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New inventory of the diversity and seasonal abundance of Tephritid fruit fly species on mango orchards in Senegal

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Abstract
In Senegal, the development of integrated appoaches for controlling *Tephritidae* fruit flies is limited by a lack of information regarding the diversity of species involved and their spatial and temporal distribution. In fact, the current related knowledges are outdated and need to be renewed, 15 years after the introduction of *Bactrocera dorsalis*, in the country, the most devasting mango pest. We've systematically monitored fruit fly populations weekly from November 2017 to October 2018. Sites were 45 orchards spread across the country's three agro-ecological mango areas. Traps *Mcphail* were used with four (4) sex attractants namely *Eugenol methyl* (ME), *Terpenyl acetate* (TA), *Cuelure* (CUE) and trimedlure (TM). DDVP (2, 2-dichlorovinyl-phosphate) insecticide was combined with lures. After 52 weeks of trapping, 10 species were caught: *B. dorsalis, C. silvestrii, C. cosyra, Z. cucurbitae, C. capitata,* C. *ditissima, C. fasciventris, D. longistilus, C. punctata* and *C. bremii*. *B. dorsalis* made up 99% of overall fruit flies caught, followed by *C. syslvestrii* (78%), *C. cosyra* (9%), *Z. curcurbitae* (8%) and *C. capitata* (2%). In Casamance *B. dorsalis* made up 92% of caught fruit flies and 74% in the Centre. In Niayes area, 65% of caught fruit flies were by *B. dorsalis* and 24% by *C. sylvestrii*. Through these recordings, C. *silvestrii* populations were surprisesingly found to becoming more dominant over those of *C. cosyra*, which had ever been the second major mango pest of this area, after *B. dorsalis*. We analyzed fruit fly abundance over the two sensitive phenology stages of mango (growing/development and maturity), across the three zones. In Niayes, *B. dorsalis*, *C. cosyra* and *C. capitata* were the prevalent species during the fruit growing and development stage and maturity stage. In the Centre zone, *C. cosyra* was the sole existing species during fruiting stages while *B. dorsalis* and *C. cosyra* occurred during maturity stage. In Casamance, *B. dorsalis, C. capitata, C. cosyra* and *Z. cucurbitae* species reached their highest population levels during the fruiting and maturity stages. Due to comparative bio-ecological and behavioural advantages of species, more knowledge is still required, to better understand their dispersal patterns. It can assist the growers in predicting population growth and taking precautionary measures.

Keywords: Tephritid fruit flies, species diversity, abundance, Senegal

Introduction
In Africa, fruit and vegetable production is one of the most dynamic sectors of agriculture, providing both income and employment to producers and exporters. However, fruit flies are a major constraint due to huge direct losses on production and market opportunities from strict quarantine measures imposed by importer countries to limit transboundary exchange of the pests [7]. In addition to the economic impacts, their presence poses a serious threat to the environment due to chemical and biological control programmes [6, 22-25, 27]. Since the invasion of the African continent by the species *Bactrocera dorsalis* (Hendel) in the early 2003, fruit flies have become a growing concern, especially for mango production [15]. In Senegal, although *B. dorsalis* has been the most damaging species of the mango, which is the major fruit crops that underpins the livelihoods of many fruit growers, it is attacked by many other fruit fly species [30]. However, information relating to the biogeography, the composition and the population dynamic of tephritid fruit fly species is outdated and due for revision now, after 15 years that we have *B. invadens* in the country. A preliminary inventory was conducted by Vayssières *et al.* (2005) [30] in a few mango orchards of Niayes zone. Their results have shown the prevalency of 18 fruit fly species, namely *Bactrocera invadens* (Drew Tsuruta - White) (current *Bactrocera dorsalis*), *B. cucurbitae* (Coquillett), *Ceratitis cosyra* (Walker), *C. silvestrii* (Bezzi), *D. longistilus* (Bezzi), *C. fasciventris* (Bezzi), *C. capitata*

(Wiedemann), *C. ditissima* (Munro), *C. anonae* (Graham), *C. bremii* (Guérin-Méneville), *C. punctata* (Wiedemann), *C. flexuosa* (Walker), *Dacus ciliatus* (Loew), *D. vertebratus* (Bezzi), *D. bivittatus* (Bigot), *D. guineensis* (Hering), *D. xanthinus* (White - Goodger) and *D. velutifrons* (White - Goodger). Two similar and more recent studies have been carried out by Konta *et al.* (2001) and Ndiaye *et al.* (2012) [12, 18]. The first had reported *B. invadens*, *Ceratitis cosyra*, *C. capitata*, *C. punctata*, *C. bremii*, *Bactrocera cucurbitae*, *Capparimyia bipustulata*, *Carpomyia sp* and *Dacus sp* as the 8 species collected in the Niayes area; while the second mentionned the inventory of 12 species in Casamance, including *B. dorsalis*, *B. cucurbitae*, *Dacus vertebratus*, *Dacus ciliatus*, *Dacus frontalis*, *Dacus longistylus*, *C. cosyra*, *C. fascivientris*, *C. bremii*, *C. capitata*, *Themarictera flaveolata* and *Ceratitis sp*. These previous results have all been confirmed by Duyck *et al.* (2008) [5], demonstrating changes of these species' ecological niches as a result of diversification of host plants, following invasions of an area by new species of fruit flies. Given the importance of these changes in terms of damage and control strategy, we built on this earlier research and extending its scope to the three agro-ecological mango-producing areas of the country. The current study thus updates the directory of fruit fly species in Senegal and their potential ecological niches. These results will support building of better predictive models for potential outbreaks of species, by better understanding how pests behave, and how these behaviors affect phytosanitary quality of fruits and vegetables that we aim to protect. In this study, 45 orchards were monitored along the three production areas, from November 2017 to October 2018. As part of an integrated management strategy, this knowledge is therefore of utmost importance. We have systematically sampled fruit flies across three mango production area in Senegal, to better understand their diversity and spatio-temporal dispersal.

2. Materials and Methods

2.1 Study sites

The Niayes zone is coastal strip that runs from Dakar to Saint Louis. It has favorable biophysical characteristics for fruit and vegetable production. Considered as one of Senegal's most important agro-ecological zones, it alone accounts for nearly 80% of national production. This area is a fairly original environment characterized by dunes and depressions often flooded by the outcrop of water table and favorable coastal climate offering its agronomic vocation. In this part of the country, inter-dunary and semi-continental movements are causing intense wind erosions, that impact its agro-sylvo-pastoral potential [3, 9, 14]. In addition, the influence of the Sudan-Sahelian drought that has started taking place in tne 70's has led to a rainfall deficit, resulting in a reduction of groundwater levels and a rise of acreage of saline soils. This progressive ecosystem imbalance has been enhanced by anthropogenic actions e.g, growing urbanization and deforestation [8]. The Centre area covers about 180,000 hectares. It extends from the natural region of Sine Saloum in northern Gambia, to the Petite-Côte in southern Dakar. The Delta Saloum National Park is ranked as a World Heritage Site, a Biosphere Reserve, and a RAMSAR site is located in this region. It constitutes a huge delta, yielded by the confluence of two rivers, the Sine and the Saloum, leading salty water deeper and deeper into the land [14]. The Casamance area is located in the extreme south of Senegal. It covers an area of 35,680 km^2 (18% of the national territory). It is a tropical climate of sub-Guinean type area with relatively high access to water, including a rainy season that lasts about five months (May to October). Its diversified water system includes the 300 km long of the Casamance River and its tributaries, and an 86 km coastline bordered by 70,000 ha of mangroves [1, 14].

2.2 Trapping

The trapping methodology was based on monitoring fruit flies guidelines issued by IAEA (2003) [10]. Traps were hung on twigs or branches in the mango canopy at about 1 to 1.5 m above the ground. The traps should be close to branches or leaves that can serve as resting places for visiting flies. However, these branches and leaves should not be too close to the trap or else they serve as a bridge for predatory ants. In addition, a thin layer of solid grease should be coated along the wire that suspends the trap, to prevent the predatory ants from accessing it. For a given monitoring orchard, four lures were placed in four mango trees, making a total of 16 lures. Trees were separated from each other by at least 50 meters. On each of the trees, four lures were hung (1 ME - 1 TA - 1 CUE - 1 TM). For ensuring a homogeneous distribution of lures, TA was always set in the east side, TM in the west, ME in the north and CUE in the south (Figure 2). All traps were labeled with codes, lure names, numbers and the dates of placement.

2.3 Collecting and counting catches

Traps were regularly serviced, lures renewed every two months, and DDVP pellets once every four months. Trap surveys were carried out weekly. Collected flies were kept in plastic bags to be taken to the entomology laboratory for counting and taxonomic identification. Sampled flies were then sorted by lure and separately counted (e.g. ME 1 - ME 2 - ME 3 - ME 4) [13].

2.4 Identification of fruit flies

A 70% ethanol solution was used to preserve unknown fly species for later identification. We used tools described by Ekesi and Billah (2006) [7] and the electronic key developed by Virgilio *et al.* (2014) [31] to identify flies to genus and species level.

2.5 Fruit flies per trap and per day (FTD)

We used fruit flies per trap per day (FTD) as a population index to estimate average daily trapped flies. FTD is a basic calculation to compare fluctuations of fly populations in different areas before, during and after the mango season [10]. It is calculated by using following formula:

$$FTD = \frac{F}{T \times D}$$

$$F = Total\,trapped\;\;flies$$

$$T = Total\;traps$$

$$D = Average\,daily\,trapped\;\;flies$$

Phenological data were used to establish the relationship between population fluctuations of each fruit fly species and mango seasonality.

2.6 Relative abundance

Abundance and frequency indexes were used to describe

relationships between the abundance and frequency of species within zones over time, calculated for each month.
We calculated the relative abundance and frequency of fruit fly species by using following formulas [21].

$$Relative\,Abundance\ (RA) = \frac{TFTS}{TTFS}$$

$$Frequency\ (\%) = \frac{TFTS}{TTFS} \times 100$$

$$TFTS = Total\ Flies\ Trapped\ per\ Species$$

$$TTFS = Total\ Trapped\ flies\ of\ all\ Species$$

2.7 Host phenology
We recorded the mango phenology throughout the study to confirm the four stages defined by previous studies done by Konta *et al.* (2015), Vayssières *et al.* (2014) and Vayssières *et al.* (2004) [12, 27, 29], which are: Vegetative, Flowering, Fruit development and Maturity

2.8 Statistical analysis
All data were first tested for assumptions of parametric tests. Data not meeting these assumptions were transformed prior to analyses or we applied appropriate non-parametric analyses. We predicted that there would be significant differences in the number of fruit flies captured per day across the sampling period. We hypothesized that there are signicant differences in the number of fruit flies captured per day, and to that end, we use an ANOVA statiscal analysis, in addition to Tukey's HDS to compare individual pairs of data To test for the relationship between population fluctuations and mango phenology, we used Games-Howell's Method posthoc analyses, because the data were non-normally distributed. We set the significance level to be α = 0. 05 and our tests were conducted on JMP Pro 14.

3. Results
3.1 Attractivness of lures
Table 1 shows fruit flies caught by the four lures within a tree during the 52 weeks of trapping. Within overall trapped flies (1, 477,486 individuals in total), 78.78% (1, 163,936 flies) were attracted by ME, 18.10% (267,360 flies) by TA, 2.10% (31,052 flies) by CUE and 1.02% (15,138 flies) by TM. In the Niayes area, 65.06% of caught flies were attracted by ME, 30.86% by TA, 2.76% by TM and 1.32% by CUE. In the Centre zone, 74.01% of flies were attracted by ME, 23.19% by TA, 2.43% by CUE and 0.37% by TM. Similarly, 92.29% flies in Casamance were attracted by ME, 4.99% by TA and 0.31% by TM. However, using a two-way ANOVA with lure and region as the independent variables and total flies trapped per lure type in each region as the dependent variable, the statistical analysis has not shown significants differences. In other words, the lure types were equally effective in Niayes, Centre and Casamance zones and there isn't an interactive effect in between lures and zone (*F= 36.06, P= 0.483; F= 28.54, P= 2.101; F= 31.6, P= 1.071*, respectively).

3.2 Abundance and frequency of species
We captured a total of ten species across the Senegal: *B. dorsalis*, *C. cosyra*, *C. sylvestrii*, *C. capitata*, *C. bremi*, *C. ditissima*, *Z. cucurbitae*, *D. longistilus*, *C. punctata* and *C. fasciventris*. Table 2 shows the abundances and frequencies of species during the study period over the 3 zones. In the Niayes, all 10 species were reported, while *D. longistilus*, *C. punctata* and *C. fasciventris* were not found in Casamance, *D. longistilus* and *C. punctata* not found in the Centre.
In the Niayes, *B. dorsalis*, *C. silvestrii*, *C. cosyra*, *C. capitata* and *Z. curcurbitae* constituted the top five species of the area, making up to 99.98% of caught flies. *C. bremii*, *C. ditissima*, *D. longistilus*, *C. punctata* and *C. fasciventris* were ranked as least represented species. At Centre zone, the top 5 species were *B. dorsalis*, *C. cosyra*, *C. silvestrii*, *Z. curcurbitae* and *C. capitata*, representing 99.95% of all caught flies. *C. ditissima*, *C. fasciventris* and *C. bremii* were the least represented species. In Casamance, *B. dorsalis*, *C. cosyra*, *Z. curcurbitae* and *C. capitata* were the four dominant species, amassing 99.99% of trapped fruit flies. *C. silvestrii*, *C. bremii* and *C. ditissima* have been the minor species.

3.3 Fruit flies trapped per day (FTD)
Changes in population dynamics of the 10 fruit fly species were expressed as the mean number of flies per trap per day. Table 3 shows the final data set for the Niayes, Centre and Casamance zones that we used for analyses. In Table 4 the Games-Howell Method additional post-hoc analyses results showed differences over time between Niayes, Centre and Casamance.

3.4 Mango phenology
The mangos exhibited the four predicted phenology stages. Vegetative stage started in October and extended until February. The flowering stage began from March and ended in May. The fruit growing stage started in June and extended until July. The maturity stage peaked in July and August, but lasted until September.
The results of the abundance of fly in accordance to the mango phenology and expressed as FTD per species are shown in Table 5. Analyses of the abundance data over the phenology stages of mango in the Niayes showed *B. dorsalis*, *C. cosyra* and *C. capitata* as the three prevalent species, starting from the late fruit growing and development stage (FTD= 484.93±0.00, FTD= 20, 43±0.32 and FTD= 8.82±2.08) to maturity stage (FTD= 709.43±0.00, FTD= 18.75±3.73 and FTD= 17.58±1.99). In Centre zone, *C. cosyra* was the only existing species during the fruiting stages (FTD= 164.82±0.00) while *B. dorsalis* and *C. cosyra* became the prevalent species during the maturity stage (FTD= 24±12.13; FTD= 2992.7±57.02), respectively. In Casamance, these two sensitive mango phenology stages coincided with the highest population levels of *B. dorsalis* (FTD= 2548,31±0,00; FTD= 2114,02±73.25), *C. capitata* (FTD= 90,66±0,78; FTD= 10,035±4.29), *C. cosyra* (FTD= 38,66±0,30; FTD= 155,57±16.82) and *Z. cucurbitae* (FTD= 22,20±0,24; FTD= 57.00±9.14). B. *dorsalis* populations in the Niayes differed across mango stages, namely vegetative growth and flowering. In contrast, no significant difference was observed in *C. cosyra* and *C. capitata* populations between the four stages. In the Centre zone, there were no significant differences in *B. dorsalis* and *C. cosyra* populations between the four phenology stages. Similar results were found in the Casamance with *B. dorsalis*, *C. cosyra* and *C. capitata* (Tables 6, 7, 8).

4. Discussion
The results of the 52 weeks of trapping show a diversity of Tephritidae species in the three mango production areas. The species specific richness within zones is higher in the Niayes (10 species recorded) than in the Centre (8 species recorded)

and Casamance (7 species recorded). According to Reitz *et al.* (2002) [20] diversity that is observed between very close species is generally a result of invasions of exotic species. Based on previous localized studies, the ten species identified during this study are different to the 18 species that were found by Vayssières *et al.* (2002) [30] in the Niayes, the 12 species inventoried by Konta *et al.* (2015) [12] in Casamance and those from Ndiaye *et al.* (2012) [18] who reported the presence of eight (8) species of Tephritidae in Casamance.

We noted that 99.98% of the fruit fly populations are composed of *B. dorsalis*, *C. silvestrii*, *C. cosyra*, *Z. curcurbitae* and *C. capitata*. The distribution of these five main species varies from one mango production zone to another. *B. dorsalis*, representing 78.75% of population, is by far the most abundant species. Its populations peaked between July and October in the Niayes and July to December at the Centre, while in Casamance, *B. dorsalis* is important throughout the year. This period of high prevalence of *B. dorsalis* coincides with the maturation period of mangoes and the rainy season, which is favorable to its development [16, 17, 19, 31].

In addition to mango phenology, abiotic factors affect distribution and abundance. Konta *et al.* (2015) [12] found a correlation between fruit fly catches with rainfall, relative humidity, and temperature. According to Vargas and Carey (1990) [26], this high prevalence could be explained by indirect effects of these abiotic factors on the availability of host plants, which is one of the important factors determining fluctuations in fruit fly populations.

Bateman (1972) [2] has demonstrated that the low relative humidity during the dry period would lead to a reduction in the fertility of female fruit flies as well as a high mortality of newly emerged pupa adults. Therefore, the high prevalence of *B. dorsalis* in the Casamance area is likely to be related to the moist forest, with a diversity of fruits, which are more favorable for the development of this species [12].

Natural enemies may have mixed effects on fruit fly populations. A study of the tri-trophic relationship between fruits, the main species of Tephritidae, and parasitoids revealed that native parasitoids inventoried in mango agro-ecosystems in Casamance do not attack *B. dorsalis* [28].

The prevalence of *C. silvestrii* (9.34%) in the Niayes is mainly observed from January to July but its presence is poorly noted in the Centre and Casamance. Nevertheless, the current level of its populations confirms its predominance on *C. Cosyra* (8.71%), which has since long time been considered as the second dominant species after *B. dorsalis*. In this new configuration, *C. cosyra* populations peaked between July and August in Niayes, May to June in the Centre and in February and July in Casamance. *Z. curcurbitae* (2.07%) has a high prevalence from October to December in the Niayes, August and January in the Centre zone and outbreaks in Casamance all year long. As for *C. capitata* populations (1.10%), they are practically recorded in the Niayes and the Centre all year round, with peaks occurring between July and August, whereas in Casamance prevalence is noted from May to July.

The lowest frequencies of the five minor species (*C. ditissima*, *C. fasciventris*, *D. longistilus*, *C. punctata* and *C. bremii*) in the Niayes, Centre and Casamance (0.022%, 0.051% and 0.006% respectively) may be explained by interspecific competition that can significantly affect the distribution and abundance of phytophagous insect populations [4].

In relation to the differences of abundance of flies over the mango phenology stages, our results demonstrated that apart from the Niayes, in the Centre and Casamance zones, the targeted species (*B. dorsalis*, *C. cosyra* and *C. capitata*) populations have the same occurrence during the four mango phenology stages. Therefore, implementing an intensive and continuous control strategy all year has become the most appropriate approach. Similar results were reported by Vayssières *et al.* 2014 [27]. According to Vargas 1997 and 1995 [22, 25], agriculture promotes the establishment of exotic species through the movement of plants and plant products and the creation of suitable niches for their multiplication. For these reasons, eradication of an already established exotic species is quite impossible; its control difficult and expensive, and monitoring for the prediction of invasions becomes a priority [11].

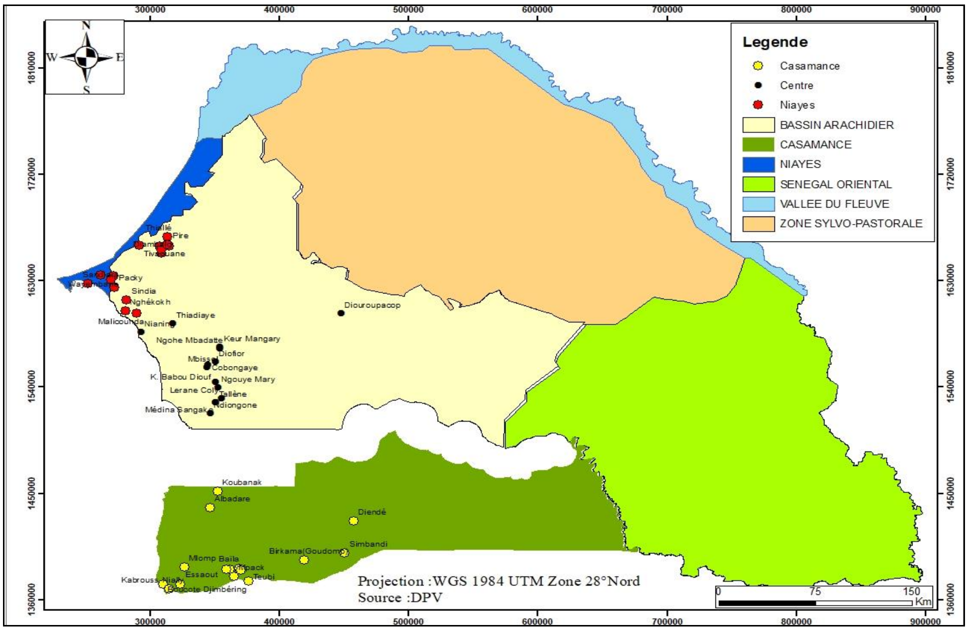

Fig 1: Map of study sites in Senegal Niayes, Centre and Casamance zones, main mango producer and exporter areas.

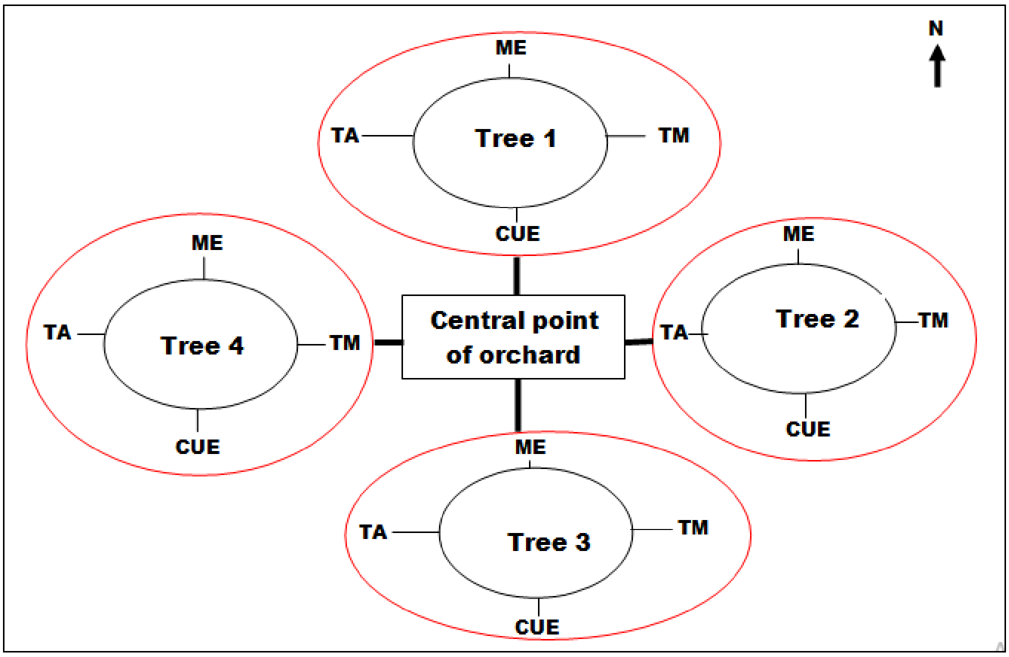

Fig 2: Scheme of the spatial distribution of the 16 lure traps within monitoring orchards

Table 1: Sums of fruit flies trapped per lure in Niayes, Centre and Casamance during the study periods. Numbers followed by the same letter are not significantly different at *F= 36.06, P= 0.483; F= 28.54, P= 2.101; F= 31.6, P= 1.071*, for each type of lure, respectively.

Lures	Niayes	Centre	Casamance
CU	5,517 a	11,357 a	14,178 a
ME	272,653 b	346,398 b	544,885 b
TA	129,337 c	108,555 c	29,468 c
TM	11,580 d	1,711 d	1,847 d
Total	419,087	468,021	590,378

Table 2: Relative abundance and frequency of tephritid species within the three mango production zones

Species	Niayes		
	Total of captures	Relative Abundance	Frequency (%)
B. dorsalis	272, 764	0.651	65.085
C. bremii	65	0.000	0.016
C. capitata	11, 937	0.028	2.848
C. cosyra	27, 082	0.065	6,462
C. ditissima	17	0.000	0.004
C. fasciventris	1	0.000	0.000
C. punctata	2	0.000	0.000
D. longistilus	6	0.000	0.001
C. silvestrii	101, 872	0.243	24.308
Z. cucurbitae	5, 341	0.013	1.274
	Centre		
B. dorsalis	346, 851	0.741	74.110
C. bremii	17	0.000	0.004
C. capitata	1, 651	0.004	0.353
C. cosyra	72, 354	0.155	15.460
C. ditissima	190	0.000	0.041
C. fasciventris	31	0.000	0.007
C. punctata	-	0.000	0.000
D. longistilus	-	0.000	0.000
C. silvestrii	35, 791	0.076	7.647
Z. cucurbitae	11, 136	0.024	2.379
	Casamance		
B. dorsalis	543, 872	0.921	92.123
C. bremii	21	0.000	0.004
C. capitata	2, 697	0.005	0.457
C. cosyra	29, 307	0.050	4.964
C. ditissima	15	0.000	0.003
C. fasciventris	-	-	-
C. punctata	-	-	-
D. longistilus	-	-	-

C. silvestrii	288	0.000	0.000
Z. cucurbitae	14, 178	0.024	2.402

Table 3: Summary statistics of ten species captured in the Niayes, Centre, and Casamance over the study period (November 2017- October 2018)

Years	Months	Species	Niayes		Centre		Casamance	
			FTD	Standard errors	FTD	Standard errors	FTD	Standard errors
2017	Nov.	B. dorsalis	7	0,04	96	3,61	392,46	0,05
		C. bremii	0	0,00	0	0,95	0,62	0,21
		C. capitata	0	0,26	2	0,75	6,99	0,36
		C. cosyra	1	2,26	3	0,81	13,47	0,22
		C. ditissima	0	0,00	0	0,87	0,00	0,00
		C. fasciventris	0	0,00	0	0,95	0,00	0,00
		C. punctata	0	0,00	0	1,06	0,00	0,00
		D. longistilus	0	0,00	1	1,22	0,02	0,00
		C. silvestrii	0	0,00	1	1,48	0,20	0,02
		Z. cucurbitae	2	2,23	23	2,03	110,87	1,92
2017	Dec.	B. dorsalis	2	0,01	52	2,54	1050	1,11
		C. bremii	0	0,00	0	0,07	0	0,01
		C. capitata	0	0,21	0	0,01	4	0,06
		C. cosyra	0	0,58	3	0,02	22	0,16
		C. ditissima	0	0,00	0	0,00	0	0,00
		C. fasciventris	0	0,00	0	0,00	0	0,00
		C. punctata	0	0,00	0	0,00	0	0,00
		D. longistilus	0	0,00	0	0,00	0	0,00
		C. silvestrii	0	0,01	2	0,00	0	0,01
		Z. cucurbitae	1	1,92	12	0,00	51	0,26
2018	Jan.	B. dorsalis	0	0,01	0	1,26	1674	0,00
		C. bremii	0	0,00	0	0,02	0	0,00
		C. capitata	0	0,30	1	0,00	5	0,12
		C. cosyra	3	1,95	39	0,00	45	0,34
		C. ditissima	0	0,00	0	0,00	0	0,00
		C. fasciventris	0	0,00	0	0,00	0	0,00
		C. punctata	0	0,00	0	0,00	0	0,00
		D. longistilus	0	0,00	0	0,00	0	0,00
		C. silvestrii	1	0,20	0	0,00	0	0,00
		Z. cucurbitae	0	0,41	3	0,00	65	0,48
2018	Feb.	B. dorsalis	0	0,06	0	0,50	1281	0,00
		C. bremii	0	0,00	0	0,00	0	0,00
		C. capitata	1	0,72	0	0,00	4	0,03
		C. cosyra	4	3,42	48	0,00	90	0,57
		C. ditissima	0	0,00	0	0,00	0	0,00
		C. fasciventris	0	0,00	0	0,00	0	0,00
		C. punctata	0	0,00	0	0,00	0	0,00
		D. longistilus	0	0,00	0	0,00	0	0,00
		C. silvestrii	3	0,53	0	0,00	51	0,27
		Z. cucurbitae	0	0,34	2	0,00	23	0,24
2018	March	B. dorsalis	3	0,04	6	0,65	480	0,00
		C. bremii	0	0,00	0	0,00	0	0,00
		C. capitata	5	10,29	2	0,00	2	0,02
		C. cosyra	9	2,31	77	0,01	85	0,63
		C. ditissima	1	0,00	5	0,12	38	0,20
		C. fasciventris	0	0,00	0	0,00	0	0,00
		C. punctata	0	0,00	0	0,00	0	0,00
		D. longistilus	0	0,00	0	0,00	0	0,00
		C. silvestrii	322	23,09	0	0,00	0	0,00
		Z. cucurbitae	7	0,64	1	0,00	60	0,18
2018	April	B. dorsalis	0	0,00	0	0,20	1282	0,00
		C. bremii	0		0	0,00	0	0,00
		C. capitata	3	12,91	1	0,00	5	0,06
		C. cosyra	3	2,79	33	0,00	291	2,32
		C. ditissima	0	0,00	1	0,00	0	0,00
		C. fasciventris	0	0,00	0	0,00	0	0,00
		C. punctata	0	0,00	0	0,00	0	0,00
		D. longistilus	0	0,00	0	0,00	0	0,00
		C. silvestrii	20	10,73	0	0,00	0	0,00
		Z. cucurbitae	0	0,79	1	0,00	26	0,17
2018	May	B. dorsalis	0	0,00	0	0,14	1466	0,00

		C. bremii	0	0,00	0	0,02	0	0,00
		C. capitata	1	4,58	0	0,00	22	0,48
		C. cosyra	1	1,87	104	0,00	110	1,17
		C. ditissima	0	0,00	0	0,00	0	0,00
		C. fasciventris	0	0,00	0	0,00	0	0,00
		C. punctata	0	0,00	0	0,00	0	0,00
		D. longistilus	0	0,00	0	0,00	0	0,00
		C. silvestrii	2	3,38	0	0,00	1	0,03
		Z. cucurbitae	0	0,00	0	0,00	16	0,16
2018	June	B. dorsalis	2	0,09	0	0,11	2548	0,00
		C. bremii	0	0,00	0	0,01	3	0,09
		C. capitata	2	4,07	0	0,00	91	0,78
		C. cosyra	4	2,15	165	0,00	39	0,30
		C. ditissima	0	0,00	0	0,00	0	0,00
		C. fasciventris	0	0,00	0	0,00	0	0,00
		C. punctata	0	0,00	0	0,00	0	0,00
		D. longistilus	0	0,00	0	0,00	0	0,00
		C. silvestrii	3	12,04	0	0,00	3	0,12
		Z. cucurbitae	0	0,13	0	0,00	22	0,24
2018	July	B. dorsalis	485	0,00	1114	0,08	4157	0,03
		C. bremii	0	0,00	0	0,08	0	0,00
		C. capitata	9	10,32	3	0,00	13	0,60
		C. cosyra	20	2,08	33	1,87	146	3,24
		C. ditissima	0	0,00	0	1,49	0	0,00
		C. fasciventris	0	0,00	0	0,00	0	0,00
		C. punctata	0	0,00	0	0,00	0	0,00
		D. longistilus	0	0,00	0	0,00	0	0,00
		C. silvestrii	1	0,00	1	0,00	4	0,14
		Z. cucurbitae	0	0,00	2	0,16	35	0,69
2018	August	B. dorsalis	790	0,00	4872	0,11	1965	0,00
		C. bremii	0	0,00	1	0,16	1	0,03
		C. capitata	18	22,68	3	0,01	7	0,22
		C. cosyra	30	31,99	15	0,10	9	0,15
		C. ditissima	0	0,00	0	0,47	0	0,00
		C. fasciventris	0	0,00	0	0,00	0	0,00
		C. punctata	0	0,00	0	0,00	0	0,00
		D. longistilus	0	0,00	0	0,00	0	0,00
		C. silvestrii	0	0,00	1	0,01	1	0,02
		Z. cucurbitae	0	0,06	2	0,04	22	0,41
2018	Sept.	B. dorsalis	629	0,00	1607	0,05	219	0,00
		C. bremii	0	0,00	0	0,04	0	0,00
		C. capitata	5	0,81	1	0,00	1	0,03
		C. cosyra	7	13,05	0	0,03	4	0,09
		C. ditissima	0	0,00	0	0,01	0	0,00
		C. fasciventris	0	0,00	0	0,00	0	0,00
		C. punctata	0	0,00	0	0,00	0	0,00
		D. longistilus	0	0,00	0	0,00	0	0,00
		C. silvestrii	0	0,00	0	0,00	0	0,00
		Z. cucurbitae	3	0,82	5	0,00	4	0,08
2018	October	B. dorsalis	45	0,00	235	0,25	73	0,00
		C. bremii	0	0,00	0	0,01	0	0,00
		C. capitata	1	4,13	1	0,00	0	0,01
		C. cosyra	0	0,00	0	0,04	1	0,02
		C. ditissima	0	0,00	0	0,00	0	0,00
		C. fasciventris	0	0,00	0	0,00	0	0,00
		C. punctata	0	0,00	0	0,00	0	0,00
		D. longistilus	0	0,00	0	0,00	0	0,00
		C. silvestrii	0	0,00	0	0,00	0	0,00
		Z. cucurbitae	15	1,68	16	0,00	14	0,34

Table 4: Post-hoc analyses results of 10 species captured in the Niayes, Centre and Casamance. Zones not connected by the same letters and colors are signficantly different.

Years	**Months**	**Species**	**Games-Howell's Method**		
			Niayes	**Centre**	**Casamance**
2017	November	B. dorsalis	B	C	C
		C. bremii	A	A	A
		C. capitata	A	A	B
		C. cosyra	A	A	B

		C. ditissima	A	A	A
		C. fasciventris	A	A	A
		C. punctata	A	A	A
		D. longistilus	A	A	A
		C. silvestrii	A	A	A
		Z. cucurbitae	A	C	C
2017	December	B. dorsalis	A	C	C
		C. bremii	A	A	A
		C. capitata	A	A	A
		C. cosyra	A	A	C
		C. ditissima	A	A	A
		C. fasciventris	A	A	A
		C. punctata	A	A	A
		D. longistilus	A	A	A
		C. silvestrii	A	A	A
		Z. cucurbitae	A	B	C
2018	January	B. dorsalis	A	A	C
		C. bremii	A	A	A
		C. capitata	A	A	A
		C. cosyra	A	C	C
		C. ditissima	A	A	A
		C. fasciventris	A	A	A
		C. punctata	A	A	A
		D. longistilus	A	A	A
		C. silvestrii	A	A	A
		Z. cucurbitae	A	A	C
2018	February	B. dorsalis	A	A	C
		C. bremii	A	A	A
		C. capitata	A	A	A
		C. cosyra	A	C	C
		C. ditissima	A	A	A
		C. fasciventris	A	A	A
		C. punctata	A	A	A
		D. longistilus	A	A	A
		C. silvestrii	A	A	C
		Z. cucurbitae	A	A	C
2018	March	B. dorsalis	A	B	C
		C. bremii	A	A	A
		C. capitata	A	A	A
		C. cosyra	B	C	C
		C. ditissima	A	A	C
		C. fasciventris	A	A	A
		C. punctata	A	A	A
		D. longistilus	A	A	A
		C. silvestrii	C	A	A
		Z. cucurbitae	B	A	C
2018	April	B. dorsalis	A	A	C
		C. bremii	A	A	A
		C. capitata	A	A	A
		C. cosyra	A	C	C
		C. ditissima	A	A	A
		C. fasciventris	A	A	A
		C. punctata	A	A	A
		D. longistilus	A	A	A
		C. silvestrii	B	A	A
		Z. cucurbitae	A	A	C
2018	May	B. dorsalis	A	A	C
		C. bremii	A	A	A
		C. capitata	A	A	C
		C. cosyra	A	C	C
		C. ditissima	A	A	A
		C. fasciventris	A	A	A
		C. punctata	A	A	A
		D. longistilus	A	A	A
		C. silvestrii	A	A	A
		Z. cucurbitae	A	A	C
2018	June	B. dorsalis	A	A	C
		C. bremii	A	A	A

		C. capitata	A	A	C
		C. cosyra	A	C	C
		C. ditissima	A	A	A
		C. fasciventris	A	A	A
		C. punctata	A	A	A
		D. longistilus	A	A	A
		C. silvestrii	A	A	A
		Z. cucurbitae	A	A	C
2018	July	B. dorsalis	C	C	C
		C. bremii	A	A	A
		C. capitata	B	A	B
		C. cosyra	B	C	C
		C. ditissima	A	A	A
		C. fasciventris	A	A	A
		C. punctata	A	A	A
		D. longistilus	A	A	A
		C. silvestrii	A	A	A
		Z. cucurbitae	A	A	C
2018	August	B. dorsalis	C	C	C
		C. bremii	A	A	A
		C. capitata	B	A	B
		C. cosyra	C	B	B
		C. ditissima	A	A	A
		C. fasciventris	A	A	A
		C. punctata	A	A	A
		D. longistilus	A	A	A
		C. silvestrii	A	A	A
		Z. cucurbitae	A	A	C
2018	September	B. dorsalis	C	C	C
		C. bremii	A	A	A
		C. capitata	A	A	A
		C. cosyra	B	A	A
		C. ditissima	A	A	A
		C. fasciventris	A	A	A
		C. punctata	A	A	A
		D. longistilus	A	A	A
		C. silvestrii	A	A	A
		Z. cucurbitae	A	A	A
2018	October	B. dorsalis	C	C	C
		C. bremii	A	A	A
		C. capitata	A	A	A
		C. cosyra	A	A	A
		C. ditissima	A	A	A
		C. fasciventris	A	A	A
		C. punctata	A	A	A
		D. longistilus	A	A	A
		C. silvestrii	A	A	A
		Z. cucurbitae	B	B	B

Table 5: Number (±SE) of fruit flies species occurring per trap and per day (FTD), according to the phenology stages of mango in the zones. Mean values followed by the same letter on the row are not significantly different by the Tukey's test at 0.05 levels.

Zones	Species	Veg. Growth	Flowering	Fruit growing	Maturity
Niayes	B. dorsalis	25.8±6.67 a	-	484.93±0.00 a	709.43±0.00 a
	C. cosyra	-	8.88±2,31 b	20.43±0.32 b	18.75±3.73 b
	C. capitata	-		8.82±2.08 c	17.58±1.99 c
F = 2.451, P = 0.006; F = 6.074, P = 0.011 ; F = 3.451, P = 0.002 ; df = 3					
Centre	B. dorsalis	74.42±1.31 a	5.94±1.01 a	-	2992.7±57.02 a
	C. cosyra	43.24±6.41 a	71.07±5.82 a	164.82±0.00 a	24.00±12.13 a
F = 5.551, P = 0.423; F = 3. 041, P = 0.423; F = 1.623, P = 0.206 ; df = 3					
Casamance	B. dorsalis	1099.43 a	1075.52±24.30 a	2548.31±0.00 a	2114.02±73.25 a
	C. cosyra	42.76±4.36 a	54.67±3.87 a	38.66±0.30 a	155.57±16.82 a
	C. capitata	6.99±1.92 a	161.75±12.27 b	90.66±0.78 b	10.04±4.29 a
F= 6.632, P = 0.098 ; F = 1.061, P = 0.073; F = 3. 041, P = 0.003 ; df = 3					

Table 6: Mean (+SE) number of the 10 fruit fly species captured per trap per day (FTD) according to the phenology stage of mango in the Niayes

Years	Months	Phenology stages			
		Vegetative growth	Flowering	Fruit growing	Maturity
2017	November	*B. dorsalis* (6.94±0.04)			
2017	December				
2018	January				
2018	February				
2018	March		*C. silvestrii* (322.20±23.09) *C. cosyra* (8.88±2.31) *Z. cucurbitae* (6.81±0.64)		
2018	April		*C. silvestrii* (19.57±10.73)		
2018	May				
2018	June				
2018	July			*B. dorsalis* (484.93±0.00) *C. capitata* (8.82±2.08) *C. cosyra* (20.43±0.32)	
2018	August				*B. dorsalis* (790.07±0.00) *C. capitata* (17.58±1.99) *C. cosyra* (30.42±2.68)
2018	September				*B. dorsalis* (628.79±0.00) *C. cosyra* (7.08±3.05)
2018	October	*B. dorsalis* (44.66±00); *Z. cucurbitae* (15.27±1.68)			

Table 7: Mean (+SE) number of the 10 fruit fly species captured per trap per day (FTD) according to the phenology stage of mango in the Centre

Years	Months	Phenology stages			
		Vegetative growth	Flowering	Fruit growing	Maturity
2017	November	*B. dorsalis* (96.47±3.61) *Z. cucurbitae* (22.95±2.03)			
2017	December	*B. dorsalis* (52.37±2.54) *Z. cucurbitae* (11.53±0.00)			
2018	January	*C. cosyra* (38.70±0.00)			
2018	February	C. cosyra (47.77±0.00)			
2018	March		*B. dorsalis* (5.94±0.01) *C. cosyra* (76.50±0.65)		
2018	April		*C. cosyra* (32.84±0.00)		
2018	May		*C. cosyra* (103.86±0.00)		
2018	June			*C. cosyra* (164.82±0.00)	
2018	July				*B. dorsalis* (1113.90±0.08) *C. cosyra* (32.58±1.87)
2018	August				*B. dorsalis* (4871.50±0.11) *C. cosyra* (15.42±0.10)
2018	September				*B. dorsalis* (1606.77±0.05)
2018	October	*B. dorsalis* (234.93±0.25) *Z. cucurbitae* (15.50±0.08)			

Table 8: Mean (+SE) number of the 10 fruit fly species captured per trap per day (FTD) according to the phenology stage of mango in the Casamance

Years	Months	Phenology stages			
		Vegetative growth	Flowering	Fruit growing	Maturity
2017	November	*B. dorsalis* (392.46±0.05) *C. capitata* (6.99±1.92) *C. cosyra* (13.47±0.22) *Z. cucurbitae* (110.87±0.36)			
2017	December	*B. dorsalis* (1050.31±1.11) *C. cosyra* (22.06±0.26) *Z. cucurbitae* (50.63±0.16)			
2018	January	*B. dorsalis* (1674.14±0.00) *C. cosyra* (45.32±0.48) *Z. cucurbitae* (64.61±0.34)			
2018	February	*B. dorsalis* (1280.79±0.00) *C. cosyra* (90.18±0.57) *C. silvestrii* (50.89±0.27) *Z. cucurbitae* (22.86±0.24)			
2018	March		*B. dorsalis* (479.51±0.00) *C. cosyra* (84.51±0.63)		

			C. ditissimi (38.26±0.18) *Z. cucurbitae* (60.14±0.20)		
2018	April		*B. dorsalis* (1281.50±0.00) *C. cosyra* (290.54±2.32) *Z. cucurbitae* (25.54±0.17)		
2018	May		*B. dorsalis* (1465.54±0.00) *C. capitata* (21.89±1.17) *C. cosyra* (110.21±0.48) *Z. cucurbitae* (15.50±0.16)		
2018	June			*B. dorsalis* (2548.31±0.00) *C. capitata* (90.66±0.78) *C. cosyra* (38.66±0.30) *Z. cucurbitae* (22.20±0.24)	
2018	July				*B. dorsalis* (4157.39±0.03) *C. capitata* (13.07±3.24) *C. cosyra* (146.25±0.69) *Z. cucurbitae* (34.96±0.60)
2018	August				*B. dorsalis* (1965.39±0.00) *C. capitata* (7.00±0.41) *C. cosyra* (9.32±0.15) *Z. cucurbitae* (22.04±0.22)
2018	September				*B. dorsalis* (219.29±0.00)
2018	October	*B. dorsalis* (72.57±0.00) *Z. cucurbitae* (13.86±0.34)			

5. Conclusions
Our study revealed a diversity of Tephritidae species across three agroecological zones, but the attractiveness of parapheromones to fruit flies depended on the zone. The presence of the ten inventoried species, *B. dorsalis*, *C. silvestrii*, *C. cosyra*, *Z. cucurbitae*, *C. Capitata*, *C. ditissima*, *C. fasciventris*, *D. longistilus*, *C. punctata* and *C. bremii* varied according to the zones. *B. dorsalis*, *C. cosyra*, *C. sylvestrii*, *C. capitata*, *C. bremi*, *C. ditissima* and *Z. cucurbitae* were detected in all three zones, while *C. fasciventris*, *D. longistilus* and *C. punctata* were only captured in the Niayes and *C. fasciventris* only in the Centre Zone. From one production area to another, species richness and prevalence changed according the period of the year. *B. dorsalis*, *C. silvestrii*, *C. cosyra*, *Z. curcurbitae* and *C. capitata* had the highest prevalence (99, 98%) but, *B. dorsalis* was the most important species regardless of the study area. *C. cosyra* has long since been considered the second most economic important species of mango orchards in Senegal by Vayssières *et al.* (2010); however, our results suggest it is becoming supplanted by *C. silvestrii* in terms of population levels.

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