos fuscescens*	LC	Non-migrant	✓		✓				
Dicruridae	*Dicrurus adsimilis*	LC	Non-migrant	✓	✓	✓				✓
Cisticolidae	*Eminia lepida*	LC	Non-migrant	✓		✓	✓	✓	✓	
Tyrannidae	*Empidonax oberholseri*	LC	Non-migrant					✓		
Ploceidae	*Euplectes axillaris*	LC	Non-migrant	✓						✓
Ploceidae	*Euplectes capensis*	LC	Non-migrant					✓		

Pycnonotidae	*Eurillas latirostris*	LC	Non-migrant	✓						
Coraciidae	*Eurystomus glaucurus*	LC	Non-migrant	✓						
Accipitridae	*Gypohierax angolensis*	LC	Non-migrant	✓						
Alcedinidae	*Halcyon senegalensis*	LC	Intra-Africa migrant		✓	✓	✓	✓	✓	✓
Accipitridae	*Haliaeetus vocifer*	LC	Non-migrant			✓	✓			
Nectariniidae	*Hedydipna collaris*	LC	Non-migrant	✓				✓		
Accipitridae	*Hieraaetus wahlbergi*	LC	Full-migrant					✓		
Hirundinidae	*Hirundo angolainsis*	LC	Non-migrant							✓
Hirundinidae	*Hirundo rustica*	LC	Full-migrant		✓		✓	✓	✓	✓
Hirundinidae	*Hirundo smithii*	LC	Non-migrant	✓	✓	✓		✓		✓
Indicatoridae	*Indicator exilis*	LC	Non-migrant	✓						✓
Indicatoridae	*Indicator indicator*	LC	Non-migrant	✓	✓	✓				
Indicatoridae	*Indicator variegatus*	LC	Non-migrant	✓					✓	
Alcedinidae	*Ispidina picta*	LC	Non-migrant	✓						
Estrildidae	*Lagonosticta rubricata*	LC	Non-migrant	✓				✓		
Estrildidae	*Lagonosticta senegala*	LC	Non-migrant			✓				
Sturnidae	*Lamprotornis chalybaeus*	LC	Non-migrant	✓						
Sturnidae	*Lamprotornis purpuroptera*	LC	Non-migrant	✓	✓	✓		✓	✓	✓
Malaconotidae	*Laniarius aethiopicus*	LC	Non-migrant	✓	✓	✓		✓	✓	✓
Malaconotidae	*Laniarius erythrogaster*	LC	Non-migrant	✓		✓				
Malaconotidae	*Laniarius mufumbiri*	NT	Non-migrant	✓		✓				
Laniidae	*Lanius excubitoroides*	LC	Non-migrant		✓	✓				✓

Laniidae	*Lanius humeralis*	LC	Non-migrant	✓		✓				
Laniidae	*Lanius mackinnoni*	LC	Non-migrant			✓				
Ciconiidae	*Leptoptilos crumeniferus*	LC	Partial migrant						✓	
Estrildidae	*Lonchura bicolor*	LC	Non-migrant			✓				
Accipitridae	*Lophaetus occipitalis*	LC	Non-migrant					✓		
Motacillidae	*Macronyx croceus*	LC	Non-migrant		✓					✓
Alcedinidae	*Megaceryle maxima*	LC	Non-migrant						✓	
Meropidae	*Merops apiaster*	LC	Full-migrant		✓	✓	✓	✓	✓	✓
Meropidae	*Merops oreobates*	LC	Non-migrant			✓				
Meropidae	*Merops pusillus*	LC	Non-migrant			✓			✓	
Phalacrocoracidae	*Microcarbo africanus*	LC	Non-migrant		✓					
Jacanidae	*Microparra capensis*	LC	Non-migrant	✓						
Accipitridae	*Milvus aegyptius*	LC	Intra-Africa migrant					✓	✓	
Motacillidae	*Motacilla aguimp*	LC	Non-migrant	✓						
Motacillidae	*Motacilla capensis*	LC	Non-migrant							✓
Muscicapidae	*Muscicapa adusta*	LC	Non-migrant						✓	
Muscicapidae	*Muscicapa aquatica*	LC	Non-migrant	✓		✓			✓	
Musophagidae	*Musophaga rossae*	LC	Non-migrant	✓		✓		✓		✓
Ciconiidae	*Mycteria ibis*	LC	Non-migrant	✓						
Nectariniidae	*Nectarinia kilimensis*	LC	Non-migrant		✓	✓	✓	✓		✓
Oriolidae	*Oriolus auratus*	LC	Non-migrant						✓	
Oriolidae	*Oriolus larvatus*	LC	Non-migrant			✓				

Oriolidae	*Oriolus larvatus*	LC	Non-migrant	✓		✓			✓	
Passeridae	*Passer griseus*	LC	Non-migrant	✓		✓				
Accipitridae	*Pernis apivorus*	LC	Full-migrant						✓	
Accipitridae	*Pernis ptilorhynchus*	LC	Non-migrant					✓		
Platysteiridae	*Platysteira cyanea*	LC	Non-migrant	✓		✓	✓	✓	✓	
Ploceidae	*Ploceus baglafecht*	LC	Non-migrant	✓	✓			✓		✓
Ploceidae	*Ploceus cucullatus*	LC	Non-migrant	✓			✓		✓	✓
Ploceidae	*Ploceus luteolus*	LC	Non-migrant	✓						
Ploceidae	*Ploceus melanocephalus*	LC	Non-migrant			✓		✓		
Ploceidae	*Ploceus ocularis*	LC	Non-migrant			✓		✓	✓	
Ploceidae	*Ploceus pelzelni*	LC	Non-migrant	✓	✓					
Ploceidae	*Ploceus xanthops*	LC	Non-migrant	✓						✓
Platysteiridae	*Plyatysteira peltata*	LC	Non-migrant		✓					
Lybiidae	*Pogoniulus bilineatus*	LC	Non-migrant	✓						
Lybiidae	*Pogoniulus subsulphureus*	LC	Non-migrant	✓						
Psittacidae	*Poicephalus meyeri*	LC	Non-migrant	✓		✓				
Accipitridae	*Polyboroides typus*	LC	Non-migrant					✓		
Cisticolidae	*Prinia subflava*	LC	Non-migrant		✓	✓		✓		
Hirundinidae	*Psalidoprocne albiceps*	LC	Non-migrant		✓	✓		✓		✓
Hirundinidae	*Psalidoprocne pristoptera*	LC	Full-migrant			✓				
Phasianidae	*Pternistis squamatus*	LC	Non-migrant	✓						
Hirundinidae	*Ptyonoprogne fuligula*	LC	Non-migrant		✓					

Pycnonotidae	*Pycnonotus barbatus*	LC	Non-migrant	✓	✓	✓	✓	✓	✓	✓
Pycnonotidae	*Pycnonotus tricolor*	LC	Non-migrant	✓		✓		✓		
Emberizidae	*Pytilia afra*	LC	Non-migrant		✓					
Estrildidae	*Pytilia melba*	LC	Non-migrant			✓				
Hirundinidae	*Riparia paludicola*	LC	Non-migrant							✓
Cisticolidae	*Schistolais leucopogon*	LC	Non-migrant	✓		✓				
Apodidae	*Schoutedenapus myoptilus*	LC	Non-migrant					✓		
Scopidae	*Scopus umbretta*	LC	Non-migrant	✓		✓		✓	✓	✓
Fringillidae	*Serinus burtoni*	LC	Non-migrant	✓						
Fringillidae	*Serinus striolatus*	LC	Non-migrant			✓				
Muscicapidae	*Sheppardia aequatorialis**	LC	Non-migrant	✓						
Estrildidae	*Spermestes cucullata*	LC	Non-migrant	✓						
Columbidae	*Spilopelia senegalensis*	LC	Full-migrant	✓	✓	✓				
Columbidae	*Streptopelia capicola*	LC	Full-migrant		✓	✓	✓			
Columbidae	*Streptopelia semitorquata*	LC	Full-migrant		✓	✓	✓			✓
Macrosphenidae	*Sylvietta whytii*	LC	Non-migrant	✓						
Musophagidae	*Tauraco porphyreolophus*	LC	Non-migrant	✓						
Malaconotidae	*Tchagra australis*	LC	Non-migrant	✓		✓		✓		
Malaconotidae	*Tchagra senegala*	LC	Non-migrant		✓					
Monarchidae	*Terpsiphone viridis*	LC	Intra-Africa migrant	✓		✓		✓		
Threskiornithidae	*Threskiornis aethiopicus*	LC	Non-migrant					✓	✓	
Bucerotidae	*Tockus alboterminatus*	LC	Non-migrant	✓						

Columbidae	*Treron calvus*	LC	Non-migrant	✓						
Lybiidae	*Tricholaema lacrymosa*	LC	Non-migrant	✓						
Leiothrichidae	*Turdoides jardineii*	LC	Non-migrant	✓						
Leiothrichidae	*Turdoides sharpei*	LC	Non-migrant	✓	✓	✓				✓
Turdidae	*Turdus pelios*	LC	Non-migrant	✓				✓	✓	
Columbidae	*Turtur afer*	LC	Non-migrant	✓	✓	✓				
Columbidae	*Turtur chalcospilos*	LC	Non-migrant	✓	✓					
Coliidae	*Urocolius macrourus*	LC	Non-migrant	✓	✓					
Viduidae	*Vidua macroura*	LC	Non-migrant		✓	✓				
Rallidae	*Zapornia flavirostra*	LC	Non-migrant				✓			✓

Annex 6. Amphibian species that are indicators of ecosystem changes. Tolerant species are considered species generalists that occupy ecosystems dominated by human disturbances and habitat-specific species have low disturbance tolerance or are completely disturbance intolerant.

Taxon	**Attributes**
Disturbance tolerant species	
Afrixalus quadrivittatus	The species occurs mainly in both dry and moist savannahs but also distributed to disturbed forests. It has been recorded mostly in wetlands dominated by anthropogenic activities
Amietia nutti	The species occurs in disturbed wetlands, mainly in or in the habitats adjacent to flowing water bodies. However, the species can also be found in natural habitats both savannas and forests near rivers and streams
Kassina senegalensis	A species that occurs in savannah wetlands and disturbed habitats such as human dominated wetlands. It occupies mainly meadows and other flooded grasses.
Hyperolius kivuensis	Found hiding in leaves axils during the day and occupying tall grasses. It has been mainly recorded in cultivated wetlands and other human dominated wetlands with tall vegetation.

Hyperolius viridiflavus	A well adaptable species mainly found in human dominated wetlands such as with rice plantations, where there are open water bodies. They are also found hidden in banana plantations during dry periods.
Hyperolius rwandae	Mostly savannah species and found in ponds and swamps in farmland and open natural wetlands. It occurs at the edges and clearings of forests and in savannahs.
Hoplobatrachus occipitalis	Dry savannahs and disturbed forests. The species is so far known from Bugarama wetland, a wetland of very low elevation (900masl) in Rwanda and dominated by rice farming
Phrynobatrachus kakamikro	Occurs in flooded habitats such as grassy areas and rice plantations
Phrynobatrachus natalensis	Occurs in irrigation channels, puddles and habitats with stagnant waters. It can also be found in grasses near water bodies
Ptychadena nilotica	A well adaptable species dominating wetlands with human activities. It is found also in forests with dominated grasses.
Ptychadena anchietae	Inhabits woodland, savannah, grassland, and agricultural areas and forest clearings, usually (but not always) in close proximity to permanent water. It breeds in shallow temporary ponds.
Ptychadena porosissima	An adaptable species that can survive in altered habitats.
Ptychadena guibei	Moist upland savannah and montane grassland. The species is also known from Bugarama wetland dominated by rice farming at the lowest elevation in Rwanda
Sclerophrys gutturalis	A very well adaptable species dominating agriculture wetlands. It is found in dried wetlands and its population is established in permanent or semi - permanent water bodies.
Sclerophrys kisoloensis	Montane forest and disturbed wetlands with remnant reed vegetation
Xenopus victorianus	A fully aquatic species of frog well adaptable to mud holes and other stagnant water bodies.
Amnirana albolabris	Secondary habitats and heavily degraded former forest and gallery forest
Amnirana galamensis	A strongly aquatic species in savannah areas
Low disturbance tolerance and disturbance intolerant amphibian species	
Arthroleptis adolfifriederici	Leaf-litter of montane forest and pristine bamboo forest
Leptopelis karissimbensis	Wetlands in forests

Leptopelis kivuensis	Montane wetlands and forest ecotones
Hyperolius castaneus	Swamps in montane grassland and forests
Hyperolius lateralis	Indicates restoration success or areas with no or very slight disturbances.
Hyperolius cinnamomeoventris	Indicates restoration success. It occurs in natural wetlands and can be easily threatened by human alteration of natural habitats.
Phrynobatrachus graueri	Interior of, and on the edge of montane forests
Xenopus wittei	Forest and in high-altitude grassland
Hyperolius jackie	Emergent vegetation at the margins of small swamps and streams in forest
Boulengerula fischeri	Primary montane forest habitat
Hyperolius discodactylus	Montane forests
Leptopelis bocagii	Leaf-litter, presumably in savannah woodlands and forests
Cardioglossa cyaneospila	Montane forests
Sclerophrys berghei	Montane forests in Leaf-litter in the interior of rainforest
Ptychadena oxyrhynchus	Savannahs, primary and secondary forest, farm bush and montane grassland.
Afrixalus phantasma	Montane forest's swamps
Hyperolius glandicolor	Emergent vegetation at the margins of swamps, rivers and lakes in all types of savannah, grassland and bush land,
Phrynobatrachus auritus	Primary, secondary and riparian rainforest, and is often associated with rivers
Xenopus vestitus	Water-dependent species of highland swamps

Annex 7. Photos of the amphibian species recorded in the sampled natural forests. A. Sclerophrys gutturalis, B. Afrixalus quadrivittatus, C. Hyperolius kivuensis, D. Hyperolius lateralis, I. Hyperolius rwandae, J. Hyperolius viridiflavus, G. Kassina senegalensis, H. Phrynobatrachus bequaerti, I. Phrynobatrachus kakamikro, J. Phrynobatrachus natalensis, K. Ptychadena anchietae, L. Ptychadena nilotica.


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Annex 8. Reptile species recorded in the sampled natural forests. A. Trioceros ellioti, B. Adolfus jacksoni, C. Pelomedusa sp, D. Python sebae, E. Trachylepis striata, F. Trachylepis sp, G. Kinixys spekii.

Annex 9. The team and their roles for the biodiversity baseline survey of the seven remnant forests of the Eastern Province, Rwanda

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