"Spatial Distribution and Ecological Determinants of Tsetse Flies in Trypanosomiasis-Endemic Regions of Mali

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ABSTRACT

Tsetse flies are harmful to humans and animals through their bites and infestations. Their distribution depends on the presence of vegetation and forest patches, etc. Visiting resting places, hunting grounds, or breeding grounds is a means of contact between human, animal, and insect populations. It encourages host–vector encounters and thus pathogen exchanges among humans, wildlife, and the environment. Controlling these insects considerably reduces their nuisance and breaks the pathogen transmission chain. Knowledge of the diversity of tsetse species and the main determinants of their geographical distribution is necessary to effectively combat this scourge. This study was initiated to determine the distribution of tsetse flies and identify the main species currently present in Mali. The 4 regions endemic for trypanosomiasis in Mali (Kayes, Koulikoro, Sikasso and Ségou) were selected for capture. In each region, 10 captures sites were randomly selected. The captures occurred from March to December 2020. The traps were placed on the banks of watercourses, in galleries, and in the Savannah. They were installed for 48 h and renewed every 24 h. A total of 1353 tsetse flies were captured, including 270 in Kayes, 527 in Koulikoro, 554 in Sikasso, and 4 in Ségou ($p = 0.009$). Two riparian species were identified, and no Savannah species were recorded. Tsetse flies were heterogeneously distributed. All sites in the Sikasso region recorded the presence of at least one tsetse fly (100%), while distribution was 80, 40 and 30%, respectively, in the Koulikoro, Kayes, and Ségou regions. These results show that tsetse flies are still present in these regions, albeit with an uneven distribution. A positive correlation was established between diversity and environmental parameters (<0.05).

*Keywords: D*istribution, vector control, distribution area, Mali.

1. INTRODUCTION

Insects are arthropods with the largest number of species (nearly 1.3 million described). They account for more than two-thirds of all living organisms and are widespread throughout the world. In Africa south of the Sahara and in tropical zones, insect biodiversity remains predominant due to environmental conditions that favor their multiplication and induce outbreaks (Duvallet *et al.*, 2012). Tsetse flies, which are responsible for human and animal trypanosomiasis, are widespread in Africa. Nearly 10 million km^2 are infested by the tsetse fly (FAO, (2002). These tsetse fly species are highly sensitive to climatic conditions (Itard *et al.*, 2003). Seasonal variations in temperature and humidity constantly drive them to seek their ecological optimum; they modify the amplitude of their niche according to seasonal conditions. The sensitivity of tsetse flies to climatic variations Itard et *al*., (2003) and their singular demographic behaviors provide information that can be used to model their spatial distributions. Tsetse are dependent on vegetation, islands, forests, and galleries. These areas are generally used by rural populations for hunting, farming, fishing, or market gardening. Anthropogenic pressure contributes to the degradation of the riparian cordon, leading to the disappearance of pupal sites or the retreat of tsetse flies to a more favorable biotope Nash, (1948). In addition, frequenting tsetse resting places, hunting grounds, or breeding grounds is a means of contact between human, animal, and insect populations. Host–vector encounters promote pathogen exchange between humans, wildlife, and the environment *Bouyer* et *al.*, (2009). The harmful bite of tsetse flies and their role in the cyclical transmission of African Animal Trypanosomiasis (AAT) and Human African Trypanosomiasis (HAT) make them very formidable insects Epstein, et *al*., (1993). It is transmitted to humans and animals by a variety of species, both male and female (Aksoy et *al*., (2003); Courtin, et *al*., (2005) ; Mbida et *al*., (2009) ; Bosson et *al*., (2012)). According to the WHO, vector-borne diseases are among the main causes of morbidity and mortality in humans and animals, and trypanosomoses are no exception. Their impact on human health is considerable. In many Central African countries, HAT alone accounts for 87% of the total number of patients diagnosed throughout Africa (WHO, 2006). Approximately 50 million people and 48 million heads of livestock are at risk from trypanosomiasis (Epstein et al., 1993). In Mali, nearly 80% of the population lives from agrosilvo - pastoral activities WHO, (2006). Tsetse fly over more than 20,000 km^2 from north to south, i.e., 16% of the national territory. Djitèye et *al.*, (1997) reported the existence of three main species. After several years of control in the river basins of the Bani and Niger systems, the density is still high at 4.37 tsetse/trap/day in the Niger River basin. *G. palpalis gambiensis* was the predominant species in the Niger and Bani river basins Traoré et *al.*, (2019). Bass et *al*., (2014) have nevertheless observed a decrease in the range of tsetse flies, especially toward the center of the country (Ségou region) Salou et *al.* ; (2012). Vector control is a means of considerably reducing nuisance and breaking the pathogen transmission chain. The Tsetse fly may be present all year round or only during certain seasons. Knowledge of the ecosystem and target species is essential for effective control of these insects. The aim of this study was to update our knowledge of the distribution of tsetse flies and to identify the species currently encountered to contribute to the adaptation of a more effective control strategy against these insects in Mali.

2. MATERIAL AND METHODS

2.1. Study area

The study was conducted from March to December 2020 in four administrative regions endemic to animal trypanosomiasis in Mali. These are Sikasso's regions, Koulikoro, Kayes, Ségou and located approximately between 9.2613°W longitude and 13.570°N latitude (tab 1)

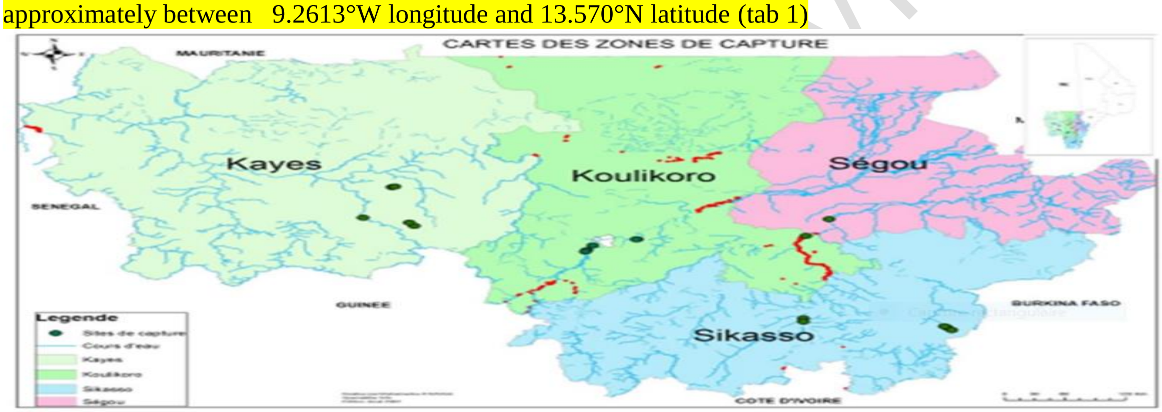

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Fig. 1: Geolocation of capture sites

Rainfall variation in the study area

Table 1 shows the recorded rainfall and number of rainy days in the 4 regions during the 2021–2022 rainy season. A large variability was found not only in the annual rainfall but also in the number of rainy days per year. The region of Sikasso received a greater amount of rain (1185 mm) and a greater number of rainy days (95) than the other regions. The lowest amount of rain (655 mm) was observed in the region of Kayes (Sahelian zone) with a signif-icant number of rainy days (53 days).

Table 1. Annual rainfall and number of rainy days in the study area during the 2021–2022 rainy season

Region	Longitude	Latitude	Annual rainfall	Number of rainy days
Kayes	11.4223° W	14.4271° N	655	53
Koulikoro	8.0226° W	12.6758° N	990	74
Sikasso	5.6680° W	11.3140° N	1185	95
Ségou	6.2520° W	13.4261° N	760	37

2.2. Tsetse fly capture

Ten sites were randomly selected from each of the above regions. Catches were made using biconical and monotonical traps set along watercourses, galleries, and savannahs. Each trap was georeferenced and labeled with the initial site, date, and capture point (or trap) number. The temperature and hygrometry were recorded. The tsetse flies were collected 24 hours after setting the traps. They were then counted and identified using magnifying glasses and the identification key. Their sex was also determined.

2.3. Data analysis

Data were saved on the Windows 2010 Excel software, which was also used to perform pro-portion calculations and produce variation curves and histograms. For all analyses, the maximum significance level was 0.05. Because of its low numbers, *G. tachinoides* was ex-cluded in the analyses. For the analysis of abundance, the Pearson correlation coefficient was applied using the number and species of tsetse and meteorological parameters as determi-nants of their dispersal.

- **Relative abundance**

The number of individuals of one species in relation to the total number of individuals of all species combined was calculated using the following formula:

$$Ar = Aa/N \times 100$$

where:
Ar = relative abundance
Aa = the number of individuals of one species
N= is the total number of individuals.

- **Apparent density (DAP)**

This corresponds to the number of tsetse fly captured per number of traps per day.

3. RESULTS AND DISCUSSION

3.1. Spatial distribution of the tsetse flies

The number of tsetse fly captured was higher in Sikasso than in the other three regions (figure 2a).

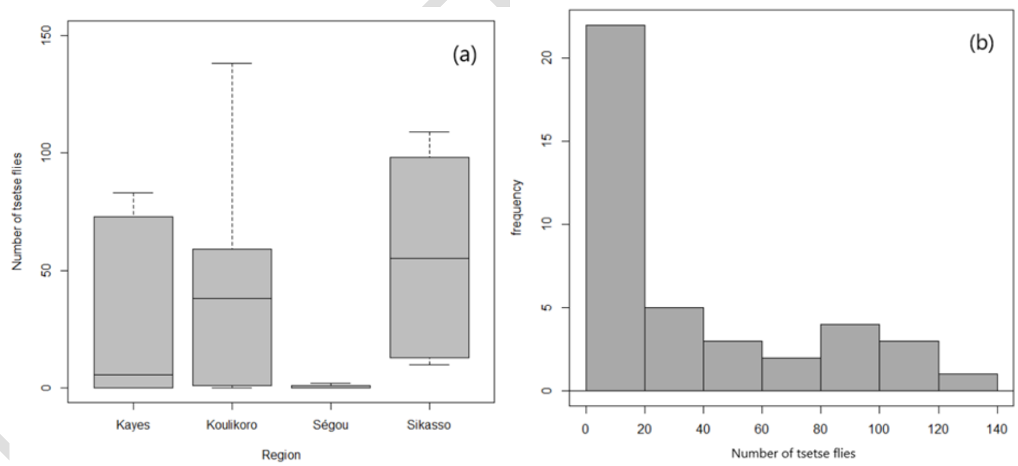

Fig. 2: Variation in the number of tsetse fly captured by region (a) and population distribution by capture site (b)

In the Koulikoro and Kayes regions, the number of tsetse flies captured is to a lesser extent high, with great intersite variability in the Koulikoro region in Mali's Sudanian zone ($p = 0.009$). Sodougouba (Baguinéda commune) recorded the highest number of tsetse flies cap-tured (138), compared with only 34 at Samanko in the Mandé commune. Among the sites surveyed in the Sikasso region, Zièkorodougou recorded 109 tsetse flies, compared with 10 in Djandougou and Tonokalakoura. The sex ratio was almost identical in the Koulikoro and Ségou sites, whereas it was largely in favor of females in the Sikasso and Kayes sites. The number of tsetse fly captured in the Ségou region is relatively low and stable. The distribution of the captured population shows that captures of less than 20 flyers per site are the most frequent (figure 2b). Estimated average densities were 0.03 in Ségou, 1.96 tsetse fly/trap/day in Kayes, 3.15 tsetse fly/trap/day in Sikasso, and 3.56 tsetse fly/trap/day in Koulikoro.

3.2. Relative tsetse fly abundance by region

Of the 1,255 tsetse fly captured, 44% were from the Sikasso region, versus 34% from the Koulikoro region (figure 3). Tsetse flies were relatively scarce in the Ségou region (0.32%). The sex ratio was almost identical in the Koulikoro and Ségou sites, whereas it was largely in favor of females in the Sikasso and Kayes sites (*p*<0.005) (figure 3).

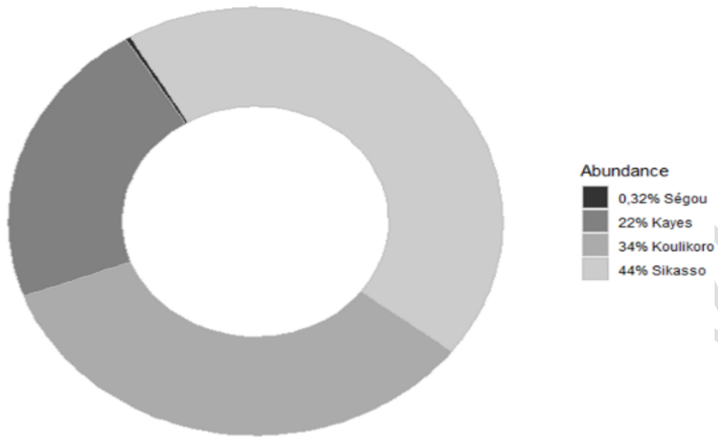

Fig. 3: Relative tsetse fly abundance according to region

3.3. Tsetse diversity according to the region

Two species were identified in the study sites (*Glossina palpalis gambiensis* and *Glossina tachnoides*). These two species were recorded in the Sikasso and Kayes regions, whereas G. palpalis gambiensis was the only species caught in the Ségou and Koulikoro regions (figure 4).

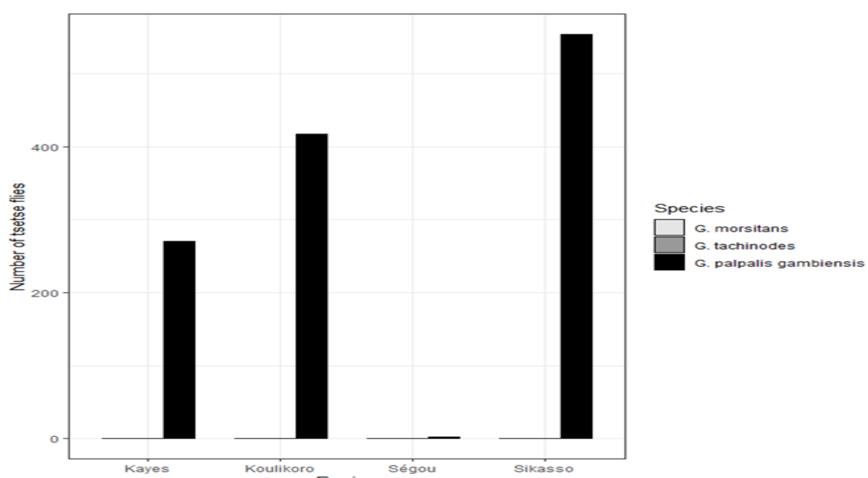

Fig. 4: Number of tsetse fly captured by species and region

Glossina palpalis gambiensis was the predominant species, accounting for over 99.5% of the total, compared with only 0.5% for *G. tachinoides*. The tsetse flies were distributed as follows: 100%, 80%, 40% and 30% respectively in the regions of Sikasso, Koulikoro, Kayes and Ségou. Average densities recorded were 0.03 in Ségou, 1.96 tsetse flies/trap/day in Kayes, 3.15 tsetse flies/trap/day in Sikasso, and 3.56 tsetse flies/trap/day in Koulikoro. *Glossina palpalis gambiensis* was the predominant species, accounting for over 99.5%, compared with just 0.5% for *G. tachinoides*

3.4. Correlation between flies density and meteorological parameters

Average temperatures ranged from 28 to 33°C, with the lowest temperatures recorded in the Sikasso region and an average relative humidity of 51%. It was higher in Kayes, with an av-erage relative humidity of 59%. Rainfall was highest in Sikasso and lowest in Kayes. The data show that the correlations are not significant at the 5% level under our rearing conditions (Table 2). However, the apparent density (DAP) of the flies was slightly sensitive to variations in meteorological parameters, particularly rainfall, compared with that outside temperature, for which the correlation coefficients were negative for the three observed parameters.

Table 2. Correlation between apparent density of flies and meteorological parameters under rearing conditions

Meteorological parameters	Correlation coefficient	p-value
Rainfall (mm)	0.72	0.28
Relative humidity (%)	-0.36	0.64
Outside temperature (°C)	-0.67	0.33

The maximum number of catches was observed in the Sikasso region and the minimum was recorded in the Ségou region. This is because the Sikasso region has a biotope more favora-ble to tsetse fly proliferation than the Ségou region, which is at the northern limit of tsetse fly distribution in Mali. Since 2019, the rarity of tsetse flies in this part of the country has been reported (Traoré *et al.*, 2019). The variability in the number of tsetse captured between the four regions could be explained by the diversity of bioclimates, as shown by Traoré A. & al., (2019). Two tsetse species, all riparian, were captured (*G. palpalis gambiensis* and *G. tachinoides*). These results confirm those of Bass *et al.*, (2014), in the Sikasso and Koulikoro regions, but differ from those of Djitèye & al. (1997), who reported the existence of three tsetse species (G. *palpalis gambiensis, G. tachinoides, G. morsitans)* in the tsetse range of Mali. *G. palpalis gambiensis* was present in all four regions surveyed and was the predominant species, whereas *G. tachinodes* was only caught in the Sikasso (Madinna Diassa) and Kayes (Taliko) regions. In a study conducted in Burkina Faso Salou et *al.*, (2012) reported a strong predominance of *G. tachionides* over *G. p. gambiensis* in Folonzo (84% versus 16% of catches, respectively), whereas in Kartasso, *G. p. gambiensis* was the only species present. Dibakou et al. (2015) in the forest zone and in the village of Doussala identified six species of tsetse fly, including *G. tahinoides*, but *G. p. gambiensis* was completely absent. According to Dibakou & al. (2015). *G. palpalis gambiensis* and *G. tachinoides* frequently coexist and occur in gallery-type vegetation, but *G. tachinoides* remains the dominant species near permanent watering holes. Gebre et *al.*, (2022) who showed an uneven distribution of tsetse flies in Ethiopia however they recorded that the G. tachinoides species was the most abundant and that the morsitans group was rare with a low density varying between 0.19 and 0.42 flies/trap/day. Given that most of the watercourses surveyed, especially in the Kayes region, were temporary, it is obvious that the numbers of this species caught were lower. The rarity of this species (*G. tahinoides*) and the absence of *G. morsitans* could be due to their ecological requirements or anthropic effects. Some authors [Darchen, (1978) ; Solano, (2008); Mbida (2009) , Buxton (1955) reported that the infestation of an environment by tsetse flies is conditioned by the simultaneous presence of suitable environmental factors (temperature between 15°C and 25°C, luminosity, relative humidity) and feeding vertebrate hosts. Solano, P., (2008), indicated that the very low presence of certain tsetse species such as *G. tahinoides* in a given biotope reflects their ecological requirements. It is clear that in our catchment areas, feeder hosts are scarce, and the climatic conditions were very unfavorable in Kayes and Ségou. The results show that tsetse flies were present in all four regions surveyed but were hetero-geneously dispersed. All the sites surveyed in the Sikasso region had an apparent density greater than or equal to one tsetse fly/trap/day, giving a representativeness of 100%. In contrast, only 30% of the sites surveyed were positive in the Ségou region, with an average density of 0.03 tsetse fly/trap/day. In Koulikoro and Kayes, **the distribution** was 80% and 40%, with average densities of 1.96 and 3.56 tsetse fly/trap/day, respectively. The results of the Pan-African Animal Trypanosomiasis Control Campaign (PATTEC, 2009) showed that the Sikasso region was 100% infested, the Koulikoro region 76%, and the Kayes and Ségou regions 46% and 44%, respectively. A study of the distribution of tsetse flies in the Savannah region showed that they are present almost everywhere in the river system, as long as there is sufficient tree vegetation to create the microclimate they need. Tsetse flies have been reported in all three of Mali's river basins. We note the absence of *Glossina morsitans* and the rarity of *G. tahinoides*. The morsitans group is more xerophilous (optimum 50-60% relative humidity) and disperses widely during the rainy season in wooded savannahs and in the dry season in the most favorable microclimates of streamside vegetation. According to Djitèye & al. (1997), the morsitans group is located in southern Mali. In a range covering approximately 200,000 km2 south of 14° 30' N and west of 4° 30' W, tsetse flies are found only in the Sahelian, Sudanian, and pre-Guinean zones. In Sahelian zones such as the Ségou region, the climate is arid or semi-arid, and tsetse flies are few or non-existent depending on the microclimate, as our results show. The Sudanian zone, a tsetse fly zone par excellence, offers a favorable biotope for tsetse proliferation and dynamics. In the homogeneous landscapes found in protected areas such as that of the Sikasso region, the forest gallery is preserved along the entire length of the river, providing tsetse with favorable living conditions (temperature, humidity, pupation sites), hence the existence of three species of tsetse in this part of the country. Under these conditions, the tsetse fly has a strong tendency to disperse, which explains their wide dispersal (100%) in this part of the country. The microclimate of the Koulikoro region (Mandé commune) borders the pre-Guinean climate. These conditions are very similar to those in the south of the country, with the repartition estimated at 80%. On the other hand, in the Kayes region, the favorable biotope is spatially fragmented and gradually degrades under the influence of climate, anthropogenic and agricultural effects, lower relative humidity, and higher temperatures. In this region, the flies are less distributed (40%) than in the previous two. (*Bouyer* e *al.,* 2009), showed that agricultural practices lead to the degradation of the riparian cordon, resulting in the disappearance of pupation sites, lower relative humidity, and higher temperatures. According to Soberón J. Peterson A. T. (2005), abiotic conditions such as altitude, climate or cover, biotic factors, the species' ability to disperse spatially, and its capacity to adapt are factors that influence the spatial distribution of a species. According to our results and Pearson's matrix analysis, the correlation between climatic variables (temperature, relative humidity, rainfall) and tsetse fly dispersal is not always positive. There is a negative correlation between relative abundance, temperature, and humidity. Diversity, rainfall, and relative humidity were positively correlated (<0.05). Traoré et *al.,* (2023), showed that there was no direct correlation between the vegetation index and the number of tsetse fly captured. Variables such as hygrometry and temperature are the main determinants of variation in plain tsetse fly density, regardless of the site surveyed. The uneven distribution of tsetse could therefore be explained by the diversity and structure of the environment, which can create specific microhabitats that are more or less favorable to tsetse development. The absence of *Glossina morsitans* does not necessarily mean that the species is extinct. In addition to abiotic factors, the survey period could also be a determining factor in tsetse dispersal. At this time of year, tsetse flies are more focused on their hunting grounds, larval breeding sites, and the microclimate suitable for this purpose, as set out (Frezil et *al.* Carnevale, 1976 ; Laveissière et Hervouët, 1981 ; Gouteux et Kiénou, 1982 ; Zinga et *al.,* (2013) and (2024). Such conditions seem to be found in the southern part of Mali (Sikasso and Koulikoro regions) and would explain the high level of tsetse fly dispersal in these areas.

4. CONCLUSION

This study aimed to document the diversity of tsetse species present in the four regions and their geographical distribution. The abundance and distribution of the tsetse fly has not been uniform. The number of tsetse fly captured varied according to the biotopes surveyed in the four regions. Two species were present, with a clear predominance of *G. pal-palis gambiensis*. Despite numerous tsetse control campaigns, tsetse are still present in the four regions mentioned above, and their density remains high outside the Ségou region. A longitudinal survey coupled with tsetse trapping at several sites along the bioclimatic gradient is required to determine the actual or seasonal density of these species.

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