Biology, Medicine, & Natural Product Chemistry
Volume 15, Number 1, April 2026 | Pages: 1439-1450 | DOI: 10.14421/biomedich.2026.151.1439-1450
ISSN 2089-6514 (paper)
ISSN 2540-9328 (online)

Specific Richness of Bats in Urban and Peri-urban Environments of Kisangani, Tshopo Province in the Democratic Republic of Congo

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Manuscript received: 15 April 2026. Revision accepted: 22 June 2026, Published: 28 July 2026.

Abstract

This study focuses on bat diversity in the urban and peri-urban areas of Kisangani. It is situated within a context marked by increasing urbanization, habitat fragmentation, and heightened human pressure on forest ecosystems. The main objective was to determine species diversity and bat composition by site and habitat type, as well as to analyze their ecological preferences. Sampling was conducted at eight sites (Bawi, Botanical Garden of the Faculty of Sciences at the University of Kisangani, Imani, Maleke, Masako, Scholasticat, Yelenge, and the Kisangani Zoological Garden) covering five habitat types: cultivated fields (CC), primary forest (FP), young fallow (JJ), old fallow (JV), and human-modified environment (MA). Two capture techniques were used: mist nets and harp traps, set for 10 nights per site. The results show that 15 species across 5 families were recorded, with dominance by Pteropodidae (fruit bats), notably *Epomops franqueti* (39.89%), *Myonycteris torquata* (25%), and *Megaloglossus woermanni* (21.81%). Diversity is generally higher in peri-urban environments and young fallow (FF) habitats, while highly anthropized environments exhibit lower diversity and a different species composition. Jaccard similarity analysis and dendrogram analysis revealed a clear structuring of communities according to the degree of habitat disturbance. Peri-urban sites more closely resemble primary forests, while urban sites mainly harbor opportunistic and disturbance-tolerant species. The study also highlights the importance of forest fragments and urban green spaces as biodiversity refuges and underscores the need for tailored conservation strategies to preserve bat populations in Kisangani.

Keywords: Diversity; Bats; Habitat; Urban; Peri-urban; Forest.

INTRODUCTION

Africa exhibits exceptional diversity at all levels of biological organization. In particular, the forests of the Guineo-Congo bloc have been identified as one of the world's biodiversity hotspots (Myers et al., 2000; Bakarr et al., 2001, 2004).

The problem facing African forests in general, and those of the DRC in particular, is anthropogenic pressure in its various forms. The bats of Kisangani are threatened by these anthropogenic pressures, despite their significant ecological role in seed dispersal and forest regeneration for frugivorous and megabat species.

On the one hand, in urban and peri-urban environments, bats face significant anthropogenic pressures. In urban areas, bats are hunted and consumed as game, sold in the central market of Kisangani and its surrounding areas. This can negatively impact local bat populations and disrupt their natural habitats. Urban expansion leads to the destruction and fragmentation of natural bat habitats, thereby reducing the number of roosting sites. In peri-urban areas, deforestation for agriculture, logging, and charcoal production are among the factors contributing to the conversion of forests to agricultural land, which also reduces the habitats available to bats (see images in the appendix).

In the Kisangani region, research on bats remains fragmented. Malekani (2018) found that species diversity is higher in rural areas near forests, due to the greater availability of roosting sites and food resources. The faunal biodiversity of the Kisangani region is closely linked to the evolution of abiotic and biotic factors in the area. Thus, while forest species (monkeys, antelopes, etc.) are increasingly retreating from the city due to disturbances caused by human activity, there is intense activity among birds and savanna rodents (Lubini, 1982; Tshipanga, 2009), notably the presence of cane rats reported by Dudu (1994; Tshipanga, 2009).

The aim of this research is to determine the diversity and distribution of bats in the urban and peri-urban environments of Kisangani.

MATERIALS AND METHODS.

The city of Kisangani is located in the northeast of the Congo Basin, almost on the equator at coordinates (0°31'0.001"N and 25°11'60"E), at an altitude of approximately 420 m in the former Orientale Province (Lisingo, 2009). Currently the capital of Tshopo Province, with an area of 1910 km² in the N35 zone, the city is crossed by three major rivers, the hydrographic map of which is shown in Figure 1 below.

Administratively, the city of Kisangani comprises six urban communes distributed as follows: Kabondo, Kisangani, Makiso, Mangobo, and Tshopo on the right bank of the Congo River, and Lubunga on the left bank, as well as the Lubuya-Bera sector (Talinabupato L, 2009).

The city of Kisangani is crossed by three major waterways: the Congo River, the Lindi River, and the Tshopo River. The average width of the Congo River is approximately 800 meters. It flows from the Wagenia Falls to its confluence with the Lindi River downstream, isolating the Lubunga district from the city's five other districts. The Tshopo River is the second river to cross the city to the north and flows into the Lindi River shortly before its confluence with the Congo River. Several smaller rivers also join these three major waterways, resulting in a large number of waterways within the city (Maréchal J., 2012).

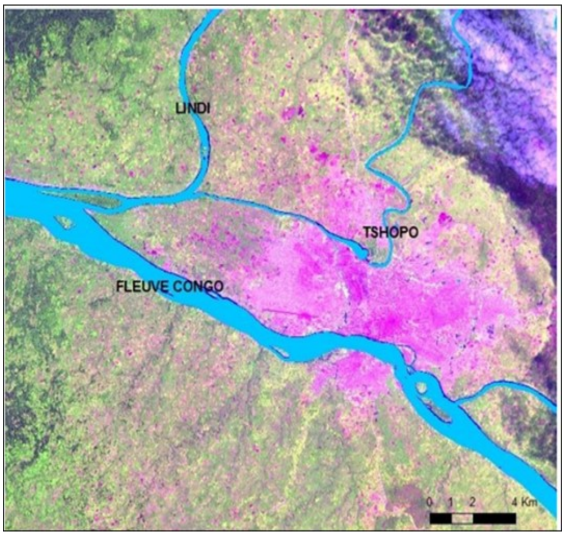

Figure 1. Main hydrographic network of Kisangani, with the SPOT 5 image from 02/03/2010 in the background (Maréchal J., 2012).

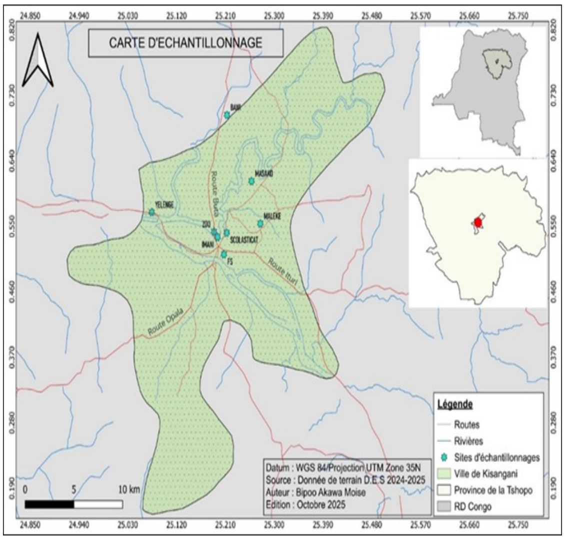

Figure 2. Sampling map of urban and peri-urban areas of Kisangani.

The original vegetation of the city of Kisangani is rainforest, which has been altered by human activity. It has given way to numerous herbaceous, adventitious, and post-cultivated ruderal communities, as well as many relicts and introduced trees. The ruderal and segetal vegetation are primarily herbaceous. While the ruderal communities are distributed throughout the city, they are particularly concentrated in the Makiso district.

On the outskirts of the city, there are secondary forest formations, a few rare patches of primary forest, and communities on hydromorphic soils. The flora of the city of Kisangani consists of an initial forest flora, primarily arboreal and native to Guinea, which has been replaced by an herbaceous flora with a wide geographical distribution. It also includes a significant proportion of cultivated plants, including numerous species of fruit trees and avenues. (Tshimpanga O., 2009)

The faunal biodiversity of the Kisangani region is closely linked to the evolution of abiotic and biotic factors in the region. Thus, while forest species (monkeys, antelopes, etc.) are increasingly retreating from the city due to disturbances caused by human activity, there is intense activity among birds and savannah rodents (Lubini, 1982; Tshimpanga, 2009), notably the presence of cane rats reported by (Dudu, 1994; Tshimpanga, 2009).

Description of the Study Sites

This study was conducted at several sites selected in the urban and peri-urban areas of Kisangani, taking into account their specific spatial characteristics. The urban sites include the Kisangani Zoological Garden, the Botanical Garden of the Faculty of Sciences, the forest surrounding the Imani Reference Health Center, and the

Sacred Heart Priests' Scholasticate. The peri-urban sites include the villages of Bawi and Yelenge, the Masako Forest Reserve, and Maleke. These eight sites were randomly selected to define the study area, with four sites from each environment.

The peri-urban sites (Bawi, Yelenge, Masako, and Maleke) were selected due to the presence of forest fragments suitable for bat capture, thus allowing for the analysis of bat diversity. In urban areas, although largely impacted by human activity, some patches of forest remain, notably those in the Zoological Garden, the Botanical Garden, and certain sectors of the Makiso district, such as the area around the Imani Reference Health Center and the Scolasticat Planted Forest, making these areas relevant to this research. This study also incorporated the findings of previous researchers in the Kisangani region on bats to assess the diversity and past distribution of this group.

Urban areas

The Kisangani Zoological Garden (JZKIS) is located in the city of Kisangani on the right bank of the Tshopo River, just across the Tshopo Bridge on National Route 4 (the Kisangani-Buta Road). It is bordered to the north by the Malkia wa Mashahidi Parish, to the east and south by the Tshopo River, and to the west by the Tshopo Moke River.

It extends downstream from the Tshopo Bridge, which connects the two banks of the Tshopo River. It lies on the right bank of the Tshopo River between the former Unibra Beach and the hydroelectric power station of the National Electricity Company (SNEL). Its geographical coordinates are 00° 32' 41.0" N, 25° 11' 16.6" E, with an altitude of approximately 419 m.

The Stanislas Lisowski Botanical Garden is located on the grounds of the Faculty of Sciences of the University of Kisangani, in the northeast of the Makiso administrative district.

The original vegetation of the Kisangani site, to which the S. Lisowski Botanical Garden of the Faculty of Sciences belongs, is that of the central Congo Basin, characterized by evergreen rainforests. The S. Lisowski Botanical Garden benefits from a continental equatorial climate, belonging to the Af classification of the Köppen climate classification (Patience K. et al. 2016), with the following coordinates: N00° 30' 41.33", E025° 12' 26.53".

The Imani Reference Health Center is located in the Makiso commune, on Mongala Avenue, diagonally opposite the Father's Convent. This center belongs to the Protestant community of CECA 20. Its northern boundary is the Tshopo River, and it benefits from vegetation specific to wetland environments along the river, including fruit trees planted by the community, such as mango, safou, bamboo, and apple trees. Its geographical coordinates are: N00°32’06.0’’ and E025°11’44.1’’.

Geographical Location of the Scholasticate Concession

The scholasticate concession is located approximately 5 km northeast of downtown Kisangani, in the Makiso commune, in the Plateau Boyoma neighborhood. Its geographical coordinates are 00°32’28.18’’N; 025°12’44.56’’ with an altitude of 425 m. It is bordered to the north by the old Buta road, to the southeast by the concessions of the Mont Fortain Fathers and the Comboni Sisters, and to the west by the Motumbe neighborhood and the Giovanni Fathers' concession (Akuboyi, 2025). This concession is dominated by a herbaceous layer, primarily Paspalum notatum (Poaceae), Panicum ripens (Poaceae), and Panicum maximum (Poaceae). In the fish ponds, the dominant species are Nymphae lotus (Nymphaeaceae) and Cyperus sp. (Cyperaceae). This concession has had significant human impact, with the natural forest replaced by a replanted forest. Some of the planted species include eucalyptus, acacia, Treculia africana, and other plants.

Peri-urban areas

Bawi Village is located at kilometer marker 23 on National Route 4 (Kisangani-Buta axis) in the ABATA Grouping, Bamanga sector, Banalia Territory, with geographical coordinates N00°42’11.29’’ and E025°12’46.59’’. Bawi 2 is located on the Alibuku (AMEX BOIS) axis, approximately 68 km from Kisangani and 45 km from Bawi 1, where the population is concentrated. The original inhabitants of the area are the M’ba (Bamanga). (Otomba I. et al., 2017), some remnants of whose forests still persist, along with certain wild plants. As the village is heavily impacted by human activity, the flora is dominated by herbaceous species. Some areas are left fallow.

The village of Yelenge is located 17 km west of the city of Kisangani, on the Kisangani-Yangambi Road. Yelenge is situated near Yakusu (5 km). Its coordinates are N00°34’10.08’’ and E025°4’27.06’’. This village is the first village in the Isangi territory, and the locality shares the same name. It is located in the Yawenda group, Turumbu chiefdom, Yaselia sector, Isangi territory. The Yaselia sector comprises two groups: Yawenda and Yelongo. The locality includes five villages: Yelenge, Yandafe, Yaongonda, Baulo, and Yelongo, of which Linoko and Lokulongo are two sub-villages. The Yawenda group extends from the village of Yelenge up to the village of Bosukulu. The population of Yelenge practices two activities: agriculture and fishing.

The village of Maleke is located 12 km from the city of Kisangani on the Elephant Road, sometimes called the Kandangba Road. This village is situated on the outskirts of Kisangani, more precisely in the Kabondo district, east of the city center, at coordinates: N00°33’13.50’’ and E025°16’28.38’’. This village served as an isolated center for people living with leprosy. It once housed lepers from the city of Kisangani who were quarantined there for treatment to prevent the spread of the disease to healthy people living in the city.

The Masako Forest Reserve, located 14 km northeast of Kisangani city center on the old Buta Road, covered an area of 2,105 hectares at the time. It is surrounded by a large loop of the Tshopo River (Iyongo, 2008). Placed under the management of the Ministry of the Environment, Nature Conservation, and Tourism, this reserve was created by Ordinance-Law No. 052/378 of November 12, 1953. Its geographical coordinates are 0°36'0.00"N and 25°12'60.00"E. It benefits from the general climate of Kisangani, which is locally modified by the presence of vegetation. However, this reserve is currently experiencing increasing pressure from the neighboring population, particularly through the widespread practice of slash-and-burn agriculture, in search of new fertile land (Iyongo, 2009).

Field Sampling

For this study, 8 sites (Bawi, Botanical Garden of the Faculty of Sciences at the University of Kisangani, Imani, Maleke, Masako, Scholasticat, Yelenge, and the Kisangani Zoological Garden), 5 habitat types (CC: Cultivated Fields, FP: Primary Forest, JJ: Young Fallow, JV: Old Fallow, and MA: Human-modified Environments), and two types of traps (Japanese nets and harp traps) were considered to maximize data collection. These traps were set up at each site for 10 nights between 2024 and 2025.

For each Japanese net, we used two poles approximately 4 meters high and 10 to 15 cm in diameter, along with nylon threads to install and secure it firmly to the ground. This ensured the net was taut and the pockets were properly arranged to facilitate the capture of animals. These nets are installed at least 1 meter above the ground from the lowest wire to prevent medium-sized animals (cattle, pigs, goats, and others) from moving them.

A total of five Japanese-style nets of varying lengths (9 to 12 meters) and widths (2 to 3 meters) are used. For installation, at each target location, the tall grass and shrubs are carefully cleared along paths using a machete. The nets are then secured to the ground with two poles. The nets are laid in the afternoon, opened in the evening around 6:30 p.m. and checked each time before 10 p.m. to record the bats captured, especially insectivores because their complex teeth (saw-like) can cut the net and escape, then leave the nets all night to be raised in the morning from 6 a.m. and then raise the nets again at the end to avoid the avian fauna being captured.

Figure 3. Bats collected using Japanese netting.

Constantine Harp Trap

This type of trap was first proposed by Constantine in 1958. Subsequent developments have improved it (Wilson et al. 1996; Palmeirim & Rodrigues, 1993). It consists of two to four parallel nylon thread nets, each held by a frame approximately 2 m square. Each nylon thread is spaced 2.5 cm from the next. The harp trap works on the principle that the threads are difficult to detect visually or by sonar calls. When a bat strikes a thread, it becomes caught between the two nets and falls into the bag designed for this purpose.

The main advantage of this trap is the time saved compared to netting and the significant reduction in associated stress. Bat handling must be as precise and quick as possible to minimize the considerable stress of capture. The handler must be positioned near the net so that they can untangle it within minutes of the capture.

Figure 4. Harp trap.

Specimen Identification

Specimen identification is based on the morphological characteristics of the individuals, using the identification keys of Patterson et al. 2012.

Once the specimens are captured alive and ready for release, a few biopsies are taken from the patagium (paw) as part of a marking process. This involves carefully cutting a small portion of the patagium, and then releasing the specimens into their respective capture habitats.

Ecological Data and Measurement

The few captured bat samples are carefully transported in a breathable fabric bag for transfer to the makeshift laboratory. On site, these specimens will undergo a series of detailed biometric measurements, carried out using a "Pesola" brand scale with gram-level precision and increments of 20g, 50g, 100g, 300g, and 500g, specifically to determine the body biomass of the individuals. Measurements of specific traits, such as tragus length (mm), ear length (mm), tail length (Lq) (mm) for insectivorous bats, and other measurements in (mm) such as forearm length (LAB), tibia length (Lti), left ear length (Lo) are recorded using a digital caliper with a precision of ± 0.01 mm. Age, sex, reproductive status (pregnant or not), net number, and capture habitat are also recorded.

Data Processing and Analysis

The data collected in the field were entered into Excel 2016. Data analysis and processing were performed using the following software:

R Studio: version 4.4.1, was used to calculate diversity indices such as abundance, species richness, evenness, and species diversity; the Jaccard similarity index; the dendrogram of similarity (clustering); and a correspondence analysis (CA) to explore species distributions by habitat and site. Ecological preference was also calculated to compare the averages of captured individuals between different sites and habitats. Excel is a software program that organizes data into structured tables (sites vs. species, abundance, presence/absence). It allows for quick calculations using formulas, enabling us to calculate species richness, relative abundance, frequency of occurrence, and diversity indices (Shannon, Simpson, Jaccard, etc., sometimes with built-in formulas). Results can be visualized using graphs, and it is easy to use everywhere, even in areas where specialized software (R, PAST, etc.) is unavailable. Finally, Excel can serve as a starting point before moving on to more complex statistical analyses.

Diversity indices are statistical tools used to assess variety within a biological or ecological community, or within a dataset. They consider both the number of species present and their relative distribution, and are widely applied not only in ecology, but also in other disciplines such as sociology, economics, and cultural studies (Magurran, 2004).

For this study, we calculated several diversity indices, including the Shannon, Simpson, Evenness, and Jaccard indices, and performed some statistical analyses.

Species richness and relative abundance of bats are obtained for the entire sample across two environments, one urban and one peri-urban. Thus: S denotes the total number of species in the sample, i.e., the species richness and $Pi = \frac{\boldsymbol{ni}}{\mathbf{N}} x\ 100$ where **ni** = number of captured specimens belonging to species i and N = total number of captured specimens constituting the study sample.

The Shannon-Wienner index (H): This index assesses the species diversity of a site. It is calculated using the formula: $\boldsymbol{H' = \sum_{i=1}^{S} (pi.log_2(\mathrm{pi})}$

Pi = the proportional abundance or percentage abundance of a species present (pi = ni/N).

ni = the number of individuals counted for a species present.

N = the total number of individuals counted; all species combined.

S = the total or cardinal number of the list of species present.

Simpson's Index: Like Simpson's Index, this index can also be used to assess the species diversity of a site.

It expresses the probability that two individuals chosen at random from a community belong to different species. It is calculated using the formula: **D= 1-∑ (pi²)**

Where D represents Simpson's diversity index and pi the proportion of each species in the community. The closer D is to 1, the greater the diversity of the studied environment. It therefore follows that as dominance increases, diversity decreases.

Evenness: also used to assess the distribution of individuals among species in the sites and habitats of urban and peri-urban environments of Kisangani, we used Pielou's evenness, the value of which is obtained by the relationship $\mathbf{J = \frac{H'}{Hmax} = \frac{H'}{lnS}}$

Where J corresponds to Pielou's evenness, H′ to the Shannon Wiener index or to the actual diversity, and Hmax to the maximum diversity.

RESULTS

Table 1. Systematic overview of bats captured in urban and peri-urban areas of Kisangani

Families	Species	Number	Ar (%)
Pteropodidae	*Casinycteris argynnis*	4	2,13
	Eidolon helvum (Kerr, 1792)	2	1,06
	Epomops franqueti (Tomes, 1860)	75	**39,89**
	Hypsignathus monstrosus (Allen, 1861)	1	0,53
	Megaloglossus woermanni (Pagenstecher, 1885)	41	**21,81**
	Myonycteris sp	1	0,53
	Myonycteris torquata (Dobson, 1878)	47	**25**
Vespertilionidae	*Afronycteris nanus* (Peters, 1852)	3	1,60
	Mimetillus moloneyi (Thomas, 1891)	1	0,53
	Pipistrellus sp	4	2,13
	Scotophilus dinganii (Smith, 1833)	4	2,13
Hipposideridae	*Hipposideros caffer* (Sundevall, 1846)	1	0,53
	Macronycteris gigas (Wagner, 1845)	1	0,53
Molossidae	*Mops condylurus* (Smith, 1833)	1	0,53
Megadermatidae	*Lavia frons* (Geoffroy, 1810)	2	1,06
5	**15**	**188**	**100**

Legend: Ar: Relative abundance

Table 1 shows that 188 bat specimens were collected in the peri-urban and urban areas of Kisangani, belonging to 5 families, 14 genera, and 15 species. The Pteropodidae family is the most represented with 7 species, followed by the Vespertilionidae family with 4 species, and the Molossidae and Megadermatidae families each with 2 species. As for relative abundance, the species Epomops franqueti is the most abundant with 75 individuals or 39.89%, followed by Myonycteris torquata with 47 individuals or 25% and then Megaloglossus woermanni with 41 individuals or 21.81% and the least represented species are Hypsignathus monstrosus, Myonycteris sp, Mimetillus moloneyi, Hipposideros caffer, Macronycteris gigas and Mops condylurus with 1 individual each or 0.53%.

Bat species richness by habitat

Table 2. Comparison of abundance (N), species richness (S), Shannon diversity index (H'), Simpson diversity index (1-D), and Pielou's evenness (J) between habitats. Cf = Cultivated fields, Pf = Primary forest, Yf = Young fallow, Of= Old fallow, Hm = Human-modified environment, F = Analysis of variance (ANOVA) value, K = Kruskal-Wallis test value.

Index		Cf	Pf	Yf	Of	Hm	Tests
N	Total	44	31	69	13	31	*F=0,2337*
	Average	14,667±13,317	15,5±1,607	17,25±17,288	6,5±4,950	15,5±0,707	*p-value=0,9117*
S	Total	4	4	8	6	6	*F=0,1969*
	Average	2,667±0,577	3,000±0,00	3,500±1,915	3,500±2,121	3,500±0,707	*p-value=0,9331*
H'	Total	0,915	0,918	1,284	1,484	1,086	*F=0,2222*
	Average	0,763±0,0087	0,603±0,188	0,771±0,530	0,932±0,418	0,858±0,182	*p-value=0,9185*
1-D	Total	0,505	0,493	0,590	0,710	0,512	*K=3,41873*
	Average	0,468±0,053	0,320±0,122	0,404±0,272	0,5222±0,110	0,478±0,086	*p-value=0,49034*
J	Total	0,661	0,663	0,617	0,828	0,606	*F=1,9694*
	Average	0,818±0,168	0,549±0,171	0,720±0,051	0,841±0,110	0,688±0,034	*p-value=0,2039*

Legend : Cf : Cultivated fields, Pf : Primary forest, Yf : Young fallow, Of : Old fallow, Hm : Human-modified environment.

Table 1 shows a comparison of abundance (N), species richness (S), Shannon-Wiener diversity index (H′), Simpson diversity index (1-D), and Pielou evenness (J) between habitats. The means shown are those of the parameters calculated for the 5 sampled habitats. The habitat with the highest abundance is Yf, followed by Cf, and the habitat with the lowest abundance is Of. Statistically, ANOVA and Kruskal-Wallis analyses show no significant differences between the habitats.

Bat species richness by site

Table 3. Comparison of abundance (N), species richness (S), Shannon diversity index (H'), Simpson diversity index (1-D), and Pielou evenness (J) between sites. BG = Botanical Garden of the Faculty of Sciences of the University of Kisangani, Zoo = Kisangani Zoological Garden, F = value of the analysis of variance (ANOVA), K = value of the Kruskal-Wallis test.

Indices		Bawi	BG	Imani	Maleke	Masako	Scolasticat	Yelenge	Zoo	Tests
N	Total	71	23	15	17	27	16	11	8	*F=4,1561*
	Average	35,5±7,778	23,0±NA	15,0±NA	8,5±0,707	9,0±7,937	16,0±NA	5,5±6,364	8,0±NA	*p-value=0,06802*
S	Total	5	3	3	5	5	4	5	3	*F=0,103*
	Average	4,00±1,414	3,00±NA	3,00±NA	3,00±0,00	3,00±1,732	4,00±NA	3,00±2,828	3,00±NA	*p-value=0,9953*
H'	Total	1,057	0,47	0,73	0,998	1,111	0,987	1,16	0,736	*F=0,2364*
	Average	1,007±0,208	0,470±NA	0,730±NA	0,792±0,080	0,803±0,241	0,987±NA	0,614±0,868	0,736±NA	*p-value=0,9569*
1-D	Total	0,557	0,234	0,418	0,478	0,557	0,539	0,562	0,406	*K= 5,73278*
	Average	0,547±0,069	0,234±NA	0,418±NA	0,450±0,062	0,490±0,041	0,539±NA	0,300±0,424	0,406±NA	*p-value=0,57127*
J	Total	0,657	0,428	0,664	0,62	0,69	0,712	0,72	0,67	*F=1,3348*
	Average	0,751±0,047	0,428±NA	0,664±NA	0,721±0,073	0,863±0,171	0,712±NA	0,763±NA	0,669±NA	*p-value=0,4113*

Table 3 presents a comparison of abundance (N), species richness (S), Shannon-Wiener diversity index (H′), Simpson diversity index (1-D), and Pielou evenness (J) between sites. The averages shown are those of the parameters calculated for the eight sampled sites in urban and peri-urban environments. The most abundant site is Bawi, followed by Masako, and the least abundant site is the Zoo. Statistically, ANOVA and Kruskal-Wallis analyses show no significant differences between habitats.

Table 4. Jaccard similarity indices for habitats

	Cf	Pf	Yf	Of
Pf	0,6			
Yf	0,333	0,333		
Of	0,429	0,667	0,4	
Hm	0,25	0,25	0,167	0,2

Legend : Cf : Cultivated fields, Pf : Primary forest, Yf : Young fallow, Of : Old fallow, Hm : Human-modified environment

Table 4 shows that Jaccard similarity analyses show some similarity of species in relation to certain habitats where the species composition is similar in habitats such as Pf and Cf and in Pf and Of, but in other habitats the analyses show that there is no similarity between species in these habitats.

Ecological preferences

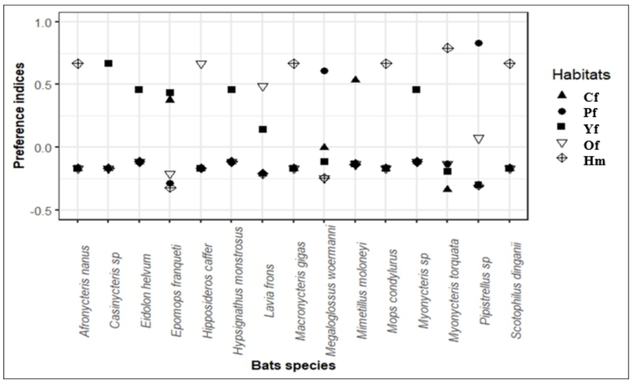

Figure 5. Ecological preference of species by habitat

This graph shows that species such as Pipistrellus sp. prefer primary forest and, to a lesser extent, old-growth fallow land; Afronycteris nanus, Macronycteris, Mops, Myonycteris torquata, and Scotophilus dinganii prefer human-modified environments; Casinycteris prefers fallow land; Lavia frons and Hipposideros caffer prefer fallow land; and Mimetillus moloneyi prefers fallow land.

Rarefaction curve according to habitats

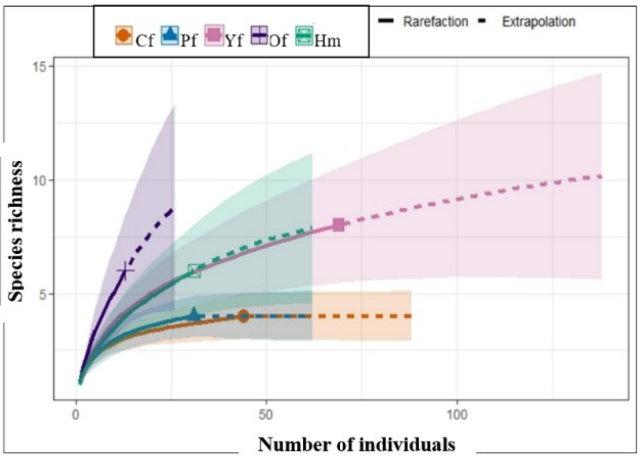

Figure 6. Species decline curve in habitats. Cf = Cultivated fields, Pf = Primary forest, Yf = Young fallow, Of = Old fallow, Hm = Human-modified environment

Figure 6 demonstrates that habitats such as **Yf** exhibit the highest species richness. Its curve shows a marked increase during the extrapolation phase, indicating great potential for the discovery of additional species and high diversity. Intermediate species richness is observed in habitats such as **Hm** and **Of**. Their curves show moderate values and a slight increase, reflecting fairly significant but partially sampled diversity. Habitats **Pf** and **Cf** exhibit the lowest species diversity, with curves that quickly plateau around 3 to 4 species. This indicates less diverse communities or more uniform habitats.

Rarefaction curve according to sites

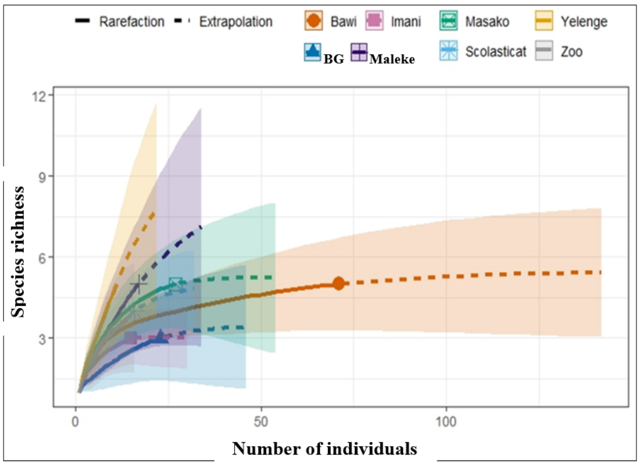

Figure 7. Species Rarity Curve at Sites

Figure 7 shows that capture sites like Bawi exhibit the highest species richness, with approximately 5 species observed and an estimated 6 to 7 species. The curve continues to rise slowly, indicating the potential for the discovery of new species. Maleke and Yelenge exhibit moderate species richness. Their rarity curves are around 5 to 7 species, showing significant growth during the extrapolation phase, indicating relatively high species diversity. However, some areas may suffer from undersampling. Masako exhibits moderate species richness, with approximately 4 to 5 species, and its stabilization is faster than at the previous sites, suggesting a smaller community or a larger sample size at this location. FS and Imani show the lowest species richness (approximately 3 species), and their distribution curves stabilize rapidly. This indicates low intrinsic diversity at these two sites, or that the environments are relatively homogeneous or disturbed. The Scholasticate and Zoo also exhibit relatively low species richness, and although extrapolated, the increase is limited, reflecting a decline in species diversity.

Jaccard's dissimilarity between habitats

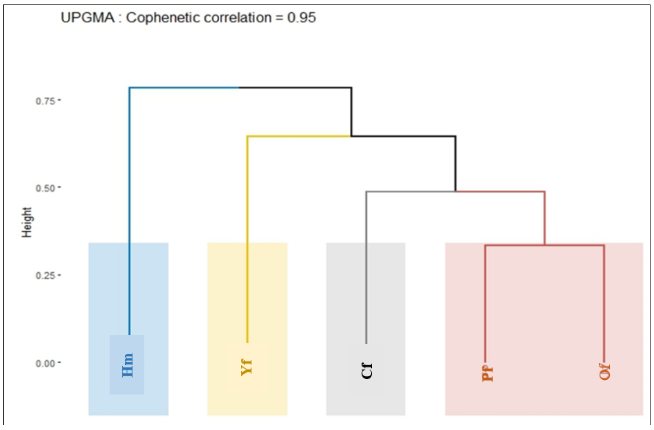

Figure 8. Jaccard Dissimilarity Between Habitats

This hierarchical dendrogram, based on the Jaccard index and the UPGMA method, highlights four habitat groupings, only one of which exhibits similar species compositions. Within this grouping, the Pf and Of habitats have the most similar or very similar bat species compositions to the other habitats, with the Cf habitat being closer to the first group and the JJ habitat closer to the second group. In contrast, the Hm habitat appears to be the most differentiated from the other habitats in the fourth group.

Table 5. Jaccard Similarity Between Sites

	Bawi	BG	Imani	Maleke	Masako	Scolasticat	Yelenge
BG	0,333						
Imani	0,143	0					
Maleke	0,429	0,333	0				
Masako	0,429	0,333	0,143	0,25			
Scolasticat	0,286	0,167	0,167	0,125	0,286		
Yelenge	0,25	0,333	0,143	0,25	0,25	0,125	
Zoo	0,333	0,5	0,2	0,143	0,333	0,4	0,333

Table 5 shows that Jaccard similarity analyses indicate that the sites similar in terms of species composition are FS and the Zoo, but the remaining sites are not similar.

DISCUSSION

Systematic Overview of Sampled Bats

This study highlights significant bat diversity in the peri-urban and urban environments of Kisangani, despite strong anthropogenic pressure. Fifteen species belonging to five families were recorded, with Pteropodidae being the most represented family with seven species, followed by Vespertilionidae with four species, and Molossidae and Megadermatidae each represented by two species. In terms of relative abundance, Epomops franqueti was the most abundant with 75 individuals (39.89%), Myonycteris torquata with 47 individuals (25%), and Megaloglossus woermanni with 41 (21.81%). These findings confirm the abundant presence of fruit bats in humid tropical regions, consistent with the observations of Gembu (2007) and Kunz et al. (2011). Their abundance testifies to the richness of food resources (fruits and nectar) present in the forest fragments and fallow lands of the Kisangani region ; on the other hand, the less represented species were Hypsignathus monstrosus, Myonycteris sp, Mimetillus moloneyi, Hipposideros caffer, Macronycteris gigas and Mops condylurus with 1 individual each or 0.53%.

In 2006, Fabienne conducted a study on the foraging and movement habitats of bats along a landscape gradient in southern Quebec. The results showed that Myotis was abundant in agricultural areas (45% of the count) and forested areas (68%), but almost absent from urban areas (0.5%). In urban areas, the big brown bat was the most common species (58%). The species Eptesicus fuscus was also abundant in urban areas (Furrionger et al. 1987, Everette et al. 2001, Ghert and Chelsg 2004). However, according to Geggie and Fenton (1985), Eptesicus fuscus was more common in rural areas. This greater abundance in forests than in cities can be explained by the abundance of insects. This can be explained by the fact that urban environments are more degraded than peri-urban ones.

The decline in bat populations is documented almost everywhere on the planet. In Quebec, four species are on the list of species likely to be designated as threatened or vulnerable due to habitat degradation (Baulieu, 1992 ; Fabienne, 2006). He observed bat habitat use along a gradient from an urbanized to a forested landscape (Fabienne, 2006).

In England, early studies on the effects of urbanization on Vespertilionidae and birdlife already highlighted that bird abundance decreased when the rate of urbanization around green spaces was high (Cousins, 1982; Dickman, 1987; Fabianek, 2008). The main consequences of urbanization are the destruction of natural habitats and forest fragmentation (Dickman, 1987 ; Wayne et al., 2000). (Mab2)

Species richness of collected bats

Diversity analysis (Shannon-Wiener index) shows that young fallow land and certain cultivated fields exhibit the greatest species richness and high evenness. This is explained by their intermediate nature between forest and open areas, offering shelter, food resources, and hunting grounds (Arlettaz et al., 2000). These transitional habitats often support a balanced coexistence between frugivores and insectivores, acting as ecological corridors between heavily human-modified areas and remaining forest fragments.

The comparison of abundance (N), species richness (S), Shannon-Wiener diversity index (H′), Simpson diversity index (1-D), and Pielou evenness (J) between habitats is shown. The means indicated are those of the parameters calculated for the 5 sampled habitats. The habitat with the highest abundance is Yf, followed by Cf, and the habitat with the lowest abundance is Of. Statistically, ANOVA and Kruskal-Wallis analyses show no significant differences between the habitats.

Jaccard similarity analyses and dendrograms confirm the differentiation of communities according to habitat type and site. The observed groupings between primary forests (Pf) and old-growth fallow land (OGL) demonstrate ecological continuity based on typical forest species (Eidolon helvum, Myonycteris torquata). Conversely, human-modified environments (Hm) are strongly differentiated, reflecting an alteration in species composition.

However, even though the territory they use can be very large, bats do not forage uniformly around their daytime roost but rather concentrate their hunting in small, preferred areas used during nocturnal activity by the entire bat community, representing 1% to 4% of available habitats. Several studies show that bats forage in well-defined locations. Several researchers (Hickey and Fenton 1996) have observed that some individuals return night after night to a specific site to feed, sometimes over several years.

Brigham and Fenton (1986) observed that bats remained faithful to their feeding sites even after their daytime roost had been sealed off. All these observations suggest that bats seek out feeding sites with specific characteristics.

Ecological Preferences

The predominance of fruit-eating bats over insectivores reflects the structure of the local landscape: peri-urban areas (Bawi, Yelenge, Masako, Maleke) still possess forest fragments and diverse vegetation, favorable to arboreal and nectar-feeding species. Conversely, highly anthropized urban areas (such as the former scholasticate concession and the Imani center) primarily harbor disturbance-tolerant species, such as Mops condylurus and Scotophilus dinganii, known for their ecological plasticity (Fahr & Kalko, 2006). Furthermore, the trapping techniques used were different; Japanese mist nets were more common than harp traps.

However, bats spend a large part of the night foraging. Characterizing feeding sites is complex and less well documented.

A bat can travel several kilometers during a night to forage, and even though the territory they use can be very large, bats do not forage uniformly around their daytime roost but rather concentrate their hunting in small, preferred areas. Walsh and Harris (1996) found that the preferred habitats used during nocturnal activity by the entire bat community represented 1% to 4% of the available habitats. Several studies show that bats forage in well-defined locations. Many researchers (Kunz 1973, Brigham 1991, Hickey and Fenton 1996) have observed that some individuals return night after night to a specific site to forage, sometimes over several years. Brigham and Fenton (1986) observed that bats remained faithful to their foraging sites even after their daytime roost had been condemned.

CONCLUSION

The study of bat diversity in the urban and peri-urban environments of Kisangani provided information on species richness, abundance, exploited habitats, and ecological preferences. Peri-urban environments are more represented than urban environments.

Jaccard similarity analyses show some species similarity in certain habitats, with similar species composition in primary forest and cultivated fields, and in primary forest and old fallow land. However, in other habitats, the analyses show little similarity among species. The Bawi area exhibits the greatest species richness, with approximately 5 species observed and an estimated 6 to 7 species. The curve continues to rise slowly, indicating the potential for the discovery of new species. Enthropization has negative effects on the species richness and abundance of these bats.

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Appendices

Figure 9: Ecological data from photos of several bat species, carbonization at Masako, anthropogenic activity (road construction, section near the Faculty of Sciences), bat survey on the Japanese net (**a**: Lavia frons, **b**: Myonycteris torquata, **c**: Macronycteris gigas, **d & e**: Scotophilus dinganii, **f & g**: Mops condylurus, **h**: Epomops franqueti, **i**: Carbonization at Masako, **j**: Road construction, **k**: Predatory snake of bats captured in the Japanese net, **l**: Bat survey in the Japanese net)