International Journal of Mosquito Research

ISSN: 2348-5906
CODEN: IJMRK2
IJMR 2022; 9(1): 61-67

www.dipterajournal.com
Received: 22-11-2021
Accepted: 24-12-2021

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Seasonal variation of mosquito breeding sites in the industrial areas of the city of Abidjan, south-eastern Cote d'Ivoire

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DOI: https://doi.org/10.22271/23487941.2022.v9.i1a.582

Abstract
The expanding of industrial activities in Côte d'Ivoire, particularly in the city of Abidjan (73% of the national industrial sector), has led to significant environmental imbalances. These have created favourable conditions for the reproduction and maintenance of many disease vectors such as mosquitoes. Controlling these insect vectors requires the understanding of their ecology, including genus diversity and their breeding sites types. It is in this context that a study was conducted on the seasonal variation of mosquito breeding sites in the industrial areas of Abidjan. Larval surveys were conducted from February to March 2019 (dry season) and from June to July 2019 (rainy season) in the industrial zones of the communes of Koumassi, Port-Bouët and Yopougon. This study led to the identification of 2,015 and 1,977 potential breeding sites in the rainy and dry seasons respectively. The breeding sites were grouped into four types : abandoned tyres, discarded containers, natural breeding sites, other breeding sites. Of these sites, 740 (36.72%) and 288 (14.57%) were positive in the rainy and dry seasons respectively. Abandoned tyres were abundant with 1,685 (85.23%) observed in the dry season and 1,593 (79.06%) in the wet season in the study sites. The presence of vegetation and sunshine negatively influenced the presence of larvae in the Vridi industrial zone (Port-Bouët). In addition, Aedes breeding sites were most frequently observed with 218 (75.69%) in the dry season and 495 (66.89%) in the rainy season. The results obtained in this study could be used to develop an effective method to fight against mosquitoes in the industrial zones of Abidjan.

Keywords: Season, breeding sites, larvae mosquitoes, industrial zone, Abidjan, Côte d'Ivoire

1. Introduction

After the success of its agriculture, Côte d'Ivoire has motivated, and based its industrial policy on the development of raw materials, which are the key to accessing the stage of a developed country, and the spearhead of its growth. The Ivoirian industrial sector abounds in a panoply of companies of various sectors of activity (agro-industry, textiles, chemicals, and derivatives) [1]. More than 73% of industries are in the south of the country, in the city of Abidjan with 45% in Yopougon, 20% in Koumassi, and 20% in Port-Bouët [2]. The urbanization of Abidjan combined with its accelerated industrialization, has altered the natural environment, and created significant environmental imbalances [3] thus offering habitats more suited to various vectors of diseases such as these mosquitoes [4, 5, 6]. These mosquito species exploit almost all types of water collections (temporary or permanent, polluted or unpolluted, and anthropogenic or natural) to lay their eggs [7, 8]. The diseases (malaria, filariasis, viruses) they transmit dramatically affect public health, and represent a major burden in terms of economy, and development in the world, particularly in sub-Saharan Africa [9, 10]. In recent years, epidemics of dengue, and yellow fever have been observed in Côte d'Ivoire, particularly in Abidjan in 2017 and 2019 [11]. During the 2017 outbreak, the co-circulation of yellow fever, and dengue viruses was demonstrated by RT-PCR in mosquito samples collected in Abidjan city. To control vector-borne diseases, the World Health Organization (WHO) recommends environmental sanitation, the use of Long-Lasting Insecticidal Nets (LLINs), and Indoor Residual Spraying [12] which implementation require a better understanding of the bio-ecology of the vectors, including the typology, and seasonal distribution of mosquito breeding sites.

Although many studies have been carried out in Africa on the bio-ecology of vectors [13, 14, 15], very few have been carried out to describe the larval habitats of mosquitoes in industrial areas, particularly in Côte d'Ivoire. However, that essential for the implementation of adapted and efficient control actions [16, 17, 6]. It is within this framework that this study on the typology, and seasonal distribution of mosquito breeding sites was carried out in the main industrial zones of the city of Abidjan in 2019.

2. Materials and methods
2.1. Presentation of the study zone
A larval survey was undertaken at the three main industrial areas of the city of Abidjan located in the commons of Koumassi, Port-Bouët, and Yopougon during the dry season (February-March, 2019) and the rainy season (June-July, 2019). The city of Abidjan (5° 20′ 11″ North and 4° 01′ 36″ West) is located in the south-east of Côte d'Ivoire (Figure 1), on the edge of the Gulf of Guinea [18]. This city, with a strong demographic growth, rapid urbanization, and strong industrialization, is crossed by the Ebrié Lagoon and covers an area of 422 km2 [19]. The climate is sub-equatorial, hot, and humid, with two rainy seasons (long rainy season April-July, and short rainy season September-November), and two dry seasons (long dry season December-March, and short dry season August), the duration of which has varied considerably in recent years [20]. Rainfall is relatively abundant with an average of 1,500 mm per year. The average temperature is about 27°C, and the average annual humidity is over 80% [18, 20].

2.2. Identification of mosquito breeding sites
Mosquito larvae were systematically searched in all available breeding sites (water collections, containers, abandoned tyres, stagnant water pools) in each industrial area. The nature of each potential breeding site encountered, and its characteristics (GPS coordinates, presence or absence of vegetation, sunlight), as well as the season, and the area, were recorded. In all two seasons, larvae mosquitoes were collected in the same locations. After visual identification of the presence of immature stage in the breeding site, their sampling was done using the dipping method [21, 22, 23]. For small breeding sites (boxes, cans, etc.), larvae, and pupae were collected using a pipette. After collection, the samples were transferred into labelled jars at the rate of one jar per breeding site, and taken to the insectary of the National Institute of Public Hygiene, and raised (at a temperature of 28 ± 5 ° C, relative humidity of 70 to 78%) to adults. The breeding sites were categorised according to criteria relating to human habitat, and their mode of impoundment [24] into discarded containers, abandoned tyres, natural breeding sites, and other breeding sites.

2.3. Statistical analysis of the data
Data collected were entered into an Excel 2013 spreadsheet and analysed using Stata version 10 software. The Pearson chi-square test was used to compare the percentages of mosquito breeding sites-types with sites and seasons in the study sites. Bivariate logistic regression was used to analyse the relationship between positivity, vegetation around the site and sunlight. The significance level used was stated at 5%.

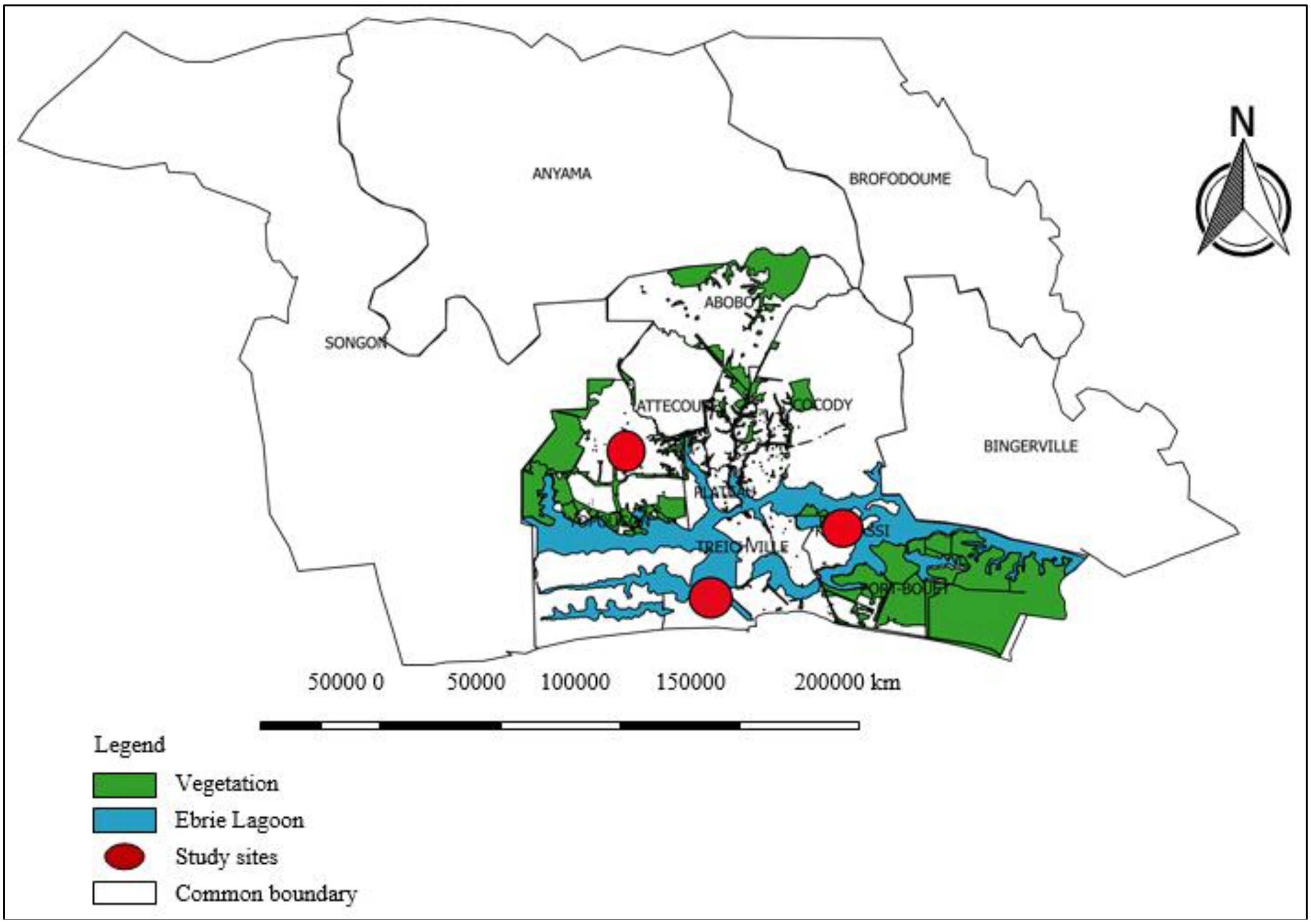


Fig 1: Location of study sites (industrial zones)

3. Results

3.1 Seasonal variation of breeding sites types

A total of 3,992 potential mosquito breeding sites, grouped into four types were found in industrial areas, of which 1,977 (49.52%) in the dry season and 2,015 (50.48%) in the rainy season. There were as many potential sites in the dry season as in the rainy season ($\chi^2 = 0.2412$; $p = 0.623$). Abandoned tyres (82.11%) were predominant and constituted 85.23%, and 79.06% of potential breeding sites identified respectively in the dry and the rainy seasons. There were also as many abandoned tyres in the dry season as in the rainy season ($\chi^2 = 1.7215$; $p = 0.189$). The other potential breeding sites were respectively other breeding sites (8.04%), discarded containers (5.26%), and natural breeding sites (1.47%) in the dry season, and other breeding sites (9.88%), natural breeding sites (5.66%), and discarded containers (4.86%) in the rainy season. The maximum number of the potential breeding site was obtained in the industrial area of Vridi (Port-Bouët), followed by the industrial area of Yopougon and that of Koumassi regardless of the season (Table 1).

3.2. Seasonal variation in mosquito breeding site positivity

In general, 25.75% (n=1,028) of breeding sites collected were colonized by mosquito larvae, with 28.02% in the dry season and 71.98% in the rainy season. Abandoned tyres were constituted by 85.42% of the positive breeding sites, both in the dry season and in the rainy season. They also represented the majority of positive breeding sites identified in the three industrial areas in each season (Table 2). Positivity by type of breeding site showed that other breeding sites were the most used in the industrial areas of Koumassi and Vridi with 9/67 and 20/51 positive sites respectively, and in the industrial area of Yopougon, these are natural breeding sites with 2/5 positive sites in the dry season. On the other hand, discarded containers with respectively 10/19 and 21/51 positive sites in the industrial zones of Koumassi and Yopougon and other breeding sites with 55/108 positive breeding sites in the industrial zone of Vridi were the most used in the rainy season. The bivariate logistic regression showed that in the industrial area of Vridi (Port-Bouët), there are 0.44 times fewer larvae in breeding sites with vegetation around than in those without vegetation (p = 0.0001). Likewise, there are 0.15 times fewer larvae in sunny breeding sites than in non-sunny roosts (p = 0.008). On the other hand, in Koumassi industrial area, the sunshine favours 1.45 times the presence of larvae in the breeding sites (p = 0.005) (Table 3)

Table 1: Seasonal variation of potential breeding sites identified in the main industrial zones of the communes of Koumassi, Vridi (Port-Bouët) and Yopougon in the city of Abidjan from February to March 2019 (dry season) and from June to July 2019 (rainy season)

	Dry season					Rainy season				
	Potential breeding site	**discarded containers**	**Abandoned tyres**	**Natural Breeding site**	**Others Breeding sites**	**Potential Breeding site**	**discarded containers**	**Abandoned tyres**	**Natural breeding site**	**Others breeding sites**
IZ Koumassi	528 (26,71)	20 (3,79)	439 (83,14)	2 (0,38)	67 (12,69)	494 (24,52)	19 (3,85)	406 (82,19)	15 (3,04)	54 (10,93)
IZ Vridi	814 (41,17)	56 (6,88)	685 (84,15)	22 (2,70)	51 (6,27)	889 (44,12)	28 (3,15)	733 (82,45)	20 (2,25)	108 (12,15)
IZ Yopougon	635 (32,12)	28 (4,41)	561 (88,35)	5 (0,79)	41 (6,46)	632 (31,36)	51 (8,07)	454 (71,84)	79 (12,5)	37 (5,85)
Total	1977 (100)	104 (5,26)	1685 (85,23)	29 (1,47)	159 (8,04)	2015 (100)	98 (4,86)	1593 (79,06)	114 (5,66)	199 (9,88)

IZ : Industrial Zone

Table 2: Seasonal variation of positive deposits identified in the main industrial zones of the communes of Koumassi, Vridi (Port-Bouët) and Yopougon in the city of Abidjan from February to March 2019 (dry season) and from June to July 2019 (rainy season)

	Dry season					Rainy season				
	Positif breeding site	**discarded containers**	**Abandoned tyres**	**Natural breeding site**	**Others breeding sites**	**Positif breeding site**	**Discarded containers**	**Abandoned tyres**	**Naturals breeding sites**	**Others breeding sites**
IZ Koumassi	39 (13,54)	0 (0,00)	30 (76,92)	0 (0,00)	9 (23,08)	178 (24,05)	10 (5,62)	140 (78,65)	1 (0,56)	27 (15,17)
IZ Vridi	190 (65,97)	3 (1,58)	167 (87,89)	0 (0,00)	20 (10,53)	330 (44,59)	14 (4,24)	255 (77,27)	6 (1,82)	55 (16,67)
IZ Yopougon	59 (20,49)	6 (10,17)	49 (83,05)	2 (3,39)	2 (3,39)	232 (31,35)	21 (9,05)	179 (77,16)	14 (6,03)	9 (3,88)
Total	288 (100)	9 (3,13)	246 (85,42)	2 (0,69)	31 (10,76)	740 (100)	45 (3,13)	574 (85,42)	21 (0,69)	91 (10,76)

IZ : Industrial Zone

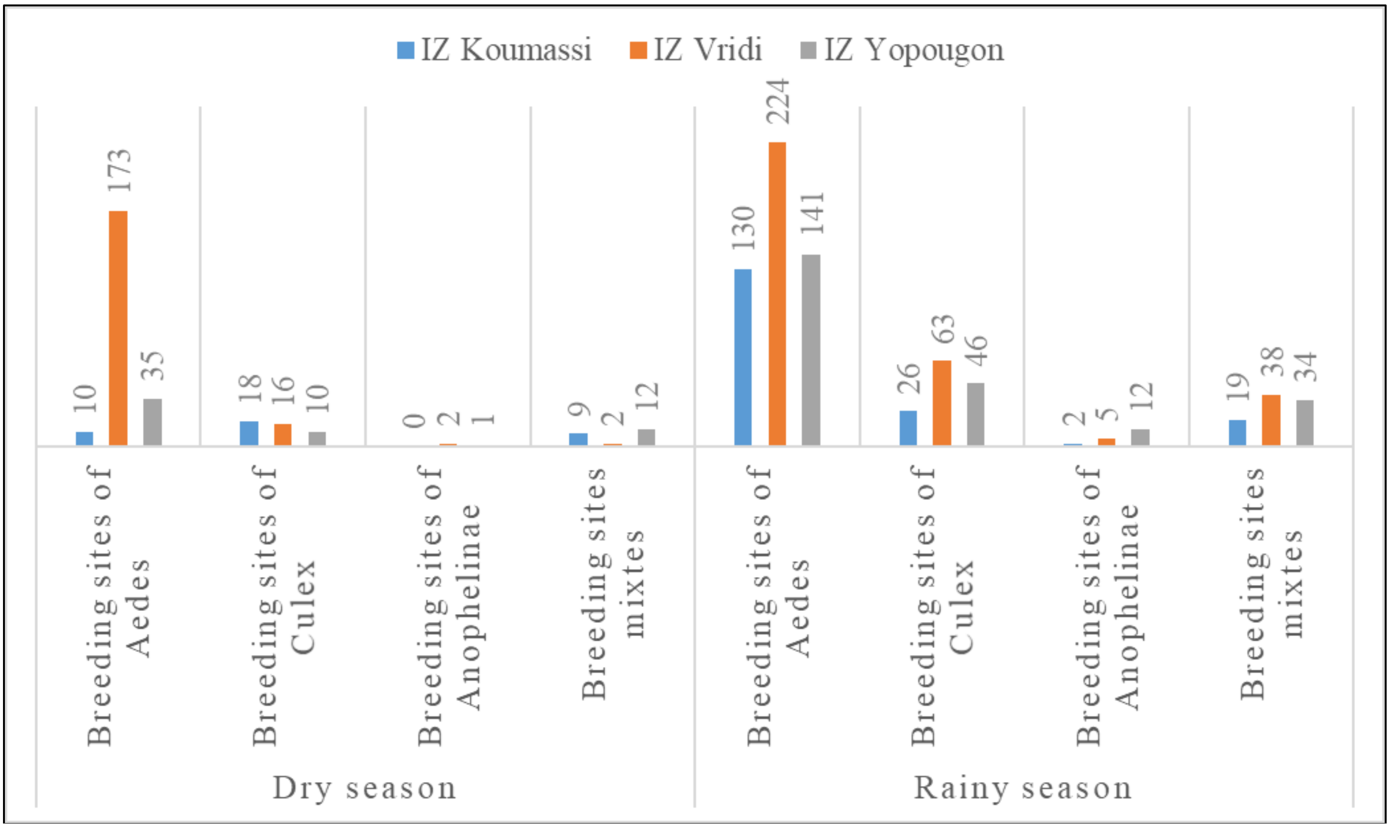
Table 3: Relationship between positivity, sunlight and vegetation around site type by industrial area

Sites	Environmental factors	Values OR	P-value	IC_i	IC_s
IZ Koumassi	Lack of vegetation around the breeding site	1			
	Presence of vegetation around the breeding site	1,27	0,626	0,48	3,35
	Shade	1			
	Sunshine	2,41	**0,005**	1,31	4,45
IZ Vridi	Lack of vegetation around the breeding site	1			
	Presence of vegetation around the breeding site	0,56	**0,0001**	0,48	0,66
	Shade	1			
	Sunshine	0,85	**0,008**	0,76	0,96
IZ Yopougon	Lack of vegetation around the breeding site	1			
	Presence of vegetation around the breeding site	1,01	0,972	0,63	1,62
	Shade	1			
	Sunshine	0,79	0,155	0,58	1,09

IZ: Industrial Zone; CI_I: Lower Confidence Interval; CI_S: Superior Confidence Interval

3.3 Seasonal variation of types of larvae associated with mosquito breeding sites

During the dry season, 75.69% (n = 218) of positive breeding sites contained larvae of *Aedes spp.*, 15.28% (n = 44) harbored larvae of *Culex spp.*, 1.04% (n = 3) harbored larvae of *Anopheles* spp., and 7.99% (n = 23) included a mixture of the three genera. On the other hand, during the rainy season, 66.89% (n = 495); 18.24% (n = 135); 2.57% (n = 19) of the breeding sites contained larvae of *Aedes* spp., *Culex* spp. and *Anopheles* sp. The roosts hosting the three genera represented 12.30% (n = 91) (Figure 2).



IZ: Industrial Zone

Fig 2: Distribution of mosquito larvae genera identified in breeding sites in the main industrial zones of the communes of Koumassi, Vridi (Port-Bouët) and Yopougon in the city of Abidjan from February to March 2019 (dry season) and from June to July 2019 (rainy season)

4. Discussion

This study showed a diversity of mosquito breeding sites in the industrial areas of the city of Abidjan. A total of 3,992 potential mosquito breeding sites were found in the industrial zones, of which 1977 (49.52%) were found in the dry season and 2015 (50.48%) in the rainy season. This abundance could be explained by the high anthropogenic activity due to the presence of the port and industries in these communes, but also by poorly controlled urbanization and the absence of appropriate hygiene measures in these industrial zones. The high diversity of breeding habitats by culicids has already been observed in other African localities [25, 26, 27, 28]. Furthermore, this multiple of mosquito breeding sites could be attributable to the lack of sanitation in the immediate environment of the populations as reported by many authors worldwide [29, 30, 31, 17]. Our results are similar to those of El Joubari *et al.* [32] and Koumba *et al.* [6] who highlighted the role of human activities in the creation of mosquito breeding sites. Abandoned tyres (82.11%) were predominant and constituted 85.23% and 79.06% of the potential breeding sites identified respectively in the dry and rainy seasons. This high frequency of tyres in industrial areas could be explained by the poor management of used tyres from goods and raw material transport vehicles. These types of mosquito breeding sites are commonly observed in Africa [25, 26, 33, 34].

In the study areas, 14.57% of the breeding sites were positive during the dry season, compared to 36.72% during the rainy season. The low proportion of positive breeding sites identified in the study areas in the dry season could be due to the study period and many other factors. In the dry season, some breeding sites dry up or disappear, resulting in the scarcity of breeding sites. Moreover, in our case, abandoned tyres, which were the majority of positive breeding sites, were sometimes dry in our study sites during the dry season. This phenomenon was also observed by Mouchet [35] who concluded that successive droughts in the Sahel regions lead to the disappearance of the usual breeding sites. These results are in agreement with those of Koumba *et al.* [6] who showed that the season influenced the quantity and quality of mosquito breeding sites in the agricultural areas of Mouila, Gabon. The abundance of breeding sites during the rainy season expands the breeding sites that are required by female mosquitoes to lay their eggs. Our results are similar to those of Saotoing *et al.* [36] and Tia *et al.* [37] who also identified more potential and positive breeding sites in the rainy season than in the dry season in their study sites.

Vegetation and sunlight negatively influenced the presence of larvae in the industrial zone of Vridi. Bivariate logistic regression showed that in the industrial zone of Vridi (Port-Bouët), there were 0.44 times fewer larvae in the sites with vegetation around than in those without vegetation (p = 0.0001). Similarly, there were 0.15 times fewer larvae in sunny sites than in no-sunny sites (p = 0.008). This could be explained by inadequate exposure to sunlight caused by high vegetation cover which affects the phytosynthetic efficiency of the algal biomass that serves as food for mosquito larvae

[38]. This result differs from that of El Ouali *et al.* [39] who showed the influence of these environmental parameters on the presence of larvae in breeding sites in the city of Fès. This difference could be explained by the difference between the study sites. It has been shown that the variation of the volume of water inside the breeding sites can modulate the attractiveness of oviposition, the availability of space and the accessibility of food resources [40]. In contrast, in the industrial zone of Koumassi, sunlight favoured the presence of larvae in the breeding sites 1.45 times ($p = 0.005$). Adequate exposure to sunlight warms the water to appropriate temperatures, as the temperature is also a key factor influencing larval development and survival [41, 42, 43].

In the main industrial areas of Abidjan, 218 sites (75.69%) were hosting *Aedes* larvae, 44 sites (15.28%) were hosting *Culex* larvae, 23 sites (7.99%) were mixed (containing *Aedes*, *Anopheles* and *Culex* larvae) and 3 sites (1.04%) hosted *Anopheles* larvae in the dry season, compared to 740 positive sites identified, of which 495 (66.89%) hosted *Aedes* sp. , 135 (18.24%) contained *Culex* sp. larvae, 91 (12.30%) were mixed (contained *Aedes sp*., *Anopheles sp.* and *Culex sp.* larvae) and 19 (2.57%) contained *Anopheles sp.* larvae in the rainy season. Two mosquito sub-families, *Anophelinae* and *Culicinae*, were identified in the water collections surveyed, with a predominance of *Culicinae* breeding sites. This could be explained by the ecological preference of the different genera of mosquitoes and the great plasticity of *Culicinae*. On the other hand, most of the breeding sites identified in the study sites were typical to Culicinae breeding sites and they were regaining in all types of breeding sites surveyed. In additional, the nature of breeding sites favours one or other *Culicidae* species depending on the characteristics of the site: stagnant or flowing, polluted or not, devoid or rich in vegetation and sunny or no [44]. This observation corroborates that made by Korba *et al.* [45] in Algeria. These authors showed that the Culicinae have strong adaptive capacities allowing them to develop in several types of breeding sites, including abandoned tyres (preferential breeding sites of Aedes) which were the most abundant positive breeding sites in our study sites. As for *Culex* females, they can lay their eggs in all types of larval sites; their predominance here would be the consequence of poor urbanization accompanied by pollution of water collections by household and industrial waste, which favours the proliferation of *Culex* populations [46, 47]. Similar observations were made by Darriet *et al.* [48] in Burkina Faso. They described the genus *Culex* as a biological marker of urbanization. The low number of *Anophelinae* breeding sites identified during this study could be explained by the bio-ecology of these diptera and their ecological requirements [6, 49]. Indeed, *Anophelinae* females have a positive tropism for clear freshwater and brackish water for egg laying [17, 50]. Most of the *Anopheles* sites identified were atypical sites (abandoned tyres and discarded containers) and typical sites (natural breeding sites: puddles). *Anophelinae* larvae were found in the same sites as *Aedes* and *Culex* larvae. These results confirm those of Akogbéto [51] and Gouagna *et al.* [26]. The coexistence of *Anopheles* and *Culex* larvae in the same sites could indicate the adaptation of *Anopheles* to polluted sites. Knowledge of these sites is essential to identify the most productive sites in a given area in order to define appropriate and effective control strategies [52].

5. Conclusion

This study showed that potential breeding sites were more abundant during the rainy season. They grouped into four types of mosquito breeding sites (abandoned tyres, discarded containers, natural breeding sites, other breeding sites) in the industrial areas of the communes of Koumassi, Port-Bouët and Yopougon. Abandoned tyres (preferred breeding sites for Aedes and Culex) were the most abundant in these three industrial areas in Abidjan city. The majority of positive breeding sites were has identified in the rainy season, and abandoned tyres were the most abundant in all seasons. Positivity by type of breeding site showed that other breeding sites and natural breeding sites are the most used respectively in the industrial zones of Koumassi and Vridi and Yopougon in the dry season. However, discarded containers, and other breeding sites were most used in the rainy season in the industrial zones of Koumassi, Yopougon, and Vridi respective. The breeding sites of *the Culicinae* sub-family (*Aedes* and *Culex)* was more abundant than the *Anophelinae* sub-family regardless of seasons. This proximity of mosquito breeding sites to areas frequented by humans highlights the exposure of these populations to the risks of arbovirosis, lymphatic filariasis and malaria. It is therefore imperative that community awareness campaigns and sanitation measures be undertaken in these industrial areas of Abidjan to reduce the incidence of diseases carried by mosquito vector populations, including the mixture of the three genera.

6. Declaration of interests

The authors declare that they have no competing interests in relation to this article. All authors have read and approved the final version.

7. Acknowledgements

The authors thank the National Institute of Public Hygiene (INHP) for technical and material support.

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