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Animal Recolonization as a Success Indicator of the Progressive Ecological Rehabilitation around a Tropical Highland Open Pit Mine

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Abstract

The Twangiza mine is located in the Mitumba mountain range, in the western part of the Albertine Rift Valley, just 20 km East of Itombwe Nature Reserve. A biological inventory was carried out within the mine's decade-old progressive ecological rehabilitation sites. This inventory covered insects, amphibians, reptiles, birds and small mammals. The main objective of the inventory was to assess the level of animal recolonization in the 100-hectares' restored areas. A total of 22 insect genera, 4 amphibian species, 11 reptile species, 43 bird species and 11 small mammal species were found. All of them were strongly settled in the core area within the afforested sites. Prior to the start of the Twangiza mine activities and 4 years before the ecological rehabilitation in the area, the avifauna was depauperate, both in number of species and their abundance. By then, no mammals or reptiles were recorded within the footprint area. The environmental and social baseline assessment identified 38 bird species in 2008, mainly grassland and mobile species, which were using scrub along valley streams as a refuge, outside the current mine footprint. Our results clearly demonstrate the positive impact of the afforestation on insect, amphibian, reptile, bird and small mammal's diversity in this area.

Keywords

Mining, Ecological Rehabilitation, Animal Recolonization

1. Introduction

From the 1990s, Biodiversity has become a key concept in ecology and environmental protection [1]. The study of biological diversity characterizes the environment in a fairly comprehensive way: it describes the environment, quantifies it, analyzes its dynamics, assesses its socio-economical values and evaluates the issues at stake; its overall study is thus necessarily multidisciplinary [2]. In recent years, and particularly since the Rio Conference in 1992, the conservation of biological diversity has become a major concern for many governments and international organizations, aiming at halting the massive loss of biodiversity and preventing a major biological crisis [3]; more so, in the mining sector where environmental impacts are aggravated. Ecosystems restored by men are of great importance for harboring and constituting a refuge for various forms of life, including birds [4]. Ecological restoration goals frequently focus on the flora component of ecosystems, whereas fauna has received much less attention [5]. The paucity of information on fauna in rehabilitation is nonetheless a shortcoming in our understanding of the process of restoration, as fauna plays many crucial roles at the ecosystem level [6].

Inventory development enhances a deeper understanding of biodiversity. The aim of a biodiversity inventory is to report on the status of flora and fauna, as well as habitats, in controlled or managed areas. It helps guide the site and develop a species management plan [7]. In July 2024, an inventory of the faunal diversity was carried out in the 100-hectares' ecosystem progressively restored since 2012 at the Twangiza mine, in the Luhwindja chiefdom, Mwenga District in the DR Congo. The taxa involved were constituted of insects, amphibians and reptiles, birds and small mammals.

Insects play a crucial role in woodlands, as pollinators, decomposers and prey for other species, contributing to the regulation of populations of other organisms and to the overall health of the ecosystem [8]. In addition, insect diversity serves as an indicator of environmental quality and woodland health, enabling researchers and managers to better assess the impacts of human activities and climate change on these habitats [9].

Birds are currently considered to be good indicators of the status and the evolution of natural habitats [10]. Species in this taxonomic group are to date reported in almost every habitat [11]. Indeed, simple modifications to their preferred habitats can be the cause of massive displacement of entire populations, jeopardizing their ecological functions in the ecosystem. On another hand, the restoration of formerly degraded ecosystems can influence colonization by birds. Birds provide essential ecosystem services, such as pollinating plants, dispersing seeds and combating insects harmful to plants and humans. They are excellent indicators of the state of the environment and are ultimately sentinels of nature [12]-[14].

Increasing the knowledge regarding birds within the restoration areas should aid the development of novel approaches to perform restoration activities that take cognizance of all the components of ecosystems [15]. Birds have often been used as a faunal indicator of restoration [16]-[18] because of their mobility and ability to colonize rehabilitated sites, and their relatively high abundance and detectability. For this reason, a survey of the avifauna was carried out at four reforested sites within the Twangiza Mining perimeter.

2. Material and Methods

2.1. Insects

2.1.1. Insect Sampling Sites

Insects were collected at 4 sites: Operators' Camp, plant nursery of Namihombo, Ciramo (Exploration Camp) and Chinjira (Camp Saio). The geographical coordinates of these sites are shown in Table 1.

Table 1. Geographical coordinates of work sites.

Sites	Elevation (m)	Latitude	Longitude
Charly Oscar (Operators' Camp)	2322	02˚52.754'	28˚44.556'
Nursery (Namihombo)	2330	02˚52.532'	28˚44.887'
Charly Sierra (Ciramo)	1816	02˚50.164'	28˚43.549'
Cinjira (Camp Saio)	2648	02˚53.243'	28˚44.914'

2.1.2. Insect Collection

Insects were collected by daytime and nightly. For diurnal insects, the manual method described by [19], which involves the use of a swath net with a 2 mm mesh and a 30 cm diameter circular opening hung on a wooden handle, was used. Insects were captured by-passing the swath net over the grasses, enabling us to capture even insects camouflaged in the grasses. We then collected the captured insects by hand, wearing gloves, and placed them in jars. For insects resting on substrates such as trees, floors or house walls, we used the [20] method of visual observation and monitoring. This method relies on direct observation of insects in their natural habitat, often used for larger or more visible species. For this method, a container or jar was used for capture. We placed the jar on top of the insect; they fled inside, and we closed the jar. Diurnal insects were captured between 8:30 and 11:30 a.m. and between 2:30 and 5:30 p.m.

For nocturnal insects, we used the method described by [21], which involves the use of light traps. Light traps attract nocturnal insects, such as butterflies and some beetles. These traps are often used to assess species diversity. So, we attached a white sheet to two pieces of tree fixed in the ground, then attached 4 flashlights to the two pieces of tree, *i.e.* two flashlights per piece of tree, with the light reaching both sides of the sheet for good illumination. Using the jars, when an insect came to rest on the sheet, we held the jar over it forcing it to fly inside the jar, which we then closed. The insects were captured from 6:30 pm at dusk until 9:30 pm, *i.e.*, 3 hours. Counts of the captured individuals took place the following morning.

2.1.3. Insect Identification

Insects specimen were identified using the identification keys of [22]-[25] and websites for each genus. Insect identification was made at the genus level.

2.1.4. Insect Data Processing

The data were presented in tables showing, for each genus, the subfamily, family, order, capture site, time, distribution in the Afrotropical region and pictures of the specimen.

2.2. Amphibians and Reptiles

2.2.1. Sampling Sites

Eight locations were sampled for Amphibians and Reptiles. The stations are located between elevations of 1789 m at the Bonded Laydown Yard (BLY) near the confluence of the Lulimbohwe and Mwana rivers, and 2700 m at the Twangiza plant nursery in Chinjira, next to the Chinjira Health Center as shown in **Figure 1**.

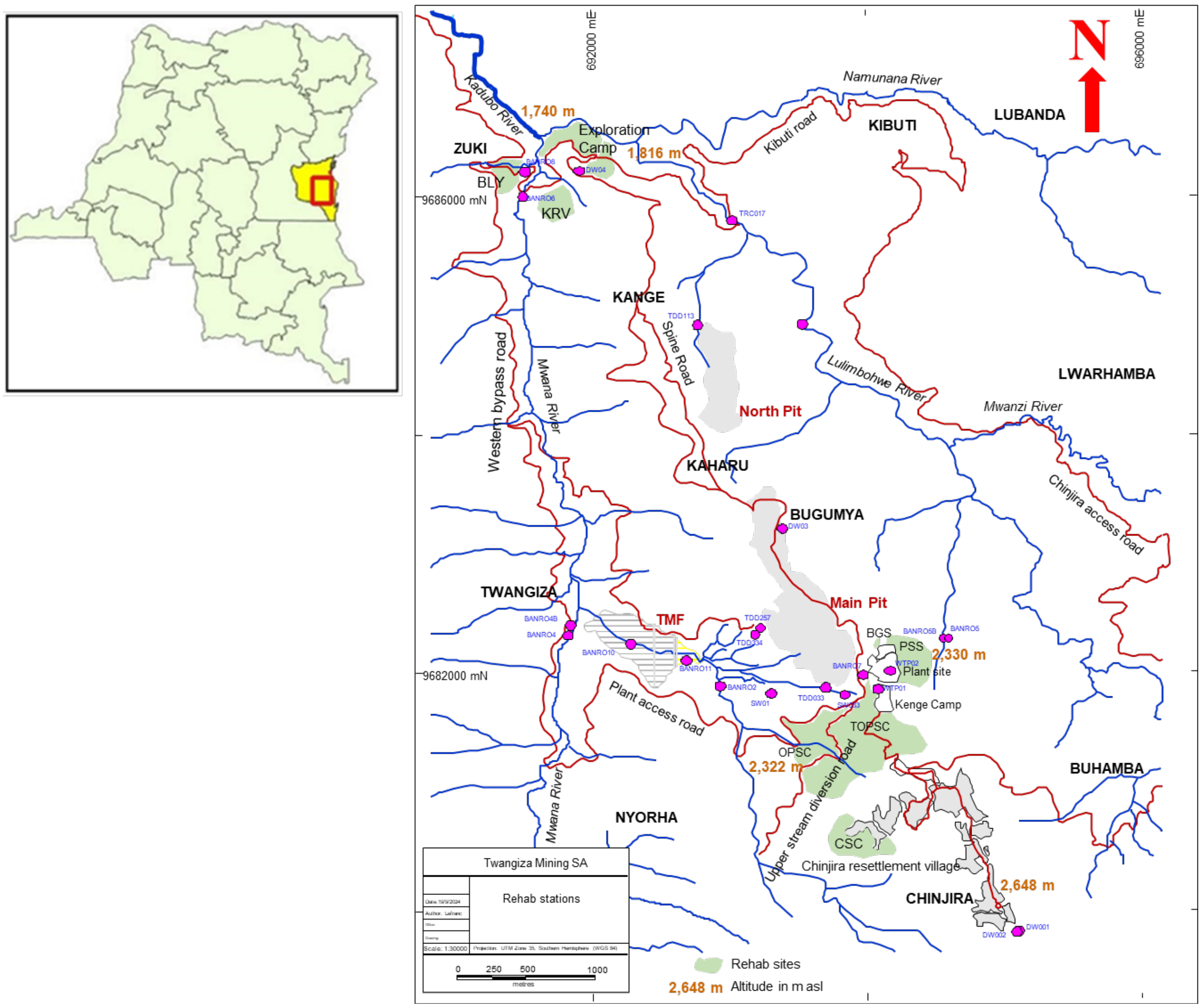

Figure 1. Sampling sites in the Twangiza Mining area.

The characteristics of the sites from which Amphibians and reptiles were collected are presented in **Table 2**.

Table 2. Characteristics of the amphibian and reptiles' data collection sites.

Locations (sites)	Length (˚)	Lat. (˚)	Height (m)	Features
Operators' Camp	28.74240	−2.87947	2306	Extensive vegetation with trees (*Grevillea* and *Eucalyptus*) and a diversified herbaceous stratum. Beans, maize and sweet potato fields. Camp with uninhabited houses.
Namihombo Nursery	28.74813	−2.87583	2323	Reforestation mainly of *Pinus* with scattered clumps of compound grasses of *Rubus*, *Clerodendron*, etc.
Bonded Laydown yard (BLY)	28.72260	−2.83723	1789	Lowest site. The vegetation is mainly composed of Poaceae (*Imperata cylindrica*). It is separated from a wooded area by the Kashalalo river.
Nyorha village	28.73864	−2.89130	2321	A small dam pond where women come to wash their clothes. Highly populated with *Xenopes* and Brook Frogs, it is bordered by *Typha latifolia* and *Cyperus latifolius*. The surrounding area is wooded with *Eucalyptus* sp. and *Cupressus lusitanica*.
Raw Water	28.76924	−2.88353	2221	A small dam on the Lulimbohwe River. The banks are covered with ferns, with a few vines of *Maessa laceolata, Myrianthus* sp.
Mwiyadrira Bridge	28.761597	−2.88660	2334	A rapid upstream of the Mwiyadrira bridge with vegetation on the right bank on which the amphibian was captured.
Chinjira: Camp Saio	28.74833	−2.88782	2619	*Pinus* woodland on a steep slope with a herbaceous layer.
Chinjira plant Nursery	28.75300	−2.89038	2700	The site is surrounded by a fenced-in area, part of which is covered with natural vegetation and a few *Pinus* and *Grevillea* trees. Another part is ploughed, and under the clods we collected burrowing lizards.

2.2.2. Equipment Used for Amphibians and Reptiles

A GARMIN MAP 64s GPS was used to pick the geographical coordinates of the data collection locations. An Android phone and an XP camera were used to capture photos of the specimens and the habitat surveyed. To facilitate capture at night, we used headlamps and jars to transport the specimen. To preserve the museum specimen, we used 10% formalin and 70% ethanol, and placed them in an airtight jar once labelled. We took care to collect a sample for molecular analysis at a later date.

2.2.3. Data Collection Method for Amphibians and Reptiles

Fieldwork was carried out during the day between 8am - 11am and 3pm - 5pm, and in the evening between 6pm - 9pm. Visual detection, opportunistic method or field raking [25] [26] were used during day and night, associated with the search of potential animal refuges such as litter, loose soil for burrowing species. Some data (lizards) were obtained by pitfall, a method that was used for small mammals' collection. Eight locations were visited (**Figure 1**) for the investigations, and their characteristics are listed in **Table 1**. The interview technique was used to obtain information on the presence of snakes that we did not have the opportunity to collect during the fieldwork. Once collected, specimen were photographed alive and some were preserved for museum collection. Identification was based on the reptile and amphibian charts of [27] and the species status from [28].

Some specimen were preserved for later molecular analysis. Specimen were first placed in 10% formalin for 48 hours. They were then washed with running water and placed in 70% ethanol. This procedure ensures long-term preservation of the specimens. Each specimen is labelled with its number in the collection.

2.3. Birds

Ornithological data were collected by direct observation and mist-netting [29] [30]. Captures were made at 5 different stations (**Figure 1**). Observations consisted of walking along the tracks of specific birds in the woodlands on non-standardized routes and recording all birds seen or heard. As most birds are most active in the morning, active searches were generally carried out every day between 6.30 and 9.30 am, with afternoon observations around 3 pm at sunset.

Birds were captured using 6 mist nets measuring 12 m in length, 4 m in width and 36 mm in mesh size. The birds captured were first removed alive from the net and placed in a small cloth bag to keep them calm. They were then identified. Before releasing them at their capture station, the specimen were marked by cutting off the end of the first left rectrix with a pair of scissors, to avoid duplication.

Birds were identified according to morphological criteria based on feather, leg and beak coloration; beak shape, color of the region around the iris using the keys of [31].

2.4. Small Mammals

Small mammals were collected by three types of traps: 1) **spring-loaded metal rod traps**; 2) **Sherman traps** are rectangular aluminum or wooden boxes measuring 7.5 × 9 × 23 cm, fitted with an entrance and a trigger device through which the animal must pass before reaching the bait. Once attracted by the bait, the animal enters the box, triggers this device which closes the entrance, imprisoning it for having stepped on the trigger platform before accessing the bait; before reaching the bait. Clappers and Shermans were used to harvest rodents. 3) **Pitfall** involves burying buckets with a capacity of 26 × 26 × 19 cm (bucket depth, upper internal diameter, basal internal diameter) at ground level, with bottoms perforated so as not to retain rainwater. The buckets are spaced 5 m apart. They are also crossed at their axes of symmetry by a sheet of tarpaulin around 45 cm high. The sheet forms a barrier to shrews, supported vertically by sticks. The part of the tarpaulin in contact with the ground is sunk to a depth of around 5 cm, to completely block the passage of the shrews underneath. We used 42 buckets, 21 per line, at each sampling site. Pitfalls were used to sample shrews.

3. Results

The inventory made revealed a total of 22 insect genera, 4 amphibian species, 11 reptile species, 43 bird species and 11 small mammal species. The results are presented in tables and graphs. The fauna, is an indicator of restoration success [32] [33], which can further influence vegetation recovery, such as through changes in seed dispersal by faunal vectors [34].

3.1. Insects

The taxonomic list of insect genera is given in **Table 3**.

Table 3. Taxonomic list of insect genera inventoried at Twangiza.

N°	Order	Family	Subfamily	Genus
1	Orthoptera	Tettigonidae	Phaneropterinae	Zeuneria
				Morgenia
			Conocephalinae	Ruspolia
		Acrididae	Acridininae	Odontomelus
			Catantopinae	Pteroptera
			Oxyinae	Caryanda
			Cyrtacanthacridinae	Cyrtacanthacris
2	Hymenoptera	Apidae	Xylocopinae	Xylocopa
			Apinae	Apis
		Vespidae	Polistinae	Belonogaster
		Sphecidae	Sphecinae	Sphex
3	Lepidoptera	Pieridae	Pierinae	Ascia
		Noctuidae	Acronictinae	Acronicta
		Sphingidae	Macroglossinae	*Euchloron megaera*
			Sphinginae	Sphinx
		Nymphalidae	Nymphalinae	Charaxes
4	Coleoptera	Curculionidae	Curculioninae	Dorytomus
		Mycetophagidae	Mycetophaginae	Litargus
		Chrysomelidae	Chrysomelinae	Aulacophora
5	Hemiptera	Miridae	Mirinae	Adelphocoris
				Phylus
6	Odonata	Libellulidae	Libellulinae	Libellula

The insects found at the Twangiza mine site belong to 6 orders, 14 families, 20 subfamilies and 22 genera. Several subfamilies here have a single genus; but the Phaneropterinae and Mirinae encompass 2 genera each. The Acrididae family encompasses 4 subfamilies and 4 genera, more than any other family, followed by the Tettigonidae with 2 subfamilies subdivided into 3 genera. The Apidae, Sphingidae and Miridae families include 2 subfamilies each, and each subfamily is divided into 1 genus. The order Orthoptera is the most represented by genus, with 7 genera on its own, followed by the order Lepideroptera with 5 genera, and last is the order Odonata with only one genus.

The high representativeness of Orthoptera in this ecosystem can be explained by their adaptability and habitat diversity, as they are known to adapt to diverse habitats ranging from grasslands to forests and even urban areas; also, their ecological flexibility enables them to colonize various environments and this contributes to their abundance [35]; this is also so considering the abundance of food resources, as they are herbivores and feed on various plant parts. The availability of food resources in a vegetation-rich ecosystem favors their growth and reproduction [36]. The presence of a diversity of habitats and food resources best explains the representativeness of Orthoptera in Twangiza, but environmental conditions such as temperature, relative humidity and available resources and the scarcity of predators or competitors must also be taken into account [37] [38]. The presence of hymenopterans, lepidopterans and coleopterans in the Twangiza ecosystem can be explained by the presence of flowering plants, as they are major pollinators [39]. During the inventory, despite the dry season, there were still plants with flowers on which these insects were looking for nectar for their diet. Therefore, we cannot undermine the presence of food resources as one of the factors explaining the presence of hymenopterans in an ecosystem; but also their adaptability to different inhabitants ranging from tropical forests to deserts [40]. Note that lepidopterans, coleopterans and hemipterans are also good indicators for assessing ecosystem health, as their diversity and abundance can reflect the state of habitats and environmental impacts such as pollution or climate change [41].

Odonata are not well represented here, as they are an order of insects that depend on water, as Twangiza is a montane environment with few flowing waters or springs.

16 genera were found at the Operators' Camp, 14 genera at the Exploration Camp (Ciramo) and 13 genera at each of the plant Nurseries (Namihombo and Cinjira) and at Cinjira (Camp Saio) sites. At the first two sites, there is still a lot of grass to provide insects with a food resources; whereas in the last two sites, the trees are tightly packed together and are already very tall, preventing the grass from developing as a result of their canopy. The number of genera is similar as the entire hill is made up of identical microhabitats. Few genera were captured at night, as a result of the strong draught. Insects do not stand strong drought, as this can either cut off their wings during flight or sweep the whole insect away;

consequently, they remain camouflaged in the grass so as not to be destroyed and die.

All of these genera are known in the Afrotropics. They occupy Central and East Africa. Their presence in tropical Africa is due to their adaptability, habitat diversity, availability of food resources and favorable environmental conditions, despite the presence of predators such as birds, reptiles, amphibians and mammals.

3.2. Amphibians and Reptiles

Reptiles were represented by the order Squamates with its two Suborders. The Suborder Saurians with four Families: the Family *Chamaeleonidae* with two species (*Trioceros ellioti* and *Trioceros rudis*), the Family *Gekkonidae* with a single species *Hemidactylus mabouia*, the Family *Lacertidae* with the species *Congolacerta vauereselli* and the Family *Scincidae* with four species: *Trachylepis maculilabris*, *Leptosiaphos graueri* and *Leptosiaphos sp*.

As for the Ophidian suborder (snakes), we learned about local species by talking to the local people. The species cited are: *Philothamnus* sp. and *Naja melanoleuca* are the most frequently encountered, while *Bitis arietans* and *Afrotyphlops* sp. have become rare in the region. These are listed in **Table 4**.

Table 4. List of snake species (reptiles) observed by local residents (interviewed).

Species	Family	Common name	Common name	IUCN status
Philothamnus sp.	Colubridae	Garter snake	Chirazi (Mashi) or Nakasé (Kilega)	-
Naja melanoleuca	Elapidae	Black forest cobra	Igu (Mashi)	LC
Bitis arientans	Viperidae	Hedge viper	Chibugusha (Mashi)	LC
Afrotyphlops sp.	Typhlopidae	Blind snake	Kikongo-pili (Kilega)	-

It shall be noted that caution must be made on the reliance on local interviews for snake species identification. However, it is clear that they are available as observed at several instances. What justifies the use of their scientific identification is the local knowledge of their vernacular names in local languages (Mashi, and Kilega).

The IUCN Red List [32] shows the endangered *Leptosiaphos graueri,* a burrowing lizard that lives in litter and loose soil in less disturbed areas and which deserves special attention for conservation.

Amphibians were represented by the Order Anurans. The specimens collected belonged to two families: Pyxicephalidae, with two species: *Amietia desaegeri* and *Amietia* sp, and Pipidae, with two species: *Xenopus laevis* and *Xenopus wittei* (photos in appendix). These are presented in **Table 5**.

Figure 2 displays Amphibians and lizards (reptiles) average counts per site.

The species *Xenopus laevis* predominates in average numbers, followed by

Amieta desaegeri, and *Xenopus wittei*. Their maxima respectively reach 29, 21 and 15 vs all the others (max 4 - 8). Regarding abundance-dominance, high similarities exist between Xenopus species and Amieta (>97%) on the one hand, and between *Triceros rudis*, (unlike *Triceros ellioti*) vs both Leptosiaph species (85% - 90%) on the other hand. *Hemidactylus mabouia* and *Trachylepis maculilabris* are very similarly distributed in abundance (>97%) and they are very distinct from the other species (55%). *Congolacerta vauereselli* and Amieta show low similarities with any other species. This is displayed in Figure 3.

Table 5. List of amphibian and lizard species observed.

Species	Common Name	IUCN Status	Operators' Camp	Namihombo Nursery	Laydown Yard	Nyorha	Raw Water	Mwiya drira Bridge	Chinjira Camp Saio	Chinjira Nursery	Total
Amietia desaegeri	De Saeger river frog	LC	0	0	0	19	2	0	0	0	21
Amietia sp.	Brook frog	-	0	0	0	0	3	1	0	0	4
Xenopus laevis	Xenope/African clawed frog	LC	0	0	0	29	0	0	0	0	29
Xenopus wittei	Wittei's Xenopus	LC	0	0	0	15	0	0	0	0	15
Trioceros ellioti	Elliot's ruffed chameleon	LC	0	2	1	1	0	0	0	0	4
Trioceros rudis	Rwenzori bearded chameleon	LC	2	0	0	2	0	0	2	2	8
Hemidactylus mabouia	Domestic gecko	LC	0	0	6	0	0	0	0	0	6
Congolacerta vauereselli	Forest sparse-scaled lizard	LC	5	1	0	0	0	0	0	0	6
Trachylepis maculilabris	Spotted-lipped mabuya	LC	0	0	2	0	0	0	0	0	2
Leptosiaphos graueri	Five-fingered skink	AT	0	0	0	0	0	0	3	2	5
Leptosiaphos sp.	-	-	0	0	0	0	0	0	2	0	2

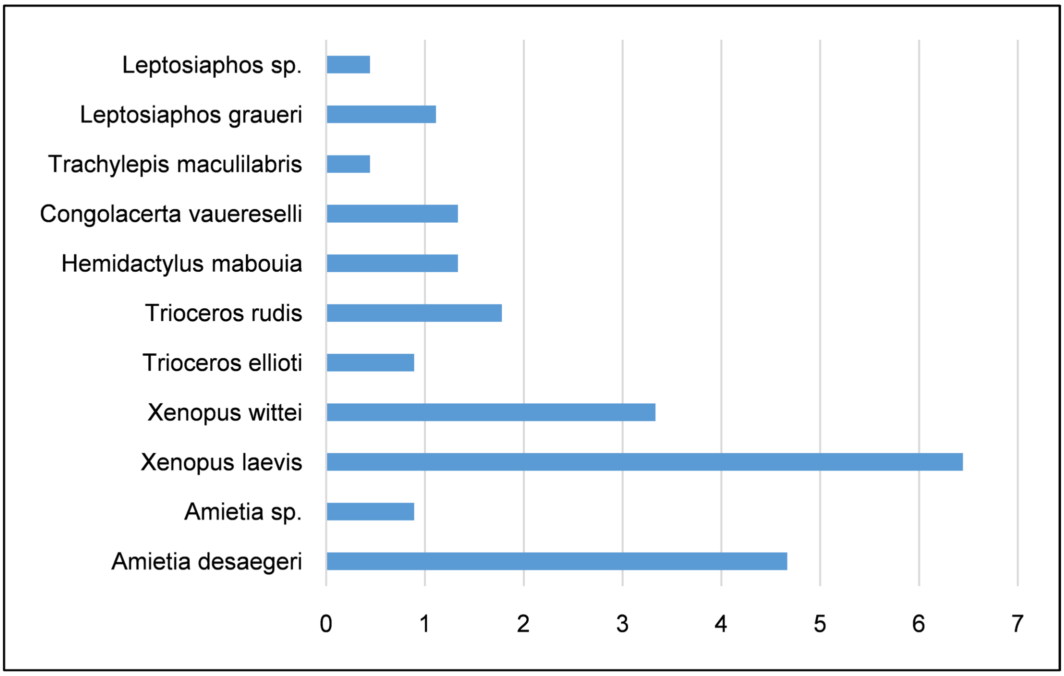

Figure 2. Amphibians and lizards average counts per site.

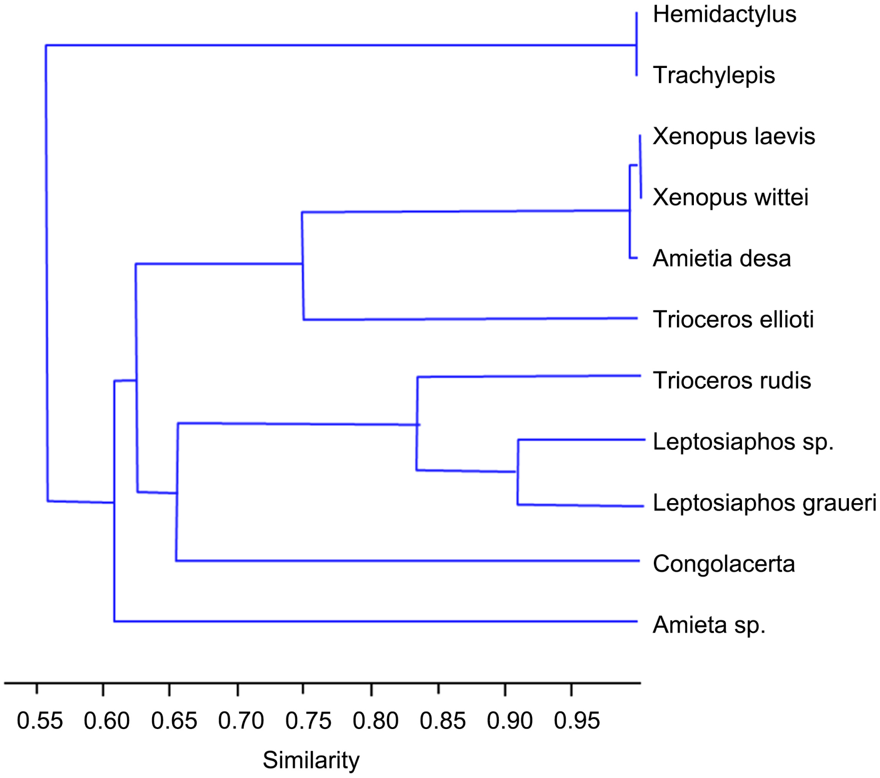

Figure 3. Abundance similarities for Amphibian species.

3.2.1. Abundance-Dominance Diversity Indices

Regarding abundance, the occurrence of some dominant amphibian species diminishes in the distance descriptor as we move from the Operators' camp towards

Cinjira Camp Saio (Dominance D). Thus, in decreasing order: Operators' camp, Namihombo, Laydown Yard, Nyorha, Raw water, Bridge, Cinjira Camp Saio and Cinjira Nursery. This is inversely illustrated by Simpson 1-D. The species with many individuals occur at Nyorha, followed with Chinjira Camp Saio and Laydown Yard. Elsewhere, the counts for various species are similar and lower. Evenness is lowest at Nyorha, as confirmed by the Menhinick index too. The equitability was slightly similar everywhere, except for the Mwiyadrira Bridge with minimum equitability, as only *Amieta sp.* was encountered there, as presented in **Table 6**.

Table 6. Indices for abundance-dominance.

	Operators' Camp	Namihombo Nursery	Laydown Yard	Nyorha	Raw Water	Mwiyadrira Bridge	Chinjira Camp Saio	Chinjira Nursery
Taxa_S	2	2	3	5	2	1	3	2
Individuals	7	3	9	66	5	1	7	4
Dominance_D	0.5238	0.3333	0.4444	0.3184	0.4	NAN	0.2381	0.3333
Simpson_1-D	0.4762	0.6667	0.5556	0.6816	0.6	NAN	0.7619	0.6667
Shannon_H	0.6697	0.8032	0.9598	1.256	0.773	0	1.222	0.8181
Evenness_e^H/S	0.9768	1.116	0.8704	0.7025	1.083	1	1.131	1.133
Brillouin	0.4349	0.3662	0.6144	1.126	0.4605	0	0.7639	0.4479
Menhinick	0.7559	1.155	1	0.6155	0.8944	1	1.134	1
Margalef	0.5139	0.9102	0.9102	0.9547	0.6213	0	1.028	0.7213
Equitability_J	0.9662	1.159	0.8736	0.7806	1.115		1.112	1.18
Fisher_alpha	0.9354	2.622	1.576	1.256	1.235	0	1.989	1.592
Berger-Parker	0.7143	0.6667	0.6667	0.4394	0.6	1	0.4286	0.5
Chao-1	2	2.333	3.444	5.492	2	1	3	2
iChao-1	2	2.333	3.444	5.492	2	1	3	2
ACE	2	3	3.938	6	2	1	3	2

3.2.2. Presence-Absence

The highest similarity in species presence-absence only occur between Xenopus species and *Amieta desa* (>80%). More species diversity was found at Nyorha (5), followed with Laydown yard and Chinjira Camp Saio (3). Elsewhere, the species richness was lower and similarly (1 - 2 species). This is shown in **Figure 4**.

The lowest diversity in terms of richness (S) was found at Mwiyadrira Bridge, as confirmed by Chao, ACE, Shannon, evenness, Brillioun and Margalef as presented in **Table 7**.

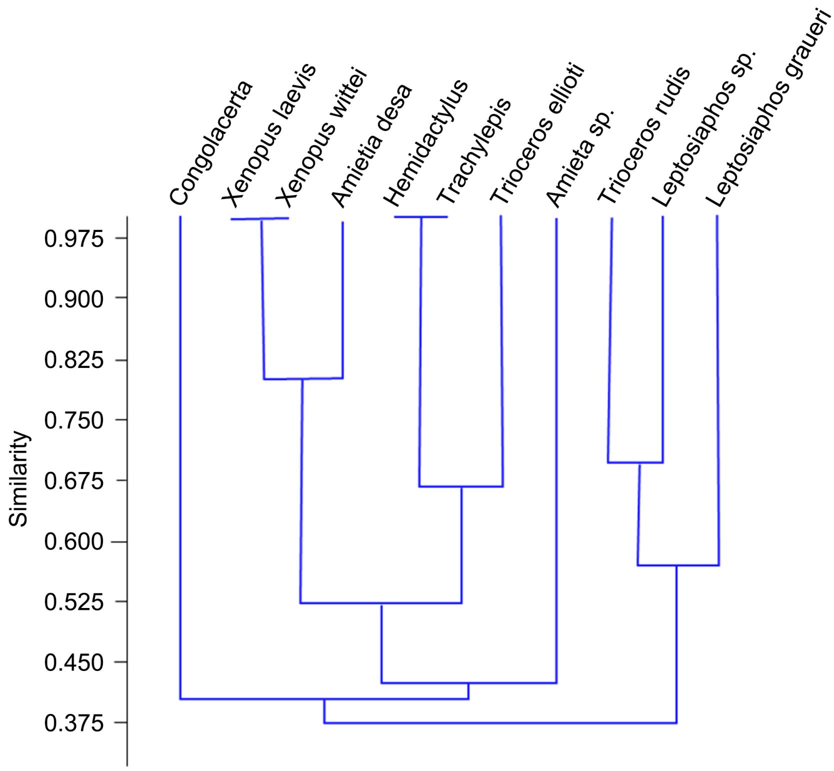

Figure 4. Presence-absence similarities for Amphibian species.

Table 7. Similarity indices for presence-absence of Amphibians.

	Kitumaini Camp	Namihombo Nursery	Laydown Yard	Nyorha	Raw Water	Mwiyadrira Bridge	Chinjira Camp Saio	Chinjira Nursery
Taxa_S	2	2	3	5	2	1	3	2
Individuals	2	2	3	5	2	1	3	3
Dominance_D	0	0	0	0	0	NAN	0	0.3333
Simpson_1-D	1	1	1	1	1	NAN	1	0.6667
Shannon_H	0.9431	0.9431	1.432	2.009	0.9431	0	1.432	0.8032
Evenness_e^H/S	1.284	1.284	1.396	1.492	1.284	1	1.396	1.116
Brillouin	0.3466	0.3466	0.5973	0.9575	0.3466	0	0.5973	0.3662
Menhinick	1.414	1.414	1.732	2.236	1.414	1	1.732	1.155
Margalef	1.443	1.443	1.82	2.485	1.443	0	1.82	0.9102
Equitability_J	1.361	1.361	1.303	1.249	1.361		1.303	1.159
Fisher_alpha	0	0	0	0	0	0	0	2.622
Berger-Parker	0.5	0.5	0.3333	0.2	0.5	1	0.3333	0.6667
Chao-1	2.5	2.5	5	13	2.5	1	5	2.333
iChao-1	2.5	2.5	5	13	2.5	1	5	2.333
ACE	2.5	2.5	5	13	2.5	1	5	3

3.3. Avifauna

3.3.1. Systematic List

Ecosystem restoration is now globally recognized as a key component in conservation programs and essential to the quest for the long-term sustainability of our human-dominated planet. The avifauna inventoried at four sites of the Twangiza mine is divided into 43 species, 22 families and 8 Orders (photos of some species in appendix).

The passeriformes order is the richest as far as families and species are concerned (15 families or around 68.2% and 36 species or 84%). This order is the most represented in the world and in tropical Africa [42]-[44]. Passeriformes (or passerines) is the largest order of birds, with over 6000 species representing 60% of birds.

The Muscicapidae family is the most represented in terms of species (6 species), followed by the Estrildidae (5 species) and three families with 3 species each (Cisticolidae, Nectarinidae and Malaconidae). Several studies have shown that the family of Muscicapidae is widely distributed in various habitats across the world. Birds of this family exhibit great diversity in morphology, behaviors, vocalizations, and life history, which makes Muscicapidae a great study group to address various questions on evolution, diversity and biogeography [45]-[47]. The systematic list of bird species recorded in the Twangiza Mining woodlands is shown in **Table 8**.

Table 8. List of bird species encountered in the restored Twangiza ecosystems.

Orders	Families	Species	Common names
Galiformes	Phasianidae	*Pternestes afer*	Red-necked Francolin
Falconiformes	Falconidae	*Falco chiquera*	Red-necked Falcon
Falconiformes	Accipitridae	*Milvus migrans*	Black Kite
Cuculiform	Cuculidae	*Centropus monacus*	Blue-headed Coucal
		Cercocossyx olivinus	Olive Long-tailed Cuckoo
Coliiforms	Coliidae	*Colius striatus*	Seckled Mousebird
Coraciiformes	Coraciidae	*Erystomus glaucurus*	Broad-billed Roller
Passeriformes	Laniidae	*Lanius makinoni*	Mackinnon's Shrike
		Lanius cullurio	Red-backed Shrike
	Corvidae	*Corvus albus*	Crow foot
	Monarchidae	*Terpsiphone viridis*	African Paradise-Flycatcher
	Hirundinidae	*Hirundo angolensis*	Angola Swallow
	Pycnonotidae	*Pycnonotus barbatus*	Common Bulbul

Continued

	Cisticolidae	*Cisticola chubby*	Chubb's Cisticola
		Cisticola erythrops	Red-faced Cisticola
		Camaroptera brachyuran	Green-backed camaroptera
	Muscicapidae	*Cossypha cafra*	Cape Robin-Chat
		Cossypha heuglini	White-browed Robin-Chat
		Muscicapa adusta	African Dusky Flycatcher
		Saxicola torquatus	African stonechat
		Saxicola rubetra	Whinchat
		Fraseria caerulescens	Ashy Flycatcher
	Platysteiridae	*Batis molitor*	Chinspot Batis
	Zosteropidae	*Zosterops senegalensis*	African Yellow White-eye
	Nectarinidae	*Nectarinia climensis*	Bronze Sunbird
		Cyanomitra verticalis	Green-Headed Sunbird
		Cinnyris chloropygius	Olive-bellied Sunbird
	Malaconotidae	*Laniarius major*	Tropical Boubou
		Dryoscopus cubla	Black-backed Puffback
		Telophorus dohertyi	Doherty's Bushshrike
	Montacillidae	*Montacilla aguimp*	African Pied Wagtail
		Anthus cinnamomeus	African Pipit
	Emberizidae	*Emberiza flaviventris*	Golden-breasted Bunting
		Linurgus olivaceus	Oriol Finch
	Fringilidae	*Crithagra frontalis*	Western Citril
		Crithagra striolatus	Streaky Seedeater
	Ploceidae	*Passer griseus*	Gray-headed Sparrow
		Ploceus baglafecht	Baglafecht Weaver
	Ploceidae	*Ploceus xanthops*	Holub's Golden-Weaver
	Estrildidae	*Euschistospiza cinereovinacea*	Dusky Twinsport
		Coccopygia cartinia	Yellow-bellied Waxbill
		Estrilda nonnula	Black-Crowned Waxbill
		Estrilda atricapila	Black-headed Waxbill
		Astrilda kandti	Kandt's Waxbill

3.3.2. Species Distribution at the Sites

Figure 5 shows the bird species richness of the sites investigated. bird species recorded.

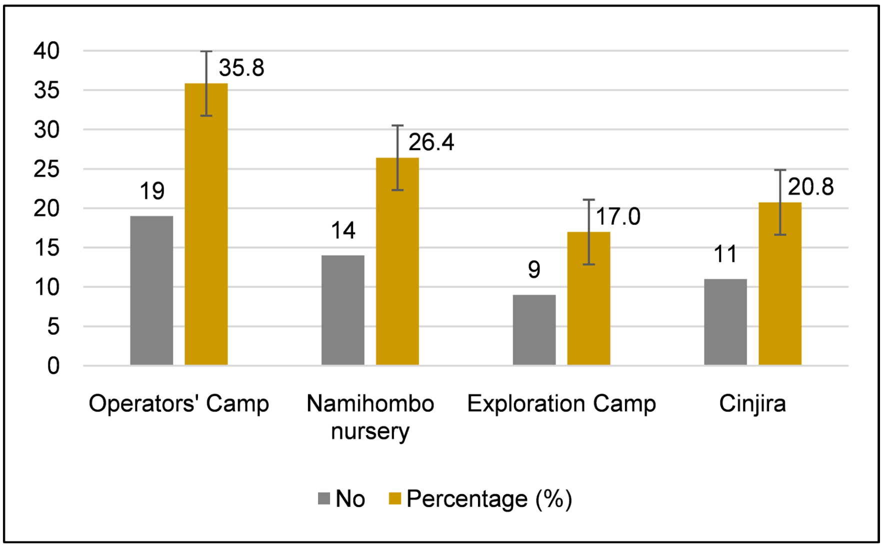

Figure 5. Number of species recorded at survey sites and percentage of occurrence per site, with confidence intervals (error bars).

It can be seen that the largest number of species (19) was recorded at the Operators' Camp and surrounding areas. The Namihombo plant Nursery site was next, with 14 species, and last site was Ciramo, with only 9 species.

The most abundant species at all sites are the Striped Collie, *Colius striatus;* followed by the Baglafecht Weaver, *Ploceus baglafesht* and the Yellow-bellied Astrid, *Coccopygia cartinia.*

Some species were only observed or captured at some sites, such as *Linurgus olivaceus*, *Fraseria caerulescens*, *Cinnyris chloropygius* and *Estrilda kandti* at the the Operators' Camp site, and *Saxicola rubetra* and *Camaroptera brachiura* at the Namihombo plant Nursery site. The species *Batis molitor* and *Cossypha heuglini* were observed only at Ciramo, and *Pternestes afer* and *Anthus cinnamomeus* at the Cinjira site.

Prior to the beginning of Twangiza Mining exploitation activities and 4 years before the ecological rehabilitation in the area, environmental and social impact studies were carried out. Thirty-eight bird species were recorded [48]. During our survey, 22 more species were added to the Twangiza bird list as encountered during these studies. These results clearly demonstrate the positive impact of the decade-fold reforestation activity on bird diversity in this area. Ecosystems restored by man are of great importance for the reception and refuge of various forms of life [4].

3.3.3. Species Richness

The following species presented in **Table 9** reached at least 2 counts at each site.

Table 9. List of species per sampling site with at least 2 counts.

Cinjira	Ciramo	Namihombo	Operators' Camp
Crithagra frontalis	*Colius striatus*	*Hirundo angolensis*	*Colius stiatus*
Motacilla aguimp	*Pycnonotus barbatus*	*Colius striatus*	*Ploceus baglafesht*
Pternestes sfer	*Milvus migrans*	*Pycnonotus barbatus*	*Coccopygia cartinia*
Crithagra striolatus	*Terpsiphone viridis*	*Crithagra frontalis*	*Estrilda atricapila*
Anthus cinnamomeus	*Nectarinia kilimensis*	*Zosterops senegalensis*	*Cisticola chubby*
	Batis molitor	*Cossypha caffra*	*Telophorus doherti*
		Motacilla aguimp	*Pycnonotus barbatus*
		Cisticola chubby	*Centropus monacus*
		Emberiza flaviventris	*Terpsifphone viridis*
			Ploceus xanthops
			Estrilda kandti
			Cinnyris chloropygius

Hirundo angolensis and *Colius striatus* outnumbered any other species at the Namihombo site. The latter also predominated at the Operators' camp and at the Ciramo camp.

Table 10 shows the confidence intervals between sampling/observation sites for bird species.

Table 10. Metrics of bird species identified at sampling/observation stations to determine significance.

	N	Mean	95% Confidence Interval		SD	Minimum	Maximum	CV
			Lower	Upper				
Cinjira	42	0.9	−0.0309	1.84	3	0	19	331.49
Ciramo	42	1	−0.0528	2.05	3.38	0	21	338
Namihombo	42	4.7	−0.5326	9.87	16.68	0	98	357.40
Operators' Camp	42	2.9	−0.1085	5.92	9.67	0	61	332.87

Birds were mostly observed in large numbers at Namihombo, followed by the Operators' camp, where the respective maxima were up to 98 and 61. It shall be noted that Namihombo is an enclosed nursery with a very large number of plant species and flowers that are believed to attract bird species in a very conducive environment. The Operators' Camp on the other hand has a very rich soil with lots of trees and a few flowers growing therein. Both Namihombo and Operators'

Camp have altitudes just above 2300 m asl.

Elsewhere, the maxima reached 19 - 21. The variations were so high whatever the site (cv = 331% - 357%); with many zero counts. The highest number of birds occurred at Namihombo and the lowest at Cinjira (high D and N; low equitability J and Pielou alpha). The numerical importance of the most abundant species is illustrated at Namihombo by the Berger-Parker Dominance index.

Table 11 shows the abundance-dominance index.

Table 11. Abundance—dominance index.

	Cinjira	Ciramo	Namihombo	Operators' Camp
Taxa_S	11	9	13	16
Individuals	19	21	98	61
Dominance_D	0.070	0.11	0.28	0.11
Simpson_1-D	0.93	0.88	0.72	0.89
Shannon_H	2.52	2.21	1.81	2.51
Evenness_e^H/S	1.13	1.01	0.47	0.77
Brillouin	1.7	1.58	1.576	2.06
Menhinick	2.52	1.96	1.31	2.05
Margalef	3.39	2.63	2.62	3.65
Equitability_J	1.05	1.01	0.71	0.90
Fisher_alpha	10.9	5.97	4.02	7.06
Berger-Parker	0.21	0.28	0.49	0.26
Chao-1	14.55	9.71	14.48	16.84
iChao-1	17.67	10.56	15.64	17.57
ACE	17.2	11.2	16.48	19.13

3.3.4. Presence-Absence

Regarding the presence-absence values, the number of species was highest at the Operator's camp followed by Namihombo as illustrated by the diversity indices (high richness S, individuals N, Shannon H, Brillioun, Menhinick, Chiao-1, ACE vs low equitability J and Berger-Parker), as shown in Table 12.

3.4. Small Mammals

Eleven species of small mammals were captured in the Twangiza mine area, including 6 rodent species, 4 shrew species and one chiropteran species as shown in Table 13.

Table 12. Indexes on presence-absence of bird species.

	Cinjira	Ciramo	Namihombo	Operators' Camp
Taxa_S	11	9	14	19
Individuals	11	9	14	19
Dominance_D	0	0	0	0
Simpson_1-D	1	1	1	1
Shannon_H	2.852	2.642	3.103	3.418
Evenness_e^H/S	1.575	1.56	1.591	1.606
Brillouin	1.591	1.422	1.799	2.071
Menhinick	3.317	3	3.742	4.359
Margalef	4.17	3.641	4.926	6.113
Equitability_J	1.19	1.202	1.176	1.161
Fisher_alpha	0	0	0	0
Berger-Parker	0.09091	0.1111	0.07143	0.05263
Chao-1	61	41	98.5	181
iChao-1	61	41	98.5	181
ACE	61	41	98.5	181

Table 13. List of small mammal species recorded in the Twangiza mining woodlands.

Families	Genus	Species	Number
Sorocidae	Crocidura	*Crocidura bicilor*	6
Sorocidae	Crocidura	*Crocidura niobe*	1
Sorocidae	Crocidura	*Crocidura sp*	1
Sorocidae	Myosorex	*Myosorex sp*	1
Muridae	Lophuromys	*Lophuromys flavopuctatus*	5
Muridae	Dendromys	*Dendromus insignis*	5
Muridae	Mastomys	*Mastomus coucha*	1
Muridae	Rattus	*Rattus rattus*	1
Muridae	Praomus	*Praomys jacksoni*	1
Muridae	Gasymus	*Dasymys incomtus*	2
Chiroptera	Epomophurus	*Epomophorus labiatus*	2

These species are divided into 9 genera and 3 families. *Crocidura bicolor* is the most abundant species, followed by *Lophuromus flavopuctatus, dendromus insignis*, *Dasymys incomtus* and *Epomophorus labiatus*. In addition, two taxa have not been identified to species level: *Crocidura sp* and *Myosorex sp.*; highlighting the need for further taxonomic work. A molecular study is therefore essential for the complete identification of these two specimen.

3.5. Contrasts with the Baseline Study [48]

[48] noted that the remaining indigenous vegetation of Twangiza was limited in extent. Thirty-eight species of birds and forty species of butterflies, but no mammals or reptiles, were recorded within the footprint area. In general, the bird fauna was depauperate both in numbers of species and in abundance. Birds recorded were mainly those of grasslands, and mobile species, which were using scrub along valley streams as a refuge. By far the most common bird was the pied crow (*Corvus albus*) a bird which is almost always associated with human habitation. No rare, threatened, endemic, specialist, protected or red data book listed bird species were encountered. Pockets of vegetation housed quite a variety of butterflies. Most of these were widespread nomadic or Afromontane species. There was one endemic, Albertine Satyrid (*Bicyclus aurivillii*) living along a valley stream. However, this species is found throughout the montane forests of the Albertine Rift region. Apart from this endemic species, no rare, threatened, specialist, protected or red data book listed butterflies were encountered.

Due to the high population density, there was also an increase in number of cattle and the little remaining grassland in the footprint area was overgrazed. Although there was some artisanal mining going on the flanks of the hill, the river itself was the main site of artisanal mining. All riverine vegetation had disappeared along the Twangiza River for several kilometers downstream from the pit. Even without the proposed development of the mine, it was clear that the remaining natural vegetation in the footprint area (apart perhaps from the sacred forest) was under threat and that it is only matter of time before this is also turned into farmland or gets totally degraded and eroded through overgrazing. An estimated 90% of the land had been transformed by anthropogenic activities. From a zoological point of view the little remaining biodiversity was of little importance and required no special attention.

4. Conclusions

The present work shows the importance of reforestation (Twangiza mining case) in the reception and refuge of fauna in the mountainous regions of South Kivu, where 22 insect genera, 4 amphibian species, 11 reptile species, 43 bird species and 11 mammal species are recorded.

Among the **insects**, the order Orthoptera is the most represented, with 7 genera on its own, including the Tettigonids Zeuneria and Morgenia, Ruspolia and the Acridid Odontomelus, Pteroptera, Caryanda and Cyrtacanthacris. Among the butterflies, 5 genera were identified; followed by the order Lepidoroptera with 5 genera, and 3 genera for beetles, and 2 genera for hemipterans. The least represented order is Odonata with only one genus. The Butterflies included the species *Euchloron Megaera* and genera Ascia, Acronicta, *Sphinx and Charaxes.* There were also a few wasps: Belonogaster, Sphex and the bees Xylocopa and Apis.

Reptiles were represented by with two chamaeleon species, *Trioceros ellioti* and *Trioceros rudis* and a single geckonid species *Hemidactylus mabouia; and the lizard Congolacerta vauereselli* and 4 *Scincid* species: *Trachylepis maculilabris*, *Leptosiaphos graueri* and *Leptosiaphos* sp. The snakes *Philothamnus* sp. and *Naja melanoleuca* are the most frequently encountered, while *Bitis arietans* and *Afrotyphlops* sp. have become rare in the region. The IUCN Red List [32] shows the endangered *Leptosiaphos graueri,* a burrowing lizard that lives in litter and loose soil in less disturbed areas and which deserves special attention for conservation. Two Pyxicephalid **amphibian** species, *Amietia desaegeri* and *Amietia* sp, and 2 *Pipids*, *Xenopus laevis* and *Xenopus wittei* were identified.

The most abundant **bird** species at all sites are the Striped Collie, *Colius striatus*, followed by the Baglafecht Weaver, *Ploceus baglafesht* and the Yellow-bellied Astrid, *Coccopygia cartinia.* Prior to mining in the area, environmental and social impact studies were carried out. Thirty-eight bird species were inventoried [48]. During our survey, 22 new species were added to the Twangiza bird list. Our results clearly demonstrate the positive impact of reforestation on bird diversity in this area.

Eleven species of **small mammals** were identified, including 6 rodent species, 4 shrew species and one chiropteran species. *Crocidura bicolor* is the most abundant species, followed by *Lophuromus flavopuctatus, dendromus insignis*, *Dasymys incomtus* and *Epomophorus labiatus*.

In addition, two taxa have not been identified to species level: *Crocidura sp* and *Myosorex sp*. A molecular study is therefore essential for the complete identification of these two specimens.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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