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(RESEARCH ARTICLE)

Entomological parameters involved in the transmission of *Plasmodium falciparum* in the Kabinda Health Zone (Lomami Province, DRC)

Gentil Nkongolo Mpunda [1], Evariste Kilembe Diango [2], Rombaut Tamasala Ndombe [3], Prince Mayombo Lubo [4], Edouard Mbungu Sisa [5,*], Eméry Metelo [6,7] and Déogratias Schie'Nkung Mutambel'Hity [8]

[1] *Biology-Chemistry Laboratory, Higher Pedagogical Institute of Kabinda (ISP-Kabinda), Lomami, DRC.*
[2] *Animal Ecology Laboratory, Faculty of Science and Technology, National Pedagogical University (UPN), P.O. Box 8815, Kinshasa, DRC.*
[3] *Plant Ecology Laboratory, Faculty of Science and Technology, National Pedagogical University (UPN), P.O. Box 8815, Kinshasa, DRC.*
[4] *Faculty of Health Sciences, Higher Institute of Medical Techniques of Kabinda (ISTM-Kabinda), Lomami, DRC.*
[5] *Hydrobiology Laboratory, Faculty of Science and Technology, National Pedagogical University (UPN), P.O. Box 8815, Kinshasa, DRC.*
[6] *Parasitology Laboratory, Faculty of Science and Technology, University of Kinshasa (UNIKIN), P.O. Box 190, Kinshasa XI, DRC.*
[7] *Department of Parasitology, National Institute for Biomedical Research (INRB), P.O. Box 1197, Kinshasa, D R Congo.*
[8] *Molecular Biology Laboratory, Faculty of Science and Technology, National Pedagogical University (UPN), P.O. Box 8815, Kinshasa, DRC.*

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Abstract

Malaria remains a major public health concern in the Democratic Republic of the Congo, where Plasmodium falciparum is responsible for the majority of severe cases. The analysis of entomological parameters constitutes an essential approach to understand local transmission dynamics and to guide vector control strategies. The present study aimed to assess the entomological parameters involved in malaria transmission in the Kabinda health zone, Lomami Province, between September 2025 and January 2026. A descriptive and analytical study was conducted in four health areas (Kabinda, Kamukungu, Zewe, and Mbandaka). Mosquitoes were collected using Human Landing Catches (HLC) and Pyrethrum Spray Catches (PSC), then morphologically identified. A total of 946 mosquitoes belonging to the genus Anopheles were collected, dominated by Anopheles gambiae and Anopheles funestus, the main malaria vectors in sub-Saharan Africa. Vector density varied significantly between health areas ($p < 0.05$), with a higher aggressiveness observed in Mbandaka. Nocturnal dynamics revealed a peak activity between 10:00 p.m. and 2:00 a.m. HLC collections showed a predominance of exophagic behavior (69%), although a non-negligible proportion (31%) was observed indoors. The trophic status of females collected by PSC highlighted a high proportion of blood-fed females (91%), reflecting intense human–vector contact. These results indicate sustained and spatially heterogeneous malaria transmission in the Kabinda area, characterized by high vector density and dominant nocturnal activity. They highlight the need to adapt control strategies to local ecological and behavioral specificities.

Keywords: Malaria; *Plasmodium falciparum*; Entomological parameters; HLC; PSC; Kabinda; Lomami Province; DRC

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[*] Corresponding author: Edouard Sisa Mbungu

1. Introduction

Malaria remains one of the most significant infectious diseases worldwide, representing a major public health problem, particularly in tropical and subtropical regions. According to the World Malaria Report published by the World Health Organization, approximately 249 million malaria cases and more than 600,000 deaths were recorded globally in 2022, of which more than 95% occurred in sub-Saharan Africa (World Health Organization, 2023). Children under five years of age and pregnant women constitute the most vulnerable groups to this disease.

In sub-Saharan Africa, malaria transmission is essentially ensured by mosquitoes of the genus Anopheles, which are the biological vectors of the parasite responsible for the disease. Among the species most involved in transmission are Anopheles gambiae and Anopheles funestus, recognized for their high vector competence and strong anthropophilic behavior (Coetzee *et al.,* 2013). These species are responsible for the majority of transmissions of the parasite Plasmodium falciparum, the most virulent etiological agent of human malaria in Africa (Bhatt *et al.,* 2015).

The Democratic Republic of the Congo is among the countries most affected by malaria worldwide. It alone accounts for a significant proportion of malaria cases and deaths in Africa (World Health Organization, 2023). Climatic, ecological, and socio-economic conditions favorable to the proliferation of mosquito vectors contribute to maintaining intense transmission in several regions of the country (National Malaria Control Program [NMCP], 2022).

The dynamics of malaria transmission depend on several key entomological parameters, notably vector density, the human biting rate (HBR), mosquito longevity, their trophic behavior, as well as the parasite infection rate (Garrett-Jones, 1964; Service, 2012). These parameters determine the intensity of transmission and make it possible to estimate the level of entomological risk within a human population.

The analysis of these parameters constitutes a key element of entomological surveillance and the evaluation of vector control strategies. Indeed, understanding the interactions between mosquito vector populations, the environment, and human populations makes it possible to adapt malaria control interventions to local ecological contexts (Smith et al., 2007).

Despite the importance of these data for planning malaria control programs, entomological information remains limited in several areas of the Democratic Republic of the Congo, particularly in newly created provinces. The Kabinda health zone, located in Lomami Province, is a region where malaria remains endemic and represents one of the main causes of morbidity in local health facilities. However, scientific data on the entomological parameters involved in malaria transmission in this area remain insufficiently documented.

In this context, the present study aims to analyze the main entomological parameters involved in the transmission of Plasmodium falciparum in the Kabinda health zone. More specifically, this research aims to identify the Anopheles species present in the study area, to estimate vector density and the human biting rate, and to analyze their relationship with malaria morbidity recorded in local health facilities. The results obtained should contribute to a better understanding of the local dynamics of malaria transmission and provide useful information for guiding vector control strategies in the region.

1.1. Study area

The present study was conducted in the Kabinda Health Zone, located in Lomami Province in the central-eastern part of the Democratic Republic of the Congo. This region belongs to the humid tropical savanna ecological zone, characterized by the alternation of a long rainy season of approximately nine months and a short dry season of about three months. These climatic conditions favor the development and proliferation of malaria vector mosquitoes, particularly those belonging to the genus Anopheles (World Health Organization, 2023).

From a health perspective, the Kabinda Health Zone comprises sixteen health areas, mostly rural and semi-urban. In this region, malaria remains one of the leading causes of morbidity and consultation in health facilities, constituting a major public health problem in the DRC. Local environmental characteristics such as the presence of watercourses, marshy areas, temporary pools, and traditional agricultural activities promote the formation of larval habitats suitable for the development of mosquitoes of the genus Anopheles (WHO, 2023).

Four health areas were selected as study sites. Figure II.1 presents the mapping of mosquito collection sites using the indoor residual spraying technique with pyrethrum (Pyrethrum Spray Catch – PSC). In each site, ten households were selected, making a total of forty households.

In addition, the Human Landing Catches (HLC) technique was also used in these same health areas. In this case, eight households were selected per site, making a total of thirty-two households, in order to assess the biting activity of mosquito vectors.

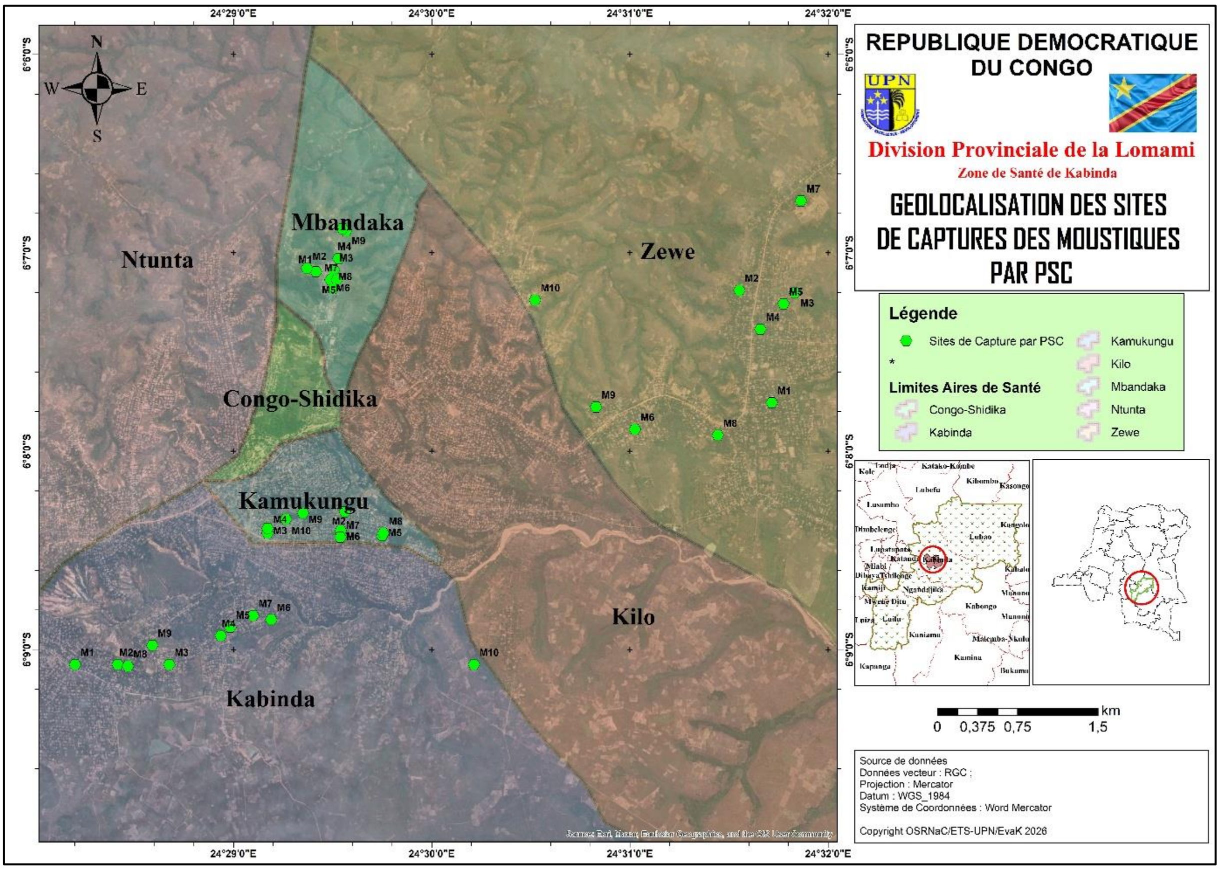

Figure 1 The mapping of mosquito collection sites using the indoor spraying technique (PSC).

2. Methods

2.1. Study Design

The present study is a cross-sectional analytical study and includes two complementary components: an entomological component aimed at assessing the density, species composition, and behavior of malaria vector mosquitoes, and an epidemiological component intended to estimate the prevalence of malaria infection using rapid diagnostic tests (RDTs) conducted in selected households.

Data collection was carried out over a period of six months, from August 2025 to January 2026, corresponding mainly to the rainy season, a period generally associated with an increase in vector density and malaria transmission risk (World Health Organization, 2013).

2.2. Entomological Data Collection

The entomological population studied consisted of adult female mosquitoes, mainly of the genus Anopheles, captured inside houses and in their immediate surroundings. The human population consisted of residents of selected households in the different health areas of the study zone, in whom rapid diagnostic tests were conducted to assess the presence of malaria infection.

The health areas were selected using a purposive non-probability sampling method, taking into account several criteria, including the level of malaria morbidity reported by the Central Office of the Health Zone, geographical accessibility, population size, and ecological diversity of the environments (rural, semi-urban, and wetland areas). In each selected health area, households were chosen using a systematic purposive approach, considering proximity to potential larval habitats and population exposure to mosquitoes. Household participation was conditional upon obtaining prior consent from the head of the household.

Adult mosquito collection was carried out using two complementary entomological techniques: Pyrethrum Spray Catch (PSC) and Human Landing Catches (HLC), methods widely used in entomological studies of malaria transmission (Silver, 2008).

2.2.1. Pyrethrum Spray Catch (PSC)

The indoor pyrethrum spray technique (PSC) consists of spraying a pyrethrum-based insecticide inside houses in order to collect mosquitoes resting on internal surfaces. This method, initially described by Gustave Holstein (1952), was used to estimate indoor mosquito density. Before spraying, occupants were asked to temporarily leave the house, and food and drinks were removed to avoid contamination. White sheets were then spread on the floor and furniture to collect mosquitoes falling after insecticide application. After an exposure time of approximately twenty minutes, mosquitoes were collected using forceps and placed in Eppendorf tubes containing silica gel for preservation.

Figure 2 Mosquito collection in Kabinda (2025). Source: author’s photograph, 2025**.**

2.2.2. Direct Capture with Human Bait (HLC)

The Human Landing Catches (HLC) method was used to assess mosquito biting activity. This technique involves capturing mosquitoes that land on the exposed legs of a collector seated indoors or outdoors. Collections were conducted between 6:00 PM and 6:00 AM, corresponding to the peak nocturnal activity of vector mosquitoes. Captured mosquitoes were placed in hemolysis tubes and then stored in labeled plastic bags indicating the time, location, and name of the collector. This method is considered the reference technique for estimating the Human Biting Rate (HBR) and for analyzing the anthropophilic behavior of mosquitoes (Silver, 2008; World Health Organization, 2013).

2.3. Preservation and Morphological Identification of Collected Mosquitoes

Collected mosquitoes were preserved dry in Eppendorf tubes (2.5 ml) containing silica gel for morphological identification and subsequent analyses of the relevant parameters.

Mosquitoes were preserved in Eppendorf tubes containing silica gel for laboratory identification. Morphological identification was carried out using binocular microscopes and standard taxonomic keys, notably those proposed by Gillies and De Meillon (1968) and Gillies and Coetzee (1987). Specimens were identified to the genus and species level or species complex level, particularly Anopheles gambiae sensu lato and Anopheles funestus.

2.4. Ethical Considerations

The study was conducted after obtaining authorization from local health authorities and the National Malaria Control Program. Informed consent was obtained from participants prior to their involvement. In addition, prior malaria screening using rapid diagnostic tests (RDTs) was performed on all collectors to ensure their health safety. Individuals who tested positive were immediately treated according to national malaria control guidelines.

2.5. Data Analysis

The entomological indicators estimated in this study include the average vector density per household, relative species frequency, the human biting rate (HBR), and the proportion of mosquitoes captured indoors, an indicator of vector endophilic behavior (Service, 2012).

The collected data were entered and analyzed using Microsoft Excel and SPSS software. Statistical analyses consisted of calculating frequencies, proportions, and means. Comparisons between study sites were performed using appropriate statistical tests, namely Student's t-test or analysis of variance (ANOVA) for comparing means. The level of statistical significance was set at $p < 0.05$.

Data related to the composition of Anopheles communities at the sites were subjected to taxonomic diversity analyses. This is represented by two components: taxonomic richness and relative abundance (Campbell & Reece, 2007). Four indices were calculated to compare site-specific taxonomic diversity: taxonomic richness, taxonomic composition, Shannon-Weaver diversity index, and the distribution of taxa within sites, or Pielou's evenness.

3. Results

3.1. Distribution of mosquito genera captured

Table 1 Distribution of mosquito genera captured by site in the Kabinda health zone during the rainy season from 2025 to 2026

Genera	**Zewe**		**Mbandaka**		**Kamukunga**		**Kabinda**		**Total**	**%**
	n	*ni/N*	*n*	*ni/N*	*n*	*ni/N*	*n*	*ni/N*		
Anopheles	155	0.731	391	0.782	149	0,539	251	0.447	946	0.61
Culex	55	0.259	107	0.214	115	0.417	292	0.52	569	0.367
Aedes	0	0	0	0	1	0.004	3	0.005	4	0.003
Mansonia	2	0.009	2	0.004	11	0.04	16	0.029	31	0.02
N	212	1	500	1	276	1	562	1	1550	1
S	3		3		4		4			
H'	0.623		0.544		0.846		0.829			
J'	0.567		0.495		0.611		0.598			

Legend : ni=Number ofidividuals per genera ; N=Number ofidividuals per a genera across ; ni/N= Relative abundance per station ; S=number of taxa ; H'=Shannon-Weaver diversity index; J'=Piélou's evenness index

It emerges from Table 1 that a total of 1,550 mosquitoes were captured in the Kabinda health zone. The Kabinda site recorded the highest number of mosquitoes, with 562 specimens representing 33.9% of the total individuals. It was followed by Mbandaka with 500 individuals (32.25%), Kamukungu with 276 specimens (17.8%), and Zewe with 212 individuals (13.7%) of the total count.

Regarding the number of genera, the Kabinda and Kamukungu sites showed the highest richness (4 genera), whereas the Mbandaka and Zewe sites each recorded 3 genera.

The Kamukungu site was the most diverse and the most evenly distributed (H' = 0.846 and J' = 0.611). It was followed by Kabinda (H' = 0.829; J' = 0.598), Zewe (H' = 0.623; J' = 0.567), and Mbandaka (H' = 0.544; J' = 0.495).

The genus Anopheles was the most represented with 946 individuals (61%), followed by *Culex* with 569 individuals (36.7%), while *Mansonia* (1.9%) and *Aedes* (0.26%) remained marginal.

3.1.1. Average distribution of mosquito genera captured by PSC

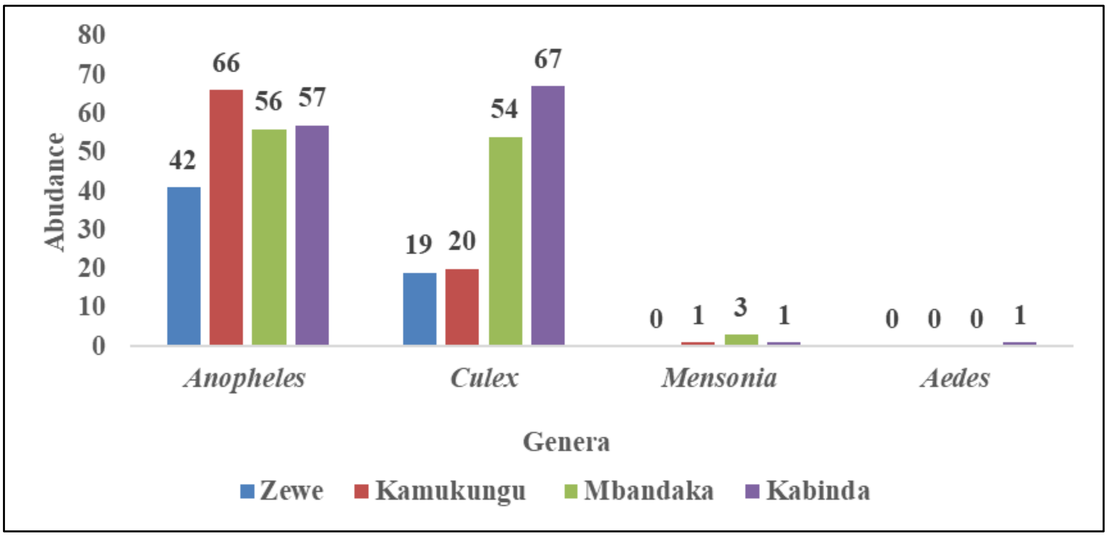

Figure 3 Distribution of mosquito genera captured by PSC in the different study areas during the rainy season from 2025 to 2026

A total of 387 mosquitoes were collected by PSC, comprising 4 genera (*Anopheles, Culex, Mansonia*, and *Aedes*), among which Anopheles accounted for 221 individuals (57.1%), followed by Culex with 160 individuals (41.3%), while *Mansonia* (1.3%) and *Aedes* (0.26%) remained marginal.

3.1.2. Spatial distribution of mosquito genera captured by HLC

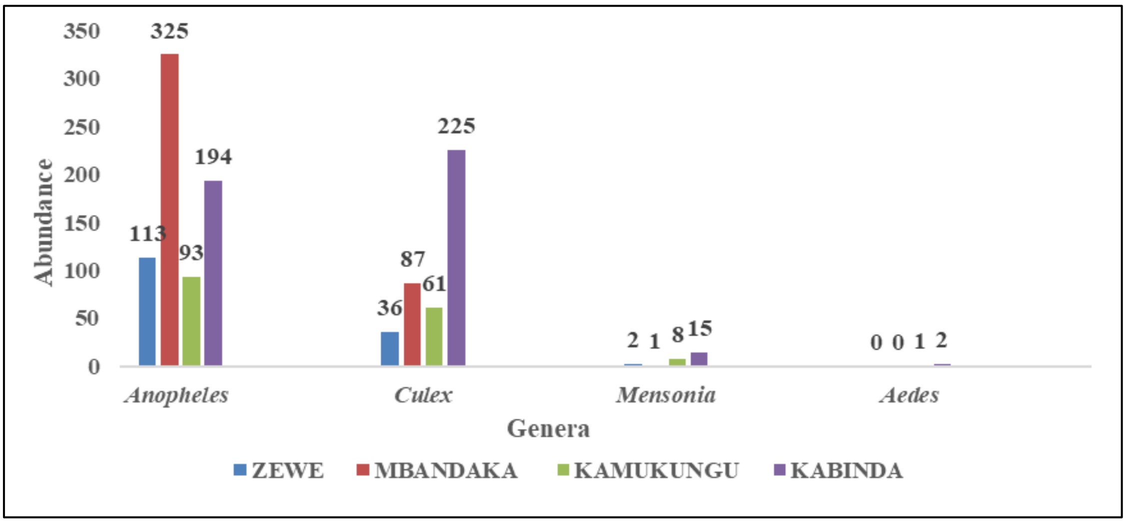

Figure 4 Distribution of genera captured by HLC according to sites during the rainy season from 2025 to 2026

The results obtained from HLC also show a predominance of the genus Anopheles (725 individuals) and a low proportion for the genera *Mansonia* and *Aedes*, although the proportions of other genera vary across households.

3.2. Distribution of Anopheles species captured by HLC

3.2.1. Distribution of Anopheles captured by sites and by capture techniques

Table 2 Distribution of Anopheles captured by sites and by capture techniques

Sampling Sites	**HLC**		**PSC**		**Total**	**%**
	Abundance	%	Abundance	%		
Zewe	113	15,6	40	18,1	153	16,17
Mbandaka	325	44,8	58	26,2	383	40,49
Kamukunga	93	12,8	66	29,9	159	16,81
Kabinda	194	26,8	57	25,8	251	26,53
Total	725	100	221	100	946	100

A parallel examination of the results from the two capture methods reveals notable heterogeneity between sites. In HLC, the Mbandaka site largely dominates with nearly 45% (40.49%) of captures, followed by Kabinda (26.53%), Kamukungu (16.81%), and Zewe (16.17%).

3.2.2. Distribution of Anopheles species captured by HLC

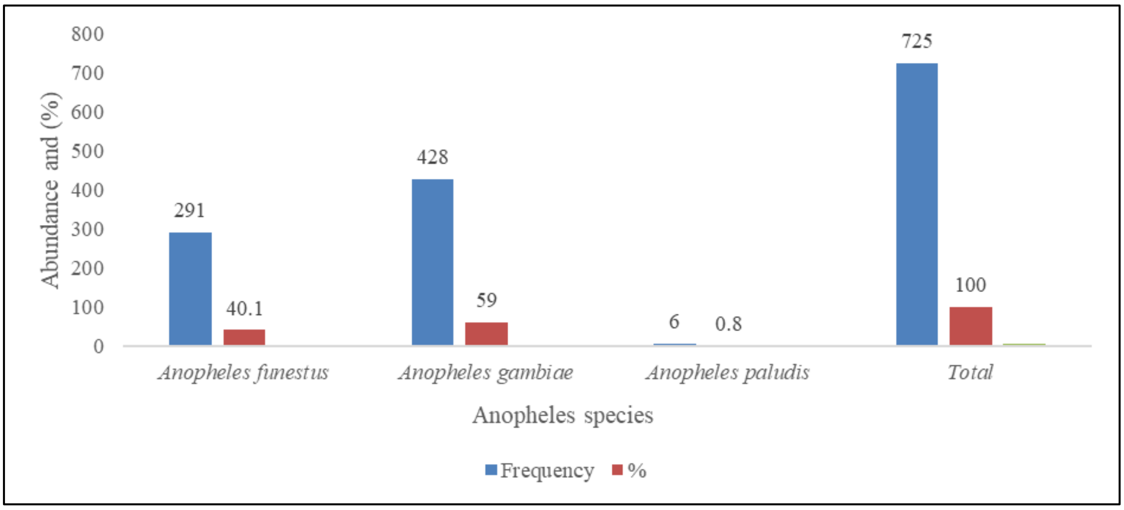

Figure 5 Distribution of Anopheles species captured by HLC in the different sites

The analysis of Figure related to the distribution of Anopheles species captured by HLC shows a predominance of *Anopheles gambiae s.l.* and *Anopheles funestus*, indicating the presence of the two major vectors in sub-Saharan Africa, with a very low percentage of *Anopheles paludis*. The coexistence of these two species creates a robust vector system capable of sustaining transmission throughout the year.

3.2.3. Distribution of Anopheles species captured by PSC

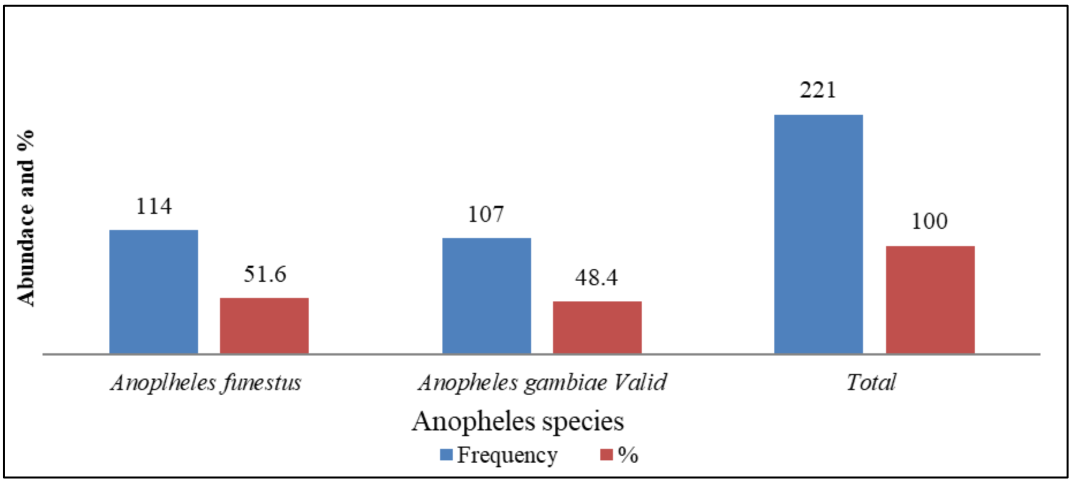

Figure 6 Distribution of Anopheles species captured by PSC

Figure related to the PSC method shows that this technique allowed the capture of 221 Anopheles specimens, with a slight predominance of *Anopheles funestus* (51.6%) compared to *Anopheles gambiae* (48.4%). This inversion compared to HLC suggests that *Anopheles funestus* may exhibit a slightly more endophilic tendency. Thus, indoor resting behaviors vary according to species, revealing significant behavioral diversity among co-circulating species.

3.2.4. Biting frequencies according to time intervals (HLC)

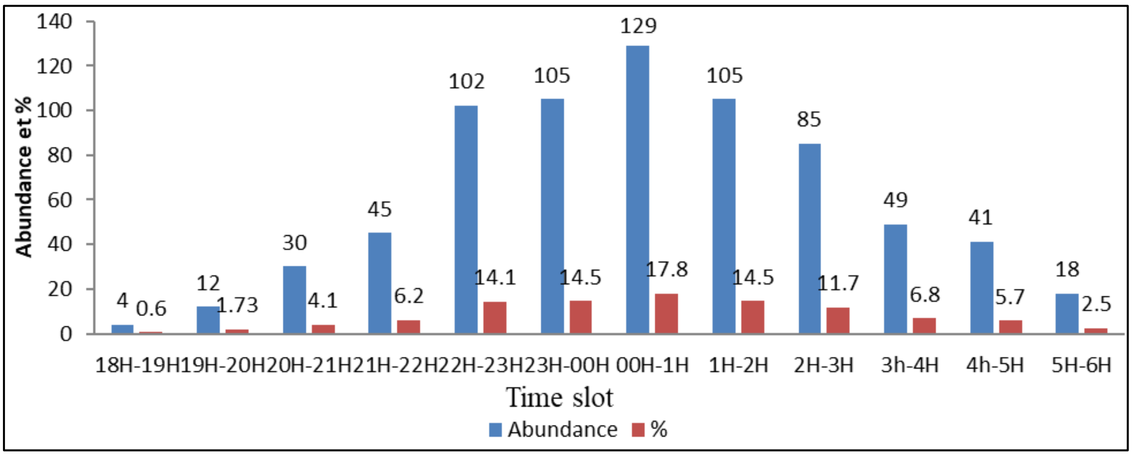

Figure 7 Variation of captures by time intervals in the Kabinda health zone

Figure 7 shows that the time interval between 10:00 PM and 3:00 AM constitutes the main biting period of Anopheles in the Kabinda health zone. The peak was reached between 12:00 AM and 1:00 AM with 129 bites.

3.2.5. Average frequencies of Anopheles captured according to location (HLC)

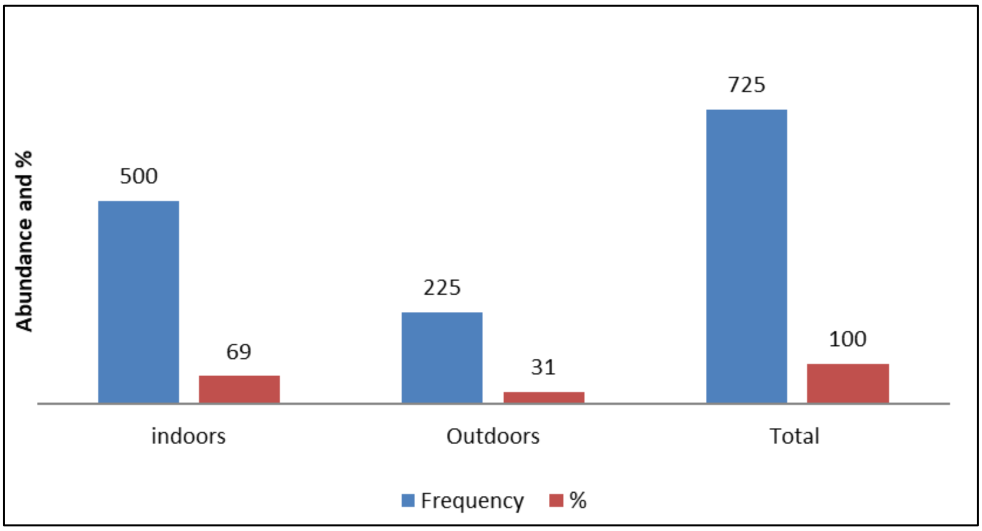

Figure 8 Distribution of Anopheles captured according to location (indoors/outdoors) using the HLC method

Figure 8 indicates that a large number of Anopheles were captured outside houses, representing 69% of the total. Specimens captured inside houses accounted for 31%.

3.3. Vector density for each health area (site)

3.3.1. Total vector density (PSC + HLC) according to capture sites

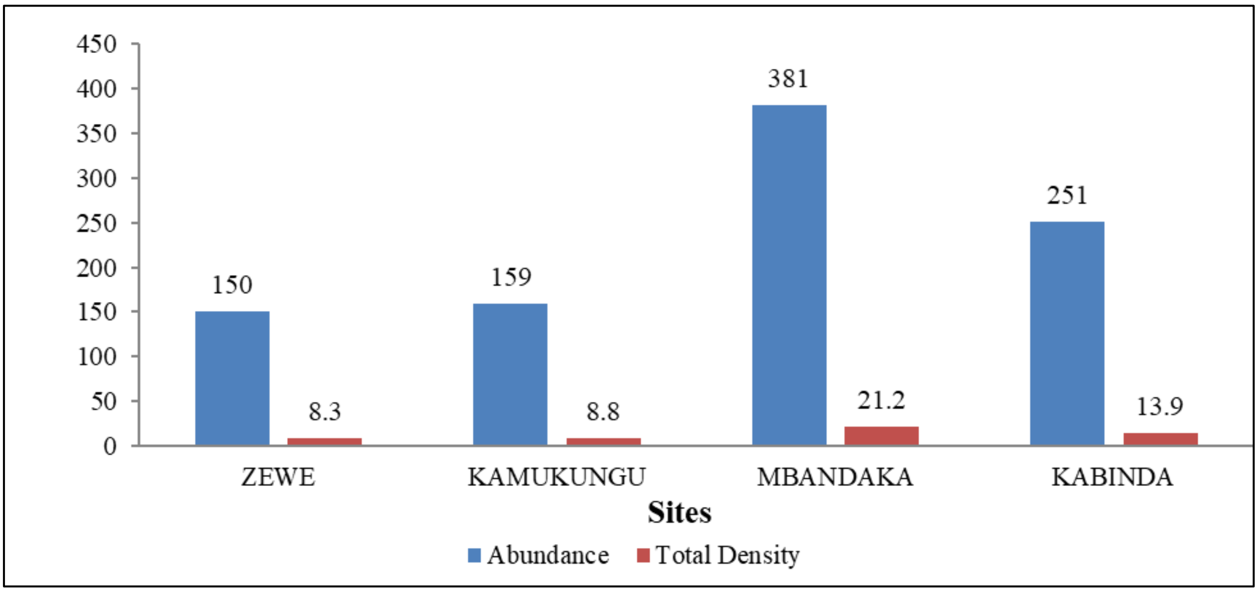

Figure 9 Total vector density by capture sites in the Kabinda health zone

The Mbandaka site showed the highest density (21.2 mosquitoes per collector per house), followed by Kabinda (13.9 mosquitoes per collector per house), Kamukungu (8.8 mosquitoes per collector per house), and Zewe (8.3 mosquitoes per collector per house).

3.3.2. Average densities of Anopheles according to HLC and PSC methods

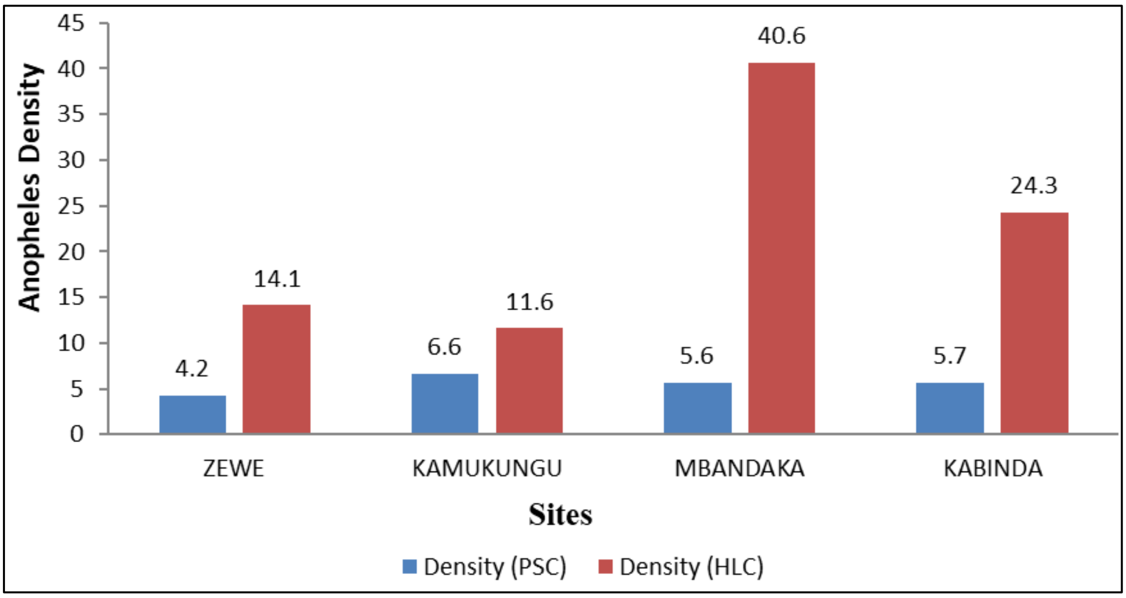

Figure 10 Average densities of Anopheles by capture techniques (HLC and PSC) in the studied sites

The HLC method showed the highest Anopheles densities, with respectively 40.6 mosquitoes per house (Mbandaka), 24.4 mosquitoes per house (Kabinda), 14.1 mosquitoes per house (Zewe), and 11.6 mosquitoes per house (Kamukungu). The PSC method recorded lower densities (6.6 mosquitoes per house in Kamukungu, 5.7 in Kabinda, 5.6 in Mbandaka, and 4.2 in Zewe).

3.4. Human Biting Rate (HBR) by health area

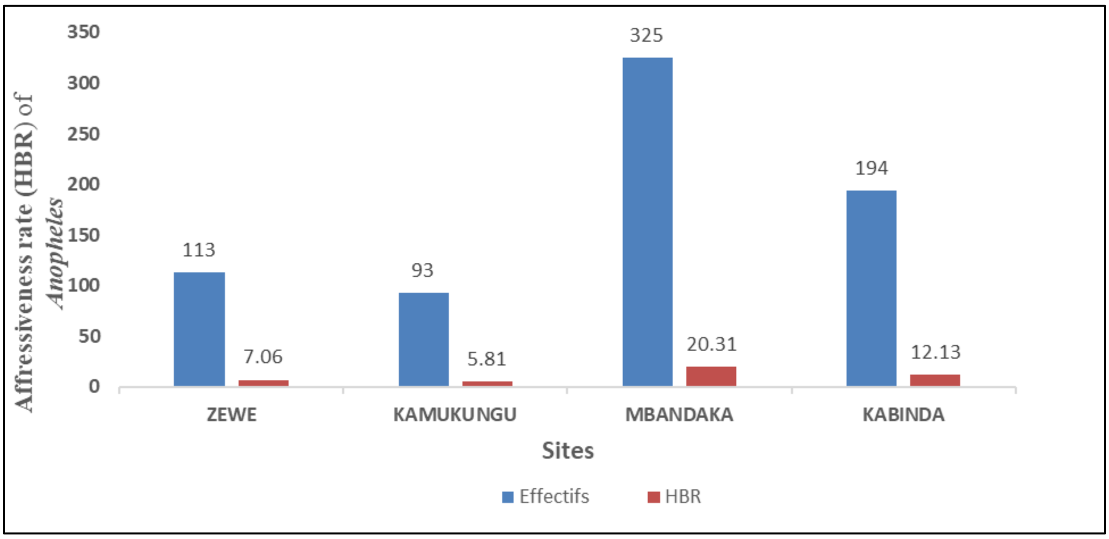

Figure 11 Human biting rate (HBR) by selected sites in the Kabinda health zone

The highest biting rate was observed in the Mbandaka site (20.31 bites per person per night). It was followed by Kabinda, Zewe, and Kamukungu with 12.13, 7.06, and 5.81 bites per person per night, respectively.

3.5. Mosquito behavior in the study area

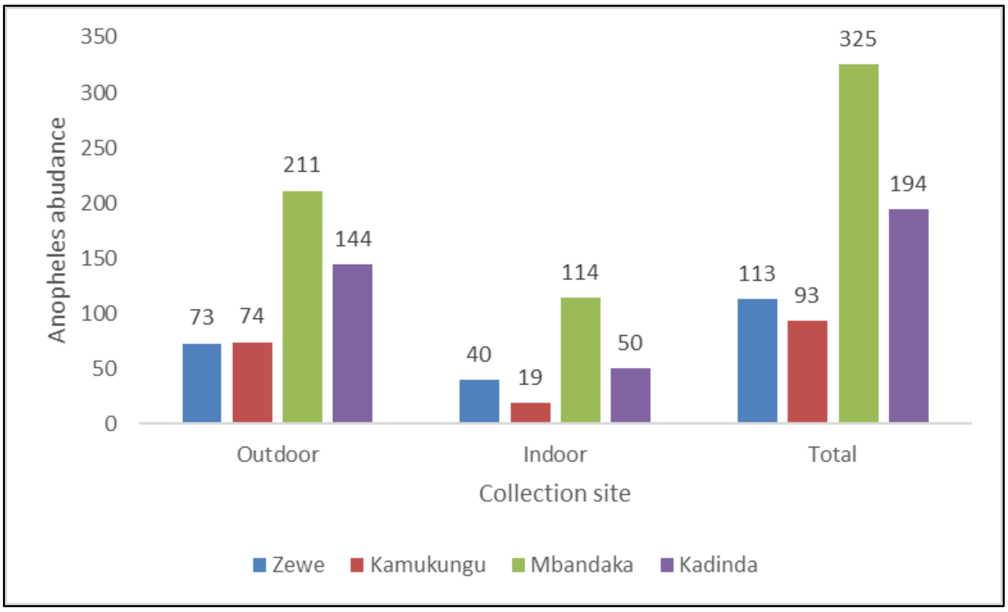

Figure 12 Number of Anopheles according to capture location in the Kabinda health zone

Figure 12 shows that 512 Anopheles were captured outside houses, representing 68.7% of the total, while 223 specimens (31.3%) were collected inside houses. The difference is statistically significant in the health zone regarding Anopheles behavior according to sites ($\chi^2 = 9.15$; $p < 0.05$).

3.6. Synthesis of Anopheles behavior according to capture sites

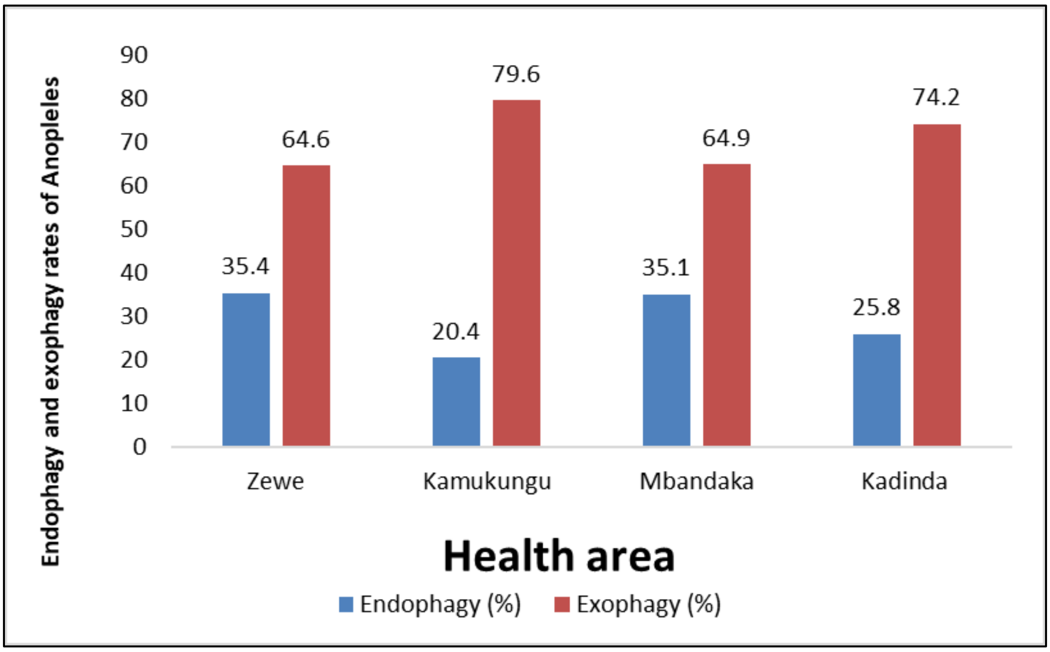

Figure 13 Endophagic and exophagic rates of Anopheles in Kabinda capture sites

The behavior of Anopheles captured in the different sites showed a predominance of exophagy with 64.6% in Zewe, 79.6% in Kamukungu, 64.9% in Mbandaka, and 74.2% in Kabinda, whereas endophagy accounted for 35.4%, 20.4%, 35.1%, and 25.8% respectively in Zewe, Kamukungu, Mbandaka, and Kabinda.

4. Discussion

The results of this study highlight a marked predominance of the genus Anopheles (61%) among the mosquitoes captured, confirming the central role of this group in malaria transmission in the Kabinda health zone. Such dominance is generally associated with a high transmission risk in tropical areas (Gillies & De Meillon, 1968; Service, 2012).

The coexistence of *Anopheles gambiae s.l.* and *Anopheles funestus* constitutes a key element of local transmission dynamics. These two species are recognized as the main vectors of Plasmodium falciparum in sub-Saharan Africa (Coetzee, 2004; World Health Organization, 2013). Their high vector competence and adaptation to human-modified environments explain their major role in transmission.

Anopheles gambiae s.l. is particularly associated with temporary larval habitats, whereas *Anopheles funestus* colonizes more permanent habitats such as marshes (Gillies & Coetzee, 1987). This ecological complementarity favors continuous malaria transmission regardless of seasonal variations (Antonio-Nkondjio *et al*., 2011).

The variations observed in vector densities between sites reflect significant spatial heterogeneity, a phenomenon widely documented in endemic areas (Snow *et al.,* 1998; Carter *et al.,* 2000). This variability is influenced by several factors, including the availability of larval habitats, local climatic conditions, human activities, and housing structure.

Studies have shown that malaria vector distribution is often aggregated into micro-foci, with localized areas of high transmission (Bousema *et al.,* 2012). The Mbandaka site, characterized by high densities, may therefore represent an active transmission hotspot.

The human biting rate (HBR) observed, particularly high in Mbandaka, reflects a significant intensity of human–vector contact. HBR is a fundamental indicator of malaria transmission risk, as it measures the frequency of human bites (World Health Organization, 2013).

An increase in HBR is directly associated with an increased risk of parasite inoculation, especially when mosquitoes are infected (Smith et al., 2010). Thus, the combination of high vector density and high HBR suggests potentially intense transmission in certain sites.

The activity peak observed between 10:00 PM and 2:00 AM corresponds to the typical behavior of the main vector species in Africa (Service, 2012; Gillies & De Meillon, 1968). This synchronization between mosquito activity and human sleeping hours favors malaria transmission (Killeen et al., 2006) and justifies the use of insecticide-treated bed nets, which remain effective during these critical periods.

The predominance of exophagy (≈ 69%) observed in this study suggests a behavioral adaptation of mosquitoes to vector control interventions. This phenomenon has been widely documented in several African countries (Reddy *et al*., 2011; Russell *et al.,* 2011).

The behavioral plasticity of Anopheles allows them to modify their biting habits to avoid indoor interventions, thereby contributing to residual transmission (Govella & Ferguson, 2012). The high proportion of blood-fed females observed indicates intense hematophagous activity. This indicator is essential for evaluating the gonotrophic cycle and mosquito reproductive dynamics (Service, 2012). An active gonotrophic cycle is associated with increased vector density and malaria transmission potential (Clements, 1999).

The results highlight a complex transmission system requiring integrated control strategies. Approaches combining insecticide-treated bed nets, indoor residual spraying, and larval habitat management are recommended (World Health Organization, 2013). However, the predominance of exophagy suggests the need for complementary interventions targeting outdoor transmission (Killeen, 2014).

5. Conclusion

This study highlights a predominance of the genus Anopheles, dominated by *Anopheles gambiae s.l.* and *Anopheles funestus*, the main malaria vectors in sub-Saharan Africa. Spatial variations in vector densities reveal the existence of localized transmission hotspots, while high biting rates indicate intense human–vector contact, a key factor in transmission risk. The temporal dynamics of biting, with a nocturnal peak, confirm the synchronization between vector activity and human behavior, reinforcing the importance of insecticide-treated bed nets. The predominance of exophagy highlights a behavioral adaptation of vectors likely to reduce the effectiveness of conventional vector control strategies. Overall, these results reflect an entomological system favorable to sustained malaria transmission. They emphasize the need to strengthen vector control strategies through integrated approaches adapted to local ecological and behavioral realities.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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