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Westra, S.A.; Mol, R.R.; Desjardins, R.B.; Visser, M.D.; Baele, A.V.M.P.C.; Montfort, D. van

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RESEARCH ARTICLE

Results of a small terrestrial mammal survey in the remote Boé region of Guinea-Bissau, with discovery of two new shrew records for the country

Sil A. Westra[1] | Roy R. Mol[1] | Rebecca B. Desjardins[2] | Marco D. Visser[3] | Amber V. M. P. C. Baele[4] | Dorien van Montfort[5]

[1]Silvavir Ecological Consultants, Schalkhaar, The Netherlands

[2]Naturalis Biodiversity Center, Leiden, The Netherlands

[3]Institute of Environmental Sciences, Leiden University, Leiden, The Netherlands

[4]Chimbo Foundation, Kesteren, The Netherlands

[5]Utrecht University, Utrecht, The Netherlands

Correspondence
Sil A. Westra, Silvavir Ecological Consultants, Schalkhaar, The Netherlands.
Email: sil.westra@silvavir.com

Abstract

The Boé region in the south-east of Guinea-Bissau has remained untouched by large-scale human influence and development due to its isolated location. The region consists mainly of savannah interspersed with gallery forests and hosts a unique and valuable biodiversity though very little is known of small terrestrial mammal diversity. In 2013, a terrestrial small mammal live trapping survey was conducted around Béli, a small village in the South of the Boé region. Five survey locations of three ecotypes were selected, and a combination of pitfall traps and live traps was used to capture and release small mammals. A selection of mammals that could not be identified as well as accidental mortalities in the traps were collected as voucher specimens and sent to Naturalis Biodiversity Center in the Netherlands. Over 96 survey days, a total of 331 small terrestrial mammals were trapped from 21 unique species, which include two new species records for the country: shrew species *Crocidura lamottei* and *Crocidura crossei*. Extrapolation from species accumulation curves suggested an overall species richness of 22 species for the region, with substantial differences in community composition among sampled habitats. The results of this study are an important part of the scientific record for small terrestrial mammals in the Boé region and set a baseline reference for future conservation efforts.

KEYWORDS
gallery forest, live trapping, mice, rats, rodents, savannah, shrews, West Africa

Résumé

La région de Boé, située au sud-est de la Guinée-Bissau, est restée épargnée par l'influence et les développements humains en raison de son isolement. La région se compose principalement de savane entrecoupée de galeries forestières et abrite une biodiversité unique et précieuse, bien que l'on sache très peu de choses sur la diversité des petits mammifères terrestres. En 2013, une enquête réalisée par la capture de petits mammifères terrestres vivants a été menée autour de Béli, un petit village du sud de la région de Boé. Cinq sites d'étude de trois écotypes ont été sélectionnés, et

A first-time live trapping survey gathered unique data and voucher specimens in the south-east of Guinea-Bissau, West Africa. The results form an important part of the scientific record for small terrestrial mammals in the Boé region.

une combinaison de pièges à fosse et de pièges vivants a été utilisée pour capturer et relâcher les petits mammifères. Une sélection de mammifères n'ayant pu être identifiés ainsi que d'autres organismes ayant trouvé la mort accidentellement dans les pièges a été collectée en tant que spécimens de référence et envoyés au Naturalis Biodiversity Centre situé aux Pays-Bas. Au cours de 96 jours d'enquête, un total de 331 petits mammifères terrestres appartenant à 21 espèces uniques ont été piégés, dont deux nouvelles espèces enregistrées dans ce pays : les espèces de musaraignes *Crocidura lamottei* et *Crocidura crossei*. L'extrapolation réalisée à partir des courbes d'accumulation d'espèces a suggéré une richesse spécifique globale de 22 espèces pour la région, avec des différences substantielles dans la composition des communautés parmi les habitats échantillonnés. Les résultats de cette étude représentent une partie importante du dossier scientifique pour les petits mammifères terrestres dans la région de Boé et établissent une base de référence pour les futurs efforts de conservation.

1 | INTRODUCTION

The Boé region is an isolated area in the south-east of Guinea-Bissau. Its vegetation consists of savannah and is interspersed with forest corridors, which provide suitable habitat for mammal species otherwise restricted to tropical rainforest elsewhere in West Africa. Accessibility of the region is restricted due to limited infrastructure and the 200-m-wide river Rio-Corubal causing the region to be relatively unaffected by human interference. This combination of a unique vegetation and isolation creates favourable conditions for conservation. Consequently, the Dutch Foundation CHIMBO set up a research station in the town of Béli with the goal of developing long-term nature conservation and development strategies including protected status for large areas of untouched savannah and gallery forests. Information on small terrestrial mammals for the region is scarce and not very recent (Grubb et al., 1998; Reiner & Simões, 1998), and therefore, a baseline reference for future studies and long-term conservation strategies cannot be built.

Mammal collecting has only been sporadic in Guinea-Bissau since 1962 (GBIF Data, 2022). Worldwide, there are 917 mammal specimens from Guinea-Bissau in museum collections (GBIF Data, 2022). This number is especially small when compared to the neighbouring nations of Guinea and Senegal, with 10,935 and 8749 mammal specimens in museum collections, respectively. Of the Guinea-Bissau specimens, the majority are *Primates*, *Artiodactyla* and *Carnivora*. Only 131 *Rodentia* specimens exist, and no *Eulipotyphla* at all. There are very few surveys which focus on the presence and distribution of small terrestrial mammals in Guinea-Bissau in general and in the Boé region (Reiner & Simões, 1998). The IUCN Red List database (2012) sums up a total of at least 42 species of small mammals (*Eulipotyphla*, *Lagomorpha* and *Rodentia*) for Senegal and Mali, against 25 for Guinea-Bissau. Apart from the obvious difference in suitable habitat size, a lack of sufficient monitoring could explain this discrepancy.

To address this Silvavir, an ecological consultancy from the Netherlands set up a monitoring survey. The goal was to quantify small mammal diversity by live trapping in a representative subset of local habitat types. We expected that each different habitat type was host to unique terrestrial small mammal communities and that, therefore, regional diversity would be substantially larger than diversity in each habitat separately. If so, this suggests that conservation of the area's small mammal diversity depends on the conservation of local habitat variability.

2 | METHODS

2.1 | Study site

The Boé region is an area of about 3200 km^2 in the south-east of Guinea-Bissau. Located in the north-western spur of the Fouta Djallon highland, it is an area characterised by massive plateaus and rolling savannahs intersected by shallow river valleys. The climate is classified as a tropical savannah climate zone (Kottek et al., 2006) with daytime temperatures between 30 and 40°C and overnight temperatures between 10 and 23°C. The dry season starts in November and lasts until May; during this time, precipitation is low, whilst the rainy season is extremely wet. The savannah vegetation consists of tall grass in the wet season, which disappears with dry season drought.

2.1.1 | Survey location selection and description

Five sites, 1 km apart and located near the village of Béli, were chosen for trapping (Figure 1). Locations were chosen as to be representative of the natural habitats in different biotopes surrounding Béli village: two locations in a savannah biotope, two in a forest corridor and one in an abandoned overgrown rice field. Trap sites were visited from the research station in Béli village by cycling remote paths and dry stream beds on mountain bikes.

Location 1 (LAT 11.8612370; LONG −13.9371810)

Savannah biotope covered with tall grass in the wet season. The location is bordered by a small gallery forest on the south side, comprising

FIGURE 1 Map of the study area and trap locations

tall shrubs and some small trees. The soil is red clay, mixed with coarse gravel and large rocks. After 20 weeks, this location was cancelled due to presence of large colonies of army ants. Traps were moved to location 6.

Location 2 (LAT 11.8688910; LONG −13.9386090)
Abandoned agricultural field formerly used for dry rice production. Now overgrown with low shrubs and tall bunches of grass. The soil consists of sand and organic materials mixed with clay.

Location 3 (LAT 11.8767270; LONG −13.9366700)
Savannah biotope covered with tall grassy vegetation during the wet season. Dry and bare in the dry season. The location is bordered by a small gallery forest to the east, primarily tall shrubs and some trees. On the west side, the location is bordered by a stream, which is small and slow flowing in dry season and swells up in the wet season. The red clay soil is mixed with coarse gravel and large rocks.

Location 4 (LAT 11.8817920; LONG −13.9376400)
Larger gallery forest within the savannah. The area has many tall trees and shrubs. Halfway through the transect, the forest is bisected by a seam of tall grass. The soil consists of red clay and organic materials.

Location 5 (LAT 11.8872000; LONG −13.9333500)
Gallery forest amid the savannah. The area is covered by tall trees and shrubs. Vegetation is very dense with a lot of thorny shrubs. The soil consists of red clay and organic materials.

Location 6 (LAT 11.8310800; LONG −13.9299800)
Cashew plantation. This location was only trapped for 7 weeks starting from survey week 20, after traps were moved here because location 1 was cancelled.

Location Beli (LAT 11.847149; LONG −13.934655)
The location where the office was located, population under 1000. Located in a savannah, no paved roads and buildings made of mud/earth with relatively tall thatched roofs. Beli was not a survey location, but trapping took place incidentally inside buildings and villagers brought dead specimens to the office.

2.2 | Live trapping

West African surveys indicate that pitfalls are essential for a representative sampling of shrew species (Nicolas et al., 2009). Both Longworth and Sherman live traps are considered the international standard for small terrestrial mammal surveys (Anadu, 2008; Decher, 2004; Decher et al., 2005, 2010; Fichet-Calvet et al., 2009; Hoffmann et al., 2010; Manu, 2011; Weber & Fahr, 2007). Using different trap types in Africa allows for a wider range of taxa to be collected, which results in a better understanding of the local ecosystem (Nicolas & Colyn, 2006). For our survey, we used a combination of five pitfall traps, 10 terrestrial live traps and 10 arboreal live traps on each of the five research locations.

2.2.1 | Pitfall traps

On all trap locations, pitfall traps were installed along drift fences. Five 10-L buckets were dug into the ground serving as pitfall traps. The buckets were buried up to their rims flush with the ground surface in a straight line, 5 metres apart. For this project, we used empty sauce-buckets, which were easily bought on the markets of the cities of Gabu and Bissau. The bottoms of the buckets were perforated with 3–5-mm holes to drain excess of rainwater. To ensure adequate drainage, the holes for the buckets were dug about 20 cm deeper than the bottom of the bucket. A few hand-sized rocks were put on the bottom of the buckets to create shelter and refuge for the captured animals. All buckets were covered with a lid in which a large hole was cut in the middle, so that a 3–4-cm-wide ring along the rim of the bucket remained when the lid was on. This ring prevented animals climbing back out of the pitfall trap after capture. The round pieces of plastic that were cut from the lid were fitted with sticks to be used to close the pitfalls whenever the traps were not in use.

A 40-cm-high drift fence was built along 20 m in a straight line right across the pitfall traps. Stakes made from local wood with a length of 80 cm and a diameter of about 10 cm were hammered 30 cm into the ground. Agricultural plastic foil with a width of 50 cm was fastened onto the stakes with a staple gun. It was installed in such a manner that the foil ran straight across the middle of the pitfall buckets (Figure 2). The foil was 40 cm in height, and a seam of 10 cm draped over the ground, which was then covered with soil so that animals could not pass underneath it. The foil was cut above the pitfall traps so pitfalls were accessible by animals from both sides. To prevent animals from stranding in the corner space between the fence and wooden stakes, these areas were filled in with soil.

FIGURE 2 Drift fence with pitfall traps at trap location 4 (Photo by Roy Mol)

2.2.2 | Sherman and Heslinga live traps

To maximise capture probability, a combination of Sherman size large and Heslinga live traps was used. Heslinga traps are a Dutch-made live trap nearly identical to the Longworth live trap. The aluminium traps were baited with dried fish, apple and mixture of peanut butter, flour and oats. Furthermore, the traps were filled with nesting material consisting of dried grassy vegetation that was gathered locally.

The traps were placed at a distance of 25 m parallel to the pitfall traps in a 200-m-long trap line. A pair of traps was placed every 20 m, consisting of one Heslinga trap and one Sherman live trap. Ten pairs with a total of 20 live traps were placed on all trap locations. Heslinga traps were placed on the ground to catch small and light species like shrews. Sherman live traps size large were fixed on large horizontal limbs of trees to catch arboreal mammals such as dormice and small squirrels (Figure 3). All individual trap locations were marked with flags of white paper tape to be able to retrieve the traps conveniently.

2.2.3 | Trapping schedule

The survey was initiated by two experienced field biologists, who sampled over 3 weeks in October 2013. After this initial setup period, the surveys were continued by volunteer biologists and students that came to Béli sequentially. The survey was executed according to the standardised method for live trapping set by the Dutch Institute for forest and nature research (IBN), known as the IBN method (Bergers, 1997; Koelman, 2007).

On trapping days, the trap checks occurred in the morning, as soon as possible after sunrise, and a second time in the evening, just before sunset. Since many small terrestrial mammals are active during dusk, night and dawn, this schedule traps the animals for the shortest period of time possible minimising the chance of trap mortalities (Bergers, 1997; Koelman, 2007). Traps were not checked during the night hours as night work was considered unsafe due to the remoteness and potentially dangerous wildlife present at the survey locations.

The trapping schedule ran from Sunday evening (setting traps active) to Friday morning (setting traps to safe). This way, every week 10 checks were conducted on both pitfall traps and live traps. Both bait and nesting material were replaced each time an animal was trapped and refreshed for all traps every week on Monday mornings.

In the dry season, outside air temperatures proved too hot to safely trap animals. Therefore, from the beginning of February, traps were closed after the morning check and re-activated in the evenings (van van Montfort, 2014). All traps were closed for the weekend.

2.2.4 | Handling and species identification

Whenever an animal was caught in one of the traps, it was transferred to a large transparent plastic bag by putting the trap inside the bag and carefully opening it and pulling out the nesting material. Once the animal was transferred to the plastic bag, the animal was then positioned head first into a small plastic tube. The tube was closed with cotton on one side, so the animal could easily be contained inside the tube for species identification and measurements (Figure 4). This tubing method is less stressful for the animal and the researcher and especially recommended for use by inexperienced small mammal researchers (Hoffmann et al., 2010).

In case a captured species could not be identified on site, the animal was taken along for further determination to the laboratory in Béli village. It was transported in a plastic container in which nesting material and food had been added. At the laboratory, the animal was transferred back into the tube in the same manner as described above. Whenever a species was identified successfully, it was kept in the laboratory inside a cage with adequate food and nesting

FIGURE 3 Sherman live trap being installed on the limb of a tree (Photo by Roy Mol)

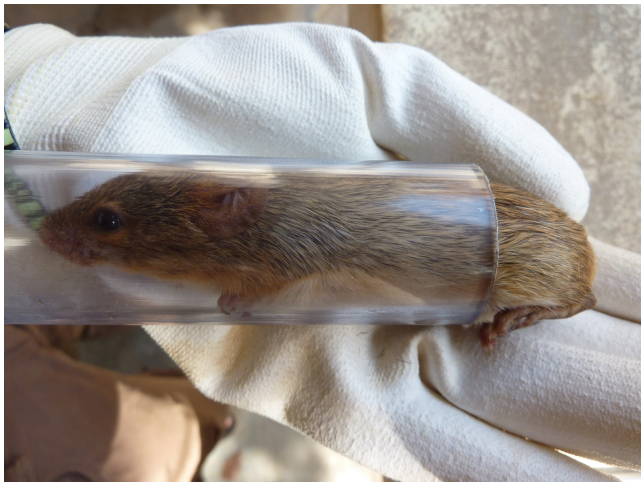


FIGURE 4 Tubing method used for handling small mammals (Photo by Amber Baele)

material, and on the next trap check, the animal was released at the exact location where it was caught.

2.2.5 | Measurement procedures

Captured animals

Captured animals were weighed, and length of body, tail, hind foot, front foot and ear measured. Whenever possible, the life stage and gender was determined as well as whether an animal was pregnant or lactating. Head, tail, ear and side view were clearly photographed, and other photographs taken as needed. Finally, fur on the base of the tail was clipped so that the animal could be identified if recaptured. Animals that were captured repeatedly in which the hair has grown back were clipped again.

All available literature on small mammals for the region that was available to us at the time was consulted for species determination, including Booth (1960), Rosevear (1969), Hutterer and Happold (1983) and Visser de et al. (2001). An intensive effort was made to identify species in the field using a species identification table that was custom composed for the project. In this table, characteristics can be found of small terrestrial mammal species known to occur in Guinea-Bissau or neighbouring countries according to references mentioned earlier and other sources (Happold, 2013; Happold & Happold, 2013; IUCN Red List, 2012).

2.3 | Collected specimens

CHIMBO has permanent permission to work in Guinea-Bissau in the areas managed by the Instituto da Biodiversitdad e das Areas Protegidas (IBAP). This project was planned as a survey to collect baseline data, rather than an expedition to collect voucher specimens. However, trap fatalities and a selection of animals that could not be identified were preserved as voucher specimens for the scientific record. A maximum of three voucher specimens per unidentified species were collected this way. The animals were preserved following guidelines by Ethridge (1996) by injecting 40% formaldehyde into the body with a syringe. Unfortunately, due to a communication error no DNA was preserved prior to formaldehyde fixing. Afterwards, the specimen was submerged into 70% ethyl alcohol in a closed container. Every individual specimen was stored in its own small plastic container and was clearly labelled with its record ID. Naturalis Biodiversity Center provided the chemicals (formaldehyde and ethyl alcohol for fixing and preserving specimens). Permission for collecting these specimens was granted by the government of Guinea-Bissau, more specifically the Director General for IBAP who issued a personal authorisation letter. This authorisation letter, along with a letter written by the head of the vertebrate department containing Naturalis' CITES permit number, was kept on site and shipped with the specimens back to the Netherlands. Shipping was done following IATA guidelines (Bentley, 2007). Upon arrival at Naturalis Biodiversity Center, skulls were removed and prepared. Specimens were weighed (wet), and the following measurements were taken: length from nose to anus, anus to end of the tail vertebrae and ear. Also, there were two measurements of the hind foot taken, with and without claws. The unidentified specimens were determined after the skulls were prepared. Skulls and spirit preserved bodies have been given collection numbers and were deposited in the collections of Naturalis Biodiversity Center (Figure 5).

Once in the collection of Naturalis Biodiversity Center, the specimens, mostly species of soft-furred mice (*Praomys*), were identified using a number of different sources: Grubb et al. (1998), Lecompte et al. (2001), Akpataou et al. (2007), Kryštufek (2008), van der Straeten (2008), Lalis et al. (2009), Reiner and Simões (1998), Meester and Setzer (1971), Van der Straeten and Kerbis Peterhans (1999) and Missoup et al. (2012). We sent Dr. Rainer Hutterer at Zoological Research Museum Alexander Koenig (ZFMK) in Bonn, Germany, photographs and skulls, and he was kind enough to identify the most challenging *Crocidura* specimens.

2.4 | Statistical analysis of trap data

Using the list of small mammals that were trapped on location L1–L6 and identified to species level, we fit species accumulation curves (SAC) for each location separately and the entire region. SAC curves were fitted using the R package vegan (Oksanen et al., 2019) with the "exact" method, which is also known as the Mao Tau estimate (Colwell et al., 2012). This is a commonly used sample-based rarefaction method described in detail in Chiarucci et al. (2008). Species accumulation curves are a good way to determine whether the survey length was long enough to yield a credible estimate of species richness (Nippon Koei UK, 2007; O'Brien et al., 2002). Therefore, in addition, we fitted a Weibull growth curve model to the survey species accumulation data to predict the asymptotic species richness for the region if sampling had continued indefinitely. We calculated confidence intervals for the asymptotic specific richness using a non-parametric bootstrap (with 10,000 iterations). A Weibull was

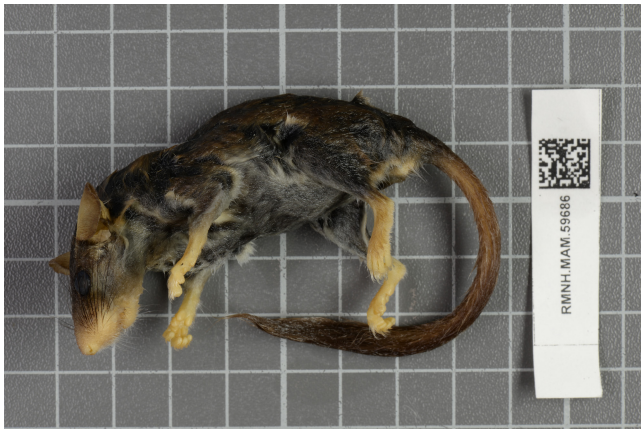


FIGURE 5 Ethanol preserved voucher specimen from the Boé region (Photo by Esther Dondorp)

fitted as earlier analysis showed that it provided the best fit to the data based on AIC scores.

3 | RESULTS

A total of 331 small terrestrial mammals were trapped on 96 survey days between 6 October 2013 and 27 April 2014. These records consist of 142 individuals (plus 189 recaptures) all of which have the status 'Least Concern' or have not yet been assessed on the IUCN Red List (2012). One species, the Striped Ground Squirrel (*Xerus erythropus*—Desmarest 1817), was observed but never captured in live traps. It was included in the results.

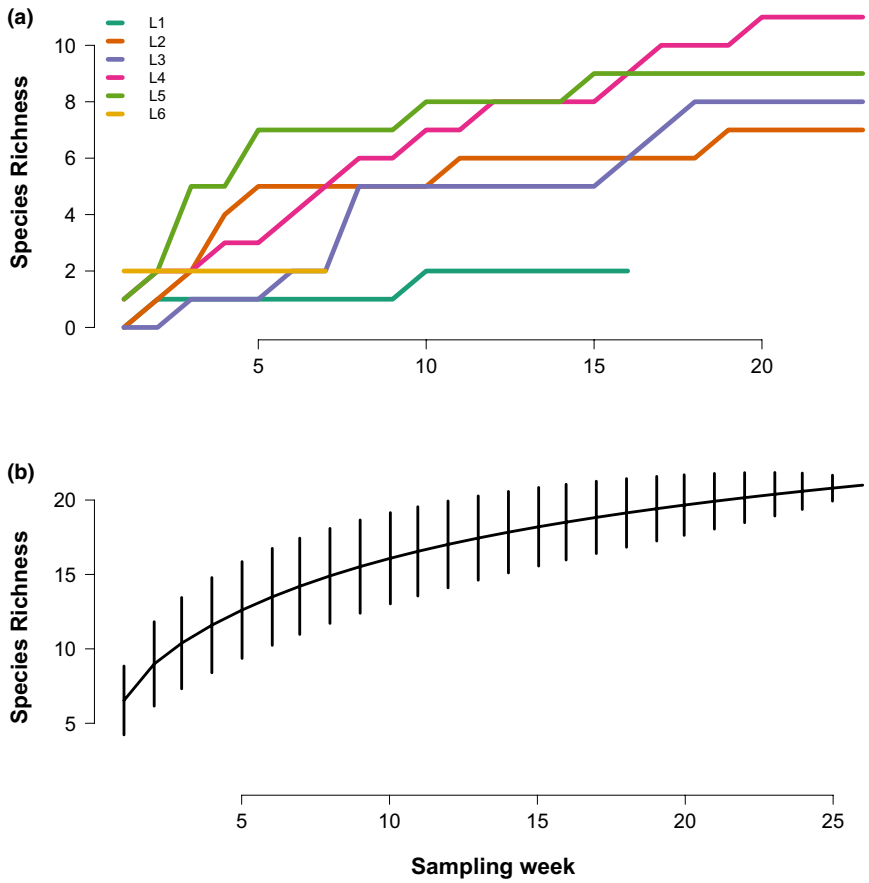
The total number of individuals that were trapped in this survey can be divided into 11 genera and 21 species. Significant numbers of captured small mammals are marked as "unknown" as we were not able to identify them in the field. *Praomys* spp., *Lemniscomys* spp. and *Mastomys* spp. were the most abundant species that we trapped. Kellen's Dormouse *(Graphiurus kelleni*—Reuvens, 1890), Gambian Sun Squirrel *(Heliosciurus gambianus*—Ogilby, 1835), Guinea Multimammate Mouse *(Mastomys erythroleucus*—Temminck, 1853), *Hubert's* Mastomys *(Mastomys huberti*—Wroughton, 1909) and all *Crocidura* spp. were trapped less than five times (Table 1).

The fitted species accumulation curve for the entire region (all locations) showed a declining rate of increase in species richness (Graph 1) though in four of the six locations the curves did not show

TABLE 1 Total number of trapped records of small terrestrial mammals

Species		Location L1	L2	L3	L4	L5	L6	Beli	Totals
SHREWS									
Crocidura	cf *olivieri*				1				1
	crossei				1				1
	lamottei					1			1
	sp.[a]				2	1			3
	viaria/ fuscomurina/ jouvenetae[a]			1		1			2
RODENTS									
Gerbilliscus	*guinea*	2	3	1					6
Grammomys	*macmillani*				6	1		1	8
Graphiurus	*kelleni*				1	3			4
Heliosciurus	*gambianus*				2				2
Lemniscomys	*linulus*		23		23				46
	striatus				23				23
	zebra	4	1						5
Mastomys	*erythroleucus*			2		1			3
	huberti			2					2
	natalensis			22			9		31
	sp.[b]					1			1
Praomys	*daltoni*		5	7	8	13	2	9	44
	rostratus		26	4	8	9			47
	tullbergi		2	1	1	1	41		46
Rattus	*rattus*		2					5	7
Unknown	Unknown[c]		5	8	15	6	2	7	43
Uranomys	*ruddi*					4			4
Xerus	*erythropus*							1	1
Total number of captures and recaptures		6	67	48	91	42	54	23	331
Number of species		2	8	9	12	12	4	5	21[d]

[a]Not conclusively identified shrews.
[b]Released and unidentified *Mastomys*.
[c]Released and unidentified rodents.
[d]Adjusted species Total.



GRAPH 1 Empirical observed species accumulation curves for each location (a) and the fit species accumulation curve for the entire region (b). Vertical bars in panel (b) indicate 95% confidence intervals

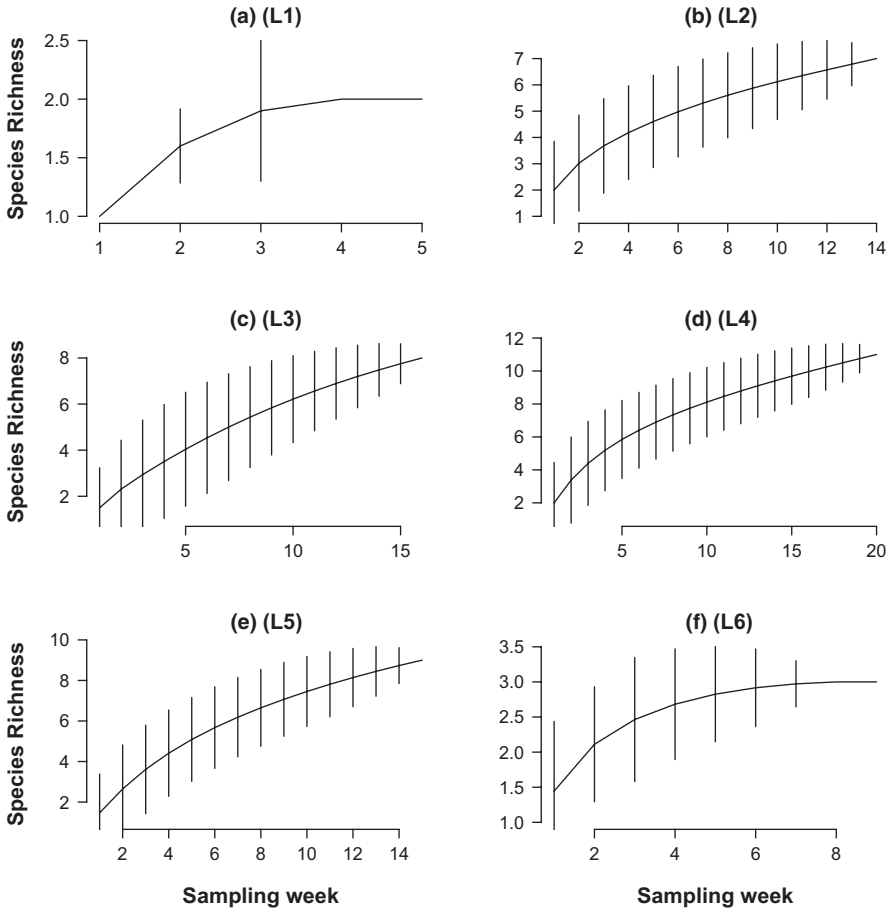
a strongly declining rate (Graph 2). Extrapolation from the fit Weibull curve suggested that an expected diversity of approximately 22 species (bootstrapped mean 22.9) would have been detected if sampling had continued indefinitely at the sites (with an upper bootstrapped 95% confidence limit of 33.7 species).

A total of 13 voucher specimens were collected and sent to Naturalis Biodiversity Center in the Netherlands (Table 2). These voucher specimens are an important part of the scientific record for the Boé region. The following collection specimens were identified: RMNH.MAM.59686 as Kellen's Dormouse (*Graphiurus kelleni*—Reuvens, 1890), RMNH.MAM.5069885 as *Gerbilliscus guinea* (Thomas, 1910), RMNH.MAM.5069876 as *Lemniscomys zebra* (Heuglin, 1864), RMNH.5069879 and RMNH.5069883 as Tullberg's Soft-furred Mouse (*Praomys tullbergi*—Thomas, 1894), RMNH.5069873 and RMNH.MAM.5069874 as *Praomys rostratus* (Miller, 1900) and RMNH.5069880 as *Praomys daltoni* (Thomas, 1892). Two specimens, RMNH.5069884 and RMNH.5069875, were identified to genus only. The former we identified as *Praomys* sp., and the latter is *Mastomys* sp. In both cases, the specimens are juveniles and the skulls are broken, which makes identification to species level challenging. Dr. Rainer Hutterer determined three specimens for us, two of which are species new for the country. RMNH.5069877 was identified as *Crocidura* cf. *olivieri* (Lesson, 1827), RMNH.5069881 is *Crocidura lamottei* (Heim de Balsac, 1968), and RMNH.5069882.a is *Crocidura crossei* (Thomas, 1895).

Two species of shrew, *Crocidura lamottei* and *C. crossei*, represent new records for Guinea-Bissau (Reiner & Simões, 1998). According to Igbokwe et al. (2019), *C. crossei* is found in rainforest, rainforest-savannah mosaic and Guinea savannah in Guinea, Sierra Leone and western Cameroon. In Nigeria, it was only found in rainforest. In the Boé region, it was found in gallery forest, as was the only specimen of *C. lamottei*. Wilson and Reeder (2005) describe the range for *C. lamottei* as savannah from Senegal to W Cameroon, but a study on the Accra Plains of Ghana found *C. lamottei* only in sacred groves (Decher & Bahian, 1999).

4 | DISCUSSION AND CONCLUSION

The total of 331 small terrestrial mammals that were trapped consist of 142 individuals and 189 recaptures. Species richness in the different assessed habitats differed substantially, ranging between two and 12 species. In the entire region, we detected a total of 21 species of small mammals, which include two new shrew species for the country. Regional diversity was much larger than any single ecotype, which suggests a crucial role for maintaining habitat variability if small mammal diversity is to be maintained. Statistical analysis suggested that the survey length was sufficient for the region as the asymptotic expected diversity at infinite effort was 22 species, very close to the detected 21 species. Considering that literature



GRAPH 2 The fit species accumulation curves for each location (a–f). Vertical bars in panel (b) indicate 95% confidence intervals

estimates on regional diversity range between 24 and 25 species (IUCN Red List, 2012; Reiner & Simões, 1998), we believe that our results indicate that the survey was of sufficient length to detect all but the rarest species.

Identification of small mammals is challenging anywhere in the world, but especially in tropical environments with relatively high species diversity. Working with inexperienced volunteers and field workers that were trained on the job in a very short period of time means that species identification mistakes are inevitably common. This caused 43 captures to be labelled as "unknown". Furthermore, we consider it possible that two individuals of either Bicolored African White-toothed Shrew (*Crocidura fuscomurina*—Heuglin, 1865) or Jouvenet's White-toothed Shrew (*Crocidura jouvenetae*—Heim de Balsac, 1958) or Savannah Path White-toothed Shrew (*Crocidura viaria*—I. Geoffroy Saint-Hilaire, 1834) could have been confused with each other (Table 1). Variety in pelage colour between the three species, overlap in species-specific characteristics and dealing with juveniles make this process difficult. Unfortunately, no voucher specimens from these species were collected.

Although collection of voucher specimens can be of great scientific importance, our fieldworkers felt that collecting was very undesirable and unethical. Injecting formaldehyde into a living animal with a syringe is not for the faint-hearted, and it explains why only 13 specimens were collected. No CO^2, acetone, chloroform or halothane was available in Guinea-Bissau for us at the time, limiting our options for alternative methods of euthanasia. Our lack of experience with collecting voucher specimens and miscommunication with Naturalis caused us to not take DNA samples prior to formaldehyde injection. This is very unfortunate, as formaldehyde destroys the DNA, an oversight unknown to the field biologists and workers at the time. We note this here, so future research efforts in the regions can take the required steps to secure DNA samples.

We identified voucher specimen RMNH.5069873 as *Praomys rostratus*, but some of its features could possibly link it to *P. jacksoni* (de Winton, 1897). RMNH.5069879 we identified as *P. tullbergi*; however, it has some features, namely and extremely V-shaped nasal-frontal suture that imply it could be *P. hartwigi* (Eisentraut, 1968; Lecompte et al., 2001). Both *P. jacksoni* and *P. hartwigi* have a restricted range in Nigeria and Cameroon and for all we know today, they do not extend to Upper Guinea. Unfortunately, we did not collect DNA samples and we collected just low numbers of voucher specimens. Without DNA samples, we cannot safely assign solid names to these specimens and, therefore, we have to assume that they are more likely to be individual variation of common *P. rostratus* and *P. tullbergi*, respectively. This underlines the importance of the collection of DNA samples for identification purposes in future studies. It is very unfortunate that we were not able to supplement our cranial and morphological analyses with genetic analyses to consolidate our results.

TABLE 2 List of voucher specimens from the Boé region that were accessioned in the collection of Naturalis Biodiversity Center, Leiden

Specimen number	Genus	Species	Location	Ecosystem
RMNH.MAM.59686	*Graphiurus*	*kelleni*	Location 5	Gallery forest
RMNH. MAM.5069882	*Crocidura*	*crossei*	Location 4	Gallery forest
RMNH. MAM.5069885	*Gerbilliscus*	*guinea*	Location 3	Savannah
RMNH. MAM.5069877	*Crocidura*	cf. *olivieri*	Location 4	Gallery forest
RMNH. MAM.5069881	*Crocidura*	*lamottei*	Location 5	Gallery forest
RMNH. MAM.5069883	*Praomys*	*tullbergi*	Location 6	Cashew plantation
RMNH. MAM.5069884	*Praomys*	sp.	Beli, office	Village
RMNH. MAM.5069876	*Lemniscomys*	*zebra*	Location 2	Abandoned ag
RMNH. MAM.5069873	*Praomys*	*rostratus*	Location 2	Abandoned ag
RMNH. MAM.5069874	*Praomys*	*rostratus*	Location 5	Gallery forest
RMNH. MAM.5069879	*Praomys*	*tullbergi*	Location 4	Gallery forest
RMNH. MAM.5069875	*Mastomys*	sp.	Location 3	Savannah
RMNH. MAM.5069880	*Praomys*	*daltoni*	Beli, bungalow 3	Village

Our results showed an increase in captured animals from late March until the end of the survey in April. This was presumably not only caused by our Heslinga trap adjustments. April is the start of the wet season and numbers of small rodents fluctuate depending on the season and the time of year (Delany, 1986). Wet season is greener and food sources such as seeds, nuts and fruits are more abundant, which would have a positive impact on small terrestrial mammal populations. Taylor and Green (1976) documented that an extensive rainy season led to an abundance of food and therefore an increase in granivorous rodent populations. In addition, assumptions are that during the dry season small terrestrial mammals cannot find adequate food sources and vegetation cover against predators and the heat of the sun in savannah habitat. They will most likely turn to the patches of gallery forests and use them as a refuge making dry season population densities higher here than during the wet season.

Ecological surveys in these remote and wild areas cause inevitable practical problems and limitations. In the dry season, high air temperatures led to the death of animals captured in live traps during daytime. As a result of this, at beginning in February, we started to deactivate traps after the morning check and re-activated in the evening so animals could not be trapped in the hottest time of day (van van Montfort, 2014). Shelters covering the traps could have prevented overheating. Future research efforts in the area should, therefore, not make the same mistakes and anticipate heat-related mortalities and aim to provide shelter. In some weather conditions, the rocks that were placed in the pitfalls as a refuge proved insufficient. Pitfalls can flood easily in heavy rain, and sediment can clog the drainage holes. Therefore, it is advisable to use a floating object such as polystyrene for refuge. This might, however, cause the trapped animal to be able to escape in heavy rain. Future work should consider the ethical balance between trap success and trap mortality when sampling with similar schemes.

Communication difficulties between field researchers in Guinea-Bissau and coordinators in The Netherlands led to practical problems in the field. This caused the Heslinga live traps to be set in an improper manner for part of the survey. Camera traps proved that animals were able to escape, and therefore, capture success was negatively influenced. In March, the traps were adjusted manually to prevent animals from escaping. Heslinga live traps work adequately only if the tunnel and nestbox of the trap are connected under an angle. This angle is crucial if working with these traps and should be taken into account in future surveys to prevent escapes.

Additional issues included interference with wild animals. Camera traps proved that Egyptian mongoose (*Herpestes ichneumon*—Linnaeus, 1758) knocked over live traps, affecting trap success. Large numbers of army ants were occasionally attracted by the bait and/or attacked and killed small mammals inside our traps. The presence of army ants presumably caused small mammals to stay away from the live traps nearby. Pitfall traps captured all small ground-dwelling creatures including spiders, centipedes, mantis, agamas, skinks and scorpions some of which are venomous. Caution is needed when checking pitfall traps in tropical areas and protective gloves can help.

Finally, an Ebola outbreak in mid-2014 made recruitment of students and volunteers difficult. This caused the survey to end prematurely, in April, after 6 months of work. Nevertheless, we successfully recorded the diversity of small terrestrial mammals using live and pitfall traps in the Boé region using the described methods. In order to conserve biodiversity in the Boé, baseline data regarding status and trends of the local environment are essential. There is a need to collect diversity data beyond small mammals, and we strongly encourage additional surveys and monitoring schemes for other clades and groups.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All collected specimens remain in the collections of Naturalis Biodiversity Center in Leiden, The Netherlands. The authors are happy to share the original live trapping data to anyone that is interested. Please contact the corresponding author.

ORCID

Sil A. Westra https://orcid.org/0000-0003-0120-0250
Rebecca B. Desjardins https://orcid.org/0000-0003-4010-6494
Marco D. Visser https://orcid.org/0000-0003-1200-0852
Amber V. M. P. C. Baele https://orcid.org/0000-0002-7820-5706
Dorien van Montfort https://orcid.org/0000-0002-8900-1338

REFERENCES

Akpataou, B., Nicolas, V., Pires, D., N'goran, E., & Colyn, M. (2007). Morphometric differentiation between two murid rodents, *Praomys tullbergi* (Thomas, 1894) and *Praomys rostratus* (Miller, 1900), in West Africa. *Zootaxa*, *1607*, 21–34. https://doi.org/10.11646/zootaxa.1607.1.2

Anadu, P. (2008). *A Preliminary survey of small terrestrial mammals in the Gola Forest, Sierra Leone*. Gola Rainforest National Park Technical research paper. Unpublished

Bentley, A. (2007). *Shipping and Handling of Natural History Wet Specimens Stored in Fluids as "Dangerous Goods" – Hazardous Materials*. Conserve-O-Gram, US National Park Service 11/13. https://decapoda.nhm.org/pdfs/31321/31321.pdf

Bergers, P. J. M. (1997). Kleine zoogdieren inventariseren: het kan efficiënter. *Journal of the Dutch Mammal Society: Zoogdier*, *8*(3), 3–6.

Booth, A. H. (1960). *Small mammals of West Africa, West African nature handbooks* (1st ed.). Longmans.

Chiarucci, A., Bacaro, G., Rocchini, D., & Fattorini, L. (2008). Discovering and rediscovering the sample-based rarefaction formula in ecological literature. *Community Ecology*, *9*, 121–123.

Colwell, R. K., Chao, A., Gotelli, N. J., Lin, S. Y., Mao, C. X., Chazdon, R. L., & Longino, J. T. (2012). Models and estimators linking individual-based and sample-based rarefaction, extrapolation and comparison of assemblages. *Journal of Plant Ecology*, *5*, 3–21.

Decher, J. (2004). A rapid survey of terrestrial small mammals (Shrews and rodents) of the Forêt Classée du Pic de Fon, Guinea. In J. McCullough (Ed.), *A rapid biological assessment of the Forêt Classée du Pic de Fon, Simandou Range, Southeastern Republic of Guinea. RAP Bulletin of Biological Assessment 35. Washington, D.C.* (pp. 78–83). Conservation International.

Decher, J., & Bahian, L. K. (1999). Diversity and structure of terrestrial small mammal communities in different vegetation types on the Accra Plains of Ghana. *Journal of Zoology*, *247*, 395–408. https://doi.org/10.1111/j.1469-7998.1999.tb01002.x

Decher, J., Oppong, J., & Fahr, J. (2005). Rapid assessment of terrestrial small mammals atDraw River, Boi Tano, and Krokosua Hills. In J. McCullough, J. Decher, & D. G. Kpelle (Eds.), *A biological assessment of the terrestrial ecosystems of the Draw River, Boi-Tano, Tano Nimiri and Krokosua Hills forest reserves, southwestern Ghana. RAP Bulletin of Biological Assessment, No. 36. Washington D.C.* (pp. 57–66). Conservation International.

Decher, J., Norris, R. W., & Fahr, J. (2010). Small mammal survey in the upper Seli River valley, Sierra Leone. *Mammalia*, *74*(2), 163–176.

Delany, M. J. (1986). Ecology of small rodents in Africa. *Mammal Review*, *16*, 1–41.

Ethridge R.E. (1996). *Preservation Techniques, University of Michigan Museum of Zoology*. Retrieved May, 2020, from https://lsa.umich.edu/ummz/herps/collections/preservation-techniques.html

Fichet-Calvet, E., Lecompte, E., Veyrunes, F., Barrière, P., Nicolas, V., & Koulémou, K. (2009). Diversity and dynamics in a community of small mammals in coastal Guinea, West Africa. *Belgian Journal of Zoology*, *139*(2), 93–102.

GBIF.org. (2022) *GBIF Occurrence*. Retrieved March, 2022, from https://doi.org/10.15468/dl.mhw3mk

Grubb, P., Jones, T. S., Davies, A. G., Edberg, E., Starin, E. D., & Hill, J. E. (1998). *Mammals of Ghana, Sierra Leone and the Gambia*. The Trendrine Press.

Happold, D. C. D. (Ed.). (2013). *Mammals of Africa. Volume III: Rodents, Hares and Rabbits*. Bloomsbury Publishing.

Happold, M., & Happold, D. C. D. (Eds.). (2013). *Mammals of Africa. Volume IV: Hedgehogs, Shrews and Bats*. Bloomsbury Publishing.

Hoffmann, A., Decher, J., Rovero, F., Schaer, J., Voigt, C., & Wibbelt, G. (2010). Field methods and techniques for monitoring mammals. In J. Eymann, J. Degreef, C. Häuser, J. C. Monje, Y. Samyn, & D. VandenSpiegel (Eds.), *Manual on field recording techniques and protocols for all Taxa biodiversity inventories and monitoring* (pp. 482–529). Pensoft Publishers.

Hutterer, R., & Happold, D. C. D. (1983). The shrews of Nigeria (Mammalia: Soricidae). *Bonner Zoologische Monographien*, *18*, 1–79.

IUCN (International Union for Conservation of Nature). (2012). *2012 IUCN Red List of threatened species*. Retrieved September, 2020, from http://www.iucnredlist.org

Igbokwe, J., Nicolas, V., Oyeyiola, A., Obadare, A., Adetunji, S. A., Awodiran, M. O., Van Houtte, N., Fichet-Calvet, E., Verheyen, E., & Olayemi, A. (2019). Molecular taxonomy of *Crocidura* species (Eulipotyphla: Soricidae) in a key biogeographical region for African shrews. *Comptes Rendus Biologies*, *342*, 108–117.

Koelman, R. M. (2007). *Handleiding inventarisatie noordse woelmuis m.b.v. inloopvallen. Dutch Mammal Society. Wildlife survey instruction manual*. Unpublished.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World Map of the Köppen-Geiger Climate Classification Updated. *Meteorologische Zeitschrift*, *15*, 259–263.

Kryštufek, B. (2008). Description of a New Thicket rat from Kenya: Grammomys Brevirostris n. sp. *Acta Zoologica Lituanica*, *18*(4), 221–227.

Lalis, A., Evin, A., & Denys, C. (2009). Morphological identification of sibling species: The case of West African *Mastomys* (Rodentia: Muridae) in sympatry. *Comptes Rendus Biologies*, *332*(5), 480–488. https://doi.org/10.1016/j.crvi.2008.11.004

Lecompte, E., Denys, C., & Granjon, L. (2001). An identification key for species within the genus *Praomys* (Rodentia: Muridae). In C. Denys, L. Granjon, & A. Poulet (Eds.), *African Small Mammals – Petits mammifères africains. Proceedings of the 8th International Symposium on African Small Mammals* (pp. 127–129). IRD Press.

Manu, A. P. (2011). *Biodiversity monitoring in Asubima and Afrensu Brohuma forest reserves, Ghana* [Unpublished technical research report]. Form International Ghana.

Meester, J., & Setzer, H. W. (1971). *The mammals of Africa. An identification manual*. Smithsonian Institution Press.

Missoup, A. D., Nicolas, V., Wendelen, W., Keming, E., Bilong Bilong, C. F., Couloux, A., Atanga, E., Hutterer, R., & Denys, C. (2012). Systematics and diversification of *Praomys* species (Rodentia: Muridae) endemic to the Cameroon Volcanic Line (West Central Africa). *Zoologica Scripta*, *41*, 327–345.

van Montfort, D. (2014). *The effect of sampling on the measurement of small mammal diversity; species abundance and species richness*. [Unpublished Bachelor Thesis]. Utrecht University, Department of Biology.

Nicolas, V., & Colyn, M. (2006). Relative efficiency of three types of small mammal traps in an African rainforest. *Belgian Journal of Zoology*, *136*(1), 107–111.

Nicolas, V., Barrière, P., Tapiero, A., & Colyn, M. (2009). Shrew species diversity and abundance in Ziama Biosphere Reserve, Guinea: Comparison among primary forest, degraded forest and restoration plots. *Biodiversity and Conservation*, *18*, 2043–2061.

Nippon Koei UK. (2007). *Completion of the Bumbuna Hydroelectric Project, Baseline Biodiversity Surveys – Baseline Small Mammal Survey*, [Unpublished technical research report]. Nippon Koei UK Co Ltd.

O'Brien, C., McShea, W., Guimondou, S., Barriere, P., & Carleton, M. (2002). Terrestrial small mammals (Soricidae and Muridae) from the Gamba complex of protected areas, Gabon: Species composition and comparison of sampling techniques. *Bulletin of the Biological Society of Washington*, *12*, 353–363.

Oksanen, J., Guillaume, B. F., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O'Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., Szoecs, E., & Wagner, H. (2019). *Vegan: Community Ecology Package*. R package version 2.5-5. https://CRAN.R-project.org/package=vegan

Reiner, F., & Simões, P. (1998). *Mamiferos Selvagens da Guiné-Bissau*. Projecto Delfim – Centro Português de Estudos dos MamÍferos Marinhos, Lisbon, Portugal.

Rosevear, D. R. (1969). *The rodents of West Africa*. Trustees of the British Museum (Natural History).

Taylor, K. D., & Green, M. G. (1976). The influence of rainfall on diet and reproduction in four African rodent species. *Journal of Zoology*, *180*, 367–389.

Van der Straeten, E. (2008). Notes on the Praomys of Angola with the description of a new species (Mammalia: Rodentia: Muridae). *Integrative Systematics: Stuttgart Contributions to Natural History*, *1*, 123–131.

Van der Straeten, E., & Kerbis Peterhans, J. C. (1999). *Praomys degraaffi*, a new species of Muridae (Mammalia) from central Africa. *South African Journal of Zoology*, *34*(2), 80–90. https://doi.org/10.1080/02541858.1999.11448492

Visser de, J., Mensah, G. A., Codjia, J. T. C., & Bokonon-Ganta, A. H. (Eds.). (2001). *Guide preliminaire de reconnaissance des rongeurs du Benin* (1st ed.). Dutch Mammal Society.

Weber, N., & Fahr, J. (2007). A rapid survey of small mammals from the Atewa Range Forest Reserve, Eastern Region, Ghana. In J. McCullough, L. E. Alonso, P. Naskrecki, H. E. Wright, & Y. Osei-Owusu (Eds.), *A Rapid Biological Assessment of the Atewa Range Forest Reserve, Eastern Ghana. RAP Bulletin of Biological Assessment, No. 47. Washington D.C* (pp. 90–98). Conservation International.

Wilson, D. E., & Reeder, D. M. (Eds.). (2005). *Mammal Species of the World. A Taxonomic and Geographic Reference* (3rd ed.). Johns Hopkins University Press.

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