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Trypanosomiasis in Kinshasa: distribution of the vector, *Glossina fuscipes quanzensis*, and risk of transmission in the peri-urban area

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Abstract. Because human and animal cases of African trypanosomiasis have been reported in and around the city of Kinshasa for a long time, the likelihood of local transmission was examined. A georeferenced image of the city was produced, based on a satellite image (SPOT 4). Urban, peri-urban and rural areas were delineated. All recent data on captures of *Glossina fuscipes quanzensis* Pires (Diptera: Glossinidae) between 1999 and 2004, as well as epidemiological data on a 1999 outbreak of human trypanosomiasis by *Trypanosoma brucei gambiense* in the Kisenso District, were entered in a geographical information system (GIS). Tsetse flies were mainly found along some of the major rivers in the rural and peri-urban area of Kinshasa. Unsupervised classification of the satellite image allowed identification of riverine habitats suitable for tsetse flies and indicated sites where further entomological surveys were needed. The study produced strong indications that local transmission of human trypanosomiasis had occurred in the recent past in the peri-urban zone of Kinshasa.

Key words. Glossina fuscipes quanzensis, distribution, geographical information system, human African trypanosomiasis, tsetse, Democratic Republic of Congo.

Introduction

Recent studies (Van Nieuwenhove *et al*., 2001) as well as the reports of the Veterinary Laboratory of Kinshasa have shown that human and animal African trypanosomiasis remain important health problems in the Democratic Republic of Congo and that these problems are not confined to the rural areas. In 1999, a spectacular increase in the number of cases of human sleeping sickness was observed in the province 'Ville de Kinshasa' (Ebeja *et al*., 2003), seemingly concentrated in four zones. In one of those, Kisenso district, more than 300 cases of sleeping sickness were diagnosed during the outbreak. As Kisenso was located on the boundary between the inner city and the peri-urban area, this report raised some controversy about the possible existence of urban transmission of trypanosomiasis.

Robays *et al*. (2004) conducted a case control study in 2003 among urban residents in Kinshasa, but found no evidence of transmission in the inner city. Most cases in urban residents were attributed to their exposure to high transmission foci in other provinces, mostly in nearby Bandundu. Because of the poor socio-economic situation of the country due to a long history of bad governance and civil war, many citizens of Kinshasa are forced, in order to survive, to engage in farming or trading of agricultural products, which brings them in close contact with the vectors and foci of human trypanosomiasis.

However, though human African trypanosomiasis transmission in the inner city seems unlikely, the risk of

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acquiring the disease in the peri-urban area of Kinshasa is not fully understood. The periphery of Kinshasa contains known historic foci of sleeping sickness and is traversed by several rivers, providing favourable habitats for the riverine *Glossina fuscipes quanzensis* Pires, which is the only tsetse fly species infesting the region. Along the riverbanks intensive market gardening and pig breeding is going on, so that local tsetse flies probably have ample opportunity to feed on men and pigs. Contacts of urban residents with those peri-urban areas and the local vector are at least as frequent or more frequent as with the inner provinces. A better understanding of the epidemiology of both human and animal trypanosomiasis in and around Kinshasa requires updated data on distribution and density of the tsetse population. This paper relates a geographical information system (GIS) based study of tsetse vector habitats in Kinshasa province and an investigation of the 1999 sleeping sickness outbreak in Kisenso, to better document the actual risk of infection in the periphery of Kinshasa.

Materials and methods

The study zone

Kinshasa, the capital and with a population of five million the largest city of the Democratic Republic of Congo, is located along the southern bank of the Congo River, directly opposite the city of Brazzaville. Kinshasa has one of the highest urbanization rates on the African continent. The city is rapidly expanding to the south and south-east and encroaching on the secondary forest surrounding the city. Besides urbanization, the preference of urban dwellers for charcoal is another cause of important deforestation in the 'Ville de Kinshasa' province. The climate is equatorial: hot and humid.

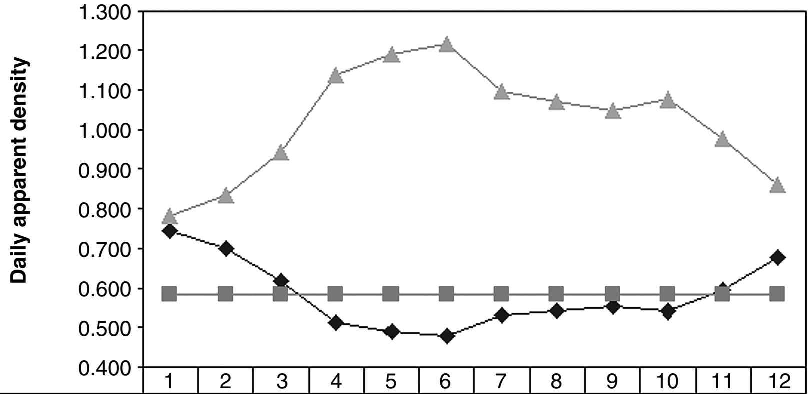
Acquisition and processing of the satellite image

First a digital and georeferenced map of Kinshasa based on a SPOT 4 satellite image was developed. The satellite image of Kinshasa was purchased at the 'Centre Nationale d'Etudes Spatiales – France' [SPOT/ISIS Program data, © CNES (2002), Distribution Spot Image S.A.]. The coloured image (SPOT 4 – multispectral mode XI), dated 2 April 2002, covered an area of 60 × 60 km and had a pixel resolution of 20 m. Using Idrisi software (Clarks Laboratories, Clarks University, Worcester, MA, U.S.A.), the four bands of satellite data were converted and 'resampled' (each pixel relocated using a set of polynomial equations) by means of the Global Positioning System (GPS) co-ordinates of some specific sites in Kinshasa that were clearly visible on the satellite image (e.g. bridges or crossroads). A composite image of the resampled bands 2, 3 and 4 was then produced and imported into Arcview GIS 3.2 (Environmental Systems Research Institute, Redlands, U.S.A.). A worldfile converted the co-ordinates of this image file to real geographical co-ordinates.

In the second phase, we demarcated three different ecozones (urban, peri-urban and rural) based on the different spectral responses in the digital image and validated this classification for a sample of discrete points identified with a handheld GPS device (Garmin eMap).

Determination of tsetse fly distribution and density in and around Kinshasa

Data on the distribution and density of *Glossina fuscipes quanzensis*, the tsetse species present in the study area, was obtained from the outcomes of entomological surveys conducted from 1999 to 2004 by the 'Programme National de Lutte contre la Trypanosomose Humaine Africaine' (PNLTHA), the Entomology Department of the 'Institut National de Recherche Biomédicale' (INRB) and the Parasitology Department of the 'Laboratoire Vétérinaire de Kinshasa' (Labovet). The fly population was sampled using an adapted version of the Lancien trap (Lancien, 1981). Sampling data originated from more than 300 sites, of which the geographical co-ordinates were recorded using a hand-held global positioning receiver. Only the 141 sites where tsetses were captured were taken into account. Because information on the length of sampling time was lacking for most capture sites, negative capture sites were not used in the habitat suitability analysis. When length of sampling time and numbers of captured flies were known, fly densities were expressed as daily apparent density (DAD) or the number of flies captured per trap per day. As fly abundance varies according to season, a monthly adjustment factor was determined so that captures carried out at different months could be compared. The correction factor will be below one during the time of the year when the vector population increases, and above 1 when the population decreases due to an unfavourable season. The monthly correction factors were calculated on the basis of 24 months of capture data gathered by PNLTHA during a permanent tsetse trapping operation performed in 2000 and 2001 near the N'Djili River at Kikimi II. Permanent trapping apparently did not affect the local fly population, as numbers of captured flies in the second year were continuously higher than in the first year. For each month the mean DAD was calculated over the 2 years. However, sudden climatic variations during this short observation period of 2 years were responsible for the bumpy aspect of the curve representing the mean DAD over the capture month. Therefore temporal smoothing was carried out by averaging the DAD of a specific month with that of the preceding and subsequent month. Division of the mean DAD over the whole period by the smoothed mean DAD for each specific month yielded a correction factor for each month (Fig. 1). In order to compare fly densities at different Kinshasa sites (along the rivers N'Djili, Lukaya, Funa and Boyé) mean DAD obtained at those sites during a specific month were multiplied by the appropriate



	1	2	3	4	5	6	7	8	9	10	11	12
Daily apparent density	0.745	0.699	0.617	0.511	0.489	0.478	0.530	0.543	0.554	0.541	0.596	0.677
Mean apparent density	0.582	0.582	0.582	0.582	0.582	0.582	0.582	0.582	0.582	0.582	0.582	0.582
Correction factor	0.78	0.83	0.94	1.14	1.19	1.22	1.10	1.07	1.05	1.08	0.98	0.86

Fig. 1. Mean daily apparent density of *Glossina fuscipes quanzensis* and tsetse capture correction factor for each month of the year (calculated on the basis of captures carried out in Kikimi II during 2000 and 2001).

correction factor of that month. All resulting data were entered in the GIS and maps on the distribution and density of the vector were produced (Fig. 2).

Identification of habitat suitable for Glossina fuscipes quanzensis

An iterative unsupervised classification using a full Maximum Likelihood procedure (the 'isoclust' classifier program of Idrisi) was used to identify clusters of similar pixels in the composite satellite image. Based on a histogram showing the frequency with which clusters occur in the image, it was decided that in the satellite image eight highly prevalent clusters covering 88.5% of the satellite image surface could be differentiated. Each of these clusters corresponds to landscape types producing similar reflectance patterns. By examining the relative frequency of tsetse captures in these eight clusters and assuming that tsetse were captured essentially in environments appropriate to the fly, we tried to assess the suitability of specific environment types to *G. f. quanzensis*. Because the distribution of *G. f. quanzensis* is restricted to the river system and its surrounding vegetation, prediction of the

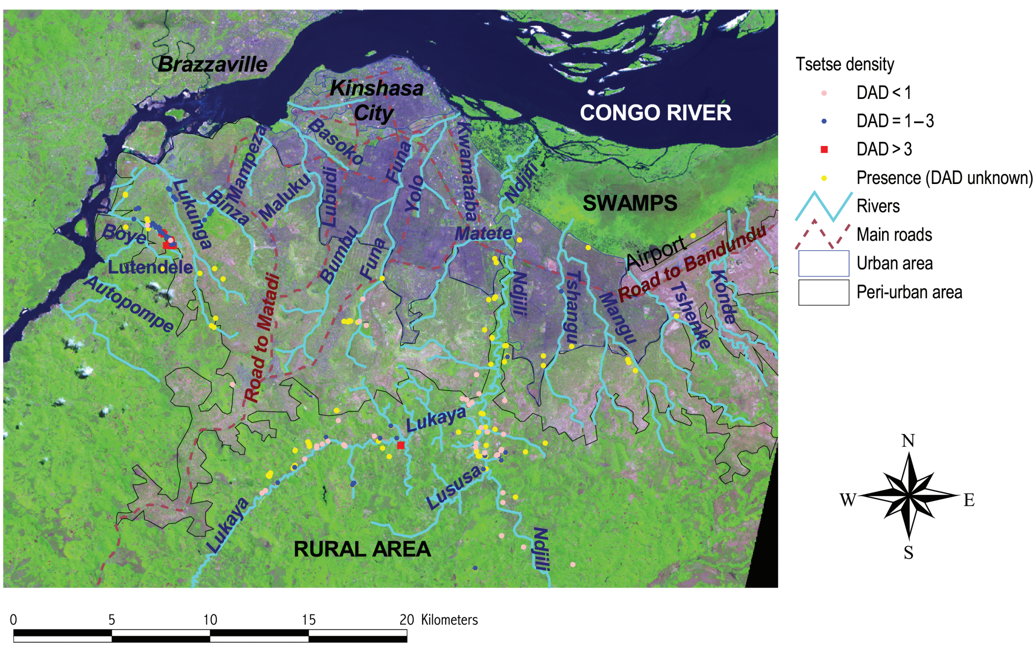


Fig. 2. Location of the various ecozones (urban, peri-urban and rural) and distribution of tsetse flies. DAD, daily apparent density.

suitability of the habitat for tsetse was limited to a buffer zone 750-m wide at each side of the river system. The accuracy of the predictions was evaluated in August/September 2004 by deploying traps at several sites in the buffer zone. Sampling was carried out where previous sampling data were scarce and was carried out both in sites classified as 'suitable' (the rivers Boyé, Lukunga, Mamboma and Binza, Mampeza, Maluku, the N'Djili estuary and part of the military camp Kokolo), as well as in sites classified as being 'less suitable tsetse habitat' (the northern parts of the rivers Thsangu and Tshenke to the east of the city).

Spatial analysis of data on the Kisenso outbreak

The Kisenso District is situated near the N'Djili River at the transition between the urban and peri-urban areas. Adjacent and south to Kisenso lays the subdistrict of Lemba-Imbu, which belongs to the Mont Ngafula district. This subdistrict is situated close to the rural zone where the Lukaya River flows in the N'Djili River. During 1999, a mobile team of PNLTAH was sent to these districts to screen the population and administer treatment to infected individuals. Simultaneously, an individual patient record card of each new detected case (319 persons in total) was established. The spatial distribution of these cases was mapped using a digital street map of Kisenso and the reported residence of the confirmed sleeping sickness cases. As many addresses could not be traced back on the digital street map of Kisenso, missing addresses were retrieved by visiting the area and mapping the missing locations with a GPS device (Garmin – eMap).

Results

The demarcation of three different ecozones in the city, as illustrated by their respective spectral responses, is shown in Fig. 2. The inner city is characterized by densely packed constructions typical of the urban habitat that are interspersed with some remaining urban vegetation (a military camp, the golf course, the old airport and the city parks close to the Congo River). The peri-urban zone shows open-space housing interspersed with small plots of irrigated arable land. To the west of the urban zone, the peri-urban zone constitutes a large residential area, which separates the city centre from the 'ribbon' housing pattern along the road to Matadi and the Avenue of the 17th May. More peripherally, this peri-urban zone changes gradually into a sparsely populated rural zone where farmers live in small villages surrounded by cultivated land, fallow land and groves. The georeferenced satellite image was used as a base for a GIS in which data on vector distribution and density were entered, analysed and visualized and habitat suitability determined.

Plotting all reported tsetse capture sites (Fig. 2) showed that flies were found mainly along rivers flowing through the rural or peri-urban zone west or south of Kinshasa. The two most important tsetse fly populations in these zones, the one in the north-west (Boyé River) and the one in the south (along the Lukaya and N'Djili), are separated by the ribbon building along the road to Matadi. With the exception of the N'Djili River, no tsetse could be captured in the riparian vegetation along the rivers traversing the urban area. All flies that were captured belonged to the species *G. f. quanzensis*.

For some sites, tsetse capture data were sufficient to allow the calculation of the DAD. Adjusting fly numbers according to the month of capture enabled comparison of DAD of tsetse captured at different moments. The corrected DADs were generally low (mean DAD: 1.8) and never exceeded 17 flies captured per trap per day. The highest corrected DADs were recorded in the north-western zone of Kinshasa (subdistrict of Ngombele-Lutendele) along the Boyé River. Captures along the Lukaya and the part of the N'Djili River located in the rural zone were generally high to moderate, whereas lower densities were recorded along the Funa River close to the urban zone (Fig. 2).

Sixty per cent of 145 sites where tsetse had been captured were located into two of the eight clusters of pixels identified in the satellite composite image. The first cluster corresponded with patches of rather dense vegetation occurring in depressions of the rural area, in small bands along all rivers and in swampland near the major rivers. The second cluster corresponded to patches of more open vegetation occurring chiefly in the peri-urban zone. Another 20% of the sites where tsetse were captured were located on the edge between both cluster types described above and a cluster describing more densely populated areas. Captures in these last sites were always extremely low and the decision to capture tsetse on those spots may have been more a consequence of a casual contact between scarce tsetse flies and a dense human population than a real tsetse problem due to suitable habitat. Based on this information, the satellite image was divided in habitat favourable for tsetse fly (pixels belonging to cluster 1 and 2) and habitat less suited for tsetse. By limiting the landscape description to an area of 750 m at each side of the major river systems, potentially favourable fly habitat could be determined more precisely (Fig. 3).

Assessment of the accuracy of the habitat prediction revealed that tsetse were indeed absent in sites classified as being 'less suitable tsetse habitat' (e.g. the rivers Thsangu and Tshenke close to the city), but the presence of the tsetse fly along the streams to the west of the city (e.g. Lukunga, Mamboma, Binza and Mampeza) was confirmed.

The field visit to Kisenso revealed that 55% of the sleeping sickness cases reported in Kisenso (160 of all 293 cases that could be traced back), originated from Lemba-Imbu, a subdistrict of the Mont Ngafula District situated to the south of Kisenso and bordered by both the N'Djili and Lukaya rivers (Fig. 4). Kisenso subdistricts harbouring numerous sleeping sickness cases were either located on the banks of the N'Djili River, such as 'Quartier des Anciens Combattants', 'Kisenso-

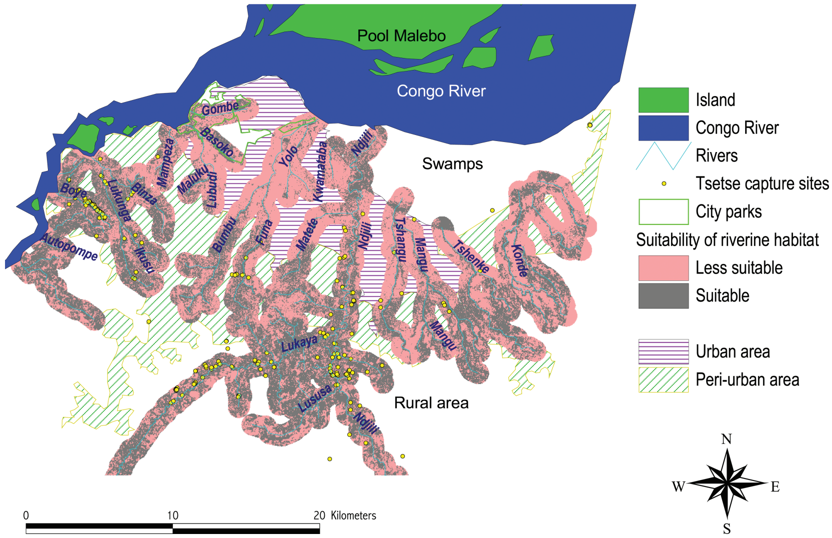


Fig. 3. Distribution of potentially suitable and unsuitable riverine habitat for *Glossina fuscipes quanzensis* around Kinshasa.

Gare' and 'Dingi-Dingi', or were traversed by a tributary of the N'Djili River, such as 'Quartier de la Révolution' and 'Quartier Kitomesa' (Fig. 4). Only 10% of the infected persons lived in the Kisenso District or Lemba-Imbu for less than 3 years, the majority of them lived there for 15 years at least. Immigrants did not constitute an important part of the local population. The population of Lemba-Imbu complained that, close to the river, they were regularly bitten by tsetse flies.

Discussion

Capture results demonstrated that a tsetse fly belt surrounds Kinshasa City. *Glossina f. quanzensis* seems to infiltrate deeply into the peri-urban area along the hydrographic system, but in the urban area tsetse flies are absent with the exception of the N'Djili riverbanks, where a broad riparian vegetation enables the fly to infiltrate into the urban area. Along the other rivers traversing the urban area, riparian vegetation is absent or probably too small and fragmented to offer a favourable environment for the fly (Figs 2 and 3). Urbanization and clearance of riverine vegetation has pushed the tsetse flies out of town. On the banks of the Congo River, tsetse are rarely found. The distribution of *Glossina f. quanzensis* around the City of Kinshasa seems not to have changed much in the last 5 years. Although not always at the same densities, tsetse flies are still found at those sites where they were captured 5 years ago (Wat'senga *et al*., 1999). A similar picture is seen in Brazzaville, on the other side of the Congo River. In Brazzaville, tsetse breeding grounds in the city disappeared over 20 years ago. Today significant tsetse breeding is only

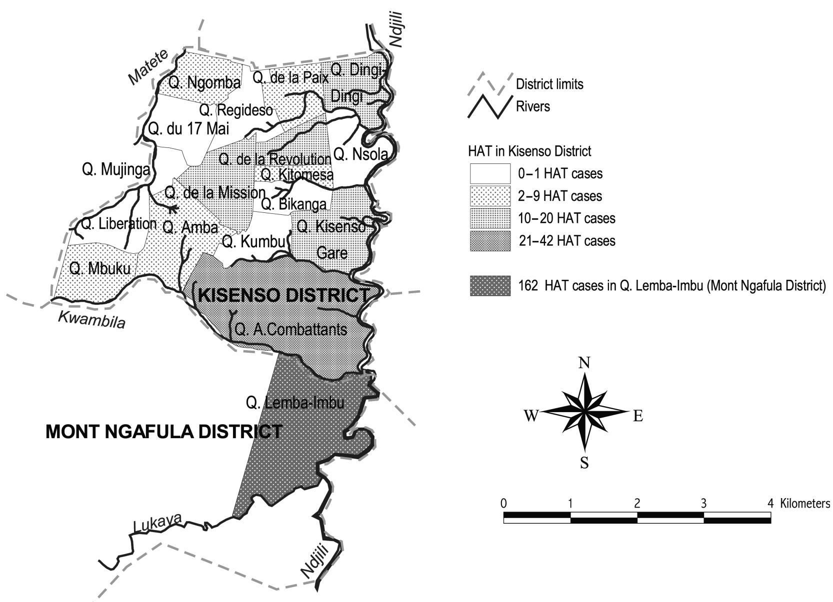


Fig. 4. Distribution of the sleeping sickness cases during the epidemic of 1999 in Kisenso District and Lemba-Imbu subdistrict (Mont Ngafula District). HAT. Human African Trypanosomiasis.

observed in peri-urban areas of Brazzaville, often in close association with local pig breeding (Gouteux *et al*., 1986).

The apparent density of tsetse observed during this study was generally low (Fig. 2), but comparable to the mean apparent density of 3.8 observed in 1991 during a survey in the same zone (Mulumba *et al*., 1993). This low apparent density is probably due to the location of the study area, which is situated at the western limit of the *G. f. quanzensis* distribution range (Elsen, 1973), and to the intensive agricultural activities around Kinshasa causing fragmentation of the fly habitat. De la Rocque *et al.* (2001b) examining changes in the distribution of *G. tachinoides* Westwood and *G. palpalis gambiensis* Vanderplank in an agropastoral area of Burkina Faso subject to increasing human population pressure and land-use change, also observed that tsetse populations declined where fields encroached on riverine vegetation. In this study, flies were most numerous during the rainy season (from October until April) and their density was lowest at the start of the dry season during the period of May to July. However, seasonal variations in fly population density were very discreet (Fig. 1) due to the location of the study area close to the equator and the shelter of the riverine habitat to the fly. Mean apparent density of tsetse flies differed between capture sites even among those lying close to each other on the same river (Fig. 2). This is attributed to local differences in the availability of feeding hosts and suitable riverine vegetation.

An attempt was made to identify the habitat favourable for *G. f. quanzensis* by combining those clusters of pixels, where this riverine tsetse fly was captured predominantly, with a buffer zone of 750 m at each side of the rivers in the study area (Fig. 3). This methodology certainly has some inherent weaknesses. Firstly, the reflectance of a pixel is dependent on several parameters, such as vegetation, temperature and humidity. Therefore all pixels in a cluster do not necessarily represent identical landscapes but they define more a restricted number of specific environments. Secondly, the methodology does not take into account other factors interfering with tsetse distribution, such as human activity, feeding hosts or specific vegetation. Riverine tsetse habitat with a width of 750 m along each river bank may seem to be exaggerated in comparison with the buffer zone for riparian tsetse used in other studies (De la Rocque *et al*., 2001a; Mahama *et al*., 2005). However, *G. f. quanzensis* is able to move relatively far away from the river. For instance, the centre of the zoo of Brazzaville, which was for long infested by *G. f. quanzensis* (Gouteux *et al*., 1987), is at a distance of 750 m from the nearest river. Furthermore, Schwetz (1922) found viable pupae of *G. f. quanzensis* under a thicket situated at a distance of approximately 1500 m from the river. However, the habitat suitability map (Fig. 3) worked out in this study was not intended to represent an exact presence/absence map of *G. f. quanzensis* around Kinshasa, but to provide in a simple and cheap method of obtaining useful information and prediction for survey planning purposes.

On the habitat suitability map, besides the urbanized part of the city, some other landscapes seem to be unsuitable for tsetse. For instance, a large part of the peri-urban area situated to the south of the international airport of Kinshasa is recognized as being unsuitable habitat. This was confirmed, as almost no flies were captured in this area along the Tshangu, Mangu and Tshenke rivers. On the other hand, the habitat suitability map showed that the major part of the islands in Pool Malebo (formerly Stanley Pool) and of the swamps to the east of Kinshasa could constitute suitable habitat for *G. f. quanzensis*. In August/September 2004, fly presence at the edge of the swamps was examined near the estuaries of the N'Djili and Tshenke, but traps remained empty. Vegetation at these sites was dense but not very suitable for tsetse, mainly consisting of tall grasses. At the edge of the urban/peri-urban area, no tsetse could be captured along the Basoko, Maluku and Lubudi rivers. In the case of camp Kikolo, no flies were captured, although the habitat suitability map indicates some suitable habitat. This probably can be explained by a stretch of cleared land between the habitat and the river. In the peri-urban area, the presence of tsetse at the Funa and Lukaya rivers corroborated the habitat suitability findings, but the presence of suitable habitat along the Bumbu River asks for more thorough entomological surveys along this river. West of the city, the study of Kalaso Omombo (2000) confirms the abundance of tsetse along the Boyé River. However, tsetse surveys carried out along the Autopompe and Lutendele-Kimbanguiste rivers yielded much lower captures. Predictions of suitable tsetse habitat along the Lukunga, Binza and Mambona rivers were also corroborated by the trapping results.

Although currently no urban trypanosomiasis transmission seems to occur (Robays *et al*., 2004), the Kisenso outbreak indicates a potential transmission risk at the periphery of Kinshasa town where intensive agricultural and livestock breeding activities are carried out close to the tsetse-infested rivers. In Kisenso, the sleeping sickness cases have most likely been infected locally, as the infected persons had lived in the area for 15 years on average. As most of the cases were encountered in the subdistricts located near the river banks (Fig. 4), it could be possible that people carrying out activities near those river banks, e.g. working in vegetable gardens or breeding livestock near the river, are at higher risk of coming into close contact with tsetse and getting infected. This observation again stresses the importance of establishing the ecological relationship between human populations, their activities and their environment in elucidating the epidemiology of human African trypanosomiasis (Fournet *et al*., 2000). Future studies need to be carried out in Kinshasa to determine the conditions that are more conducive to disease transmission.

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