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Variations in the Composition and Structure of Muridae Communities along Gradients of Anthropogenic Disturbance in the Northern Sector of Virunga National Park (PNVi, Democratic Republic of the Congo, Central Africa)

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Abstract

Murid dynamics serve as a sensitive indicator of the conservation status of tropical ecosystems subjected to intense anthropogenic pressures. This study, conducted in the northern sector of Virunga National Park (DRC), assessed the relative abundance, diversity, and spatial distribution of Muridae along a gradient of anthropogenic disturbance to guide sustainable conservation strategies. Data were collected using indirect methods (droppings, footprints, and tracks) along geo-referenced reconnaissance transects. Diversity indices (Shannon, Simpson, evenness), similarity measures, and non-parametric tests (Kendall, Chi-square, Correspondence Analysis) were applied to characterize community structure in relation to habitat types and disturbance intensity. Results revealed high species diversity (H′ = 1.936) and three functional groups: 1) a group restricted to lightly disturbed habitats, composed of *Hybomys lunaris*, *Dasymys montanus*, and *Praomys jacksoni*; 2) a ubiquitous group inhabiting moderately disturbed habitats, including *Lemniscomys striatus* and *Mastomys natalensis*; and 3) an anthropophilic group dominant in heavily disturbed habitats, represented by *Arvicanthis niloticus*. The presence of threatened species such as *Dasymys montanus* (EN) and *Hybomys lunaris* (VU) highlights the high conservation value of lightly disturbed habitats. A significant negative correlation between disturbance intensity and presence indices ($\tau = -0.54$; $p = 0.04$) confirms the detrimental effects of village hunting (37%) and unsustainable agriculture (25%) on forest-specialist species. These findings emphasize that Muridae richness and resilience strongly depend on habitat quality, continuity, and integrity. Strengthening forest relic protection, promoting sustainable community-based management, and establishing integrated ecological monitoring are key conservation priorities.

Keywords

Anthropogenic Disturbance, Conservation, Muridae, Relative Abundance, Species Diversity

1. Introduction

Virunga National Park (PNVi), located in eastern Democratic Republic of the Congo (North Kivu province), on the border with Uganda and Rwanda, is one of Africa's most iconic protected areas [1]-[3]. Created on April 21, 1925 (then under the name "Albert National Park"), it is the continent's first national park and was inscribed on the UNESCO World Heritage List in 1979 for its exceptional volcanic natural values [4]-[6]. With an area of approximately 7800 km^2 and central coordinates close to 0˚S - 29˚15'E, it is home to a mosaic of ecosystems including plains, swamps, Afro-montane forests, volcanic massifs, and areas of the Rwenzori Mountains. Since 1994, due to conflicts and increasing human pressure, it has been regularly included on the List of World Heritage in Danger [2] [3] [5].

The biodiversity of the PNVi is remarkable: more than 200 species of mammals (forest and savanna elephants, hippopotamuses, buffaloes, okapis, bongos, lions, leopards, as well as a rich community of primates, including the mountain gorilla *Gorilla beringei beringei*, *Grauer's gorilla Gorilla beringei graueri*, and the eastern chimpanzee *Pan troglodytes schweinfurthii*), more than 700 species of birds, around 100 reptiles, nearly 80 amphibians, and extremely diverse flora (more than 2000 plant species, including many endemic to the Albertine Rift). These characteristics make the PNVi a true biodiversity hotspot and an ecological pillar on a regional and global scale [6]-[8].

Within this group, rodents (Muridae in particular) play a fundamental functional role. They disperse seeds, contribute to the recycling of organic matter, improve soil dynamics through their burrowing activity, and constitute a key food source for many predators (carnivores, birds of prey, reptiles). Their ecological importance is crucial in maintaining trophic balances and ecosystem regeneration processes [4]-[6]. However, despite this functional value, Muridae are often neglected in conservation strategies, as they are rarely included in international conventions, except in a general way through the Convention on Biological Diversity and the Aichi Targets [2] [3] [5].

However, the sustainability of Muridae populations in the PNVi is seriously compromised by increasing anthropogenic pressures. These include: land conversion and subsistence agriculture, leading to habitat fragmentation and the loss of ecological corridors; fuelwood collection and charcoal production, which degrade the undergrowth and impoverish the habitats of small mammals; mining (often illegal), which causes habitat destruction, pollution, and disturbance; poaching and subsistence hunting, which disrupt food webs by reducing the natural predators of Muridae and can upset population dynamics; armed conflict and insecurity, which promote deforestation and uncontrolled exploitation of resources; and finally, climate change, which alters rainfall patterns and mountain habitats, leading to a spatial redistribution of Muridae communities and their food resources [4]-[6].

These cumulative and synergistic threats exacerbate the degradation of habitats favorable to Muridae, causing the isolation of populations and compromising their ecological role [9]-[11]. Some species are already listed on the IUCN Red List, reflecting their increasing vulnerability [4]-[6].

In this context, there is an urgent need to assess the conservation status of Muridae in the northern sector of the PNVi, by characterizing their relative abundance and diversity along gradients of anthropogenic disturbance. Such an analysis is a prerequisite for guiding the implementation of sustainable management strategies integrated into the long-term planning of Virunga landscape conservation.

2. Material and Methods

2.1. Study Area

The study was conducted in the northern sector of Virunga National Park (PNVi), located in North Kivu Province, in the eastern Democratic Republic of the Congo (**Figure 1**). Covering an area of approximately 7900 km^2, this park stretches from the Virunga volcanic massifs to the Ruwenzori Mountains, encompassing the Rwindi plains and part of Lake Edward, all of which are recognized for their high biological diversity [4]-[6].

Listed as a UNESCO World Heritage Site since 1979, the PNVi presents a unique ecological mosaic that combines three major ecoregions: The Afro-alpine zone, the Afro-montane forest, and the forest-savanna mosaic, to which are added aquatic systems of high ecological and socio-economic value [1]-[3]. Geographically, it is located between 01˚35'S latitude and 29˚01'E-30˚01'E longitude, giving it a strategic position in the Albertine Rift, one of the world's major biodiversity hotspots [4]-[6].

2.2. Data Collection

The data used in this study were derived from both secondary and primary

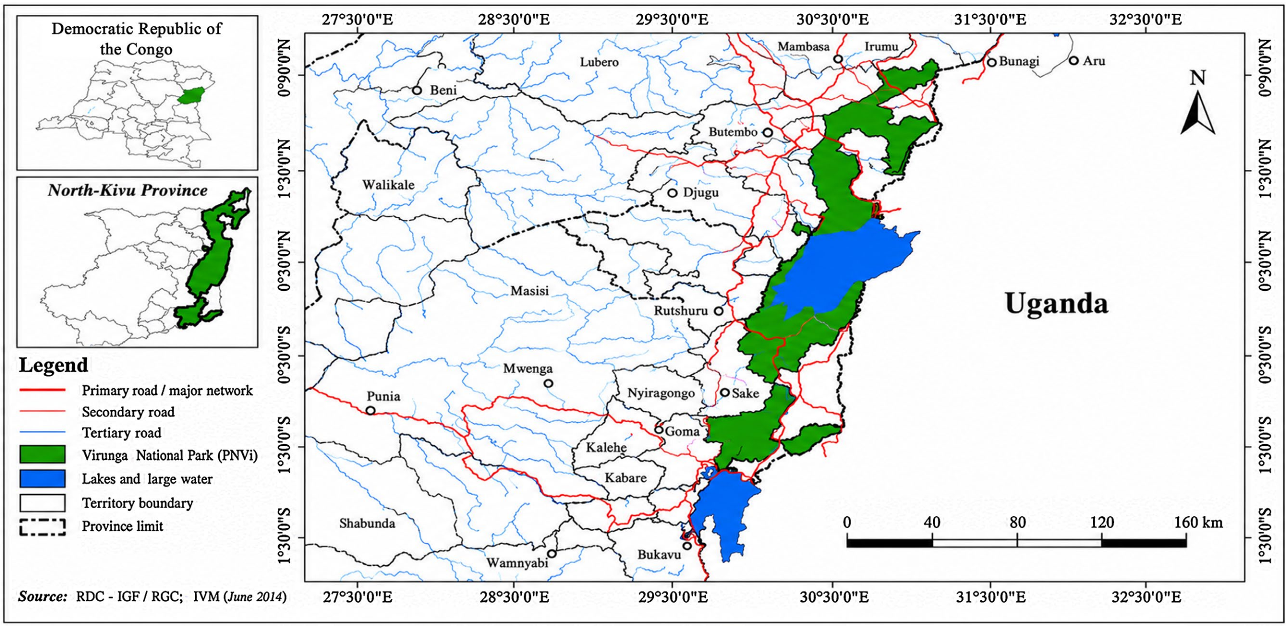

Figure 1. Location of the study area.

sources. Secondary data were obtained through an extensive review of scientific publications, institutional reports, and technical documents related to Muridae and anthropogenic pressures within Virunga National Park.

Primary data were collected between April and June 2025, following a preliminary exploratory survey conducted in March 2025 after obtaining the necessary research permits. This reconnaissance phase enabled the georeferencing of study sites, the characterization of anthropogenic disturbance gradients, and the adaptation of the sampling protocol to local environmental conditions.

Field sampling was carried out along eleven 2-km recce transects (**Figure 2**), randomly distributed within a 2 × 2 km grid system and representing three levels of anthropogenic disturbance (low, high, and very high). Each transect was surveyed for approximately two hours by a team of four observers. Geographic coordinates were recorded using a Garmin eTrex 32x GPS receiver.

Evidence of Muridae occurrence was systematically recorded through both direct and indirect observations. Direct observations consisted of visual sightings of individuals, whereas indirect evidence included footprints, feces, burrows, hair, remains, and carcasses. Species identification was based on the field identification guides developed by [12]. In addition, signs of anthropogenic activities, including traps, fire traces, hunting camps, and cleared areas, were systematically documented along each transect. The collected data were organized and managed using Microsoft Excel 2021 and subsequently analyzed with R version 4.1.0 for statistical analyses, QGIS version 3.44.0 and ArcGIS version 10.8 for spatial analyses and cartographic production, and Google Earth Pro for geographic data visualization and validation.

In the northern sector of the PNVi, sampling was carried out along reconnaissance transects established in the three anthropogenic disturbance gradients. The

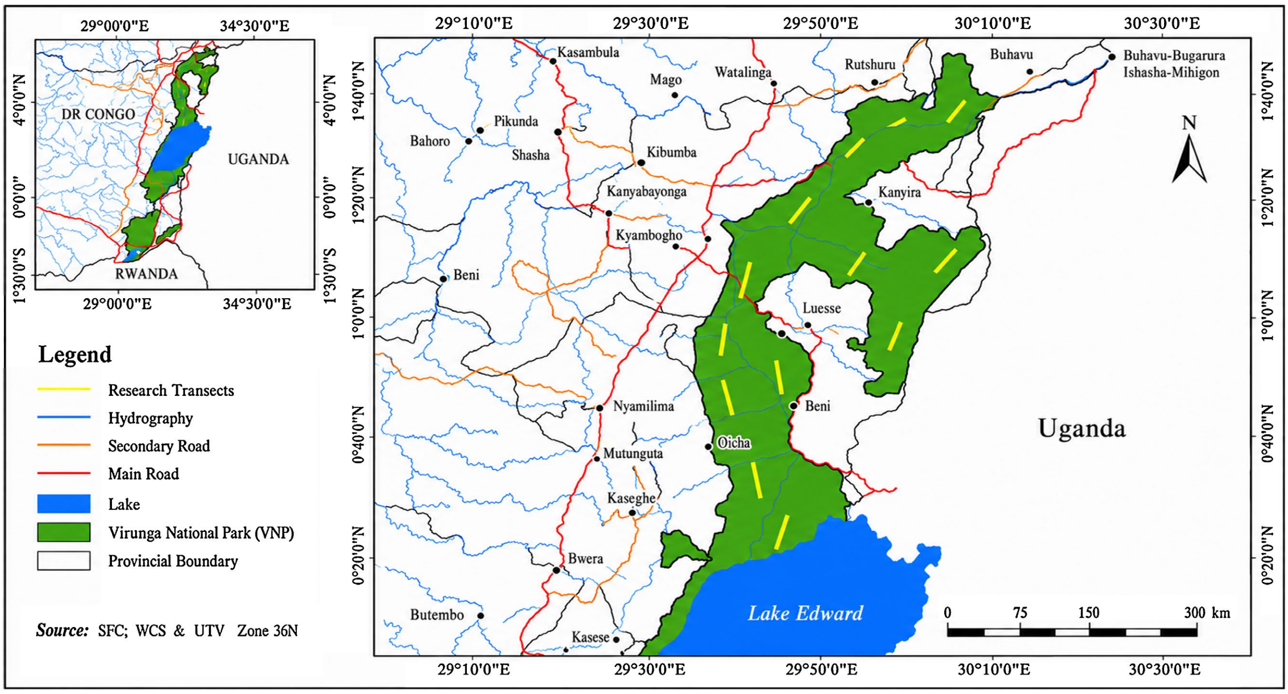

Figure 2. Location of Recce transects in the study area.

operation involved a team of four observers with complementary roles, ensuring the standardization of the surveys. A total of eleven 2 km recce transects were covered at a constant speed (≈two hours per transect) to ensure uniform coverage of the different habitats. The geographical coordinates of the transects and observations were recorded using a Garmin eTrex 32x GPS and systematically recorded on standardized field sheets.

Evidence of Muridae presence was collected in two categories: 1) direct evidence (visual observations of individuals) and 2) indirect evidence (feces, footprints, burrows, hair, food remains, carcasses). Identification was carried out using field guides developed by Kingdon [12]. Simultaneously, signs of human activity (traps, bush fires, temporary huts, and agricultural clearings) were recorded in accordance with the ICCN monitoring protocol [7].

Data from Muridae presence indices were used to estimate their abundance, specific diversity, and spatial distribution according to disturbance gradients. Information on anthropogenic pressures was used to develop a map of human activities, which was integrated and superimposed on the official PNVi Map using Google Earth and ArcGIS, in order to analyze the spatial correspondence between disturbances and the dynamics of Muridae communities.

2.3. Data Analysis

2.3.1. Specific Abundance and Presence Indices of Muridae

The frequency of occurrence was estimated using the encounter rate (ER), defined by the following formula:

$$ER = (n/L) \times 100,$$

where n is the total number of indices observed and L is the total length of the transects (in km).

2.3.2. Mapping the Spatial Distribution of Muridae

The GPS coordinates of Muridae presence indices and signs of human activity were integrated into QGIS 3.44.0, ArcGIS 10.8, and Google Earth (2025). These data were then overlaid on the official map of Virunga National Park to generate accurate georeferenced maps illustrating the location of recce transects, the spatial distribution of Muridae species, and the distribution of anthropogenic disturbance gradients in the northern sector of the park.

2.3.3. Diversity Indices

Specific diversity, following the approaches proposed by Jost [13] and Piélou [14], was measured using three ecological indices:

- Shannon-Wiener index (H′): $H' = -\sum (pi \times \log_2 pi)$, where $pi = ni/N$;
- Simpson index (IS): $D = \sum [ni\ (ni - 1)]/[N\ (N - 1)]$; $IS = 1 - D$;
- Piélou's evenness index (J′): $J' = H'/\log S$.

2.3.4. Correspondence Factor Analysis (CFA)

A correspondence factor analysis (CFA) was performed to examine the relationships between the relative abundance of Muridae and anthropogenic disturbance gradients. This multivariate method allows for the visualization of associations and dissociations between species and habitats, while quantifying the contribution of each species and each habitat to the total inertia of the data set [15].

2.3.5. Statistical Tests

Two statistical tests were used to examine the relationships between anthropogenic disturbance gradients and Muridae presence indices. Kendall's correlation test, which is non-parametric and robust to extreme values, was chosen because of the non-normality of the variable distributions. At the same time, the Chi-square (χ^2) test was used to assess the association between the distribution of Muridae presence indices and the intensity of disturbances, as defined according to anthropogenic disturbance gradients.

3. Results

3.1. Relative Abundance and Diversity of Muridae in the Study Area

3.1.1. Encounter Rate of Muridae Based on Presence Indices

In the northern sector of Virunga National Park, the presence of Muridae was confirmed using ten types of indirect indices (**Figure 3**). Among these, the most frequently observed were droppings (21.7%) and footprints (17.4%), followed by carcasses (13.8%), gnaw marks (12.2%), burrows (11.7%), and food remains and hair (8.3% each). These results highlight the diversity of evidence that can be used to assess the presence and activity of Muridae in different habitats and disturbance gradients.

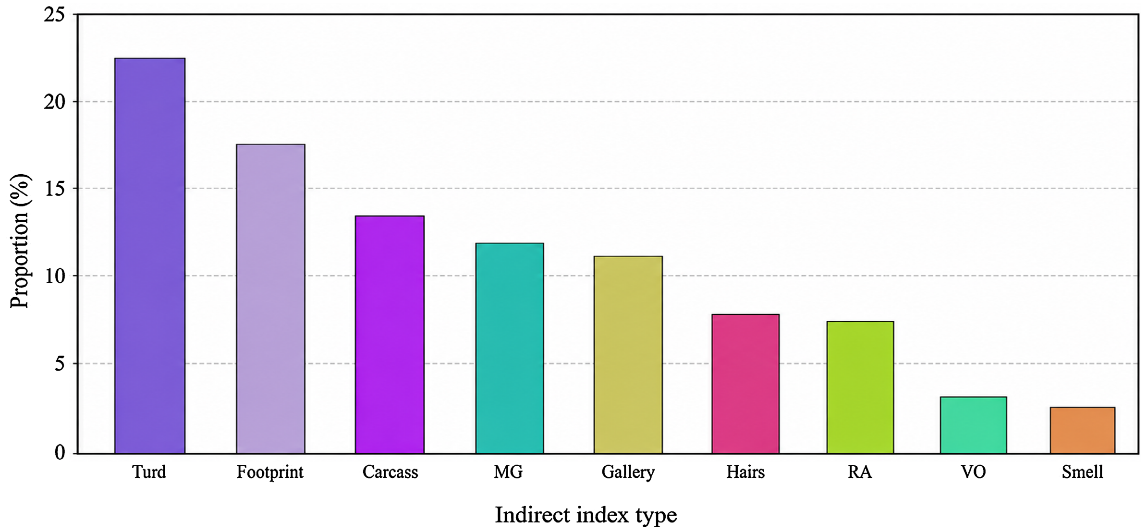

Figure 3. Proportion of indirect signs of rodent presence in the PNVi (MG = gnaw marks; RA = food remains; VO = vocalization).

3.1.2. Relative Abundance of Muridae in the Study Area

Table 1 shows the encounter rates of Muridae along 11 survey transects distributed according to the three anthropogenic disturbance gradients, based on 253 direct indices recorded. The most frequently observed species are *Arvicanthis niloticus* (22.1%; 2.54 signs/km) and *Lemniscomys striatus* (17.8%; 2.04 signs/km), indicating high abundance or activity in the study area. Conversely, *Dasymys montanus* (5.9%; 0.68 signs/km), *Oenomys hypoxanthus* (5.1%; 0.59 signs/km) and *Praomys jacksoni* (4.7%; 0.54 signs/km) had lower encounter rates, suggesting either a low presence or a reduced probability of detection in these habitats.

Table 1. Encounter rate (number/km) and relative abundance (%) of Muridae.

Species	Distance (km)	Number of direct observations	Encounter rate (number/km)	%
D. montanus	22	15	0.68	5.9
L. striatus	22	45	2.04	17.8
M. natalensis	22	31	1.40	12.3
G. kuru	22	25	1.13	9.9
O. tropicalis	22	37	1.68	14.6
O. hypoxanthus	22	13	0.59	5.1
H. lunanis	22	19	0.86	7.5
A. niloticus	22	56	2.54	22.1
P. jacksoni	22	12	0.54	4.7

3.1.3. Grouping of Muridae Species According to Relative Abundance

In Virunga National Park (PNVi), correspondence analysis (CA) based on the relative abundance of Muridae species revealed three groups structured along gradients of anthropogenic disturbance (**Figure 4**). The first group, associated with habitats subject to moderate disturbance, includes five species typical of relatively preserved environments: *Hybomys lunaris, Dasymys montanus*, *Praomys jacksoni*, *Oenomys hypoxanthus*, and *Grammomys kuru*. The second group, present in all habitats but strongly linked to areas affected by marked disturbance, includes generalist and tolerant species such as *Lemniscomys striatus*, *Otomys tropicalis*, and *Mastomys natalensis*. Finally, the third group, consisting exclusively of *Arvicanthis niloticus*, is concentrated in environments characterized by very high anthropization, particularly fallow land, wasteland, and peri-urban areas.

This structuring along the disturbance gradient illustrates a clear differentiation between sensitive species, dependent on relatively intact habitats, and opportunistic species capable of colonizing environments that have been heavily transformed by humans. It highlights the role of Muridae as relevant bioindicators of the impact of anthropogenic pressures on the dynamics and resilience of ecosystems in the PNVi.

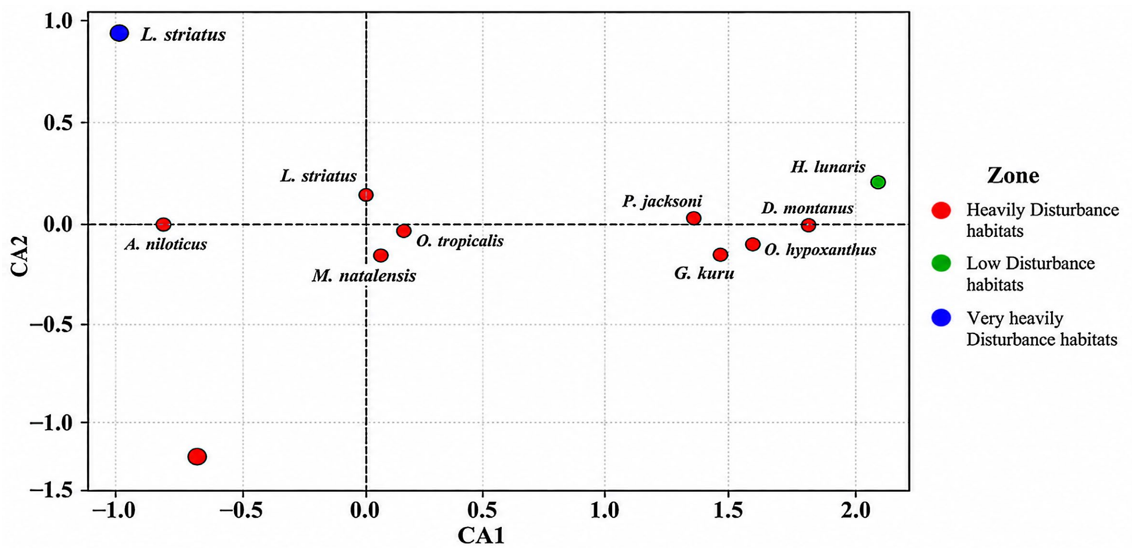

Figure 4. Biplot ordination by habitat gradients and anthropogenic disturbance in the study area.

3.1.4. Diversity of Muridae in the Study Area

According to **Table 2**, nine species of Muridae have been recorded in the northern sector of the PNVi, two of which are threatened according to the IUCN: *Dasymys montanus* (Endangered) and *Hybomys lunaris* (Vulnerable). The other species are classified as "Least Concern." Local knowledge indicates a high perceived abundance for *Arvicanthis niloticus*, *Lemniscomys striatus*, and *Otomys tropicalis*, while *D. montanus* and *H. lunaris* are considered less abundant, corroborating the low encounter rates observed in the field.

3.1.5. Specific Diversity Indices

The accumulation curves (**Figure 5**) and diversity indices (**Table 3**) indicate that the specific diversity of Muridae is significantly higher in the PNVi, particularly

Table 2. Specific richness and conservation status of Muridae.

N°	Common name	Scientific name	IUCN Conservation Status	Local Status
01.	Ndolo	*Dasymys montanus*	Endangered (EN)	–
02.	Mbule	*Hybomys lunaris*	Vulnerable (VU)	+
03.	Lutera	*Lemiscomys striatus*	Least Concern (LC)	+++
04.	Omupima	*Grammomys kuru*	Least Concern (LC)	++
05.	Erisungu	*Otomys tropicalis*	Least Concern (LC)	+++
06.	Munzanda,	*Oenomys hypoxanthus*	Least Concern (LC)	++
07.	Mulyavuligha	*Mastomys natalensis*	Least Concern (LC)	++
08.	Etsiani	*Arvicanthis niloticus*	Least Concern (LC)	+++
09.	Kaliambono	*Praomys jacksoni*	Least Concern (LC)	++

(−): Very rare, (+++): Very abundant, (++): Abundant, (+): Rare.

Table 3. Shannon, Simpson, and Piélou diversity of Muridae in the study area.

Habitat	Shannon Diversity Index (H')	Simpson Diversity Index (D)	Piélou's Evenness (J')
Highly disturbance habitats	1.18 ± 0.007	0.581 ± 0.003	0.538
Low disturbance habitats	1.94 ± 0.006	0.83 ± 0.002	0.881
Very highly disturbance habitats	1.01 ± 0.005	0.55 ± 0.003	0.630
Global	**1.46 ± 0.004**	**0.68 ± 0.001**	**0.665**

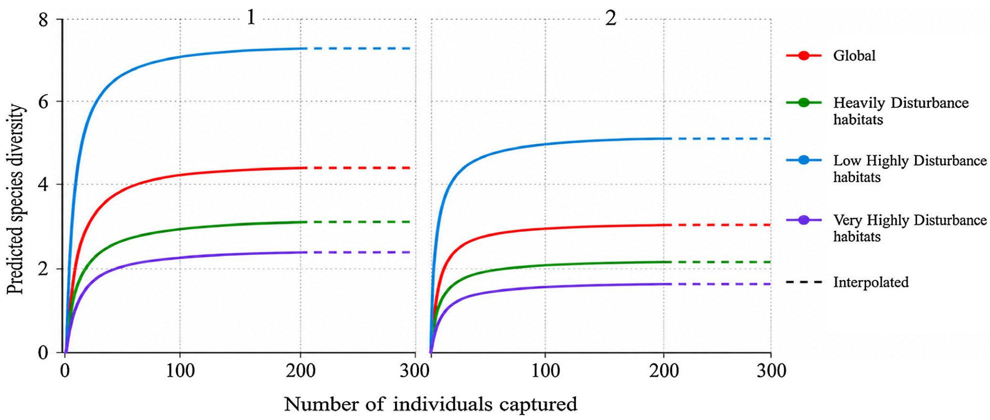

Figure 5. Accumulation curve for Muridae diversity (1 = Shannon diversity; 2 = Simpson diversity).

in lightly disturbed habitats (H′ = 1.936; D = 0.825; J′ = 0.881), compared to heavily disturbed habitats (H′ = 1.182; D = 0.581) and very heavily disturbed habitats (H′ = 1.014; D = 0.545). These results highlight the fundamental role of the PNVi in maintaining and conserving small mammal biodiversity. Across all habitats studied, the average diversity of Muridae was H′ = 1.457 and D = 0.684, reflecting a significant reduction in diversity in environments heavily transformed by human activities.

3.1.6. Similarity of Specific Composition

The specific composition of Muridae is strictly identical between lightly disturbed habitats and heavily disturbed habitats (r = 1.00), reflecting relatively similar ecological conditions in these two types of habitat. In contrast, highly disturbed habitats have an impoverished composition (r = 0.714), marked by the absence of four species sensitive to disturbance: *Dasymys montanus*, *Grammomys kuru*, *Hybomys lunaris*, and *Oenomys hypoxanthus* (Figure 6). These results highlight the negative impact of intense anthropogenic disturbances on the species diversity of Muridae and the potential loss of certain species that are indicators of habitat quality.

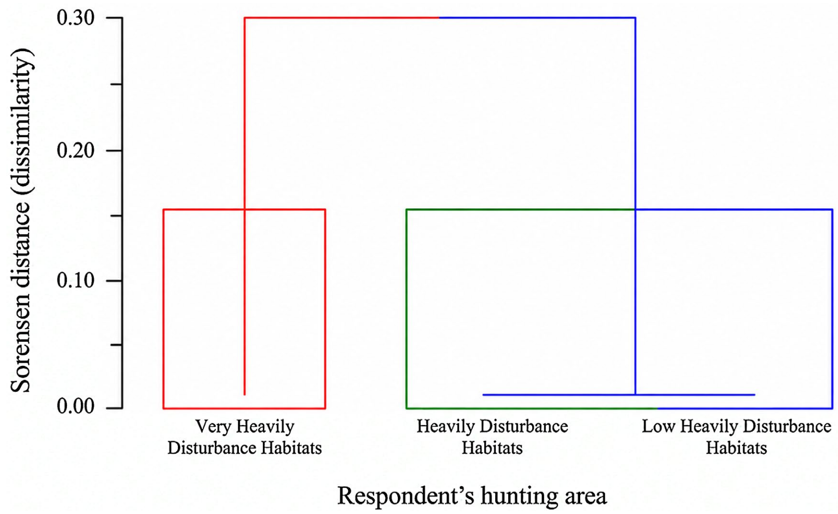

Figure 6. Clustering dendrogram showing the similarity of the specific composition of Muridae in the study area (slightly disturbed habitats, heavily disturbed habitats, and very heavily disturbed habitats).

3.1.7. Spatial Distribution of Muridae in the Study Area

Mapping of Muridae presence indices (Figure 7) highlights a heterogeneous distribution of Muridae in the northern sector of the PNVi, with relative abundance varying across transects: high (red dots) in heavily disturbed habitats, moderate (black dots) and low (blue dots) in lightly and heavily disturbed habitats. This spatial distribution illustrates the combined influence of habitat characteristics and local anthropogenic pressures on the dynamics and density of Muridae populations.

3.1.8. Frequency of Anthropogenic Activities in the Study Area

Table 4 shows that hunting is the main pressure on Muridae populations (6.81 signs/km), followed by inappropriate agricultural practices (2.27 signs/km) and deforestation (1.5 signs/km). Although less frequent, the settlement of displaced populations (1.13 signs/km), as well as other anthropogenic activities such as fishing, charcoal production, grazing, and urbanization, also contribute to habitat degradation and disturbance of Muridae communities, increasing the vulnerability of certain species sensitive to human pressures.

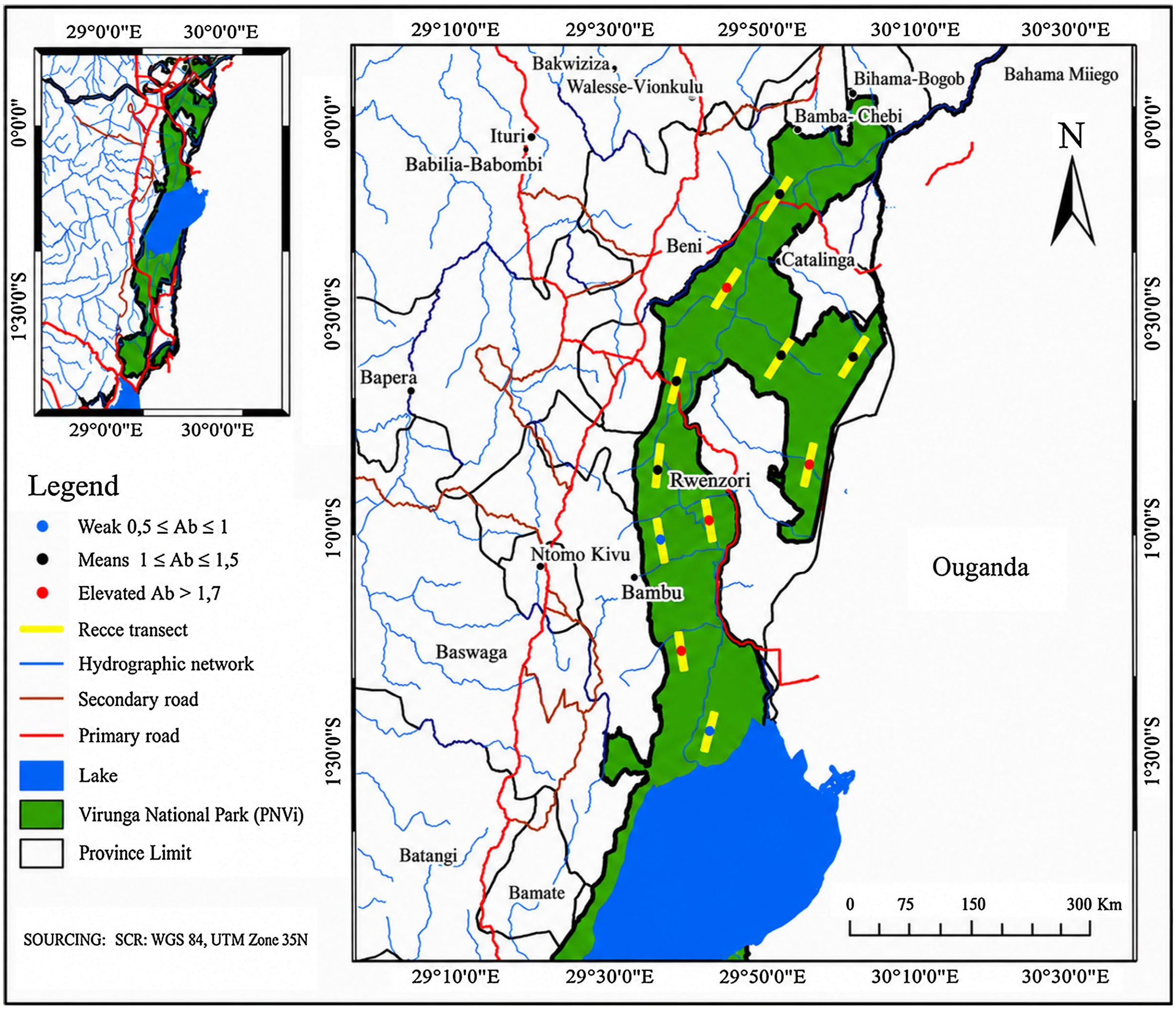

Figure 7. Location of evidence of rodent presence in the study area.

Table 4. Frequency of anthropogenic activities in the study area.

Types of activities	DT (km)	Nomber of signs	ER (Signs/DT)
Poor Agricultural Pratice	22	50	2.27
Deforestation	22	33	1.5
Fishing	22	17	0.77
Artisanal Mining	22	19	0.86
Coal Mining	22	15	0.68
Hunting	22	150	6.81
Pastures	22	13	0.59
Urbanization	22	10	0.45
Settlement of internally Displaced Persons	22	25	1.13

3.1.9. Spatial Distribution of Anthropogenic Activities in the Study Area

Figure 8 illustrates a contrasting spatial distribution of anthropogenic activities in the northern sector of the PNVi, with high intensity (blue dots) localized in highly disturbed habitats, moderate intensity (black dots) and low intensity (red dots) in slightly and strongly disturbed habitats, depending on the areas studied. This mapping is based on indices recorded in the field (tracks, human installations, signs of disturbance) and allows the spatial impact of anthropogenic pressures on Muridae habitats to be visualized.

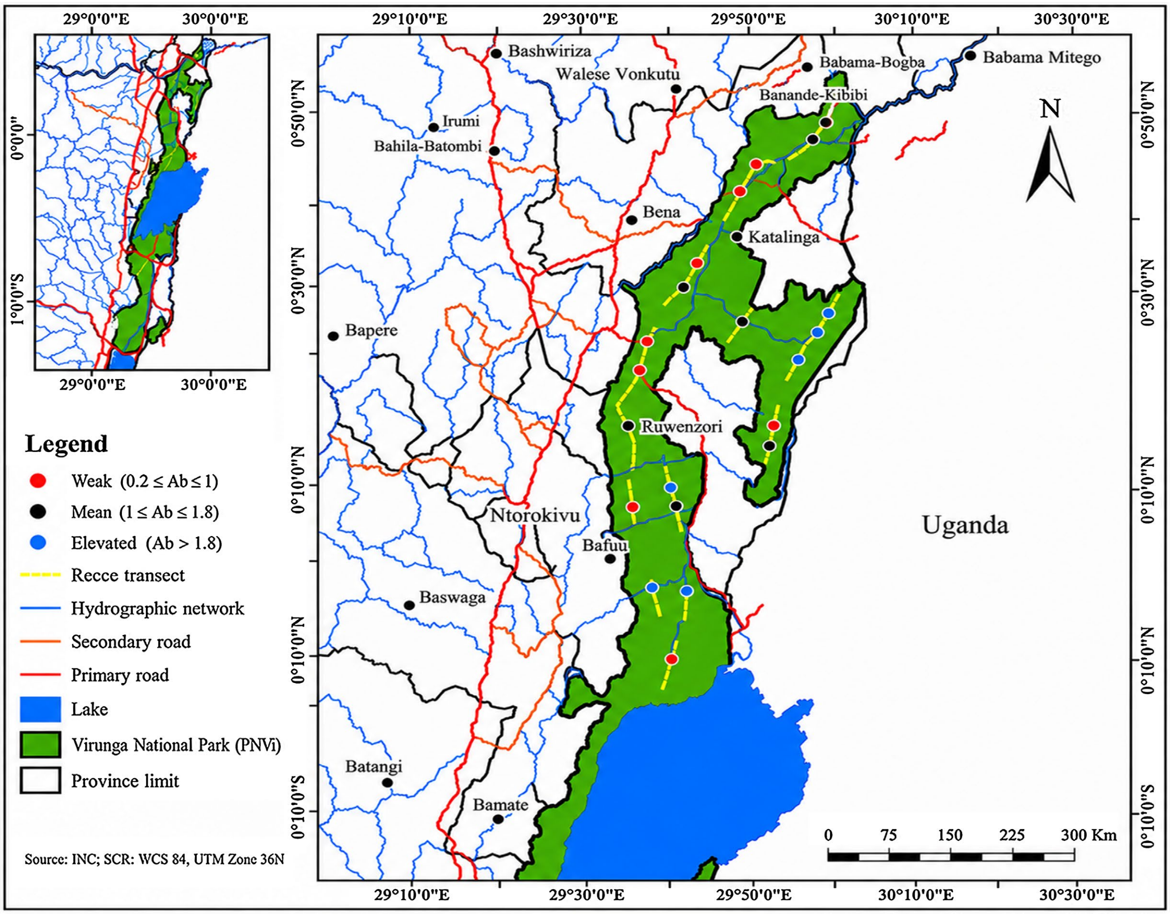

Figure 8. Location of signs of human activity in the study area.

3.2. Effects of Anthropogenic Disturbances on the Distribution of Signs of Rodent Presence in the Study Area

3.2.1. Influence of Anthropogenic Activities on Signs of Rodent Presence in the Study Area

Kendall's correlation test reveals a significant negative correlation between the intensity of anthropogenic activities and indirect signs of Muridae presence ($\tau = -0.54$; $p = 0.04$), indicating an adverse impact of human disturbances on these populations. A moderate but non-significant negative association was also observed with direct indices ($\tau = -0.44$; $p = 0.12$) (Figure 9), suggesting that direct detection of individuals is less sensitive to local variations in anthropogenic pressures.

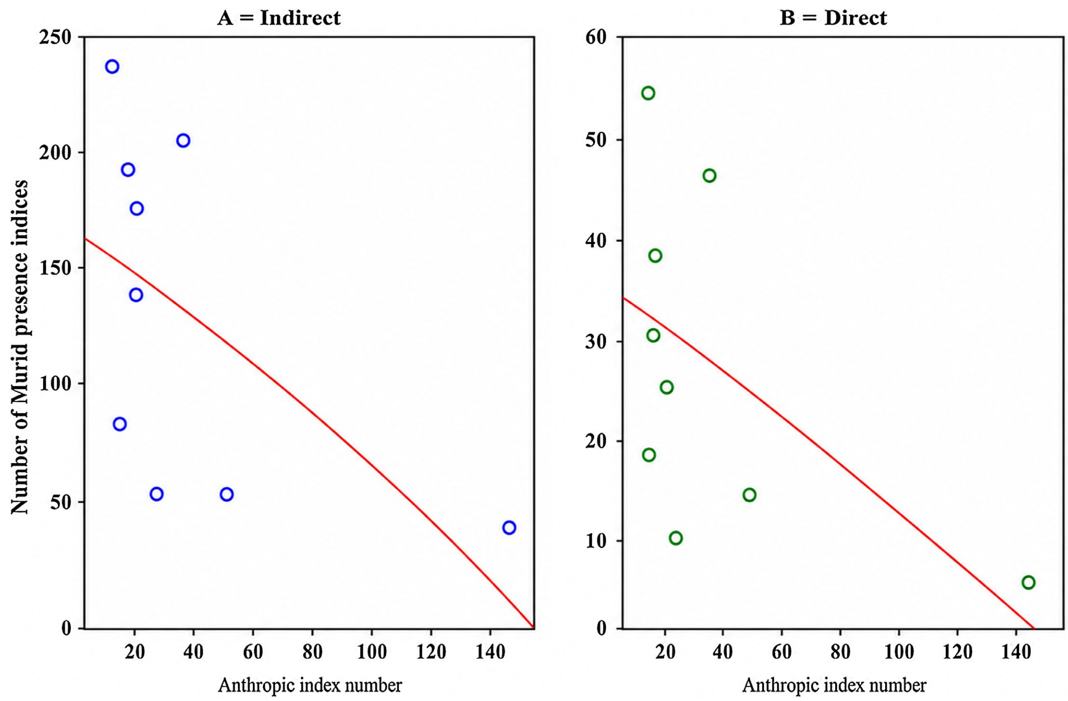

Figure 9. Relationship between the presence indices (indirect and direct) of Muridae and the presence of entropic indices.

3.2.2. Spatial Variation in Muridae Presence Indices in Relation to Anthropogenic Activity Gradients in the Study Area

The analysis revealed a significant variation in Muridae occurrence indices across different types of anthropogenic disturbances ($\chi^2 = 439.8$, df = 8, $p < 0.001$). The proportion of occurrence indices was highest in urbanized areas (21%) and lowest in hunting zones (2.4%) (Figure 10). These findings indicate that the distribution

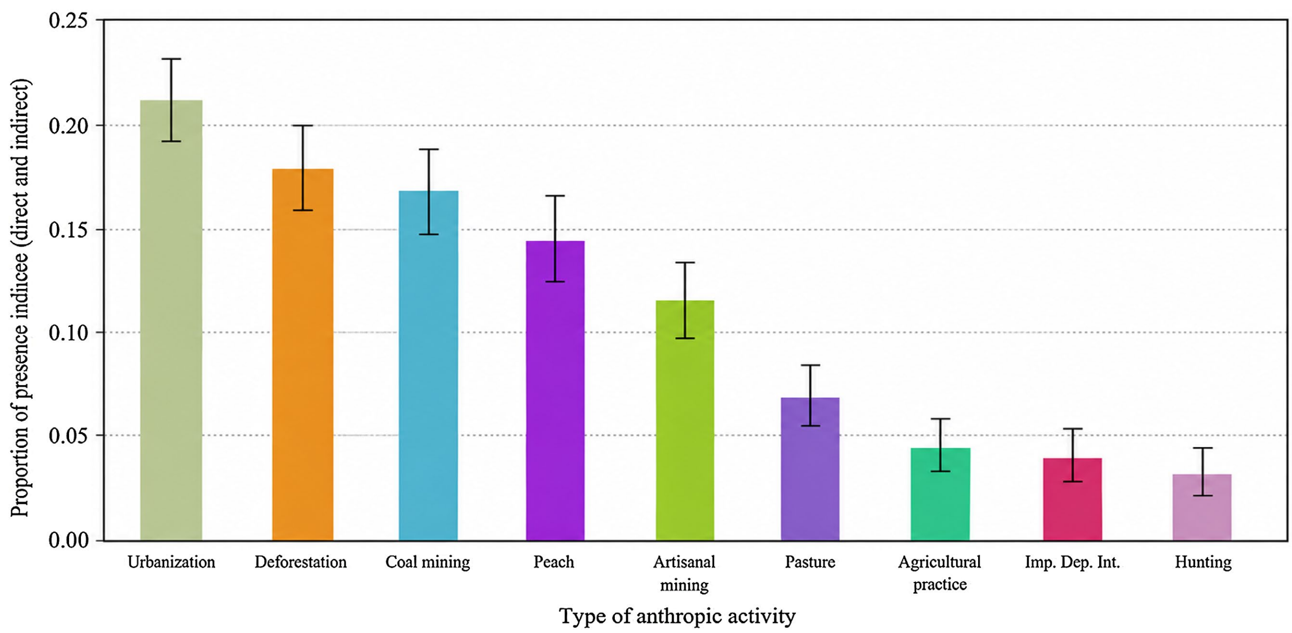

Figure 10. Proportion of Muridae presence indices according to type of anthropogenic disturbance.

and detectability of Muridae are significantly influenced by the nature and intensity of human-induced habitat modifications.

4. Discussion

4.1. Relative Abundance, Species Richness and Diversity of Muridae Collected in the Northern Sector of Virunga National Parc, Democratic Republic of the Congo

The high diversity of indirect signs recorded in the northern sector of Virunga National Park indicates substantial Muridae activity within this protected area. The predominance of feces (21.7%) and footprints (17.4%) suggests not only a regular presence of these small mammals but also their active use of the various microhabitats available. Indirect signs constitute particularly effective tools for assessing the presence and activity of small mammals in forest habitats, where direct observations are often difficult. Similar findings have highlighted the importance of indirect evidence in evaluating species richness and ecological integrity in forest ecosystems [16].

The high relative abundances of *Arvicanthis niloticus* (22.1%) and *Lemniscomys striatus* (17.8%) reflect the ability of these species to exploit open or disturbed habitats. These rodents are known for their ecological plasticity, opportunistic feeding behavior, and high reproductive capacity, characteristics that enable them to rapidly colonize environments modified by human activities. The predominance of these generalist species in disturbed habitats is consistent with observations from Nairobi National Park, where habitat degradation favored disturbance-tolerant species at the expense of specialized forest taxa [11].

The grouping of species into three functional assemblages, as revealed by Correspondence Factor Analysis, clearly reflects the influence of the anthropogenic disturbance gradient on Muridae communities. The forest-associated group, including *Hybomys lunaris*, *Dasymys montanus*, *Praomys jacksoni*, *Oenomys hypoxanthus*, and *Grammomys kuru*, remained strongly linked to relatively intact forest habitats. These species generally exhibit strict ecological requirements related to vegetation cover, humidity, and habitat structural complexity. In contrast, the anthropophilic group, dominated by *Arvicanthis niloticus*, was primarily associated with open and degraded environments, whereas ubiquitous species occupied a broader range of habitats owing to their high adaptive capacity. Similar studies have emphasized the role of closed-canopy forests as refugia for specialized species [17].

Furthermore, the results suggest that moderate levels of disturbance may temporarily increase environmental heterogeneity and promote the coexistence of species with different ecological requirements. According to the Intermediate Disturbance Hypothesis, the creation of new microhabitats and increased structural diversity may locally enhance biological communities [18]. However, when disturbances become more intense or frequent, they generally lead to habitat simplification, reduced resource availability, and the gradual disappearance of highly specialized species. Similar patterns have been reported in heavily disturbed habitats, where a decline in small mammal diversity was observed [19].

The occurrence of *Dasymys montanus*, classified as Endangered (EN), and *Hybomys lunaris*, classified as Vulnerable (VU), highlights the conservation importance of the study area. Combined with the relatively high Shannon diversity index (H′ = 1.936), this finding underscores the role of Virunga National Park as a refuge for species sensitive to anthropogenic disturbances. The high similarity observed between the park and fallow lands (r = 1.00) may indicate ecological connectivity that facilitates movement and recolonization of surrounding habitats. Conversely, the lower similarity observed in urbanized areas (r = 0.714) suggests community simplification resulting from urbanization, characterized by the dominance of a limited number of generalist species. Comparable trends have demonstrated that increasing human activities progressively promote the biotic homogenization of small mammal communities [16] [18].

Overall, these findings highlight the critical role of habitat quality and anthropogenic disturbance intensity in shaping Muridae communities. They confirm the importance of the forest habitats of Virunga National Park for maintaining specialized and threatened species while emphasizing the need to reduce anthropogenic pressures to preserve the diversity and ecological functionality of small mammal communities.

4.2. Effects of Anthropogenic Disturbances on the Distribution of Muridae Occurrence Indices in Study Area

The significant negative correlation observed between anthropogenic activities and indirect Muridae occurrence indices ($\tau = -0.54$, $p = 0.04$) highlights the overall detrimental influence of human disturbances on these communities. This relationship suggests that as the intensity of anthropogenic activities increases, Muridae occurrence tends to decline, particularly among the most specialized and disturbance-sensitive species. The similar trend observed for direct occurrence indices ($\tau = -0.44$) further supports this interpretation.

However, the significant variation in occurrence indices among disturbance types ($\chi^2 = 439.8$, df = 8, $p < 0.001$) indicates that Muridae species do not respond uniformly to different forms of anthropogenic disturbance. Urbanized environments exhibited the highest proportion of occurrence indices (21%), suggesting that certain opportunistic species, particularly *Arvicanthis niloticus* and *Lemniscomys striatus*, benefit from food resources, artificial shelters, and ecological conditions generated by human activities. Similar observations have been reported in Gabon and Kenya, where generalist species dominate highly modified habitats [11] [16].

In contrast, hunting areas exhibited the lowest proportion of occurrence indices (2.4%). This pattern may result from disturbances associated with human presence, hunting dogs, trapping activities, and progressive habitat degradation. Although Muridae are not always the primary target species, traditional hunting practices exert non-selective pressure on wildlife and alter the ecological conditions required for the persistence of numerous species. Comparable findings have been reported in West and Central Africa [20]-[22].

The variation in Muridae distribution across habitats further confirms the importance of habitat structural characteristics. Forest habitats, characterized by closed canopies, dense understories, and extensive vegetation cover, provide greater availability of shelter, breeding sites, and food resources, thereby supporting more diverse communities. In contrast, fallow lands and urbanized areas, which are characterized by canopy opening and habitat simplification, are primarily inhabited by disturbance-tolerant species.

These results are consistent with findings from several African ecosystems, including the savannas of Gabon [16], the Mabira Forest Reserve in Uganda [9], the Mukwe villages in Namibia [23], and the Mau Forest Complex in Kenya [10]. In these ecosystems, anthropogenic disturbances generally favor generalist species at the expense of forest specialists. Similarly, declines in specialized forest species within agricultural landscapes of southern Africa have been documented [24].

Taken together, these findings indicate that anthropogenic activities promote the progressive homogenization of Muridae communities, characterized by the increasing dominance of opportunistic species capable of adapting to disturbed habitats. The conservation of continuous forest blocks, the reduction of habitat fragmentation, and the sustainable management of human activities therefore appear essential for maintaining species diversity and the ecological functioning of small mammal communities [25].

It should be noted, however, that species identification in this study relied primarily on indirect evidence (footprints, feces, burrows, hair, and other traces), the interpretation of which can be challenging for cryptic Muridae species exhibiting similar morphological or ecological characteristics. Consequently, this approach may have led to occasional species misidentifications and influenced relative abundance estimates for certain taxa. Nevertheless, the combined use of multiple evidence types and specialized identification guides helped minimize this potential source of bias as much as possible.

5. Conclusions

This study, conducted from a conservation perspective, assessed the status of Muridae in the northern sector of Virunga National Park by examining their relative abundance and diversity along a gradient of anthropogenic disturbance. The results revealed a significant structuring of Muridae communities according to the intensity and nature of human-induced pressures. Forest habitats were characterized by high species diversity and the occurrence of conservation-priority species, notably *Dasymys montanus* and *Hybomys lunaris*, highlighting their role as essential ecological refugia for specialized taxa.

In contrast, highly anthropogenic habitats, particularly urbanized and agricultural areas, were dominated by generalist and opportunistic species such as *Arvicanthis niloticus* and *Lemniscomys striatus*. This pattern was accompanied by a progressive homogenization of Muridae communities and a decline in species strictly associated with forest environments. Consequently, the diversity and distribution of Muridae appear to be closely linked to habitat quality, ecological connectivity, and the level of anthropogenic disturbance.

These findings demonstrate that the maintenance of Muridae taxonomic and functional diversity largely depends on the conservation of relatively intact forest ecosystems and the sustainable management of human activities. Protecting forest remnants, limiting habitat fragmentation, and mitigating anthropogenic pressures should therefore be considered key conservation priorities for preserving Muridae communities and enhancing the ecological resilience of the Virunga National Park landscape.

Overall, this study provides valuable scientific evidence to support biodiversity conservation planning and sustainable management strategies in one of the most important protected areas in Central Africa. Furthermore, it establishes an important baseline for future monitoring of Muridae populations and for assessing the long-term ecological consequences of anthropogenic disturbances within and around Virunga National Park.

6. Recommendations

In light of the findings on variations in the composition and structure of Muridae communities along anthropogenic disturbance gradients in the northern sector of Virunga National Park (PNVi, Democratic Republic of the Congo), it appears essential to formulate strategic recommendations and open up avenues for research and management in order to ensure sustainability:

- Strengthen the protection of remnant forest habitats, reduce habitat fragmentation, and promote ecological restoration programs in degraded areas in order to maintain habitat connectivity and ensure the long-term viability of Muridae populations in the northern sector of Virunga National Park.
- Promote sustainable natural resource use practices while reinforcing monitoring, law enforcement, and awareness-raising mechanisms among local communities living adjacent to the protected area.
- Integrate Muridae into the ecological monitoring programs of Virunga National Park, as they represent valuable bioindicators of habitat quality and ecosystem disturbance.

7. Outlook

- Conduct further investigations into the ecology, distribution patterns, and population dynamics of Muridae species to improve understanding of their responses to environmental changes and anthropogenic pressures.
- Assess the impacts of habitat fragmentation and land-use change on the diversity, abundance, and spatial distribution of Muridae populations across different ecological landscapes.
- Develop integrated research approaches linking biodiversity conservation, eco-

system health, and the One Health framework to better understand the ecological and epidemiological roles of Muridae in protected and human-modified environments.

Ethical Clearance

This study was conducted in accordance with international and national ethical and scientific standards. Muridae inventories were carried out without intrusive manipulation or direct disturbance of individuals, focusing on the observation of indirect signs of presence (droppings, footprints, tracks) and captures in accordance with the standard protocols of the American Society of Mammalogists.

All field activities were officially authorized by the Congolese Institute for Nature Conservation (ICCN). No experiments were conducted on live animals outside of recognized sampling protocols, and all necessary precautions were taken to limit impacts on individuals and their habitats.

The results are presented in a strictly scientific framework and in accordance with the principles of the IUCN Declaration on Ethical Research in Conservation, thus ensuring respect for animal welfare and the integrity of the ecosystems studied.

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Conflicts of Interest

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

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