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ORIGINAL PAPER

Tsetse diversity and abundance in Southern Burkina Faso in relation with the vegetation

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Abstract The increase of human population, combined with climatic changes, contributed to the modification of spatial distribution of tsetse flies, main vector of trypanosomiasis. In order to establish and compare tsetse presence and their relationship with vegetation, entomological survey was performed using biconical traps deployed in transects, simultaneously with phyto-sociological study, on the Comoe river at its source in the village of Moussodougou, and in the semi-protected area of Folonzo, both localities in Southern Burkina Faso. In Folonzo, the survey revealed a diversity of tsetse with 4 species occurring with apparent densities as follows: *Glossina tachinoides* (8.9 tsetse/trap/day); *G. morsitans submorsitans* (1.8 tsetse/trap/day); *G. palpalis gambiensis* (0.6/trap/day) and *G. medicorum* (0.15 tsetse/trap/day). In Moussodougou, a highly anthropized area, mainly *G. p. gambiensis* was caught (2.06 tsetse/trap/day), and rarely *G. tachinoides*. The phyto-sociological study allowed discrimination of 6 types of vegetation in both localities, with 3 concordances that are riparian forest, shrubby and woody savannah. In Moussodougou, all tsetse were caught in the riparian forest. That was also the case in Folonzo where a great proportion (95 to 99 % following the season) of *G. p. gambiensis* and *G. tachinoides* were caught in the gallery, while *G. m. submorsitans* was occurring as well in the gallery as in the savannah, and *G. medicorum* in the forest gallery. This study showed that although *G. tachinoides* and G.*p. gambiensis* are both riparian, they do not have the same preference in terms of biotope.

Keywords Tsetse · Diversity · Vegetation · Comoe · Burkina Faso

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Introduction

Tsetse flies (*Diptera*/*Glossinidae*) are constituted by a single genus (*Glossina*) comprising 31 tsetse species and subspecies, all restricted to sub-saharan Africa. The genus has been divided into three subgenera (or groups) according to external morphologic characteristics, geographical distribution and bio-ecological factors (Itard and Cuisance 2003). Therefore, we have the fusca group, gathering about 15 species occurring in the forests and thick forest gallery in Central Africa: the morsitan group with 7 species, inhabiting woody savannah all across the continent and the palpalis group (9 species), infesting mainly the dense vegetation along the hydrographical system in West and Central Africa. In this latter, are found the major vectors of both human and animal African trypanosomoses.

The impact of vegetation on the species occurring in Burkina Faso has been described for long, but mainly along the Mouhoun river (Bouyer et al. 2005, 2006; Guerrini and Bouyer 2007; Guerrini et al. 2008; Koné et al. 2011a, b).

Despite a huge degradation of their habitats, an old theory enacted by Morel (1983) is still valid along the Mouhoun river: *Glossina palpalis gambiensis* is predominant upstream, in the Guinean riparian forests corresponding to closed tree environments, whereas *G. tachinoides* becomes predominant downstream, in the more open and bushy Sudanese riparian forests.

The main purpose of the current study was to confirm this pattern in another river basin, the Comoe river. Moreover, we wanted to better characterize the relationship between the different species and how they segregate in their biotope when they occur together in the same area in order to better define their respective ecological niches.

Material and methods

Study area

The study was carried out all along the Comoe river in two localities of the Comoe province, southern Burkina in the villages of Moussodougou and Folonzo.

The sites in Moussodougou (~10° 49′ N, 04° 57′ W) were located, on a portion of the Lobi river (which constitutes the source of the Comoe river) where the "small dam" of Moussodougou is built, and also on the Comoe river itself a bit downstream, after the junction of the Koba river (big dam of Moussodougou) and the Lobi river. This area, located in the Turka ethnic group territory, is an agricultural area (sorghum, sweet potatoes, maize, rice, cashew nut, etc.) with a population density of ~35 inhabitants/km^2.

The second locality was the game reserve of Folonzo (~09° 54′ N, 04° 36′ W), southern Burkina Faso. People do not cultivate inside, but wild fauna is currently rare, because of poaching. In this area, ~150 km still downstream on the Comoe river, four tsetse species occur sympatrically (Rayaissé et al. 2009; Salou et al. 2012). This area, with a population density of ~19 inhabitants/km^2, is located in the Diula ethnic group territory where people cultivate sesame, sorghum, maize, cotton, cashew nut, etc.

Trials were undertaken in both dry and rainy seasons (December and end of June, respectively, in Moussodougou, mid January and end of May, respectively, in Folonzo).

The entomological survey

The survey aimed to confirm the presence of tsetse species and consisted in deploying Challier-Laveissière biconical traps in 5 radial transects starting from the immediate bank of the river, going into the savannah (Fig. 1). The 5 transects are separated from each over by a distance of 1.5 to 2 km, while the distance between the different traps of the same transect is about 200–300 m. In total, 25 traps were set for this survey during 5 days at each location and season.

The phyto-sociological survey

This survey consisted to perform an inventory of vegetation species within a rectangular parcel of 50*20 m for every trap used for the entomological survey. In each parcel, general ecological observations were first done on qualitative data, such as the type of soil, topography, human activities. Quantitative methods were then applied to enumerate vegetal species, and a record on the abundance of each species was attributed, using the scale of Braun-Blanquet (1932).

Data analysis

From data of the entomological survey, the Shannon index (index of biodiversity) was first calculated within each respective locality, which formula is $H' = \sum_{i=1}^{y} pilnpi$, where i represents the different species of the area, pi the proportion of a species i out of the total number of species (S) within the area. Pi=ni/N, with ni the number of individuals of the species i and N the total number of individuals of all the species in the area (Shannon 1948). The calculation was made on one hand for traps set immediately on the bank of the river, and on the other hand for the 20 traps (4 traps * 5 transects) set in different level in the savannah to compare biodiversity in the riverine and savannah landscapes. They were assessed for each season.

The aim was to explain tsetse numbers by the following factors: trap distance to the river, season during which tsetse where trapped, tsetse species and their interactions, which were used as fixed effects within a generalized linear mixed model, using a Poisson distribution as a link function (Laird and Ware 1982). Trapping sites were considered as a random effect. The best model was considered as the one with the lowest corrected Akaike information criterion (AICc) (Hurvich and Tsai 1995; Burnham and Anderson 2002).

For the phyto-sociological survey, presence/absence of species within a parcel (site) was noted and coded in a binary way (0,1), then submitted to factorial correspondence analysis. R software was used for all analyses (R Core Team 2014).

Results

Entomological survey

In Moussodougou, a total of 343 tsetse flies were caught during the dry season, and 183 (Table 1) during the rainy season by the 25 traps set during 5 days, with a great proportion (97.4 %) of *G. palpalis gambiensis*.

Most of the tsetse (97.15 %) were caught by the traps deployed along the river bank, except 15 of them (2.85 %)

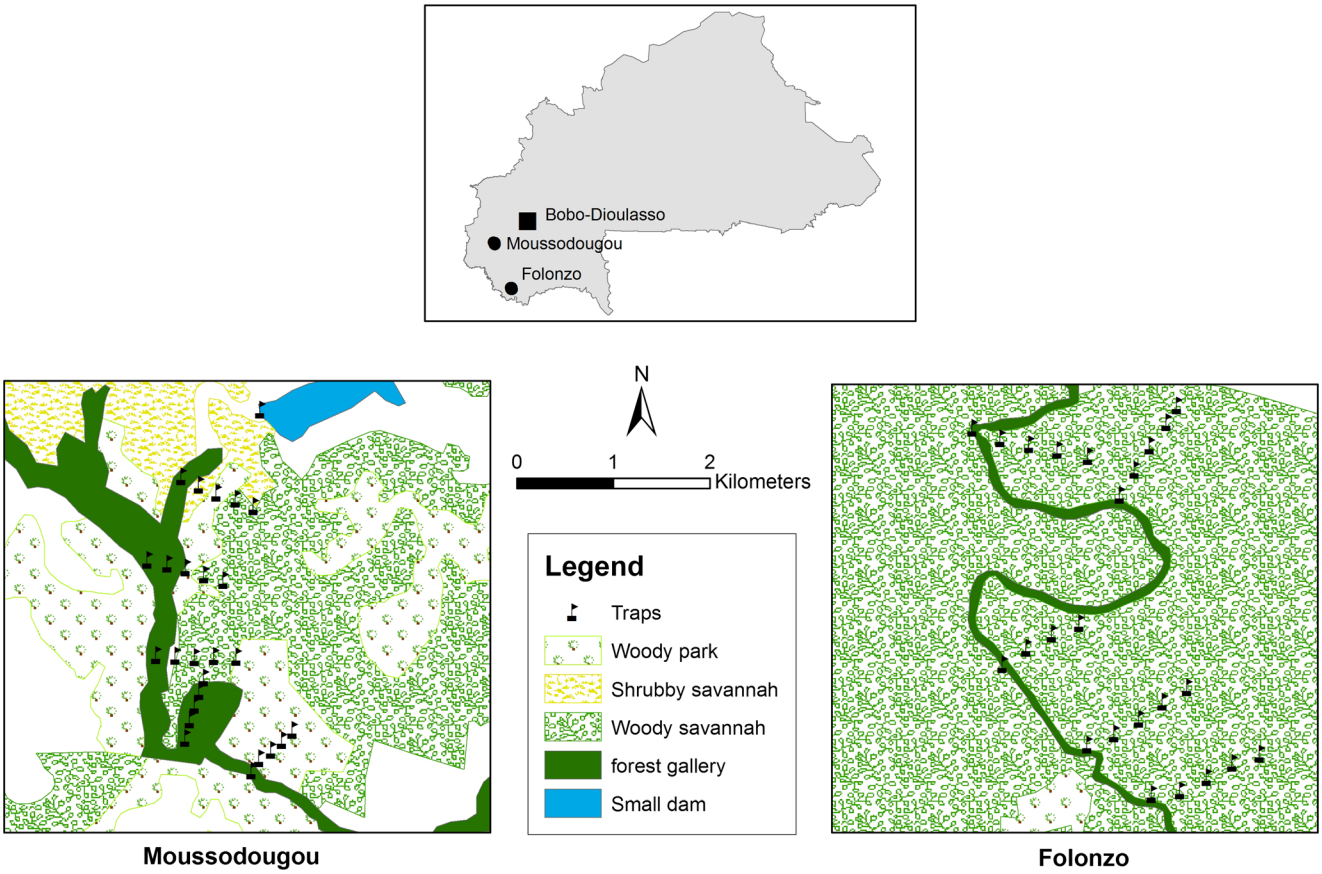

Fig. 1 Traps disposition in Moussodougou and Folonzo along the Comoe River

caught by a trap set on a tributary of a water course, also in the gallery. Therefore, when considering only the traps set in the gallery, daily apparent density of *G. p. gambiensis* was 12.8 flies/trap/day during the dry season and 7.2 during the wet season, respectively. In this area, the biodiversity was very low during both seasons (Shannon index of 0.11 during the dry season and 0.03 during the rainy season on the fiver bank) and 0 for both in the savannah whatever the season.

In Folonzo, up to 2870 tsetse were caught (41 % during the dry season and 59 % during the wet season), including four species, with 78 % of *G. tachinoides*, 16 %*G. morsitans submorsitans*, 5% *G. p. gambiensis* and 1 %*G. medicorum*. Daily apparent densities per species and per season are indicated on Fig. 2 with most of the tsetse caught on the near vicinity of the river. During the dry season, the biodiversity, indicated by the Shannon index value, was medium on the immediate vicinity of the river (0.51) and low in the savannah (0.19). During the wet season at the opposite, diversity was low on the riverbank (0.36) and high in the savannah (0.76).

Table 1 Total number of tsetse caught in Moussodougou

	Glossina palpalis gambiensis			*Glossina tachinoides*		
	Males	Females	Total	Males	Females	Total
Dry season	131	203	334	4	5	9
Wet season	101	81	182	1	0	1

Factors affecting tsetse distribution

In Moussodougou, only season and tsetse species were considered as factors in the model, as all the tsetse were caught in the gallery all along the river. For the analysis, *G. p. gambiensis* was considered as the reference species. More tsetse were caught during the dry than the wet season ($p<0.001$), and *G. p. gambiensis* was more abundant than *G. tachinoides* ($p<0.001$).

In Folonzo, the best model was the one including trap distance to the river, the season, tsetse species and also the interaction between trap distance and the species.

G. medicorum and the wet season were considered as reference categories. Overall, densities were higher during the rainy season ($p<0.001$) and decreased with distance to the river for all species, but significantly less for *G. m. submorsitans* than *G. medicorum*, and significantly more for *G. tachinoides* and *G. p. gambiensis*.

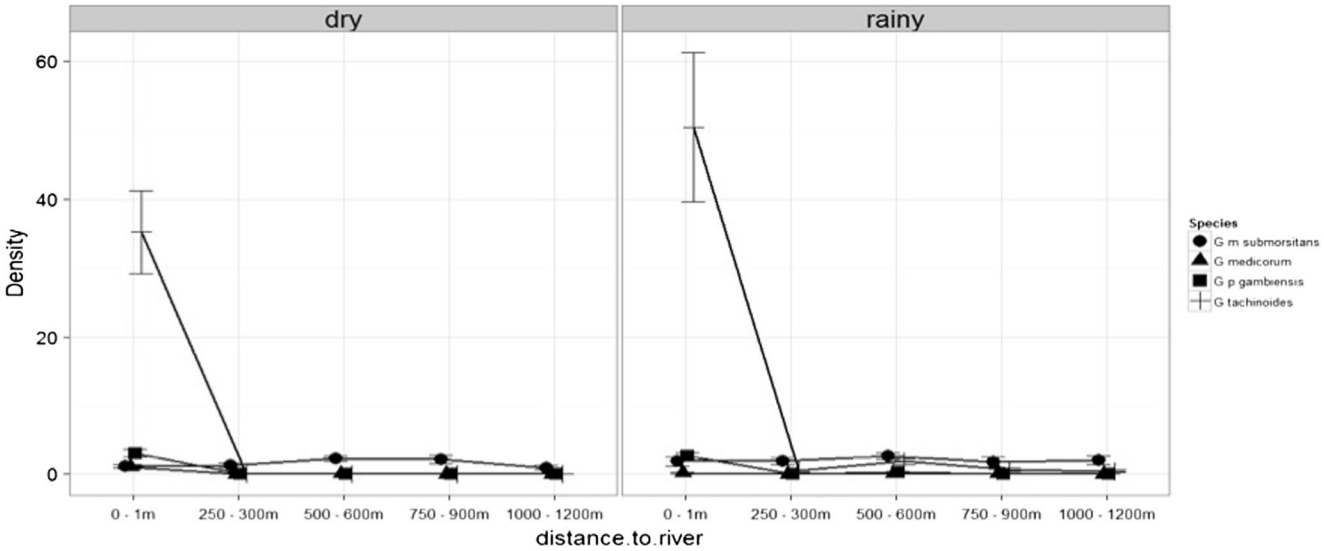

Fig. 2 Seasonal variation of tsetse densities depending on the distance to the river

The phytosociological survey

In Folonzo (Table 2) as well as in Moussodogou (Table 3), the phytosociological survey established 6 different groups of vegetation.

Vegetation in Folonzo was more conserved, with riparian forest (gallery) along the riverbank, which corresponds to a typical Sudanese riverine forest. When moving through the savannah from the riverbank, there was a succession of forest gallery, clear dry forest, shrubby savannah, shrubby to woody savannah and finally woody,

Vegetation in Moussodougou was more disturbed by human activities. Therefore, one can distinguish (1) riparian forest surrounded by orchards, farms and fallow lands; (2) farms on woody parks; (3) woody parks on fresh fallow land. The three remaining groups were (4) shrubby savannah on old fallow land, (5) shrubby savannah and (6) woody savannah.

Relation between tsetse and vegetation

Tsetse (mostly *G. p. gambiensis*) in Moussodougou were caught in the riparian forest, all along the main river or its tributaries. In Folonzo at the opposite, the distribution was depending on the species, and the main one was *G. tachinoides*. *G. tachinoides* and *G. p. gambiensis* mainly prefer the riparian forest (gallery forest), while *G. m. submorsitans* is found between the gallery and the shrubby savannah and *G. medicorum* between the forest gallery and the riparian forest (Fig. 3).

Table 2 Types of vegetation in the semi-protected area of Folonzo

Number	Type of vegetation	Sites/placette	Dominant species
I	Riparian forest	P11, P21, P31, P41, P51	*Dialium guineense, Syzygium guineense, Manilkara multinervis, Morelia senegalensis, Cola laurifolia, Berlinia grandiflora* (P11, 21, 41, 51) with *Mitragyna inermis (Willd.) O.Ktze*, *Landolphia dulcis (R.Br. ex Sabine) Pichon* in open portions where trees have small size (P 31)
II	Forest gallery	P25	*Cola cordifolia, Anogeissus leiocarpus, Tamarindus indica L., Diospyros mespiliformis Hochst. ex A.DC.*
III	Clear forest	P24, P55	*Isoberlinia doka, Pterocarpus erinaceus, Afzelia africana Sm. ex Pers.*, sometimes associated to *Vitellaria paradoxa, Monotes kerstingii Gilg* and *Burkea africana*
IV	Shrubby to woody	P34, P44	Woody stratum: *Burkea africana, Erythrophleum africanum (Welw. ex Benth.) Harms, Daniellia oliveri, Monotes kerstingii* Shrubby stratum: *Terminalia laxiflora, Terminalia mollis, Detarium microcarpum Guill. & Perr., Pteleopsis suberosa, Gardenia erubescens Stapf & Hutch.*
V	Shrubby savannah	P12, P14, P22, P23, P32, P33, P42, P35	*Terminalia mollis, Pteleopsis suberosa, Detarium microcarpum, Combretum adenogonium Steud ex A.Rich., Crossopteryx febrifuga (Afzel. ex G.Don) Benth., Pseudocedrela kotschyi (Schweinf.) Harms, Gardenia ternifolia Schum. & Thon* on relative deep soils, with *Uapaca togoensis Pax, Monotes kerstingii* and *Parinari curatellifolia Planch. ex Benth.* on shallow
VI	Woody savannah	P13, P15, P43, P45, P52, P53, P54	*Vitellaria paradoxa, Burkea africana, Erythrophleum suaveolens (Guill. & Perr.) Brenan, Anogeissus leiocarpus* and *Diospyros mespiliformis* on sites with old termite mounds

Table 3 Types of vegetation in Moussodougou

Number	Type of vegetation	Sites/Palette	Dominant species
I	Riparian forest	P11, P21, P31, P41, P51, P35	Riparian forest surrounded by orchards, farms and fallow lands with *Berlinia grandiflora, Uvaria chamae, Carapa procera DC., Khaya senegalensis (Desr.) A.Juss., Anogeissus leiocarpus, Tetracera alnifolia Willd., Uapaca togoensis, Syzygium guineense, Raphia sudanica A. Chev., Phyllanthus discoideus (Baill.) Müll. Arg.* to which are added *Breonadia salicina (Vahl) Hepper & Wood* in the stream. Some anthropogenic species (*Borassus aethiopum* and *Anacardium occidentale*) are present in the farms and orchards around the gallery
II	Farms on woody parks	P43, P44, P45	*Borassus aethiopum* and *Parkia biglobosa*
III	Woody parks on fresh fallow land	P32, P42 P12, P22	*Parkia biglobosa, Borassus aethiopum, Vitellaria paradoxa* and domestic fruit species (*Mangifera indica* and *Anacardium occidentale*)
IV	Shrubby savannah on old fallow land	P14, P15, P33, P34, P52, P53	*Terminalia laxiflora, Annona senegalensis, Acacia dudgeoni, Entada africana, Combretum adenogonium*
V	Shrubby savannah	P13, P23, P24, P54, P55	*Acacia dudgeoni, Entada africana, Gardenia erubescens, Terminalia laxiflora, Combretum collinum Fres., Combretum adenogonium*
VI	Woody savannah	P25	*Daniellia oliveri*

Discussion

Tsetse presence and diversity within the two localities

First, we confirmed that within the riverine species, the sequence observed along the Mouhoun river and described by Morel (1983) is also observed along the Comoe river, i.e. *G. p. gambiensis* is predominant upstream and is replaced by *G. tachinoides* downstream. While in Folonzo, four tsetse species are occurring sympatrically in relatively high densities, especially for *G. tachinoides*, *G. p. gambiensis* is over predominant in Moussodougou, together with a few *G. tachinoides*. This diversity of tsetse species in Folonzo was already observed (Laveissière et al. 1981; Rayaissé et al. 2009; Salou et al. 2012) and is certainly explained by the suitable ecological conditions, i.e. conserved vegetation and the presence of wild hosts on which tsetse can feed. Particularly, the presence of *G. morsitans submorsitans*, a savannah species and *G. medicorum*, a forest one belonging to fusca group, is directly linked to the presence of wild games in the area, including warthogs, hippopotamus, hartebeest, buffalo, Buffon kob, etc. (Rayaisse et al. 2010). Within Folonzo, a big difference has been noted for *G. m. submorsitans*, being still present in the protected area, but having disappeared in the non-protected one, following disappearance of wildlife (Rayaissé et al. 2009). In Moussodougou, only the vegetation

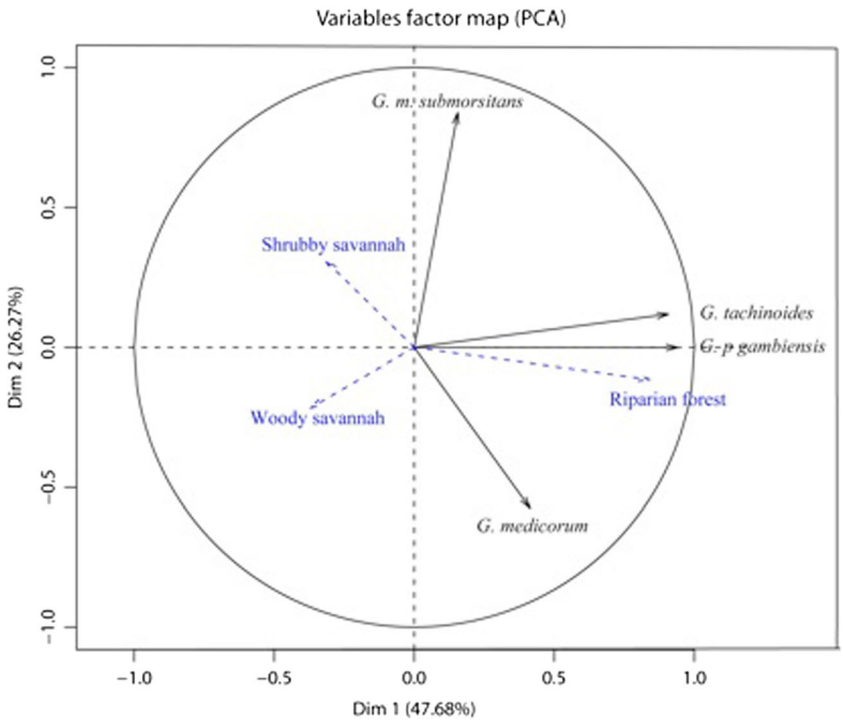

Fig. 3 Tsetse distribution following the type of vegetation

all along the river is preserved, the great part of the savannah having been destroyed by humans for farming purpose. This leads to the disappearance of wildlife, and as consequences the disappearance of *G. m. submorsitans* and *G. medicorum*. This confirms other studies (Reid et al. 2000) reporting that *G. m. submorsitans* disappears when human density is over 5 habitants per sq km (Van den Bossche et al. 2010).

The phyto-sociological survey

Despite that the same number (six) of classes of vegetation were commonly found in both areas, vegetation in Folonzo and Moussodougou is different. Although riparian forest, shrubby and woody savannah were found in the two localities, their specific compositions were not the same.

Moreover, the three other remaining groups of vegetation (farms on woody parks, woody parks on fresh fallow land, shrubby savannah on old fallow) found in Moussodougou only clearly indicate the impact of human action. At the opposite, the fact that the area is protected in Folonzo preserves it from humans for settlement, farming or for hunting.

Importance of water, vegetation and season in tsetse distribution

The global trend is that tsetse densities decrease when distance from the water increases. This is especially the case for *G. p. gambiensis*, which is not caught out from the immediate vicinity of the river. This situation is a normal illustration of the tight link existing between this species with water sources and the vegetation around (Challier 1973; Terrible 1984; Bouyer et al. 2005). *G. medicorum* neither occurs out from the gallery, but is only found in small humid forests constituted of high trees along the riparian vegetation and called gallery forests, where hosts may be easily found. Although *G. tachinoides* density drastically decreases from the bank of the river to the savannah, it does not completely disappear in this second area, traducing its capacity to adapt to drier conditions than *G. p. gambiensis*. This behaviour also explains why riverine watersheds induce more genetic structuring in *G. p. gambiensis* than *G. tachinoides* populations (Koné et al. 2011a, b). Distribution of *G. m. submorsitans* is homogenous in the savannah, its natural biotope.

Seasonal effects are more visible on the riparian species (*G. tachinoides* and *G. p. gambiensis*), which occur only in the gallery, at the near vicinity of the riverbank during the dry season. These species are also caught out of this gallery, although in very low densities. Tsetse are usually more spread in wet season, when suitable climatic conditions (temperature and humidity) can be found everywhere, even out from the gallery (Cuisance et al. 1985), which explains why the indices of biodiversity increased in that area during the wet season.

Interactions between species

The relationship between vegetation and tsetse densities (Fig. 3) shows that whereas *G. medicorum* and *G. m. submorsitans* occupy quite different niches compared to the two riverine species, the two latter co-exist in the same sites. When occurring sympatrically, as in Folonzo, they are probably in competition for hosts (Salou et al. 2012). This is all the more probable than they have a similar host spectrum (de La Rocque et al. 2005) and even bite in the same sites, i.e. the extremities of the legs in cattle, particularly the anterior one (Bouyer et al. 2007). Actually, competition for food has been demonstrated between individuals of the same species (Rogers and Randolph 1984). As a matter of fact, even tsetse of the same species and occurring within the same location may be scattered by sex (Hoppenheit et al. 2013), what may confirm existence of competition within the same species. This is likely to occur between species, since they are linked to a reduction of successful meals with host defence behaviours increasing with the density of the biting flies, which has also been shown for *Stomoxys* (Torr and Mangwiro 2000). Our results bring further arguments to this hypothesis, since slight differences in the composition of the vegetation of the gallery forest were associated to a clear predominance of one species over the other, suggesting interactions between these tsetse species, in particular competition.

Conclusion

G. p. gambiensis predominance in Moussodougou confirms that this species mainly occurs in river sources, where vegetation is shaded and the gallery is thin. It also shows that this species can adapt itself to human colonized environment, in opposition to *G. morsitans submorsitans. G. tachinoides* is dominant in Folonzo along the Comoe River downstream surrounded by an open, wide gallery and adapted open vegetation with presence of wild game as hosts. Presence of *G. medicorum* and *G. m. submorsitans* may be explained by the presence of relicts of wildlife and the presence of dense natural forests. These two factors are due to the fact that the area is a protected one, what limited human disturbance (hunting, farming). A next step would be to know what individual vegetal species are preferred by tsetse and to seek if that may be used for vector control purpose.

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