Original article

Annual population dynamics of mango fruit flies (Diptera: Tephritidae) in West Africa: socio-economic aspects, host phenology and implications for management

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Annual population dynamics of mango fruit flies (Diptera: Tephritidae) in West Africa: socio-economic aspects, host phenology and implications for management.

Abstract – Introduction. Losses in West African commercial mango orchards due to fruit fly infestations have exceeded 50% by the middle of the crop season since 2005, resulting in considerable income loss for the growers. **Materials and methods**. In 2009, weekly monitoring of adult fruit fly species of economic significance was carried out in eight West African countries at 12 sites across five agro-ecological zones: (i) Humid Forest, (ii) Guinean savanna, (iii) Southern Sudan, (iv) Northern Sudan, and (v) Sahelian. Trapping was performed using methyl eugenol and terpinyl acetate in 288 Tephritraps, targeting *Bactrocera invadens* and *Ceratitis cosyra*. **Results**. The data showed that *B. invadens* was present throughout the year in the Forest zone, abundant for 7 months, with a peak in May at the end of the mango season, *C. cosyra* being totally absent. In the Guinean savanna zone, *B. invadens* was abundant for 6-7 months, with a peak at the beginning of June coinciding with the season, with a few *C. cosyra*. In the Southern Sudan zone, *B. invadens* was abundant for 6 months, with a peak in mid-June during the season, *C. cosyra* peaking in April. In the Northern Sudan zone, *B. invadens* was abundant for 5 months, with a peak at the end of June at the end of the season, *C. cosyra* peaking in May. In the Sahelian zone, *B. invadens* was abundant for 4 months, peaking in August during the season, *C. cosyra* peaking just before. These preliminary results showed that the exotic species, *B. invadens*, was present at high levels [mean peak of 378 flies per trap per day (FTD)] in all agro-ecological zones, while the native species, *C. cosyra*, preferred the drier zones of West Africa, with lower population levels (mean peak of 77 FTD). **Conclusion**. Detection trapping of male flies with parapheromones is a useful indicator of field population levels and could be used to deploy control measures (IPM package) in a timely manner when the Economic Injury Level is reached. Control strategies for these quarantine mango fruit fly species are discussed with respect to agro-ecological zones and the phenological stages of the mango tree.

West Africa / *Mangifera indica* / fruits / exports / *Bactrocera invadens* / *Ceratitis cosyra* / agroclimatic zones / plant developmental stages

Dynamique annuelle des populations de mouches des fruits du manguier en Afrique de l'Ouest: aspects socio-économiques, phénologie de l'hôte et implications pour leur gestion.

Résumé – Introduction. En Afrique de l'Ouest les pertes dues aux mouches des fruits dépassent 50 % pour les cultivars d'intérêt commercial à partir du milieu de la campagne mangue depuis 2005, impliquant des pertes considérables de revenus pour les planteurs. **Matériel et méthodes**. En 2009, le suivi hebdomadaire des adultes de mouches des fruits a été mené simultanément dans huit pays ouest-africains au niveau de 12 sites différents dans cinq zones agro-écologiques : (i) forêt humide, (ii) savane guinéenne, (iii) soudanienne méridionale, (iv) soudanienne septentrionale, (v) sahélienne. Le piégeage des adultes a été effectué en utilisant le méthyl eugenol et le terpinyl acétate dans 288 *Tephritraps* en ciblant *Bactrocera invadens* et *Ceratitis cosyra*. **Résultats**. Les données de 2009 ont montré que, en forêt, *B. invadens* était présente toute l'année, abondante durant 7 mois, avec un pic en fin de la campagne mangue (mai), mais *C. cosyra* absente. Dans la savane guinéenne, *B. invadens* était très abondante durant 6-7 mois, avec un pic début juin durant la campagne, avec peu de *C. cosyra*. Dans la zone soudanienne méridionale, *B. invadens* était abondante durant 6 mois, avec un pic à mi-juin durant la campagne, et *C. cosyra* avec un pic début avril. Dans la zone soudanienne septentrionale, *B. invadens* était abondante durant 5 mois, présentant un pic fin juin à la fin de la campagne, et *C. cosyra* avec un pic en mai. Dans la zone sahélienne, *B. invadens* était abondante durant 4 mois, présentant un pic en août durant la campagne, et *C. cosyra* avec un pic juste avant. Ces résultats préliminaires ont montré que *B. invadens* était abondante [moyenne des pics : 378 mouches par piège par jour (MPJ)] dans toutes les zones tandis que *C. cosyra* préférait les zones sèches (moyenne des pics : 77 MPJ). **Conclusion**. Le piégeage de détection des mâles avec les paraphéromones est un indicateur du niveau des populations de Tephritidae utilisable pour déclencher des activités de lutte (*IPM-package*) quand le Seuil Economique de Nuisibilité est atteint. Les stratégies de lutte contre ces insectes de quarantaine sont discutées en fonction du zonage agro-écologique et des stades phénologiques du manguier.

Afrique occidentale / *Mangifera indica* / fruits / exportation / *Bactrocera invadens* / *Ceratitis cosyra* / zone agroclimatique / stade de développement végétal

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1. Introduction

Sub-Saharan African exports of horticultural crops have a high potential for contribution to economic growth. In West Africa, horticultural value chains are handled mainly by smallholders who create significant added value and sustainable employment, enhance food and nutritional security, and may also reduce poverty.

Mango has the highest potential for providing food security and revenue incomes. The increase in the international demand for mango has led to higher production in West African countries which were not originally producing mango for export [1]. Mango production in West Africa is estimated at more than 1 Mt per year [2], higher than citrus production. The mango exports from West Africa were estimated at between 35 000 t and 40 000 t, equivalent to US$ 45 M [2]. In Senegal, for example, the production of fruits was estimated at 150 000 t per year, of which 60 000 t are mango alone [1, 3], with 6 000 t exported to the European Union (EU). Africa has the potential to increase mango quality and the volume of exports, and competes against the main world mango exporters for the European market. However the economic benefits of the mango value chain are greatly hampered by fruit fly (Diptera: Tephritidae) attacks in West Africa [4].

Agricultural research has contributed for the past 40 years to the extension of the mango production season over a longer period, resulting in availability of fruit for consumption during the major part of the year. The mango season increased from 2 months in the 60s to almost 10 months in some countries in 2000, with a large portfolio of cultivars. Unfortunately, fruit flies in West Africa, and mango bacterial canker in some countries, are compromising 40 years of research with the following consequences: (i) an oversupply of fruit during a very short production cycle, (ii) cessation of exports after a brief mango season, (iii) a decrease in the length of temporary labor contracts (iv), problems of amortization of farm equipment, and (v) too short export period, reducing the competitiveness of West Africa mangoes on international markets. Losses due to mango bacterial canker recently detected in Ghana [5], Mali and Burkina Faso and due to fruit flies occur at the same period during the rainy season at the peak of the mango export season. Every year, fruit flies reduce the amount of pest-free produce and also shorten the period of availability because fruits are picked prematurely by farmers to avoid infestation.

In Sub-Saharan Africa, mango production has suffered from fruit fly infestation for decades, with native species of the genus *Ceratitis,* mainly *Ceratitis cosyra* (Walker) [6], representing the major native pest [7]. Since 2003, the introduction [8, 9], establishment and spread of an exotic species, *Bactrocera invadens* Drew Tsuruta & White*,* has considerably increased the damage levels to mango fruits, reaching, for instance, infestation levels of over 50% after mid-crop in Benin [10]. This was corroborated by mango export data from West Africa to the EU (*figure 1*), where the arrival of *B. invadens* decreased mango exports from Côte d'Ivoire in 2005 and mainly after 2006-2007 in all major exporting countries. In East Africa, where *B. invadens* was detected earlier [8] than in West Africa, yield losses due to fruit flies, especially *B. invadens*, were also considerable [11, 12]. It is noteworthy that the taxonomic status of *B. invadens*, closely related to *Bactrocera dorsalis* (Hendel), is presently under revision [13]. Such a major phytosanitary pest is posing huge difficulties in accessing national, regional and international markets, resulting in substantial losses of income for the West African growers and populations for whom the mango is a staple food crop [4].

The simultaneous regional monitoring of mango fruit flies is poorly documented, especially for Sub-Saharan Africa. In order to get an overview of the level of fruit fly populations throughout West Africa, a monitoring/trapping system was implemented to obtain comparative information through captured males of the two main fruit flies of economic significance, *B. invadens* and *C. cosyra*. This weekly fruit fly monitoring system was implemented in the framework of the West African Fruit Fly Initiative (WAFFI). In West Africa, WAFFI has several linked goals: (i) setting up a yearly fruit fly

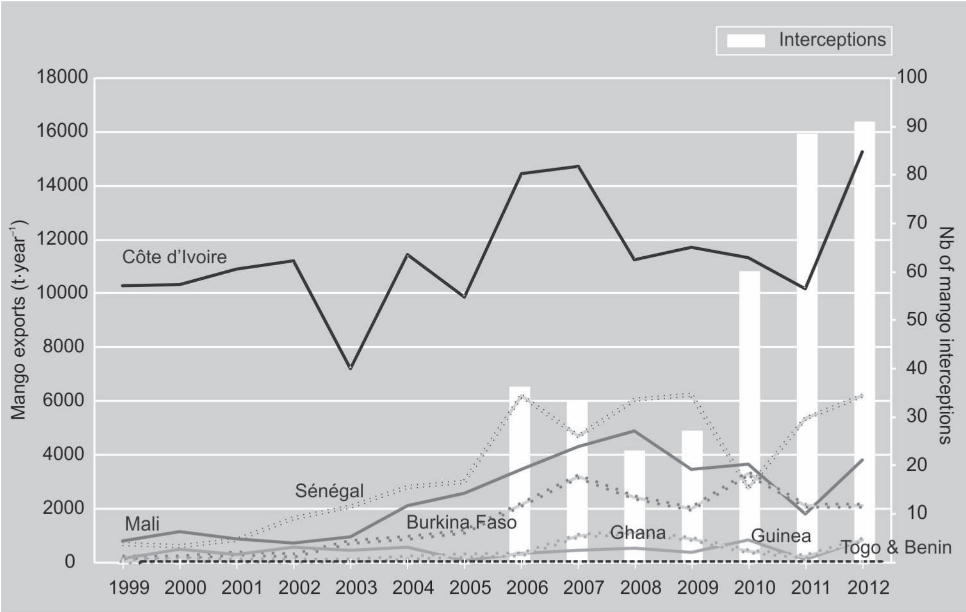

Figure 1.
Evolution of the main mango exports from West Africa to the European Union with interceptions of mangoes infested by fruit flies, from 1999 to 2012.

monitoring trapping system, (ii) developing an IPM package adapted to different agro-ecological zones and presented to farmers, and (iii) organizing training sessions for trainers, farmers, exporters and students.

Through this regional monitoring system of adult fruit flies in different agro-ecological zones (AEZ), the overall goal was to provide basic regional information in order to initiate and promote an IPM program to reduce fly damage throughout West Africa. Specifically, we seek: (i) to understand the importance of *B. invadens* and *C. cosyra* populations in relation to mango seasons in different agro-ecological zones and to the different fruit stages, (ii) to monitor their population dynamics all year round in relation to the fruit season, and (iii) to assess the importance of *B. invadens* populations *versus C. cosyra* populations in relation to each agro-ecological zone.

2. Materials and methods

2.1. The study areas in West Africa

Data was collected in mango production areas in West Africa through multiple field visits during the past years. Previous field experiments in Côte d'Ivoire, Guinea, Mali and Senegal were instrumental in figuring out the evolution of the mango value chain. This provided information for the five main agro-ecological zones occurring in eight West African countries: Benin, Burkina Faso, Côte d'Ivoire, Ghana, Guinea, Mali, Senegal and Togo. Monitoring of economically important mango fruit flies was carried out in the eight West African countries at twelve sites distributed across five main agro-ecological zones: (i) Humid Forest, (ii) Guinean savanna, (iii) Southern Sudan, (iv) Northern Sudan, and (v) Sahelian (including Niayes under Atlantic influence). We synthesized three maps using the Length of Growing Periods reported by the FAO [14], an updated Koppen-Geiger's climate classification [15], and a biodiversity study [16] to express prevailing vegetation types in West Africa, where the Sudan zone was divided into two (Southern & Northern).

2.2. Mango production and export from West Africa to the European Union

We used FAO data [2] to estimate the area of mango crops and mango production in

West Africa. We used Fruitrop data[1] to estimate mango exports from the eight West African countries to the EU. Some data of West African mango interceptions (containers and air freight arriving in the EU) were also provided (*figure 1*).

2.3. Fruit fly monitoring in West Africa

We present results for the entire year of 2009 (from January to December), except for Ghana (February to September). Fruit fly trapping was conducted using Tephritraps (Sorygar SL, Spain), 2.2-dichlorovinyl dimethyl phosphate (DDVP) (IPS Ltd., England) insecticide cubes, and two highly attractive parapheromones, methyl eugenol and terpinyl acetate (IPS Ltd., England), targeting two key fruit fly pests, respectively: the exotic *B. invadens* and a native species, *C. cosyra*. The traps were set up in mango orchards that were 100% mango trees without any insecticide treatment in or around them. Three mango pilot orchards (PO) were selected in each of the twelve sites. In each pilot orchard, there were eight Tephritraps, four with methyl eugenol and four with terpinyl acetate, for a total of 24 traps. Traps were suspended on mango branches in the lower third of the foliage. The central coil of wire holding the trap was coated with thick grease to prevent any predatory activity, particularly by weaver ants, *Oecophylla longinoda* (Latreille) (Hymenoptera: Formicidae), on dead flies in the traps. There were two traps per hectare irrespective of the attractant. In each orchard, the traps were checked and flies were collected and stored in alcohol (70°) on a weekly basis. Parapheromone plugs and DDVP were replaced monthly. Daily averages per trap of fruit fly populations captured were calculated and recorded.

For each mango tree holding a trap in Benin, we recorded on a weekly basis the developmental stages of the tree based on five different reproductive and vegetative phenological stages: (i) flowering stage, (ii) fruit-growing stages (fruit set stage A and fruit set stage B), (iii) fruit pre-maturity, (iv) fruit maturity, and (v) vegetative stages using the *Biologische Bundesantalt Bundessortenamt und Chemische Industrie* (BBCH) method [17]. No differentiation between FSA and FSB was made. During a fruit maturity period of about 15 weeks, March to June in Benin, for instance, the first four weeks (mid-March to mid-April) concern ungrafted cultivars (polyembryonic mangoes also called “mangots”) and the later weeks (mid-April to the end of June) concern grafted cultivars (monoembryonic mangoes). The same trend is followed in the other countries.

2.4. Statistical analysis

All fly counts were $\log_{10}(x+1)$-transformed to stabilize the variance and normalize the data. Analysis of variance was performed using the general linear model (GLM) procedure in SAS [18], and mean separations were performed using the SAS LSMEANS t-test (pair-wise comparisons at P = 0.05). Each site was analyzed separately to quantify significant differences among various fruit growth stages. Combined analysis of all sites was done to test for site effects.

3. Results

3.1. Distribution of mango tree crops in West Africa

The main areas of mango production in West Africa emphasize the importance of mango crops in a “zone of excellence” situated in the Sudan area from Banjul to Abuja, *i.e.*, from 8° N to 14° N latitude (*figure 2*). This area covers Southern and Western Senegal, Gambia, Southern Mali, Eastern Guinea, Northern Côte d’Ivoire, Southern Burkina Faso, Northern-central Ghana, Northern-central Togo, Northern-central Benin and Northern-central Nigeria. Within these parameters, the ideal zone for mango [19] can be delimited by three cities: Bobo Dioulasso, Kankan and Korhogo (*figure 2*).

[1] EUROSTAT, 2012, http://epp.eurostat.ec.europa.eu/newxtweb/

3.2. Mango production and export from West Africa to the European Union

For the eight West African countries studied, the estimated area of the mango production was 192 098 ha in 2011 (*table I*), showing an increase in mango production from 1999 (243 142 t) to 2011 (427 217 t) (*table II*). According to our different field visits in West Africa it can be stated that the production areas of mango provided by the FAO (*table I*) in Burkina (1 448 ha) and Mali (2 566 ha) in 2011 are underestimated.

Although West African mango production has slightly increased since 1999, this is not true for West African mango exports until the years 2011-2012. We can see a regular decreasing trend (*figure 1*) of mango exports from West African countries to the EU until 2011. We noted a clear recovery of mango exports during the year 2012. We also stress several interceptions of infested mangoes (*figure 1*) by the EU quarantine services from 2006 to 2012, with about 90 interceptions (= number of containers) in 2011 and 2012. Most of the intercepted flies were the Asian species, *B. invadens*.

3.3. Fruit fly monitoring in eight West African countries

The characteristics of the different monitoring sites (*figure 3*) and occurrence of the two main mango fruit fly species were studied in one site for Forest, and one for Sahelian zones, and data were pooled for the Guinean Savanna zone (Guinea Kindia, Ghana-Sunyani and Benin-Dassa), for the Southern Sudan zone (Guinea-Kankan, Côte d'Ivoire-Korhogo, Burkina-Bobo and Benin-Parakou), and for the Northern Sudan zone (Mali-Bamako, Senegal-Ziguinchor and Benin-Kopargo) (*table III*). Beninese analyzed data were compared for *B. invadens* populations (*table IV*) and *C. cosyra* populations (*table V*), respectively, during reproductive and vegetative developmental stages of the mango tree.

Only one site in the Humid Forest zone (3 PO) was available. The mean data of 2009 show that in that zone, *Bactrocera invadens* was present throughout the year, with a peak in May [mean of (314 ± 34.91) flies per trap per day], *e.g.*, in Togo-Kpalimé during the second half of the mango season (*figure 4*). No capture of *C. cosyra* was observed during 2009.

In the Guinean Savanna zone, *Bactrocera invadens* was abundant for six to seven months, with a peak at the beginning of June [mean of (413 ± 79.50) flies per trap per day] during the second half of the mango season (*figure 5*). A few adults of *C. cosyra* were trapped [mean of (30 ± 3.28) flies per trap per day] in this zone. The peaks represent the means of three sites (9 PO).

In the Southern Sudan zone, *Bactrocera. invadens* was abundant for six months, with a peak in mid-June [mean of (353 ± 33.08) flies per trap per day] during the second half of the mango season (*figure 6*), and adults of *C. cosyra* were relatively abundant with a peak in April [mean of (102 ± 24.89) flies per trap per day]. Populations of *C. cosyra* were present during the dry season during flowering and fruit growing before those of *B. invadens*. The peaks represent the means of four sites (12 PO).

In the Northern Sudan zone, *Bactrocera invadens* was abundant for five months, peaking at the end of June [mean of (399 ± 46.27) flies per trap per day] at the end of the mango season (*figure 7*), and adults of *C. cosyra* peaking in May and the beginning of June [mean of (74 ± 7.78) flies per trap per day]. Populations of *C. cosyra*

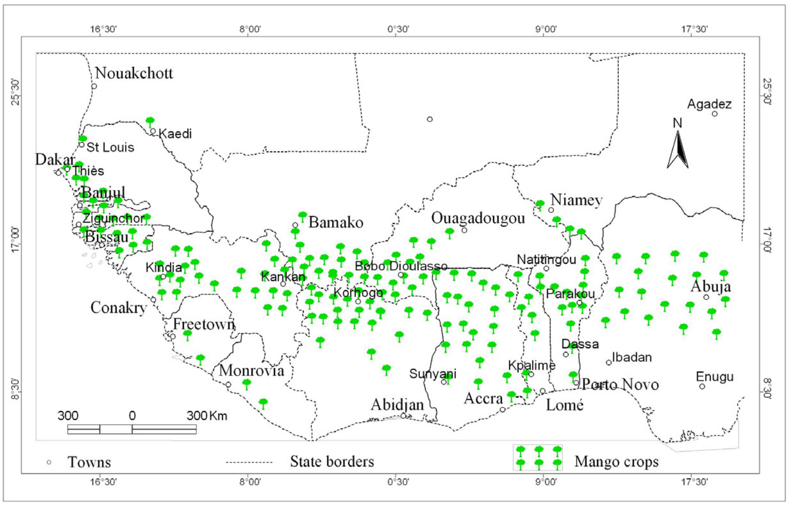

Figure 2.
Main areas of mango crops in West Africa.

Table I.
Estimations of surfaces of mango crops (in ha) for main West African countries [2].

Country	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Benin	4 740	4 681	4 846	4 915	4 952	4 958	2 400	2 300	2 350	2 400	3 307	3 370	3 459
Burkina	2 060	2 034	2 106	1 300	1 500	1 848	1 550	1 500	1 600	1 590	1 385	1 411	1 448
Côte d'Ivoire	48 219	50 331	58 317	54 643	53 149	65 477	64 550	75 000	79 000	80 000	82 183	84 000	86 210
Ghana	977	945	1 025	1 071	550	600	650	636	650	664	691	697	715
Guinea	50 423	52 936	60 000	78 000	80 000	82 000	80 000	82 000	61 855	82 500	86 232	76 900	80 000
Senegal	12 326	10 500	12 166	11 400	11 000	6 733	6 638	13 335	14 000	16 000	16 724	14 900	17 700
Mali	1 990	2 380	2 400	2 553	2 574	2 600	3 030	3 810	2 874	2 695	2 489	2500	2 566
Total	120 735	123807	140 860	153 882	153 725	164 216	158 818	178 581	162 329	185 849	193 011	183 778	192 098

Table II.
Estimations of mango production (in tons) for main West African countries [2].

Country	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Benin	16 166	15 398	18 130	16 764	21 466	12 200	12 500	12 000	12 500	13 000	14 412	13 700	13 900
Burkina	6 610	6 296	7 413	7 500	9 000	7 882	9 300	9 000	9 600	10 105	10 737	10 962	13 154
Côte d'Ivoire	22 663	23 655	27 490	25 758	25 054	30 865	30 428	35 342	37 504	39 798	42 232	45 206	45 703
Ghana	8 690	4 000	5 000	5 494	5 500	6 000	6 600	6 996	6 800	7 019	7 000	7 000	7 100
Guinea	83 000	79 055	120 000	155 812	160 000	164 000	162 000	164 000	165 000	166 000	165 000	163 900	170 000
Senegal	75 236	73 000	83 715	78 523	85 365	65 840	61 646	82 194	95 000	100 000	100 000	100 000	120 000
Mali	30 777	25 905	33 097	29 145	60 434	55 000	61 424	65 386	69 277	48 943	47 392	47 800	57 360
Total	243 142	227 309	294 845	318 996	366 819	341 787	343 898	374 918	395 681	384 865	386 773	388 568	427 217

were present during the dry season during both flowering and fruit development before the population peaks of *B. invadens*. The peaks represent the means of three sites (9 PO).

In the Sahelian zone, *Bactrocera invadens* was abundant for four months, peaking in August [mean of (429 ± 63.70) flies per trap per day] just after the middle of the mango season (*figure 8*). Adults of *C. cosyra* were also present, peaking at the beginning of August [mean of (37 ± 7.29) flies per trap per day] but dominated by the populations of the Asian fly species. We only had one site (3 PO).

These preliminary results show that the exotic species *B. invadens* is present everywhere at high population levels in all agro-ecological zones of West Africa, while the native species, *Ceratitis cosyra*, is mainly present from Southern Sudan to Sahelian zones at much lower levels. The key point is the high abundance of *B. invadens* populations during three-quarters of the mango season in Sudan zones but during the entire mango season in both Forest Guinean and Sahelian zones.

There were significant differences (*table IV*) between fruit growth stages and *B. invadens* populations in all Beninese sites (P = 0.887 and P < 0.0001) in three sites (9 PO). The pattern of *B. invadens* population distribution is similar across growth stages in all sites, with insect counts highest during the maturity period (*table IV*). However, there were no significant differences among sites for counts of *B. invadens* species in Benin. *Bactrocera invadens* distribution with respect to abundance by site could be classified as follows: hot-spot sites for Kindia (Guinean Savanna), Ziguinchor (North Sudan), Kankan (South Sudan), Kpalime (Forest) and Bamako (North Sudan); moderate sites for Thiès (Sahelian), Bobo (South Sudan) and Korhogo (South Sudan); and relatively low-abundance sites for Dassa (Guinea Savanna), Korobourou (South Sudan) and Papatia (North Sudan).

There were significant differences (*table V*) between fruit growth stages and abundance of *C. cosyra* in all Beninese sites (P = 0.047 and P < 0.0001). The pattern of *C. cosyra* species population distribution is similar across growth stages in all sites, with insect counts highest during the maturity and pre-maturity periods, followed by the fruit growth period and then flowering and without-fruit periods. Also, there were significant differences among sites for counts of *C. cosyra* species (P < 0.0001). *Ceratitis cosyra* distribution with respect to abundance by site is as follows: hot-spot sites for Bamako (North Sudan) and Kankan (South Sudan); moderate sites for Koro (South Sudan), Papatia (North Sudan), Thies (Sahelian) and Zinguichor (North Sudan); and low-abundance sites for Kindia (Guinean Savanna), Bobo (South Sudan), Dassa (Guinea Savanna) and Korhogo (South Sudan), (*table V*).

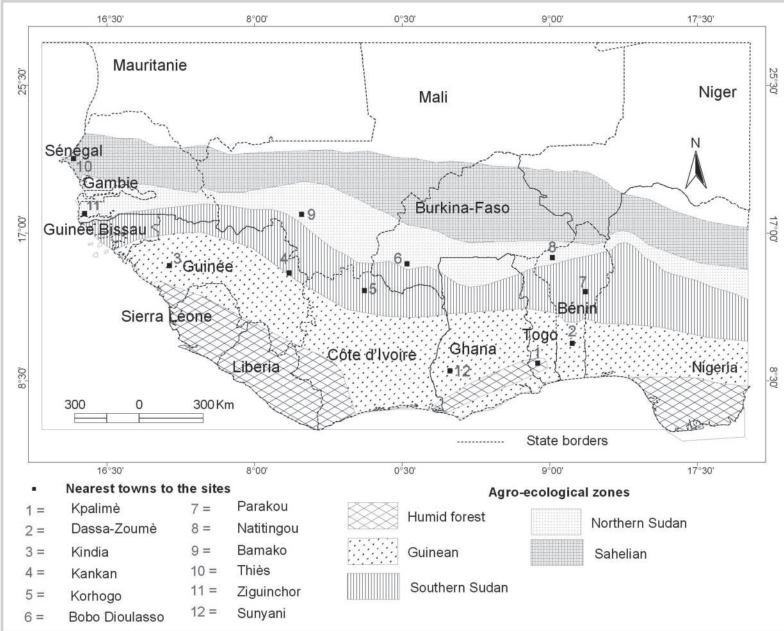

Figure 3.
West African map with 12 sites of the framework of the West African Fruit Fly Initiative (WAFFI) among five agro-ecological zones.

4. Discussion

The large Sudan zone is the most important zone for mango production in West Africa; it can be divided into two parts (Southern and Northern), the most humid one being the Southern one. Although mango trees can also grow and produce fruits in northern areas (*i.e.,* the Sahelian zone) and in southern ones (*i.e.*, the Guinean and Forest

Table III.
Fruit fly monitoring sites and occurrence of two main mango fruit flies, *Ceratitis cosyra* and *Bactrocera invadens*, in West Africa.

Country	Nearby city	Locality	Geographical coordinates	Agro-ecological zone	Mean rain (mm)	*C. cosyra* peak (FTD)	Period of *C. cosyra* peak	*B. invadens* peak (FTD)	Period of *B. invadens* peak
Benin	Kopargo	Papatia	10°04'52" N 01°48'40" E	Northern Sudan	~ 1000	62	Beginning of June	201	End of June
	Parakou	Koro	09°37'01" N 02°58'08" E	Southern Sudan	~ 1200	86	Mid-April	321	Mid-June
	Dassa	Akofodioulé	07°54'59" N 02°37'44" E	Guinean	~ 1400	26	Mid-May	346	Beginning of June
Burkina	Bobo	Toussiana	12°09'50" N 03°00'53" E	Southern Sudan	~ 1200	100	End of April	500	Mid-June
Côte d'Ivoire	Korhogo	Lataha	09°34'31" N 05°37'29" E	Southern Sudan	~ 1200	50	End of April	257	Mid-June
Ghana	Sunyani	Botim Farms	05°56'43" N 00°01'37" E	Guinean	~ 1300	20	Mid-April	322	Beginning of June
Guinea	Kankan	Karifamoria h	10°44'07" N 09°28'12" E	Southern Sudan	~ 1200	171	Beginning of May	343	Mid-June
	Kindia	Sèguèya	10°00'31" N 12°58'19" E	Guinean	~ 1800	43	Mid-May	571	Beginning of June
Mali	Bamako	Kognini	12°64'16" N 07°59'10" E	Northern Sudan	~ 900	70	End of May	221	End of June
Senegal	Thiès	Noto	14°59'13" N 17°00'11" E	Sahelian	~ 400	37	Beginning of August	429	Mid-August
	Ziguinchor	Dar Salam	12°29'48" N 16°20'20" E	Northern Soudan	~ 1000	90	Beginning of June	775	End of June
Togo	Kpalimé	Kpalimé	06°54'15" N 00°45'59" E	Forest	~ 2500	0	None	314	End of May

FTD: number of flies per trap and day.

Table IV.
Comparison of *Bactrocera invadens* populations during reproductive and vegetative development of the mango tree in Benin.

Growth stage of the mango tree	Papatia-Northern Sudan		Koro-Southern Sudan		Dassa-Guinean Savanna		All sites	
	N	Mean ± standard error	*N*	Mean ± standard error	*N*	Mean ± standard error	*N*	Mean ± standard error
Flowering	8	0.6 ± 0.1 c	7	1.0 ± 0.2 c	6	0.6 ± 0.3 c	21	0.77 ± 0.11 c
Fruit growing	9	0.5 ± 0.2 c	9	1.4 ± 0.6 c	9	0.6 ± 0.2 c	27	0.83 ± 0.22 c
Pre-maturity	3	3.0 ± 1.0 bc	3	4.2 ± 0.7 bc	3	4.1 ± 1.9 bc	9	3.76 ± 0.68 b
Maturity	11	100.6 ± 17.4 a	11	46.9 ± 11.3 a	9	111.6 ± 22.3 a	31	84.76 ± 10.79 a
Without fruit	21	10.8 ± 4.0 b	22	11.8 ± 3.3 b	25	14.1 ± 3.4 b	68	12.31 ± 2.04 b
F-value (df)*	(4.47)	39.9	(4.47)	18.5	(4.47)	28.1	(4.8)	66.3
P-value*		< 0.0001	–	< 0.0001	–	< 0.0001	–	< 0.0001
Site mean	52	26 ± 6.7	52	15.5 ± 3.6	52	26.5 ± 6.8	F(2, 8) = 0.12 ns	*P* = 0.887

Means with the same letter(s) in a column are not significantly different at the 0.05 level of significance.
* Significance test across growth stages.
ns: not significant across sites.

Table V.
Comparison of *Ceratitis cosyra* populations during reproductive and vegetative development of the mango tree in Benin.

Growth stage of the mango tree	Papatia-Northern Sudan		Koro-Southern Sudan		Dassa-Guinean Savanna		All sites	
	N	Mean ± standard error	*N*	Mean ± standard error	*N*	Mean ± standard error	*N*	Mean ± standard error
Flowering	8	4.3 ± 0.9 c	7	11.2 ± 4.1 b	6	1.1 ± 0.6 c	21	5.67 ± 1.64 bc
Fruit growing	9	21.7 ± 3.2 b	9	42.1 ± 4.2 a	9	0.1 ± 0.0 c	27	21.33 ± 3.77 ab
Pre-maturity	3	42.2 ± 7.0 a	3	57.7± 4.4 a	3	3.6 ± 2.1 b	9	34049 ± 8041 ab
Maturity	11	48.5 ± 8.2 a	11	48.6 ± 10.6 a	9	9.7 ± 1.8 a	31	37.25 ± 5.64 a
Without fruit	21	1.0 ± 004 d	22	0.3 ± 0.1 c	25	0.6 ± 0.2 c	68	0.65 ±0.16 c
F-value (df)*	(4.47)	91.7	(4.47)	72.1	(4.47)	36.0	(4.8)	7.27
P-value*	–	< 0.0001	–	< 0.0001	–	< 0.0001	–	< 0.0001
Site mean	52	17.5 ± 3.3	52	22.6 ± 3.9	52	2.3 ± 0.6	F(2, 8) = 4.57 **	*P* = 0.047

Means with the same letter(s) in a column are not significantly different at the 0.05 level of significance.
* Significance test across growth stages.
** Significance test across sites.

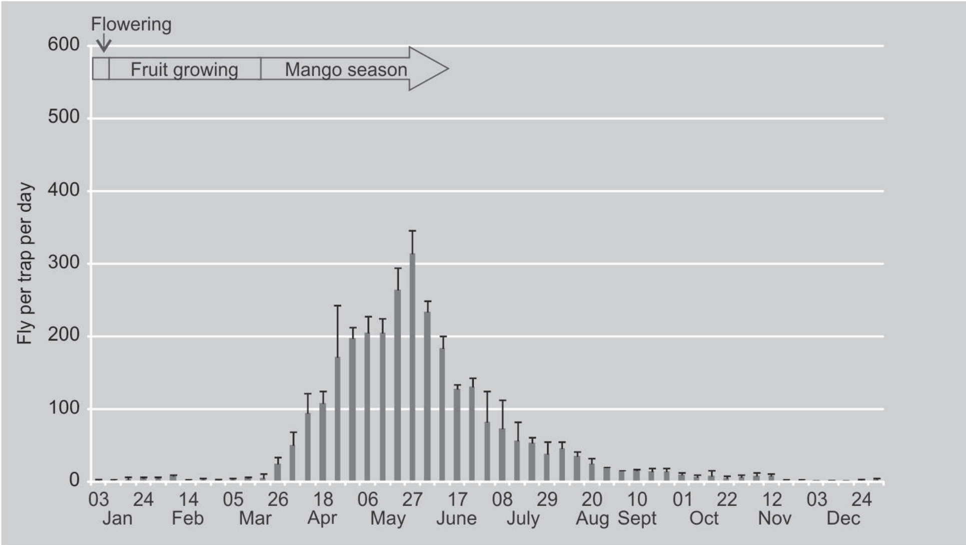

Figure 4.
Mean population dynamics of mango tephritids (*Bactrocera invadens*) in the Humid Forest zone of West Africa in relation to the mango season.

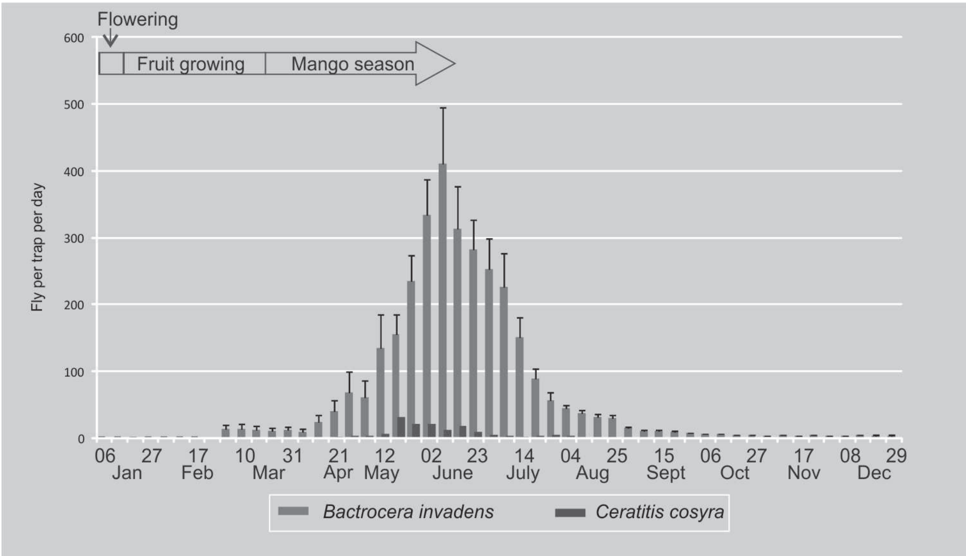

Figure 5.
Mean population dynamics of mango tephritids in the Guinean Savanna zone in relation to the mango season.

zones), the mango quality is lower than in Sudan zones [19] where the agro-climate symbiosis gives higher nutrients for the fruit and lower prevalence of pathogens on both trees and fruits.

In this close relationship between mango tree and fruit flies, the importance of the phenological coincidence between high abundance of fly pests and fruit maturity is crucial for the mango fruiting season and thus for growers. It is not surprising to obtain the highest *B. invadens* counts during the maturity period (for season and late mango cultivars), the highest counts of which are also correlated with daily rainfall [10]. Following the same general trend, *Ceratitis cosyra* counts are highest during the maturity and pre-maturity periods (for early mango cultivars only), followed by the fruit growth period and then flowering periods. In the Southern Sudan zone, *Ceratitis cosyra* populations are present during all reproductive developments of the mango tree. It is noteworthy that mango flowers can be attractive for *Ceratitis* adults, as already recorded for other fly species [20]. As we

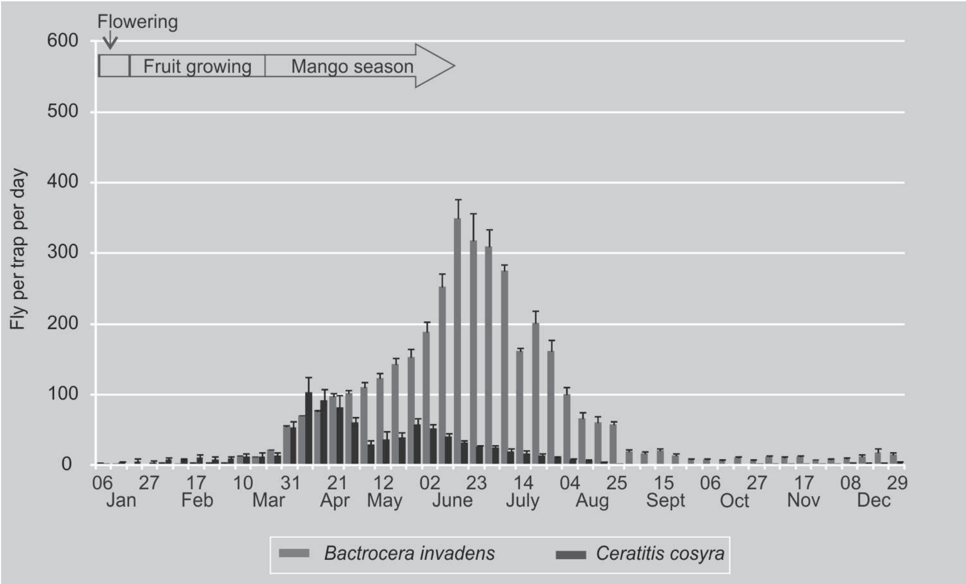

Figure 6.
Mean population dynamics of mango tephritids in the Southern Sudan zone in relation to the mango season.

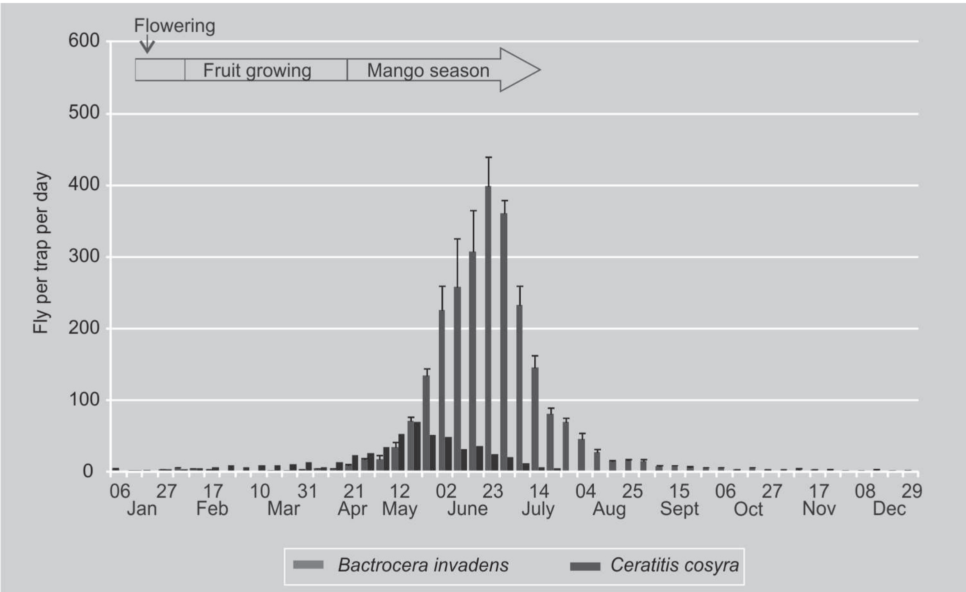

Figure 7.
Mean population dynamics of mango tephritids in the Northern Sudan zone in relation to the mango season.

have a large panel of mango cultivars present in Benin [4] through a mango season of three consecutive months (mid-March to mid-June) as in Guinea, Mali and Senegal [21] with a later mango season, the fruit availability is quite abundant during the outbreaks of different fly species.

Previous studies indicated that *C. cosyra* caused damage in the Southern Sudan zone (Guinea-Kankan [22], Korhogo-Côte d'Ivoire [23], Burkina-Bobo [24] and Parakou-Benin [25]) on early mango cultivars. The same trend was observed in the Northern Sudan zone (Mali-Bamako [26] and Benin-Natitingou). For mid- and late mango cultivars, *Bactrocera invadens* caused more than 90% of the damage in both Southern Sudan and Northern Sudan zones [4, 27]. In the Sahelian zone (in Senegal-Niayes), *Bactrocera invadens* was considered to be the principal pest for mangoes during the rainy season [3, 10, 28]. Previous studies

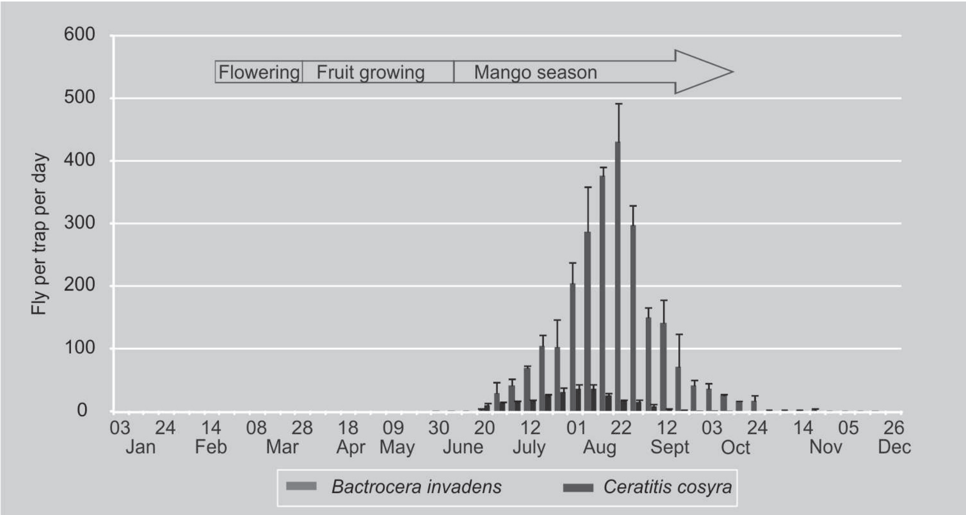

Figure 8.
Mean population dynamics of mango tephritids in the Sahelian zone (*sensu lato*) in relation to the mango season.

indicated that, in the Forest zone [29, 30] and in the Guinean Savanna zone (Guinea-Kindia [31]), the impact of *B. invadens* was high during the whole mango season. *Bactrocera invadens* remains the major pest species throughout West Africa. Most growers try to avoid fruit fly infestations by picking mangoes before they mature, reducing fruit quality.

Several actions are suggested to mitigate this problem. Integrated Pest management (IPM) measures should be initiated three months prior to maturity of the earlier mango cultivars to prevent high infestation of fruit fly populations. To implement timely and effective control measures, we need to establish early fly trapping, if possible four months before the maturity of the earlier mango cultivars (Amélie, Julie). We have several kinds of fly trapping such as (i) "detection trapping" to determine preliminary activity of flies in various regions [11, 32], and (ii) "mass-trapping" as an important component of a pest management program [33]. Only detection trapping can also provide some accurate data on population dynamics in relation to fruit stages, especially fruit growing, pre-maturity and maturity [34]. This type of trapping is a key element for pest control as it provides essential data on the fruit fly population fluctuations in relation to the time of occurrence. Data gathered during this process is important, as it is often the first step for the launch and timely implementation of control measures (IPM) in accordance with the Economic Injury Level (EIL) [35]. The Economic Injury Level is the population density at which the cost of controlling the pest equals the amount of damage it inflicts. This EIL calculation does not differentiate between the different species of fruit flies. Thus, all fruit fly species that have an economic impact on mango production are included. The EIL calculation is therefore an indicator for initiating pest control [using spinosad (GF-120), for instance] at the right time and for neutralizing any large increase in the fly populations [36]. According to our previous activities in the larger mango production basin of central Benin, treatments with GF-120 should be launched at least five weeks [37] before the pre-maturity stage of earlier mango cultivars. It is of paramount importance because, if fruit fly populations reach high levels, none of the control methods would be effective. Thus, this method is based on the introduction of detection traps in the mango orchards from the mango flowering period onward. Weekly monitoring of trapped adults is used to compute the EIL and make a decision about launching pest control measures.

From 2007 to 2012, the WAFFI project (IITA-CIRAD project) developed a comprehensive fruit fly IPM package including sanitation activities with bait sprays containing GF-120 [38], and important biological control options with weaver ants [39, 40] and parasitoids [41, 42]. All these control measures are compatible with each other. At the beginning of this project, some diagnostic studies were implemented under a participatory approach and by using local knowledge [43] in the mango production basin. It was necessary to adapt the "IPM package" for the different agro-ecological zones (AEZ), as the different pest management components may not be equally effective for each one. For instance, biocontrol using weaver ants, *Oecophylla longinoda*, seems to be most appropriate in woody areas of the Forest, the Guinean Savanna and both Sudan zones [39]. This is similar to *O. smaragdina* (Fabricius) in forests of northern Australia [44]. In the same way, the use of parasitoids may be more suitable in humid areas of the Forest, the Guinean and Sudan zones, as was previously observed for *Fopius* and *Psyttalia* spp. in many other tropical zones [45]. Bait sprays with GF-120 are expected to be effective in the Guinean Savanna, and mainly in both Sudan-Sahelian zones. Lastly, sanitation activities can be applied to all agro-ecological zones (AEZ) since FSA. A model-based characterization of biotic and abiotic drivers of *B. invadens* population dynamics could help the development of much-needed prediction and forecasting tools for this key pest in the West African region.

In the Southern-Northern Sudan zones, which are the most productive areas for mango both in terms of quality and quantity, it is noteworthy that the prevalence of *B. invadens* is very significant when compared with other agro-ecological zones of West Africa. Since 2003, this exotic fly species has quickly become a major pest of high economic significance by its infestation of many cultivated and wild fruits throughout the whole of West Africa. With more than 40 fruit species infested in Benin by *B. invadens* [46], the management of this exotic species still remains an important constraint for mango production. Apart from a very large host range for *B. invadens* compared with that of *C. cosyra* (a dozen hosts in Benin), the Asian fly species also has other important comparative advantages *vs.* the native species. Biological advantages are the shorter length of immature stages and also longer life span fecundity for *B.invadens vs. C. cosyra* [47]. Other advantages include behavioral traits, including its dispersal, since the exotic species is a strong flyer able to move about 10 km per week, contrary to the native fly (Vayssières *et al.*, pers. commun.). All of these advantages have led to a general displacement of *C. cosyra* by *B. invadens* in mango orchards throughout West Africa, just as we have observed the displacement of *C. capitata* (Wiedemann) by the Asian fly species in citrus orchards of the Southern zones of Ghana-Togo-Benin. These advantages may lead to other countries being invaded by this invasive fly [48].

5. Conclusion

Our results regarding the annual population dynamics of mango fruit flies in West Africa show that the exotic species *B. invadens* is present everywhere with high populations in all agro-ecological zones, while the native species *C. cosyra* is mainly present from Southern Sudan to Sahelian zones at lower populations. *Bactrocera invadens* populations are high during three-quarters of the mango season in Sudan zones but throughout the entire mango season in the Humid Forest, Guinean Savanna and Sahelian zones. Through the five agro-ecological zones of West Africa, the management of *B. invadens - C. cosyra* populations should be implemented by disseminating an adapted IPM package to provide environmentally friendly, efficient technologies and appropriate skills for fly management.

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Dinámica anual de las poblaciones de moscas de las frutas del mango en África Occidental: aspectos socioeconómicos, fenología del huésped e implicaciones para su gestión.

Resumen – **Introducción**. En África Occidental, las pérdidas debidas a las moscas de las frutas superan el 50 % en los cultivares de interés comercial, a partir de la mitad de la campaña mango, desde 2005, lo que implica considerables pérdidas de ingresos para los agricultores. **Material y métodos**. En 2009, se realizó el seguimiento semanal de los adultos de moscas de las frutas, simultáneamente en ocho países del África Occidental, a nivel de 12 sitios diferentes, en cinco zonas agroecológicas: (i) bosque húmedo, (ii) sabana guineana, (iii) sudanesa meridional, (iv) sudanesa septentrional, (v) saheliana. El trampeo de los adultos se efectuó mediante el uso de metileugenol y de terpinil acetato en 288 Tephritraps enfocando a *Bactrocera invadens* y a *Ceratitis cosyra*. **Resultados**. Los datos de 2009 mostraron que, en bosque, *B. invadens* estaba presente todo el año, abundante durante 7 meses, con un pico a finales de la campaña mango (mayo), pero que *C. cosyra* estaba ausente. En la sabana guineana, *B. invadens* abundaba mucho durante 6-7 meses, con un pico a principios de junio durante la campaña, y C. cosyra escaseaba. En la zona sudanesa meridional, *B. invadens* era abundante durante 6 meses, con un pico a mediados de junio durante la campaña, y *C. cosyra* con un pico a principios de abril. En la zona sudanesa septentrional, *B. invadens* abundaba durante 5 meses, presentando un pico a finales de junio, a finales de la campaña, y *C. cosyra* con un pico en mayo. En la zona saheliana, *B. invadens* abundaba durante 4 meses, presentando un pico en agosto durante la campaña, y *C. cosyra* con un pico justo antes. Estos resultados preliminares mostraron que *B. invadens* abundaba [media de los picos: 378 moscas por trampa por día (MTD)] en todas las zonas, mientras que C. cosyra prefería las zonas secas (media de los picos: 77 MTD). **Conclusión**. El trampeo de detección de los machos con paraferomonas es un indicador del nivel de las poblaciones de Tephritidae que puede emplearse para impulsar las actividades de lucha (*IPM-package*) una vez alcanzado el Umbral Económico de Nocividad. Se debaten las estrategias de lucha contra estos insectos de cuarentena en función de la zona agroecológica y de las fases fenológicas del mango.

África Occidental / *Mangifera indica* / frutas / exportaciones /*Bactrocera invadens* / *Ceratitis cosyra* / zonas agroclimáticas / etapas de desarrollo de la planta