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Optimizing Field Taxonomy: Development of a Field-Adapted Identification Key to the Rodents of an Afromontane Tropical Rainforest

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ABSTRACT

Identification keys for terrestrial small mammals are often based on scientific details that require close examination of museum specimens. This paper builds on external morphological characteristics of the rodents recorded through live trapping from 2011 to 2023 in Nyungwe National Park, a tropical rainforest in Rwanda, to formulate a taxonomic key suitable for both expert and non-expert researchers working in similar ecosystems across Africa. We reviewed the literature on taxonomic keys and field guide documents for small mammals to assess their practicality and identify gaps, with a special focus on their relevance to tropical regions and our study area. We then integrated our field records to harmonize this new development. We describe 23 rodent species, identified and confirmed using advanced taxonomic techniques, including DNA barcoding and voucher specimens. The study emphasizes that external features—particularly field photographs, body coloration (dorsal, ventral, and lateral views), and other distinctive anatomical traits—can serve as an effective field taxonomic key for rodents and other terrestrial small mammals, accessible to a broad scientific community. The paper also discusses the limitations of traditional dichotomous keys compared to short descriptions paired with photographic illustrations. The resulting key can be used as a template and is open to refinement as additional species are confirmed, re-assessed, or validated through advanced tools. Future studies may adapt this approach for other terrestrial small mammals and different locations across African tropical rainforests.

Keywords: External Character; Fur Color; Identification; Nyungwe; Rodents; Tropical Forest

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1. Introduction

Conventionally, "small mammals" refers to a diverse group of relatively small-sized mammals that lack obvious anatomical or morphological similarities. This group includes rodents (Rodentia), bats (Chiroptera), shrews (Eulipotyphla) and allies (Afrosoricida and Macroscelidea), and many small marsupials [1,2]. Identifying small mammal species identification remains challenging without advanced taxonomic techniques; for example, if cranial measures are used for identification, this would require the preparation of specimens [3]. Dichotomous keys have been used to identify many groups of terrestrial small mammals, with a recent example [4]. While most scientists focus on a single group, such as rodents, shrews, or bats, a study [5] combined those groups. These taxonomic keys often rely on a combination of characteristics. The rodents comprise the most species-rich order among mammals [6,7]. They are significant vertebrate components of tropical ecosystems owing to their high species diversity, relatively significant biomass, and roles in food chains. When voucher specimens are involved, accurate identification of rodents should rely on properly prepared specimens, individuals of the same age, and skull characteristics [8]. A taxonomic key to rodents does not automatically apply to the species described outside the study zone due to the variations associated with biogeography [9]. As a result, researchers may adopt different strategies for constructing taxonomic keys depending on the intended users.

Various approaches were employed in identifying rodents: a combination of approaches including illustrations and museum specimens [10], a description of external characteristics with skull characteristics and illustration of character states or geographic distribution [11,12], or a dichotomous key accompanied by photographic illustrations, mainly field photos [4]. Regional descriptions of the species of small mammals exist for Uganda, a country bordering Rwanda to the North, with identification keys to the rodents [10] and small mammals other than rodents [13]. In these resources, rodents were described from family to species level based on both external and cranial morphological features [10]. Both authors utilized voucher specimen characteristics in their field guides and identification keys.

Over time, some scientists focused on external characteristics for identifying rodents and shrews [1,9,14,15]. As earlier scientists noted, using external characters is especially essential when field assistants are non-experts [1]. However, increased fieldwork is necessary for identifying rodent species based on their external characteristics [4]. Field identification keys based on visual characteristics of animals, such as pelage color and patterns, are necessary [1]. Color descriptions have not been easy to describe objectively, as they are often based on the observer's opinions [16], and printed colors cannot be more effective [1]. However, in the era when camera traps were used in wildlife studies for various purposes, it was possible to identify species of rodents using photographs from camera traps [17].

In ecosystems with high species richness in vertebrates, such as tropical rainforests, a field identification key for rodents is imperative. Many African countries have been considered understudied regarding rodents, with Rwanda being one of the few countries known to experience a significant knowledge gap [18]. If at least 248 species of rodents were newly described between 2000 and 2017 globally, then we should be in the age of discoveries of rodents [19]. However, underdeveloped countries still lack adequate means of utilizing advanced and up-to-date methods for identifying species, including DNA barcodes and museum specimens. Therefore, to advance local knowledge and build long-term capacity, field identification of rodents should take precedence for local researchers. Rodents have small sizes and cryptic morphologies that make field identification a challenging task in regions with high endemism and limited access to specialized laboratories for identification, especially in Afromontane regions [19]. In-situ recognition of species requires a practical field identification key to guide researchers and conservation practitioners in collecting high-accuracy data without the need for specialized taxonomic training. Additionally, Although genetic databases are being developed to provide free access to advanced taxonomic information, such as the National Center for Biotechnology Information portal (https://www.ncbi.nlm.nih.gov/), data associated with field context are lacking for most species of rodents, which should be an integral part of comprehensive taxonomic work.

The complications of identification of rodents based on external morphology are recognized in recent studies [4]. The scarcity of studies on terrestrial small mammals in Rwanda led to complications in species identification in the field, which often resulted in a lack of publication of more recent surveys. The most recent publications include the small mammals of the Volcanoes National Park [20] and those of Nyungwe and Cyamudongo forests [21]. Eighteen rodents and twelve shrews are described in the only available identification key to the small mammals (rodents and shrews) for Nyungwe National Park [22]. Accurate identification of rodents has direct ecological applications as it enhances our understanding of the functional traits of rodents in mountain ecosystems. Such functional traits that are essential in environmental studies of mountain ecosystems of temperate regions [23] are also imperative in tropical mountain ecosystems such as Nyungwe in Rwanda. There are also opportunities to bridge the knowledge gap in conservation and protected area management planning by using rodents, which could expend our understanding of species distribution and their responses to wildlife habitat alteration and climate change. Our identification key summarizes morphological features observed in the field during live trapping conducted from 2011 to 2023 in Nyungwe National Park. It describes each species recently studied and confirmed through DNA analysis or other unambiguous methods. We aim to support conservationists and early-career scientists who favor live-capture or field-based observational methods in African tropical forests similar to Nyungwe, ensuring that such scientific knowledge is effectively communicated to all interested stakeholders and thereby optimizing conservation science.

2. Materials and Methods

2.1. Study Area

The study area is Nyungwe National Park, also referred to as Nyungwe. Nyungwe, a mountainous rainforest in Southwestern Rwanda, lies between −2°15′36″ and −2°50′24″ South, and 28°58′12″ and 29°26′60″ East, as visualized using the ggmap function in RStudio [24]. Nyungwe extends to −2°15′36″ to −2°50′24″ S and 28°58′12″ to 29°26′60″ E on the western side when Cyamudongo forest, located 10 km away, is included. Nyungwe was officially designated a UNESCO World Heritage Site in September 2023. Its total surface area is 1,019.637 km² (or 1,019.637 ha), comprising 1,015.156 km² of Nyungwe natural forest, 4.304 km² of Cyamudongo natural forest, and 0.177 km² of Gisakura natural forest [25]. Five main sites within Nyungwe were covered during small mammal studies conducted from 2011 to 2023 (**Figure 1**). To the South, Nyungwe is contiguous with Kibira National Park in Burundi. The Park also includes the Cyamudongo fragment, approximately 10 km from the main Nyungwe forest block. The taxonomic key developed for the rodents of Nyungwe is based on the study of terrestrial small mammals conducted in Nyungwe from 2011 to 2023.

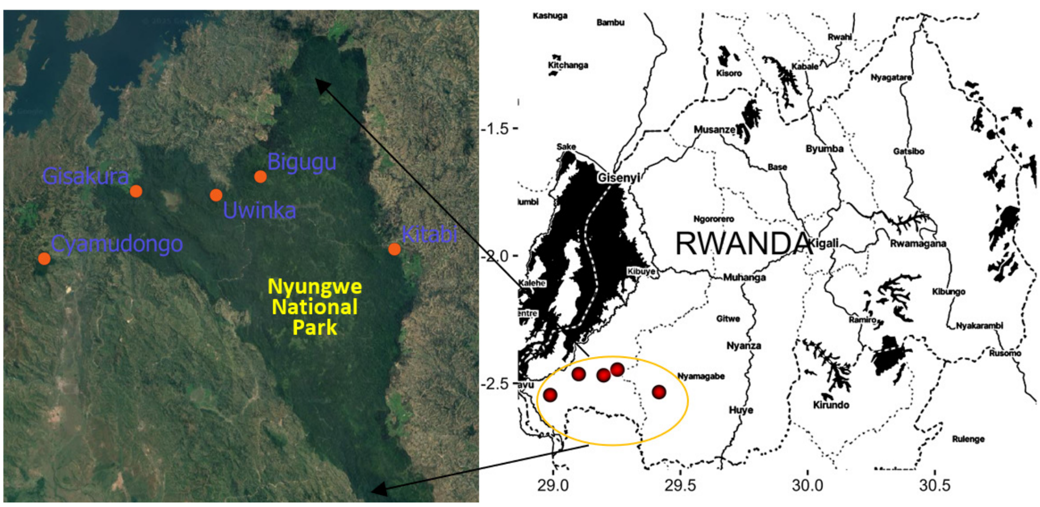

Figure 1. Location of Nyungwe in Rwanda and the five main sites.

2.2. Species Description and Classification

Information on rodent families was summarized from two main sources [26,27]. During fieldwork, standard measurements were collected for individuals from different species: body weight or mass (WT), head-body length

(BL), tail length (TL), hind foot length (FL), and ear length (EL). Mass was measured in grams (g), and all length measurements were in millimeters (mm). The sex and age of individuals were also recorded in the field. We considered variations associated with age classes for young and juvenile individuals and analyzed contrasting morphologies within the same species. We took photographs of rodents in the field to characterize striking features and differentiate species. We revised species descriptions, starting with an existing key [22]. Additional information was collected by re-examining voucher specimens that followed the molecular analysis results. The scientific names and taxonomic authority were confirmed based on the ASM mammal diversity database (https://www.mammaldiversity.org/) [28].

2.3. Identification Features

All descriptive features and photographs were considered for adult individuals only, as emphasized by several authors. Various body parts and features were examined for inclusion in the key, such as the nose, hair, rump, muzzle, belly, back, lateral line, ear hairs, tail tip, hair root, and speckles (**Figure 2**). After reviewing relevant information and linking it with field observations, a description of the species was supported by information from two general references [26,27]. Identification features and their various character states were applied. For example, when the feature is body-tail proportions, the TL can be slightly longer, longer, or much longer than the HB, among other options.

Figure 2. Parts of a mouse showing morphological features for species description: 1. Muzzle; 2. Ears; 3. Head-Body Length; 4. Total Length; 5. Dorsal side (or back); 6. Rump; 7. Tail Length; 8. Hindfoot Length; 9. Dorsal line; 10. Vibrissae; 11. Forefoot; 12. Ventral side (or belly); 13. Hindfoot; 14. Inguinal zone; 15. Basal tail section; 16. Tail tip; 17. Middle section of tail; 18. Flank; 19. Demarcation or lateral line; 20. Pectoral zone; 21. Ear Length; 22. Eye.

2.4. Photos and Illustrations

The image silhouettes for families are from PhyloPic (https://www.phylopic.org/; T. Michael Keesey, 2025); however, we constructed the porcupine's image silhouette, as the existing one did not match the Nyungwe species. All the photos used in this paper are from the small mammal records of Nyungwe from June 2011 to March 2023. When we could not find the photos recorded in the field, we photographed prepared specimens. The backgrounds of some field photos were adjusted using photo editing tools (https://www.fotor.com/; 'Paint', or 'Picture format'). Fur colors were taken from field photos; otherwise, freshly prepared specimens were used.

2.5. DNA-Based Identification

Laboratory work for Cytb gene sequencing was conducted at the Institute of Vertebrate Biology of the Czech Academy of Sciences in October 2024. Lab analysis was performed on 95 samples representing the observed variety of species in the field. We included only rodents in this key because most shrew samples resulted in *Crocidura olivieri*, while other shrew species could not be identified to the species level. Incomplete identification occurred for the *Hybomys* and *Grammomys* genera, which led us not to consider *Hybomys* sp. and *Grammomys* sp. instead of specific members known at the species level in Rwanda. One species was named *Lophuromys cf. cinereus* as it is recorded in the GenBank under that name, and another is named *Lophuromys cf. luteogaster* as provisional based on morphological characteristics, as there were no nucleotide sequences for this species were available in the GenBank for comparison.

2.6. Data Analysis

We analyzed the morphological features using an existing identification key, field guidebooks on African mammals, and our own field records, including photographs and morphometric measurements. Species identification was further refined by comparing field records with DNA barcoding data. Voucher specimens were used to complement the field identifications. We grouped the 23 species by family,arranging the families alphabetically, starting with the one containing the most species. Photographic illustrations were essential to this key and were included to support its effective use. We included average measurements recorded in the field (we used N to denote the number of individuals considered during the measurements), if applicable, and species that can be confused in the same area.

3. Results

Rodent species in Nyungwe belong to five families. A total of 23 species were selected and described in this illustrated taxonomic key. Each species is briefly described based on observable external characteristics, accompanied by one illustrative photo. The main descriptive part was summarized in a tabular form, including short notes on ecological conditions for each species (**Table 1**). Finally, a future complementary protocol is proposed, including illustrations of the body pelage (dorsal, ventral, and lateral views) and other body parts.

Table 1. Identification key to the species of rodents of Nyungwe in Rwanda.

	Species	General Morphological Description	Body Measurements	Similar Species	Microhabitat Preferences	Geographical Distribution
1	*Colomys goslingi* O. Thomas & Wroughton, 1907	Belly pure white to hair roots; woolly belly fur; hind foot long (34–40), ears short (18–20); grey/black on back; muzzle swollen; semi-aquatic (lives near running waters).	BL 105, TL 128, HFL 34, and EL 20 (N = 1).	*Malacomys longipes; Deomys ferrugineus; Thamnomys kempi.*	Presence of a river or stream, canopy, or place concealed from human presence	Narrow; restricted to streams; rare
2	*Deomys ferrugineus* O. Thomas, 1888	Belly pure white to hair roots; foot long (35–36); ears long (27–28); muzzle narrow; back color intense reddish brown to reddish brown, sometimes blackish over most of back and rump; very long tail with a whitish tip with sparse long hairs.	WT 44.9, BL 120.6, TL 167.6, HFL 34.8, and EL 27.9 (N = 8).	*Colomys goslingi*; *Malacomys longipes.*	Proximity to river or stream; shrubs or steep places with a closed canopy	Narrow; patchy occurrence; rare
3	*Grammomys* sp.	Small arboreal rat; belly pure white to hair roots, foot short (21–25 mm), with very long tail (ca. 160% HB); dorsal pelage varies in the range of tawny-brown, rich ochraceous, reddish-brown, or brownish-yellow; flanks and ventral pelage separated by thin line of buff; tail uniformly in color (dark brown) and size, with pencil at tip.	WT 36.1, BL 107.9, TL 162.3, HFL 22.9, and EL 19 (N = 6).	*Oenomys hypoxanthus; Hylomyscus* spp.	High mountains and alpine vegetation; open or semi-open canopy	Restricted to a higher-altitude range, or rare

Table 1. *Cont.*

	Species	General Morphological Description	Body Measurements	Similar Species	Microhabitat Preferences	Geographical Distribution
4	*Hybomys* sp.	Medium to large size; HF large (27–31); dorsal pelage dark reddish-brown to very dark brown, with yellowish-brown speckling; black mid-dorsal stripe from nape of neck or shoulders to base of tail (sometimes inconspicuous); ventral pelage tawny to whitish-grey, hairs grey with off-white; dorsal and ventral pelage delineated; ears small and round and appearing naked; eyes relatively large; feet black; tail long but shorter than HB, black, mostly naked, with dense rings of very short bristles; tail may be slightly bicolored; color variations prevalent body; tail bicolored with variations	WT 51.5, BL 106.3, TL 107.6, HFL 27.7, and EL 19.8 (N > 10).	*Oenomys hypoxanthus*	Trees with a closed or semi-open canopy	Large; rare at some places (e.g., very rare at Cyamudongo)
5	*Hylomyscus aeta* O. Thomas, 1911	Small size; cinnamon-brown dorsal pelage; very long tail (ca. 145% of HB) with short hairs on the end; belly pure white in appearance (white tip with minimal grey base to belly hair); longer guard hairs present; dorsal and ventral pelage delineated on flanks and separated by buffy line; long vibrissae; ears large relative to head size; HF short (18–20), broad; feet covered with short white hairs; nipple structure: 1 + 2 = 6.	WT 18.8, BL 85.1, TL 125.5, HFL 18.9, and EL 18.0 (N > 10).	*Hylomyscus stella*; *Grammomys* sp.; *Delanymys brooksi; Dendromus spp.*	Trees or shrubs with closed or semi-open canopies.	Common in the forest wherever there are shrubs.
6	*Hylomyscus stella* O. Thomas, 1911	Small climbing mouse; very long tail (ca. 150% of HB), dark, almost naked but with very short bristles (not always); HF short (16–18) and broad; dorsal pelage rufous-brown; hairs dark grey, rufous-brown or dark brown at tip; belly more grey in appearance (grey base to belly hair is more prevalent); ventral pelage delineated from dorsal pelage; ears large, rounded, with very short hairs; nipple structure: 2 + 2 = 8. Age variations: dorsal darker grey pelage in juveniles, without rufous tinge.	WT 18.2, BL 81.8.3, TL 121.6, HFL 16.9, and EL 16.7 (N > 10).	*Hylomyscus aeta*; *Grammomys* sp.; *Delanymys brooksi; Dendromus* spp.	Trees or shrubs with closed or a semi-open canopy	Common in the forest wherever there are shrubs
7	*Hylomyscus vulcanorum* Lönnberg & Gyldenstolpe, 1925	Comparatively large size in the genus; HF short (17–23), tail tip can be tufted; dorsal hairs dark grey with brownish tip; belly more grey in appearance (grey base is more prevalent); very long dark tail (ca. 140% of HB), tip can be tufted; flanks similar to dorsum with tinge of rufous; ventral pelage whitish-grey (dark grey hairs with white tips); rufous-buff on cheek between eye and ear; large eyes surrounded by narrow ring of black hairs; nipple structure: 2 + 2 = 8.	WT 29.0, BL 97.5, TL 130.1, HFL 20.5, and EL 18.9 (N > 10).	*Hylomyscus stella*; *Hylomyscus aeta; Grammomys* sp.	High altitude habitats; often habitats with small canopy trees; prefer mountains	Wide but with low abundances

Table 1. *Cont.*

	Species	General Morphological Description	Body Measurements	Similar Species	Microhabitat Preferences	Geographical Distribution
8	*Lophuromys cf. cinereus* Dieterlen & Gelmroth, 1974	Very rare medium-sized grey unspeckled rat; relatively short tail (ca. 57% of HB) darkly pigmented; pelage harsh and brush-like (common feature of the *Lophuromys* genus), generally brownish-grey; ventral pelage pale grey or soft brownish-grey; whitish spot on the chest in some individuals; nipple structure: 2 + 1 = 6.	WT 62.0, BL 131.2, TL 63.2, HFL 17.5, and EL 18.9 (N = 4).	*Lophuromys laticeps; Lophuromys woosnami*; *Lophuromys luteogaster*	Not yet documented	Small; rare
9	*Lophuromys laticeps* O. Thomas & Wroughton, 1907	Reddish-brown speckled rat; short HF (21–23) with long claws; tail short (ca. 50% of HB); ears small (16–18) darkly pigmented and naked; dorsal pelage blackish-brownish, brownish-reddish or tawny; ventral pelage pale brown tinged with cinnamon; feet brown or dark brown; male scrotum often hidden; slight variations in size and coloration; nipple structure: 2 + 1 = 6 or 1 + 1 = 4. Age variation: ventral pelage more reddish in subadults.	WT 42.8, BL 108.0, TL 56.7, HFL 19.8, and EL 18.0 (N > 10).	*Lophuromys cinereus; Lophuromys rahmi*	Associated with any type of habitat in a tropical forest; grassy vegetation and wet places sometimes disturbed are more typical	Large; it is found everywhere
10	*Lophuromys medicaudatus* Dieterlen, 1975	Brightly colored unspeckled pelage; medium tail length (ca. 85% of HB); dorsal pelage and head uniform dark olive-brown; dorsal hairs paler at base, olive-brown at tip; ventral pelage dark orange tinged with olive, coloration most intense on the chest; ears darkly pigmented, sparsely haired; darkish above, paler below; nipple structure: 2 + 1 = 6.	WT 38.1, BL 109.2, TL 85.4, HFL 21.4, and EL 17.8 (N = 7).	*Lophuromys woosnami; L. luteogaster; Lophuromys cinereus; Lophuromys rahmi.*	Overlaps with other Lophuromys species, but its particularities not documented	Rare; recorded at medium altitude levels, and in high altitudes
11	*Lophuromys rahmi* W. N. Verheyen, 1964	Small dark reddish unspeckled rat with short-tail (ca. 51% of HB), very short hind-feet and short rounded ears; dorsal pelage reddish-brown or hairs pale reddish usually with dark tip, pale tips to dorsal hairs give slight speckling to pelage; ventral pelage reddish-orange; flanks paler than dorsal pelage; ears short and rounded.	WT 29.8, BL 88.3, TL 50.8, HFL 15.7, and EL 12.5 (N = 7).	*Lophuromys medicaudatus; Lophuromys laticeps; Lophuromys cinereus*	Overlaps with other Lophuromys species, but its particularities not documented	Rare; recorded only at medium altitude levels
12	*Lophuromys woosnami* O. Thomas, 1906	Medium-sized unspeckled slender-bodied rat; ears long (24–26) and naked, and long HF (<27); tail long (ca. 105% of HB), dark above and whitish below (with color variations); pelage soft and conspicuously glossy; dorsal pelage brown tinged with olive-grey, with reddish-brown hair base; ventral pelage pale brown tinged with reddish; nipple structure: 1 + 1 = 4. Age variation: brighter and more intense reddish dorsal and ventral pelage coloration.	WT 34, BL 110, TL 111, HFL 24, and EL 22 (N = 1).	*Lophuromys luteogaster; Lophuromys medicaudatus*	Broad, but mostly associated with closed canopy and forest floor with more leaf litter than undergrowth cover	Wide; found everywhere but its abundance is lower than *L. laticeps*

Table 1. *Cont.*

	Species	General Morphological Description	Body Measurements	Similar Species	Microhabitat Preferences	Geographical Distribution
13	*Malacomys longipes* A. Milne-Edwards, 1876	Large-sized rat with long hindlimbs, large naked ears, elongated muzzle, and long vibrissae; tail longer than HB; dorsal pelage brown or very dark grey with a velvet-like texture; ventral pelage white or greyish-white, short and velvet-like. Age variation: dorsal pelage dark grey in juveniles and subadults, rufous in adults, and deep rufous in old adults; greyish color retained in some adult individuals.	WT 82.6, BL 131.9, TL 166.8, HFL 37.4, and EL 27.5 (N > 10).	*Colomys goslingi*; *Deomys ferrugineus*; *Thamnomys kempi*	Near river, streams, or swamps; proximity of water source is key, but extends more than 100 m away from water source; steep places justify its use of long hindfeet	Wide; occasional records, yet more common among the water-dependent rodents; absent in high-altitude habitats
14	*Mus bufo* O. Thomas, 1906	Small-sized mouse; tail shorter or about equal to HB (ca. 97%); reddish tips to hairs on belly; dorsal pelage dark coppery-brown, rather variable; rump darkish; ventral pelage buff to greyish-buff, shorter than dorsal pelage; ears dark with scattered short buffy hairs; skull stoutly built; nipple structure: 3 + 1 = 8.	WT 11.5, BL 64.1, TL 63.4, HFL 16.3, and EL 14.8 (N > 10).	*Mus minutoides; Mus gratus*	Heavy grassy vegetation or space covered with ferns; found often in open habitat patches, rarely under a closed canopy	Widel; abundant in some zones (e.g., Cyamudongo) and uncommon in most sites
15	*Oenomys hypoxanthus* Pucheran, 1855	Large size rat with rufous nose and cheeks, white belly, large tail (ca. 114–133% of HB), and large HF; dorsal dense and harsh pelage greyish-brown to rufous-brown, slightly speckled with yellowish-buff, with grey hair base; rump and upper thighs orange or russet; ventral pelage pure white or creamy-white, often richly suffused with orange, delineated from the flanks; ears large, rounded, covered by short reddish hairs; long vibrissae; tail scaly and almost naked, dark above, yellowish below.	WT 40, BL 93.5, TL 124.0, HFL 25.5, and EL 20.0 (N > 10).	*Grammomys* sp.; *Hybomys* sp.	Open canopy forest with shrubby vegetation, sometimes shrubby unforested zones, high-altitude zones, rarely near wetlands	Large, with low abundance
16	*Praomys degraaffi* van der Straeten & Kerbis Peterhans, 1999	Medium-sized mouse; tail longer than HB (ca. 129%); HF medium (23–27), tail tip naked; overall pelage typically dark grey or sooty-black; hindfoot narrow; tail relatively longer than its sympatric *P. jacksoni*; nipple structure 2 + 2 = 8.	WT 36.1, BL 100.1, TL 133.1, HFL 24.4, and EL 21.8 (N > 10).	*Praomys jacksoni*	Its habitat preferences overlap with P. jacksoni	Wide; however, its abundances are not yet documented
17	*Praomys jacksoni* de Winton, 1897	Medium-sized mouse; tail longer than HB, naked, dark grey above, with various lengths; HF medium (23–27); flanks often with a buffy lateral line; rufous-grey soft pelage; hairs dark grey at base, grey or rufous at tip; ventral pelage greyish-white with hairs grey at base, white at tip. Age variation: dorsal pelage dark grey in juveniles and subadults, rufous in adults, and deep rufous in old adults; one morphological variant is large and brownish in color, with a very long tail indicated by DNA data in Clade Ib group [29].	WT 39.7, BL 104.0, TL 133.1, HFL 23.3, and EL 20.8 (N > 10). WT 50.0, BL 119.6, TL 141.2, HFL 23.4, and HFL 22.5 for Clade Ib (N = 9).	*P. degraaffi; Hylomyscus vulcanorum.* The large brownish type of *Praomys jacksoni* will also be similar to *Malacomys longipes* and *Thamnomys kempi.*	Associated with any habitat in a tropical forest	Large; it is found everywhere

Table 1. *Cont.*

	Species	General Morphological Description	Body Measurements	Similar Species	Microhabitat Preferences	Geographical Distribution
18	*Thamnomys kempi* Dollman, 1911	Large arboreal rat (the largest in the genus); soft and long bright orange-rufous dorsal pelage, especially on rump; very long tail (always more than body) with short bristles and longer hairs at tip; ventral pelage whitish with hairs dark at base, whitish at tip; flanks delineated from ventral pelage; narrow dark eye-ring; ears hairy in inner and outer surface; hindfeet broad and comparatively short.	WT 65, BL 143, TL 199, HFL 28, and EL 22 (N = 1).	*Praomys jacksoni* (especially, Clade Ib group); *Malacomys longipes*; *Thamnomys venustus; Colomys goslingi*	Presence of streams or small rivers, with vegetation and without disturbance	Narrow; rare
19	*Funisciurus carruthersi* O. Thomas, 1906	Medium to large with grizzled olive-green and black back; long black guard hairs on mid-dorsal line; flanks paler, with fewer black-tipped hairs; ventral pelage grey or greyish-white from throat to tail; tail long (ca. 100% of HB), ochre and black; nipple structure: 1 + 2 = 6.	WT 307.5, BL 205.9, TL 195.7, HFL 50.3, and EL 18.5 (N > 10).	*Funisciurus pyrropus*	Large trees, often associated with shrubs; some populations are used to human presence others hide	Large; it is the most common squirrel in Nyungwe
20	*Funisciurus pyrropus* F. Cuvier in É. Geoffroy Saint-Hilaire & F. Cuvier, 1833	Medium-sized squirrel with white or pale grey side-stripes, and bright reddish limbs; dorsal pelage grizzled greyish or blackish; hairs banded black with buff tip; ventral pelage pure white or off-white; bushy long tail, shorter than HB (ca. 80%)	WT 223.0, BL 216.7, TL 145.7, HFL 41.0, and EL 18.0 (N = 3).	*Funisciurus carruthersi*	Large trees and places concealed from human disturbances	Large, but rare sightings; must be associated with large trees
21	*Graphiurus murinus* A. G. Desmarest, 1822	Small size; dorsal pelage with various shades of golden- or greyish-brown; ventral pelage grey, lightly suffused with white or cream; dorsal and ventral pelage colors usually not delineated; eyes large and eye-mask sometimes conspicuous; ears brown, medium-sized, rounded; tail moderately long (ca. 84% of HB); tail hair shorter at the base (2–4 mm) and longer at the tip (up to 21 mm).	WT 20.5, BL 79.6, TL 69.8, HFL 16.9, and EL 16.0 (N = 5)	*G. microtis* (not yet been recorded in Nyungwe, but in Rwanda)	Trees with lichens or mixed with shrubs.	Rare; can only be found by chance; at least one individual was recorded in three of the surveyed sites
22	*Cricetomys emini* Wroughton, 1910	Dorsal pelage orange-brown to dark greyish-brown or brownish-black (the one of sympatric *Cricetomys kivuensis* is greyish or dark greyish); head and flanks generally paler; ventral pelage white usually well delineated from flanks; large, pale, naked ears; numerous and long whiskers; tail very long (ca. 115% of HB), smooth without scales, dark on basal half, white on terminal half.	BL 310, TL 205, HFL 72, and EL 45 (N = 1).	*Cricetomys kivuensis.*	Broad; however, it focuses on the main forest with a closed canopy.	Large, across all the corners of the forest, but in low abundance.
23	*Atherurus africanus* J. E. Gray, 1842	The body is covered by short, dark quills rather than hairs; the back quills do not form a crest in this species, and the tail has a terminal end in the form of a brush.	Not measured.	None present in Nyungwe.	Not yet documented.	Narrow; prefers habitat concealed from human disturbance.

3.1. Illustrative Guide to the Families and Species

Silhouette images represent the rodent families found in Nyungwe (**Figure 3**). A short guide to these families is provided in the order of Rodentia (rodents) recorded in Nyungwe National Park. Twenty-three species are illustrated with photographs (**Figure 4**). Individuals 1-19 belong to the Muridae family. Other families included fewer species: Sciuridae (2), Gliridae (1), Nesomyidae (1), and Hystricidae (1).

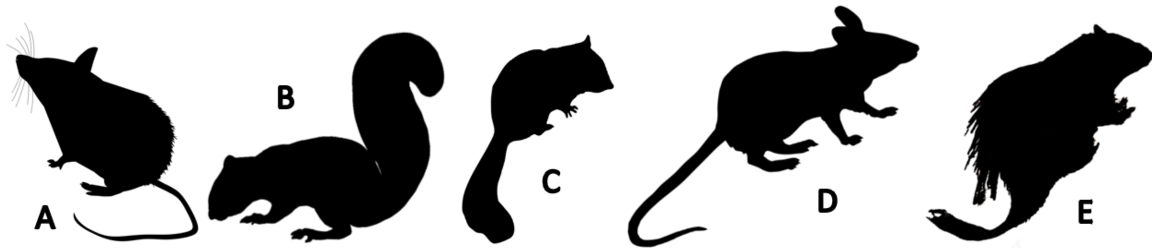

Figure 3. Representation of rodent families of Nyungwe (**A**: Muridae, **B**: Sciuridae, **C**: Gliridae, **D**: Nesomyidae, **E**: Hystricidae).

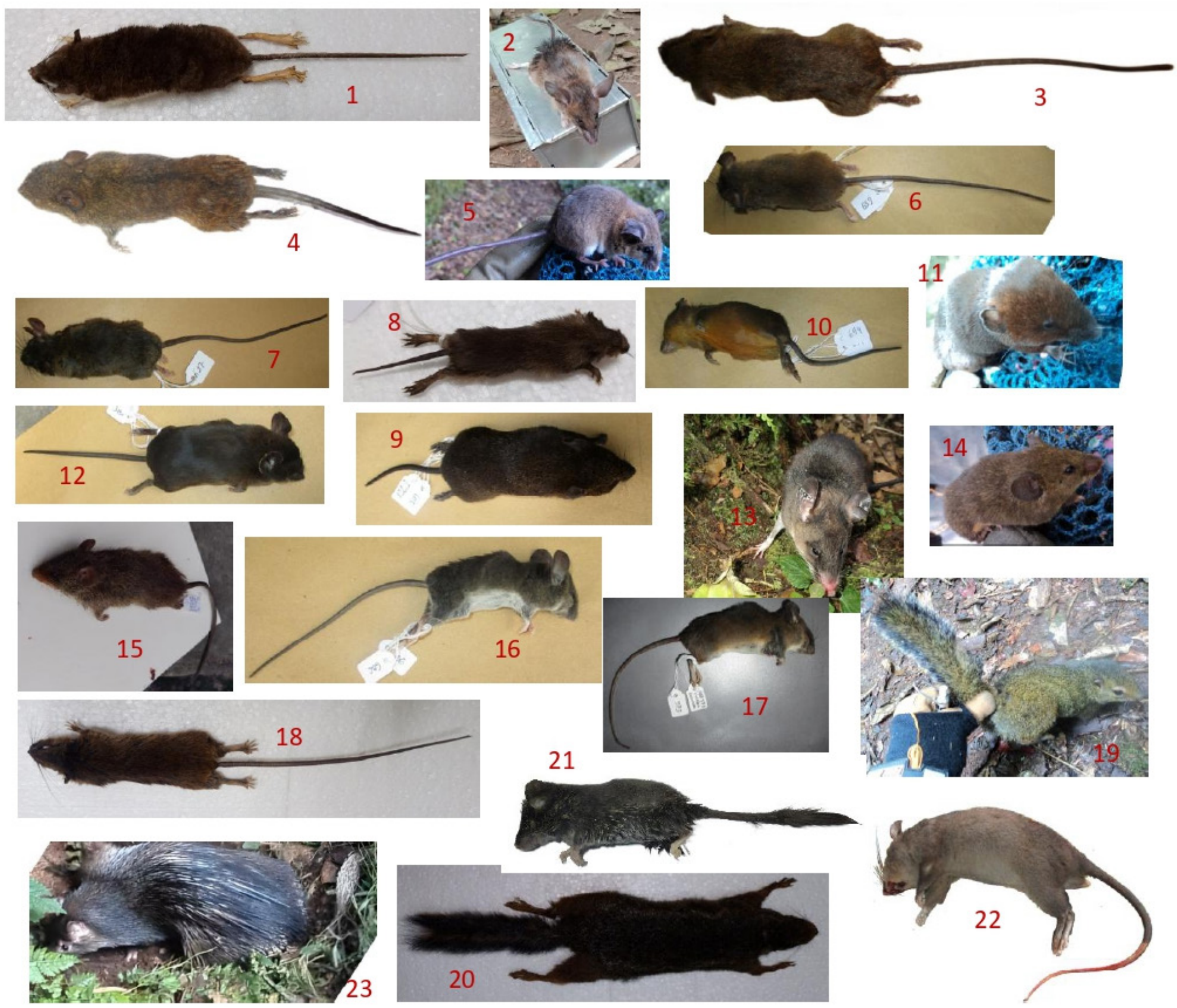

Figure 4. Photographic illustrations of the species used for the key, where the numbers 1 to 23 correspond to the species number in the key.

3.2. Future Directions in African Tropical Rodent Taxonomic Keys

Body coloration on three parts of the animal can be important for distinguishing rodent species (**Figure 5**). For some species, sample illustrations of these color patterns are provided. As this key is preliminary, we propose the future inclusion of such photographic details for all species, as they are essential for accurate identification and may, in some cases, serve as standalone features without the need for body measurements:

- Dorsal view: Head and torso, and Total length
- Ventral view: Head and torso, and Total length
- Lateral view: Head and torso, and Total length
- Muzzle: Frontal view, and Lateral view with ears (**Figure 6**)
- Tail: Upper side, Lower side, and Tail end (~ last ¼)
- Hindfoot (Lateral view, Foot with toes, and Plantar pads – see **Figure 6**)

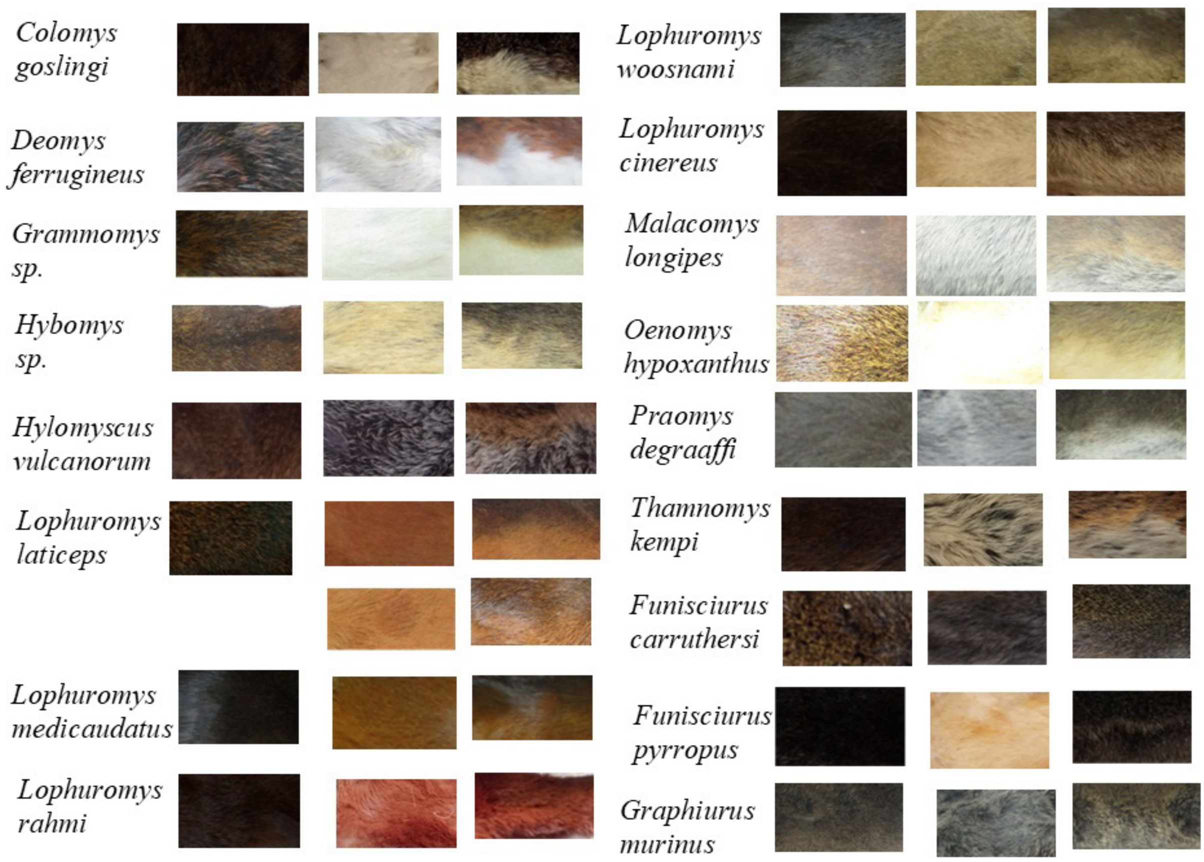

Figure 5. Guide to fur colors (back, belly, and flanks) of a sample of rodents.

Figure 6. Additional features for the extended key (1–3—frontal view; 4—plantar pads).

4. Discussion

4.1. Optimizing Field Taxonomic Studies on Rodents

Identification keys or field guidebooks for small mammals (rodents, bats, and shrews) are often lengthy and broad in scope, extending beyond a particular ecosystem. Such documents are not easily usable in the field. Moreover, most field guidebooks are based on outdated observations that have not been verified against recent field data. Our initial approach was to address these limitations by providing data derived from recent fieldwork in a specific tropical rainforest ecosystem. However, the procedures used to develop this identification key are replicable in other African tropical forests. Another emphasis was on external characteristics of rodents, with photographic illustrations. Many other scientists [1,4,9,14,15] have focused on external characteristics to provide field identification guidelines. We found two publications especially aligned with our approach: Teta and Jayat [4] and Godinez et al. [11]. However, we integrated the differences based on insight into the field use of the taxonomic key without dependency on field museums or other invasive methods. External characters are essential for the knowledge of rodents when field assistants are non-experts [1], and increased fieldwork is necessary for performing such identification work [4]. One of the published keys [11] was specifically designed for taxonomic specialists. Nevertheless, the principles behind those approaches have informed our work. In our case, images and photographs play a vital role in assisting non-expert users in Nyungwe and similar African tropical forests. While our current identification key is grounded in extensive fieldwork, although it is not exhaustive. Further field surveys will help refine and expand the key, which will be subject to ongoing revisions. The main innovative perspective for the future work is the photographic visualizations of the three sides of the fur.

This article is intended to initiate the development of an identification key tailored for practical use in tropical rainforests in Africa, similar to Nyungwe. In Rwanda, a dichotomous key was used for rodents and shrews [22]. The rodent species covered in the previous short key were included, except for two species we never recorded in 2011–2023. Some of the described species have no recent records in the studies conducted in Nyungwe before 2023, following a comprehensive checklist of mammals for Nyungwe [30]. We report the presence of *Lophuromys cf. medicaudatus* and *Lophuromys cf. cinereus,* species not previously known from Rwanda. The current paper indicates the differences between sympatric and cryptic species that can be easily confused when using brief dichotomous keys. Such species that can be delineated include two species of *Cricetomys* and the three species of *Hylomyscus*. We anticipate increased interest in terrestrial small mammals as the growing number of young scientists in our African tropical region requires mentorship and the provision of proper tools to initiate their research. Furthermore, knowledge of rodents needs to be mainstreamed in the park's wildlife monitoring and management planning.

Dichotomous keys relying on craniometric measurements are not well-suited for field use. Their application overemphasizes the traditional approach that small mammal taxonomy should be founded on the extensive study of museum specimens. Skull measurements should be continuously published separately and associated with biogeography, phylogenetics, taxonomic trees, anatomical examinations, and paleontological studies. In some cases, museum specimens are associated with misidentification or incomplete information (e.g., younger individuals are mistakenly identified as adults, or one or two specimens that do not reflect morphological variability) or features have been slightly modified by museum conditions (such as lost colors, modified parts, e.g., nails, or lost hairs). The collection of new specimens should be controlled in the current period, as many species of mammals are more threatened by habitat fragmentation and other anthropogenic disturbances than ever before. Furthermore, the pace of conservation has accelerated, and DNA analysis for species identification is highly appreciated.

Our perspective is based on the assumption that reliance on museum specimens will be minimized as field identification keys become more efficient, thereby optimizing field taxonomy for rodents and other small mammals. Any scientist can use the current version of the identification key by adapting it to the species present at various localities in African tropical forests similar to Nyungwe, as many species are shared between such rainforests. When planning fieldwork, it is important to familiarize oneself with the appearance of animals, and photographic collections of specimens are helpful [1]. Future scientists should examine specimens of small mammals housed in local collections before conducting fieldwork. Taxonomic dichotomous keys for rodents or shrews are often conceived assuming the same species possesses a single or a few key distinctive characters. This is not evident since many similar species show geographical variations; therefore, no single key could be versatile [9]. Powerful cameras should be used to produce high-quality photos to illustrate such variations. One or more characters for a key could be unfamiliar to an expert, either because they are not apparent to everybody, or local species demonstrate them differently or with variations. A basic character in an identification key, e.g., dorsal stripe, can be found in a new species at a site.

We have proposed focusing on fur colors to resolve many difficulties associated with describing colors in several field-guiding documents that are either not accompanied by photos or provide only one photo of a species. This implies that, instead of describing colors, they will be added to the key as variations in one species are documented through reliable identification, especially with the use of DNA barcoding. It is often possible to describe those colors more objectively by searching for their codes online (various online tools exist). Familiarity with illustrated fur colors will be supplemented by regular examination of specimens. Camera trap photos will most likely take photographs of the animal's sides, allowing us to see any of the three coloration levels we defined (belly, sides, and back). When familiar with the field and the species at a given site, body measurements will not always be necessary to identify the species [1]. Furthermore, we proposed the future use of photographic illustrations of the key parts for each species on live specimens, which could be a complement or a faster solution to the tedious work with morphometric measurements. Such approaches include the animal's full and partial external profiles (dorsal, ventral, and lateral views) [4], the muzzle, the tail, and the hind foot. We also recommend using plantar pads for different species of terrestrial small mammals, as demonstrated by some authors [4,11], which we had not yet considered. Also, different photos will be taken for the variations of such colors within the same species, as done for *Lophuromys laticeps*.

Unlike many challenging keys, the current field-adapted key can easily be edited. Additionally, as many new species are being recognized through DNA barcodes, future work should re-examine the factors associated with the morphological variability of the same species with further insights into the age class, sex, and biogeography (including microhabitats). Furthermore, the species that become rare in the records or have no recent records should be documented by targeting specialized habitats such as wetlands, mountaintops, and remote or previously overlooked areas.

4.2. Ecological Research Implications, Applications, and Limitations

Some recent studies were interested in analysis functional traits of rodents and other mammals, such as how they responses by altitudinal shifts in mountains [31], their morphologies reflect functional similarity in less closely related species [32], history of their assemblages have been affected by anthropogenic stressors [33], rodent size, seed predation, and ecological interactions are interlinked [34], or environmental filters effect their assemblages in mountains [23]. In comparison to those studies, our study in Nyungwe yields valuable implications. The distribution of rodent species is correlated with their ecological functions. Large-sized rodents are often less abundant in the ecosystems. Specialized rodents, such as those partially or wholly dependent on aquatic or semi-aquatic systems, were often difficult to detect in surveys. These include *Malacomys*, *Delanymys*, *Deomys*, and *Colomys*, the least of which is the large swamp rat, *Malacomys.* Some rodents have adapted to specific habitats; they include *Grammomys*, which is recorded mostly at high altitudes, such as Bigugu. Altitudinal position affects the behaviors of rodents and their physiological adaptations, a topic subject to further investigation in Nyungwe. Rodents living at high altitudes were generally more docile and had a comparatively thicker fur coat. The highest altitude in Nyungwe has revealed a variety of rodents, among which most still have unresolved species identities; yet, the high-altitude zone is simpler in terms of vegetation, with rare canopy cover near the summit of the wet and humid mountain. Additional studies will be interesting to assess the dietary behaviors of those rodents, which can be studied in two possible ways: either camera traps can be used to record an array of rodents, allowing their feeding to be documented at specific locations, or diet composition can be determined by employing eDNA techniques (next-generation sequencing). The diet and forest canopy do not appear to play a significant role in determining the occurrence and distribution of rare small mammals in Nyungwe, in comparison to habitat quality and aversion to disturbance.

Research on rodents in Nyungwe has consistently demonstrated their high diversity; however, park managers often develop biodiversity monitoring plans that largely overlook rodents in key surveys. The presence of rodents can be fascinating when local staff and guides are interested in them or understand the reasons for studying them. The rodents need to be recognized by park managers and staff, not only for their appreciation of the diversity of mammals, but also for their distribution and reproductive traits that impact the entire forest ecosystem. To maintain mammal assemblages in tropical regions, strict law enforcement measures are imperative [35], which is particularly necessary in Nyungwe, where the taxonomy of a significant portion of rodent species remains unresolved. If the rodents in Nyungwe that range from the large-sized members, such as porcupines, squirrels, and the giant pouched rats, to the small species weighing a few grams, such as Delany's swamp mouse (*Delanymys brooksi*) and climbing mice (*Dendromus* spp.) did not occur in a habitat, the habitat could be rated as a barren tropical ecosystem. The abundance and selective distribution of rodents can increasingly open the way for further investigations into the effects of anthropogenic disturbances and climate change. In particular, high mountain areas may serve as ecological refuges in the face of these growing environmental challenges.

Our study was limited by a lack of technical skills, which constrained data collection during the early phases of research. More substantial data were gathered during the most recent field sessions (2022–2023). Financial limitations affected the amount of time we spent in the field (often live trapping relied on Sherman traps, and pitfall traps were seldom used, and many habitats could not be reached), quantity of tools for trapping (e.g., number of traps), the quality and standards of tools to record information (e.g., camera device), and lack or inaccessibility of laboratory facilities for genetic analyses which resulted in delays. Nonetheless, this study encourages the move to further improve local science by leveraging and building local resources, whereby field identification tools will reduce the costs and time required to secure acceptable and standard information for knowledge of mammal taxonomy, contributing to global science in rodents and their conservation in Afromontane tropical ecosystems and beyond.

5. Conclusions

This taxonomic key illustrates for 23 species of rodents and is intended as a starting point for a consolidated key for all terrestrial small mammals in Nyungwe and similar Afromontane regions, especially within the Albertine Rift. This paper emphasizes that taxonomic keys to rodents that do not rely on specimens or craniometric features can lead to efficient taxonomic work while conserving the rodents, as they can be studied by live trapping with consultation of existing museum specimens when necessary. Field photographs should be accompanied by brief morphological descriptions of each species to ensure accessibility for a broad audience, including scientists and local protected area managers and staff. Photographs of the rodents from specific field sites should record dorsal, ventral, and lateral views of each species to be integrated in the taxonomic keys, and frontal and lateral views of the head, the tail, and the plantar pads will improve future keys. As this document is designed for use by a wide range of users, including non-experts, its immediate outcomes should include: promoting cost-effective acquisition of taxonomic knowledge, assisting researchers and field assistants with local expertise on small mammals, raising awareness among protected area visitors and funders, and supporting practical conservation efforts for small mammal populations. The key should be freely editable by further users who can improve it, start a new site-specific key, or add more species; it can then be extended to other small mammals and similar ecosystems in Rwanda, in the East African region, across Africa, or beyond.

Author Contributions

M.M.: conceptualization, methodology, data collection, formal analysis, and draft writing; P.N.: methodology, data analysis, curation, and specimen work; and A.N.:

review, supervision, and validation. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

All the data generated by this study are freely available. Most of the information on the small mammal specimens used in our stud will be integrated into databases and online platforms (e.g., https://rbis.ur.ac.rw/, https://rwandabiodiversity.net/). The authors have no conflict in freely sharing any data associated with this publication when formally requested.

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Conflicts of Interest

The authors declare no conflicts of interest at any stage of this manuscript.

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