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Population dynamics of the main necrophagous Diptera in the sub-Sudanese zone of Côte d'Ivoire

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Abstract

The objective of this work was to identify the population variation of the main necrophagous Diptera in the sub-Sudanese zone of Côte d'Ivoire. Three traps, inspired by Upton's and using pig liver and viscera as bait were placed on the site of the Botanical Garden of Peleforo Gon Coulibaly University and Lataha located 10 km from the Botanical Garden. Weekly captures were taken from October 4, 2018 to October 3, 2019. In total, 194,853 individuals from the *Calliphoridae, Sarcophagidae* and *Muscidae* were collected. Calliphoridae represented 48%, Sarcophagidae 24% and Muscidae 28% in the Botanical Garden site and in Lataha, Calliphoridae presented 52%, Sarcophagidae 27% and Muscidae 21%. *Chrysomya albiceps, Sarcophaga carnaria* and *Musca domestica* were the majority species. The numbers of these three species were higher at relative humidity levels reaching 70 to 85%. A correlation between relative humidity and the numbers of these three species was observed. Apart from relative humidity, these results show that other climatic parameters have a weak influence on the activity of *Chrysomya albiceps, Sarcophaga carnaria* and *Musca domestica*. During this study, temperature and rainfall had little influence on the variation in the numbers of these three main species of necrophagous insects. However, the numbers of the three species were correlated with relative humidity levels.

Keywords: *Chrysomya albiceps; Sarcophaga carnaria; Musca domestica*; Climatic parameters

1. Introduction

Many organisms such as bacteria, fungi and arthropods, including insects, rapidly visit and colonize animal carcasses [1, 2]. Within ecosystems, among the animals that feed on vertebrate remains, necrophagous insects are the most abundant [3, 4]. Remains constitutes for these different species a nourishing substrate, a place of reproduction, a refuge even an ideal territory although fluctuating with the rhythm of decomposition processes [2]. Carcasses decompose according to five (05) stages: fresh corpse, bloating stage, active decomposition, advanced decomposition and skeletonization [5, 6]. Two orders of necrophagous insects are commonly represented on decomposing animal carcasses: Diptera and Coleoptera [6]. The first Dipteran to colonize carcasses exposed to the open air are Calliphoridae, Muscidae and Sarcophagidae according to the work of Wyss and Chérix [5], Koffi *et al.* [6] and Kpama-Yapo *et al.* [4]. Concerning Coleoptera, it is the Cleridae and the Scarabaeidae, which are the first families to appear on carcasses at the active decomposition stage [4, 6]. These species appear on carcasses at the bloating stage and active decomposition but are rarely found at the stage of advanced decomposition and skeletonization [7, 8]. According to the work of Dekeirsschieter [9], Johansen *et al.* [10], Armstrong *et al.* [11] and those of Trumbo and Newton [12], the VOC profile was highly dynamic during the bloated stage, changing both hourly and daily. Several works on necrophagous insects have been carried out in most countries of

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Europe and America but in Africa in general, and in Côte d'Ivoire in particular, little work has been carried out on them. The literature does not mention any study on the dynamics of necrophagous insect populations in the sub-Sudanese zone of Côte d'Ivoire. The study objective was to determine the fluctuation of the main necrophagous Diptera populations in the sub-Sudanese zone characterized by two seasons, one rainy and one dry.

2. Material and methods

2.1. Study site

This study was carried out in the sub-Sudanese zone of Côte d'Ivoire. The area is characterized by grassy savannah and wooded savannah vegetation. The sites were located in Korhogo, a town located in North of Côte d'Ivoire. Diptera trapping was carried out at the botanical garden of the Peleforo Gon Coulibaly University with the geographical coordinates 9°26' N - 5°38' W, altitude 380m and in Lataha, a village located at 10 km in the North of Korhogo (9 °33' N - 5°34' W, altitude 377m) (Figure 1). The University site is an experimentation site where several experiments were carried out. Students always visit it on internships and by supervising teachers. The site is located on the edge of the city. Apart from the student's experiments, no other human activity is carried out on the site. Additionally, the traps were well away from the students' agricultural experiment plots.

Regarding the Lataha site, it should be noted that it was located two km from the village and little frequented by people. Human activities there were very low. This site had the same characteristics in terms of vegetation as that of the botanical garden. The only difference was that it was sprinkled with cashew trees.

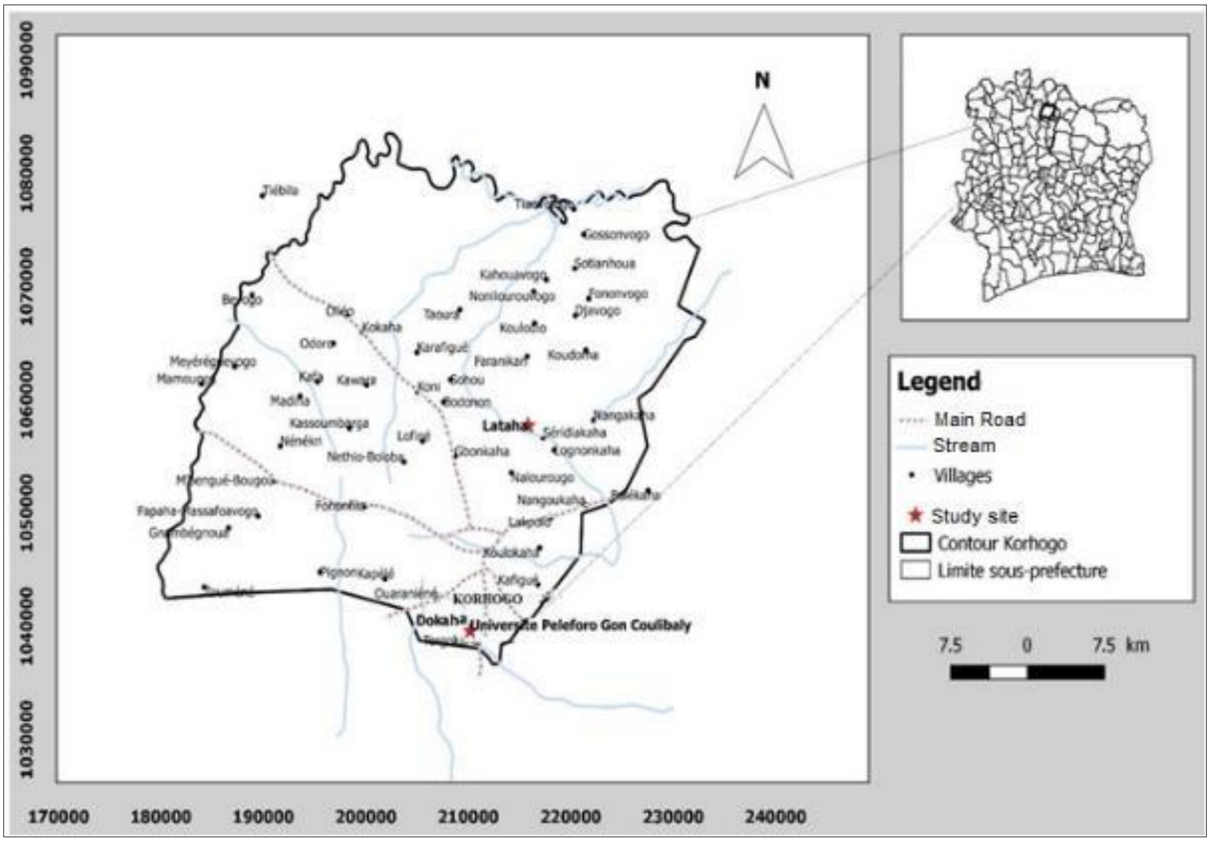

Figure 1 Study site

2.2. Experimental equipment

The experimental device consisted of a trap inspired by that of Upton [13]. This trap consisted of a transparent plastic tray measuring Length = 45 cm, Width = 30 cm and Height = 25 cm (Figure 2). This cage was completely closed by a lid. The cover was held in place by two padlocks. On each side, a cone (funnel) 1.5 cm in diameter is placed to allow insects access to the inside of the cage. On two sides of the cage, two openings are made, then covered with muslin. This opening allows the diffusion of odors from the substrate introduced inside the cage (Figure 2). The support on which the cage is placed measures 1.3 m. On each site, three traps were placed 500 m apart from each other in order to avoid competition between traps. In this study, two substrates were used: pig liver and pig viscera. The simultaneous use of these two substrates was intended to allow a significant diffusion and for a whole week of the characteristic odors which promote the attractiveness of the different necrophagous insects.

Figure 2 Capture trap inspired by that of Upton

2.3. Collections, identification and counting of insects

Two portions of pig' substrate (250 g of pig liver and 250 g of pig viscera) were placed in a plastic tray covered with a mosquito net, to prevent trapped Diptera from accessing the bait. The plastic tub containing the bait was then placed inside the cage. Seven days later, the bait was removed and replaced. The trapped insects, still alive when the trap was released, were killed using CO_2 gas, then transported to the laboratory in paper envelopes. The identification of the collected necrophagous insects was carried out using a brand and model binocular magnifying glass (Optika LAB20), and identification keys [5, 14, 15, 16, 17]. The collected insects were identified down to the taxonomic level of the species. To quantify necrophagous species, adults collected using attractant traps were sorted and grouped by species in order to be counted. The trapping period extended over 52 weeks, from October 4, 2018 to October 3, 2019.

2.4. Collection and processing of climate data

A brand and model IHM-172SI thermo-hygrometer and a rain gauge were used to collect respective data on temperature, relative humidity and precipitation. The temperature and relative humidity recorded daily were used to calculate monthly averages.

2.5. Data processing

2.5.1. Relative abundance

Relative abundance (Ar) expresses the ratio between the number of individuals of a species (Ni) taken into account, and the total number of individuals of all species combined (N).

$$Ar\ (\%) = (Ni/N) \times 100$$

Four (4) classes of relative abundance have been defined as follows:

- Very abundant species (Ar ≥ 10%)
- Abundant species (5% ≤ Ar < 10%)
- Quite abundant species (1% ≤ Ar < 5%)
- Low abundance species (Ar < 1%)

2.5.2. Frequency of occurrence

According to Dajoz [18], the frequency of occurrence (**C**) represents the ratio between the number of records where the species was found (**Pi**) and the total number of records (**P**) in each study site.

$$C(\%) = \frac{Pi}{P} x100$$

Five (5) frequency of occurrence classes were determined as follows:

- Ubiquitous species (C = 100%)
- Constant species (50% ≤ C < 100%)
- Common species (25% ≤ C < 50%)
- Incidental species (5% ≤ C < 25%)
- Rare species (C < 5%).

2.6. Statistical analyzes

The collected data were processed statistically using R 4.2.1 software. The Shapiro-Wilk test was performed to determine the normal distribution of the data. But there is an absence of normality, therefore, the Levene test was carried out to compare the variances. These two tests were done using rstatix R package. Kruskal-Wallis' test was done to compare the abundance of species in each site. The correlation of Pearson between le numbers of different especies and the climatic parameters was done by correlation R package.

3. Results

3.1. Experimental temperature and rainfall conditions

The recorded climatic data were used to represent the ombro-thermal diagram corresponding to the period of necrophagous insect trapping operations. This diagram made it possible to highlight two main seasons (Figure 3). The first is from October 2018 to April 2019. In this interval, there is no point of intersection between the temperature curve and the precipitation histogram. Precipitation was zero from December 2018 to January 2019, and remained low from February to April 2019. This period was then characteristic of a dry season (Figure 3). The second started in May and ended in September 2019. In this time interval, the temperature curve intercepts the precipitation histogram. During this period, monthly precipitation increased from 70.6 to 310 mm with a peak in August. The period May-September 2019 could therefore be considered a rainy season (Figure 3). No differences were observed between the climatic data of the two sites. These two belonged to the same agroecological zone of Côte d'Ivoire.

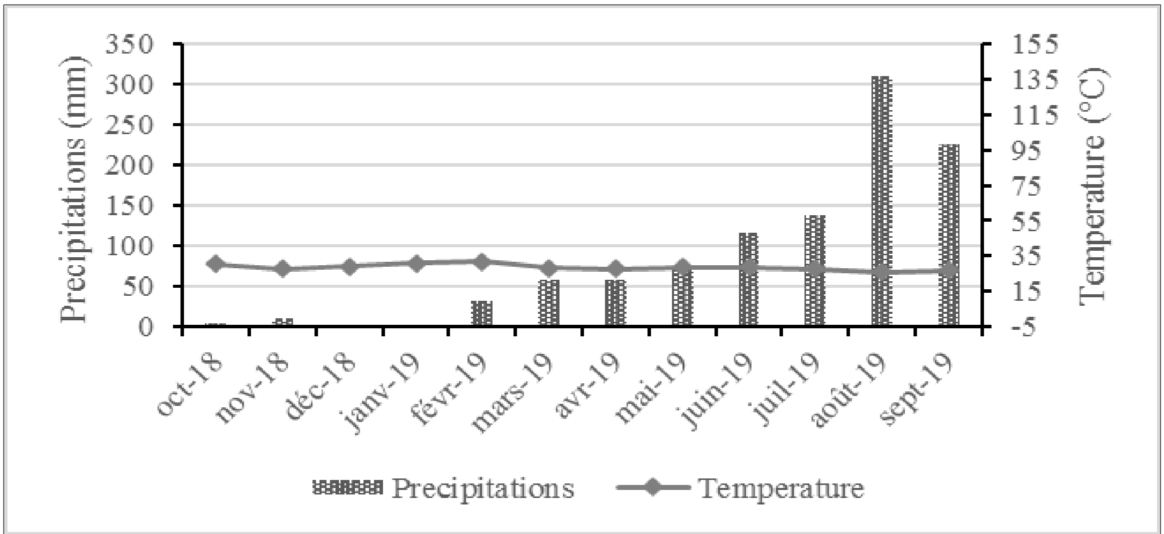

Figure 3 Ombro-thermal diagram of the trapping period

3.2. Abundance of necrophagous Diptera captured

The necrophagous Diptera belonged to the families Calliphoridae, Sarcophagidae and Muscidae. In total, 119,856 individuals were collected at the botanical garden and 74,997 individuals at Lataha, from October 2018 to September 2019 (Figure 4 and 5). The Calliphoridae family is the most abundant at the botanical garden and at Lataha (Figure 4 and 5).

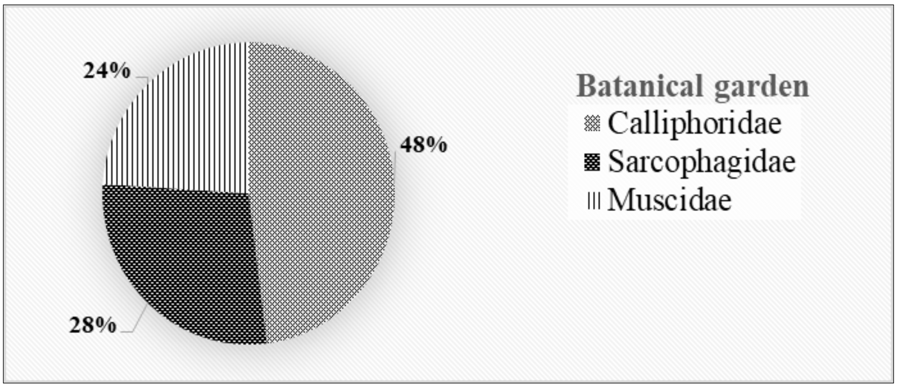

Figure 4 Proportion of the main families of necrophagous Diptera captured in the botanical garden

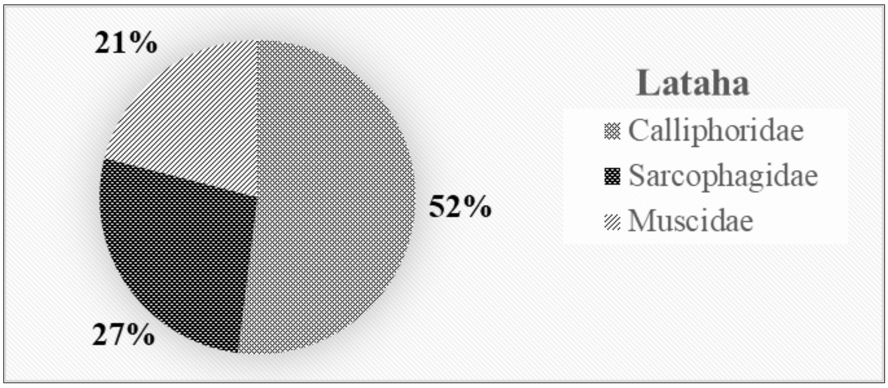

Figure 5 Proportion of the main families of necrophagous Diptera captured at Lataha

3.3. Abundance of the main species collected

Fifteen species of necrophagous Diptera were collected both at the botanical garden and at Lataha (Table 1 and 2). Shapiro-Wilk test (W = 0.79033, p-value < 0.001) indicated no normality in the distribution of abundances. This led to the test of equality of variances using the Levene test (F = 0.0008; df = 1; P = 0.9769) carried out to compare the variances, indicated that there are equality variances in species abundance at the two sites.

At both sites, fifteen species were collected and identified in three families: Calliphoridae, Sarcophagidae and Muscidae. A significant difference was observed between the abundances of species collected at the botanical garden level (X^2 = 34.758, df = 14, p-value < 0.001) (Table 1). Abundances of species collected from Lataha also indicated significant (X^2 = 42.319, df = 14, p-value < 0.001) (Table 1). *Musca domestica* was the most abundant species at both sites. *Chrysomya albiceps*, *Sarcophaga carnaria* and *Musca domestica* were omnipresent according to the calculated frequency of occurrence (C = 100%) at the different sites (Table 2).

Numbers followed by the same letters in the same column are not significantly different at the 5% threshold according to the Newman Keuls test.

Kruskal-Wallis' test followed by the Newman-Keuls test at the 5% threshold (post hoc), species trapped in the Botanical Garden: (X^2 = 34.758, df = 14, p-value < 0.001); species trapped in Lataha (X^2 = 42.319, df = 14, p-value < 0.001).

Table 1 Relative abundance of the main necrophagous species trapped in the both sites

Relative abundance (Ar%)			
Families	**Species**	**Site 1: Botanical garden**	**Site 2: Lataha**
Calliphoridae	*Calliphora vicina*	1.18 ± 0.27^{i}	4.46 ± 0.45^{gh}
	Calliphora vomitoria	4.14 ± 1.39^{hi}	5.8 ± 1.21^{gh}
	*Chrysomya albiceps***	55.74 ± 5.74^{b}	35.63 ± 1.08^{bc}
	*Chrysomya marginalis**	5.39 ± 0.91^{hi}	4.60 ± 1.28^{gh}
	Chrysomya megacephala	5.93 ± 2.13^{ghi}	6.42 ± 1.09^{gh}
	Chrysomya putoria	6.03 ± 1.43^{ghi}	2.21 ± 0.34^{h}
	Lucilia caesar	12.35 ± 3.63^{efgh}	20.46 ± 1.71^{def}
	Lucilia sericata	0.95 ± 0.14^{i}	15.08 ± 3.71^{efg}
	Protophormia terraenovae	8.25 ± 0.92^{fghi}	5.25 ± 0.26^{gh}
Sarcophagidae	*Sarcophaga africa*	23.83 ± 2.80^{cd}	31.47 ± 5.05^{cd}
	*Sarcophaga carnaria***	28.11 ± 7.59^{c}	46.69 ± 6.11^{b}
	Sarcophaga haemorrhoidalis	16.51 ± 2.84^{defg}	9.83 ± 3.17^{fgh}
	Wohlfahrtia nuba	21.93 ± 4.25^{cde}	12.00 ± 4.63^{fgh}
Muscidae	*Musca domestica***	81.43 ± 4.34^{a}	73.87 ± 7.62^{a}
	Stomoxys calcitrans	18.57 ± 4.34^{cdef}	26.12 ± 7.63^{de}

****** : Most abundant species within the same family, and omnipresent, ***** : First species to colonize the carcasses,

Table 2 Frequency of occurrence of the main necrophagous species trapped in the both sites

Frequency of occurrence C (%) of different species in each site			
Families	**Species**	**Site 1: Botanical Garden**	**Site 2: Lataha**
Calliphoridae	*Calliphora vicina*	86	65
	Calliphora vomitoria	54	78
	Chrysomya albiceps	100	100
	Chrysomya marginalis	88	78
	Chrysomya megacephala	79	81
	Chrysomya putoria	58	76
	Lucilia caesar	87	100
	Lucilia sericata	23	61
	Protophormia terraenovae	78	54
Sarcophagidae	*Sarcophaga africa*	92	90
	Sarcophaga carnaria	100	100
	Sarcophaga haemorrhoidalis	89	77
	Wohlfahrtia nuba	46	54
Muscidae	*Musca domestica*	100	100
	Stomoxys calcitrans	58	43

3.4. Variation in necrophagous Diptera population levels

The species of major medicolegal importance considered were all more abundant at the two sites with a predominance of *Sarcophaga carnaria* and *Chrysomya albiceps* and *Musca domestica*. Therefore, the numbers of species from the two sites were combined to determine their dynamics.

3.5. Population dynamics of *Chrysomya albiceps*

The weekly number of *C. albiceps* underwent significant variations during the collection period. However, the variation in these numbers did not consistently follow temperature variations (Figure 6).

Concerning the effect of precipitation, variations in the number of this species did not regularly follow its variations (Figure 6).

Concerning the influence of relative humidity, the weekly number of *C. albiceps* underwent significant variations during the collection period.

Variations in *C. albiceps* numbers consistently followed those in relative humidity (Figure 6). From the 41st to the 43rd week the number of *C. albiceps* (2199 to 1203 individuals) decreases with the drop in relative humidity (78.5 to 70.4%).

The table below (Table 3) showed correlation between *C. albiceps*' population levels and those in climatic parameters.

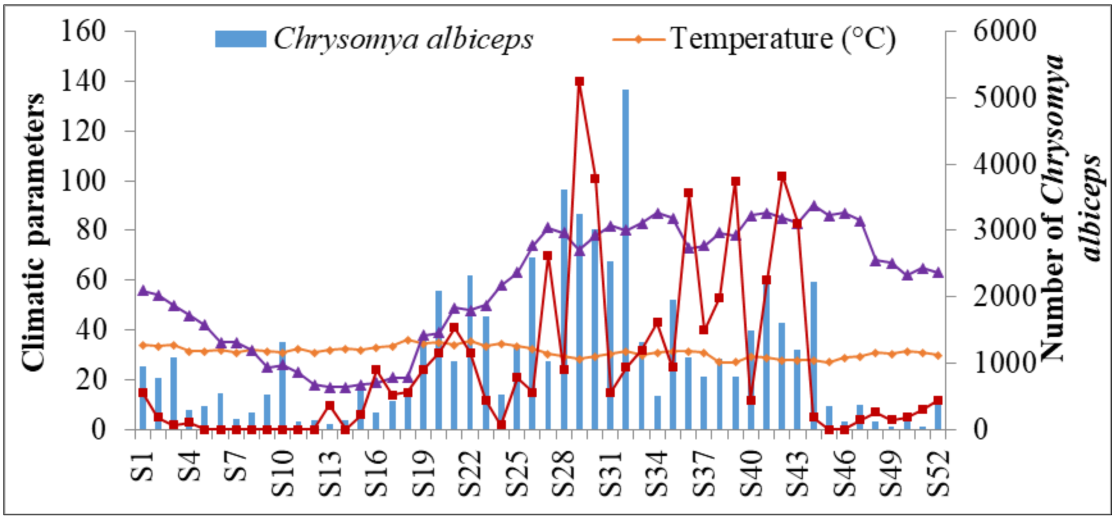

Figure 6 Variations in the weekly number of *Chrysomya albiceps* populations and the variation in climatic parameters

Table 3 Relation between le number of *Chrysomya albiceps* and the different climatic parameters

Species	Climatic parameters	r	95% CI	t(50)	p-value
Chrysomya albiceps	Temperature	-0.18	[-0.43, 0.10]	-1.29	0.406
Chrysomya albiceps	Relative Humidity	0.45	[0.20, 0.64]	3.52	0.009**
Chrysomya albiceps	Precipitations	0.37	[0.11, 0.59]	2.85	0.051

3.6. Populations of *Musca domestica*

Musca domestica did not regularly follow variations in temperature and precipitation.

Data analysis showed that variations in the number of *M. domestica* followed more or less regularly the variation in relative humidity (Figure 7). The weekly values of relative humidity evolved in the same direction as the numbers of this species.

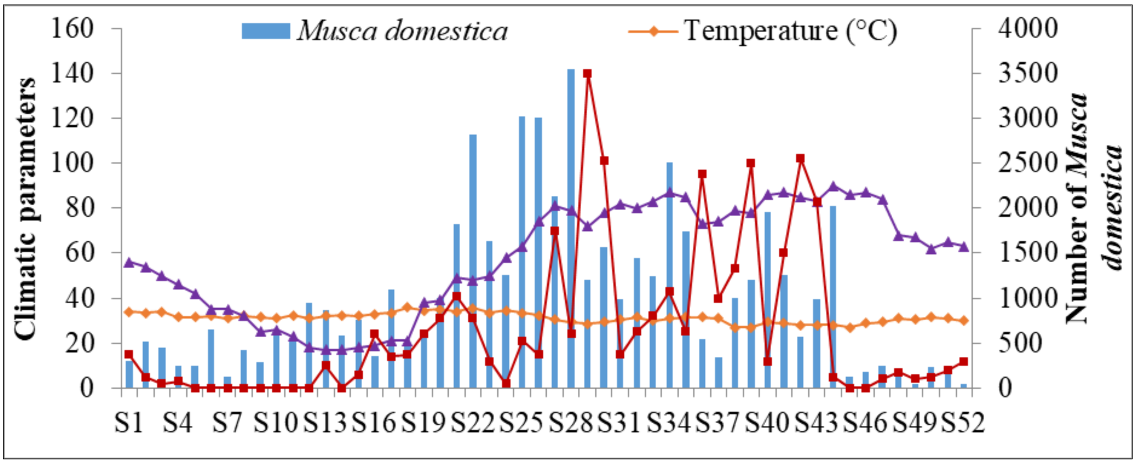

Figure 7 Variations in the weekly number of *Musca domestica* populations and variation in climatic parameters

Table 4 Relation between le number of *Musca domestica* and the different climatic parameters

Species	Climatic parameters	r	95% CI	t (50)	p-value
Musca domestica	Temperature	0.10	[-0.18, 0.36]	0.71	0.479
Musca domestica	Relative Humidity	0.31	[0.04, 0.54]	2.31	0.124
Musca domestica	Precipitations	0.23	[-0.04, 0.48]	1.71	0.282

The table below (Table 4) showed correlations between le number of *M. domestica* and the different climatic parameters.

3.7. Populations of *Sarcophaga carnaria*

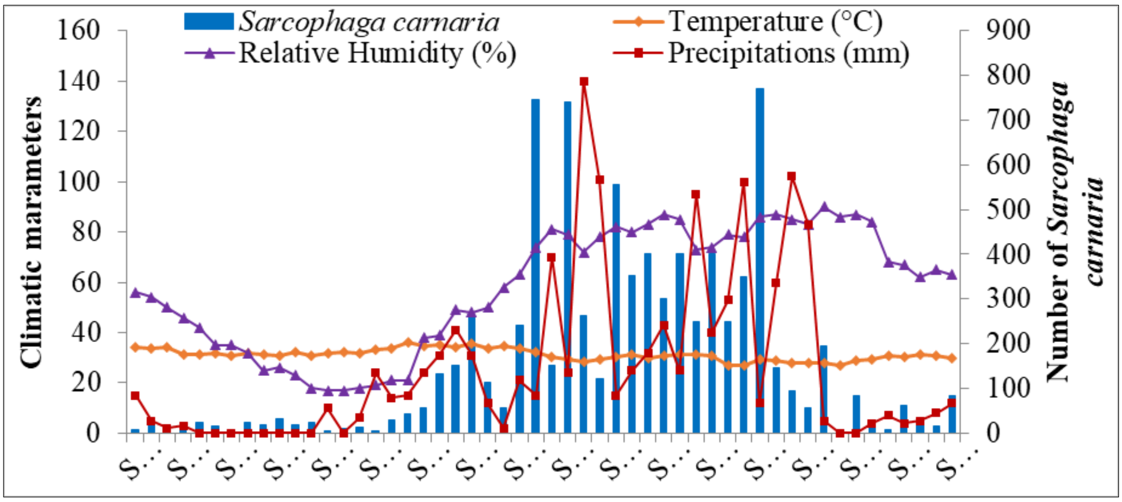

Figure 8 Variations in the weekly number of *Sarcophaga carnaria* populations, and the variation in climatic parameters

Analysis of the results showed that variations in the number of this species did not regularly follow the temperature variation (Figure 8).

Regarding precipitation, when rainfall values are zero, the number of *C. carnaria* remains very low (Figure 8). Regarding variations in weekly total precipitation, variations in *S. carnaria* numbers did not follow these variations consistently. Fluctuation in *S. carnaria* numbers regularly followed variations in relative humidity.

The table below (Table 5) showed correlations between the number of *Sarcophaga carnaria* and the different climatic parameters.

Table 5 Relation between le number of *Sarcophaga carnaria* and the different climatic parameters

Species	Climatic parameters	r	95% CI	t(50)	p-value
Sarcophaga carnaria	Temperature	-0.26	[-0.50, 0.01]	-1.93	0.236
Sarcophaga carnaria	Relative Humidity	0.50	[0.26, 0.68]	4.08	0.002**
Sarcophaga carnaria	Precipitations	0.33	[0.06, 0.55]	2.44	0.110

4. Discussion

The main species of necrophagous Diptera collected belonged to the families of Calliphoridae, Sarcophagidae and Muscidae. According to Al-Qahtni *et al*. [19], some flies such as *Musca domestica* L. (Diptera: Muscidae) and *Chrysomya albiceps* Wiedemann (Diptera: Calliphoridae) were presented on the carcasses by different developmental instars (larvae, pupae, and adults). The families of these Diptera were the first to colonize the carcasses of pigs exposed to the open air [4, 5, 20]. Their almost permanent presence in the catches made could be explained by the complexity of their olfactory system, which would capture the very weak odors emitted by the pig's liver and viscera [9, 12, 21].

Among the species of the Calliphoridae family, *C. albiceps* was the most abundant. Among the Sarcophagidae, *S. carnaria* was the most represented. *Musca domestica* and *S. calcitrans* were the species collected, belonging to the Muscidae family [7]. *Chrysomya albiceps, Sarcophaga carnaria* and *Musca domestica* were omnipresent in the different traps. The abundance of Dipteran could be explained by the substrates used in the traps, which emit odorous chemical molecules that are captured by these insects [9, 12].

The weekly counts of *C. albiceps, M. domestica* and *S. carnaria* showed significant variations during our different captures. However, variations in the number of these species do not consistently follow variations in temperature and precipitation [22]. These irregular variations could be explained by the fact that during the rainy season, it rains incessantly for several successive days or only for one to two hours, followed by very strong sunshine [6, 22]. Indeed, according to Hédouin *et al.* [23] and to Charabidze *et al.* [22] among the different climatic parameters, temperature is the factor which significantly influences the flight and reproduction activities of insects in general, and those of necrophagous Diptera in particular. Growth in *C. albiceps* numbers was achieved at temperatures between 24 and 27°C. These temperature values would be favorable for the good development of this species [24]. Significantly, increased variations in the number of *S. carnaria* were obtained at temperatures between 25 and 27°C. Indeed, according to Gilles *et al*. [25], high temperatures (above 30°C) are associated with reduced survival of immature stages, female fecundity and average longevity of females and males.

Variations in *M. domestica* numbers showed significant increases at high temperature values. According to LaBrecque *et al*. [26], the density of *M. domestica* was highest at temperatures between 25.5°C and 27.2°C. These temperatures would be favorable for the good development of this species. The work of Hafez [27] revealed that *M. domestica* was active between 28°C and 35°C. However, no correlation was observed between variations in the number of these four species and those in temperature. Although certain temperature ranges are favorable for the development of these species, it seems that certain (higher) temperature thresholds play an inhibitory role on the functioning of wing muscles, and therefore on flight activity [28]. The temperature variance/seasonality is the main factor affecting the time presence and activity of these species [8, 29]. However, the absence of correlation observed could be explained by the effect of the association of the different climatic parameters [22].

Concerning precipitation, increases in the number of these species were obtained at values between 20 and 100 mm while when the amount of rain is greater than 100 mm, the number of these species is very low or even zero. These observations could be explained by the fact that high amounts of rain reduce the flight activity of individuals of these species, due to the disturbance of the environment by the high speed of falling raindrops [28]. According to Nazni *et al*. [30], heavy precipitation (greater than 40 mm) had a negative influence on fly activity and density.

Weekly variations in the number of *C. albiceps*, *M. domestica* and *S. carnaria* consistently followed relative humidity levels. This observation is contrary to that of Koffi *et al*. [6] who, during their work in the Guinean zone of Côte d'Ivoire, found that the number of necrophagous Diptera did not regularly follow the variation in relative humidity. This difference could be explained by the fact that the relative humidity in the Guinean zone varies very little while in the sub-Sudanese zone, this relative humidity is very variable. These relative humidity levels can vary considerably, from 14% during the harmattan period to over 80% during the rainy season.

A correlation between variations in relative humidity and variations in the number of these three species was observed. This correlation could be explained by the fact that when humidity increases, individuals of this species become more active [31]. These species are widely distributed across Africa, suggesting that they have broad climatic tolerances, although their physiological tolerances to temperature extremes are not unusual [32, 33]. Also, the significant variations observed when relative humidity values were high would be due to an increase in the survival of individuals at the immature stage providing a higher number of adult individuals of this species [25, 34].

5. Conclusion

The presence or not, as well as the activity of necrophagous Diptera that can be found in a given environment, are strongly influenced, both by the attractiveness and accessibility of the carcass, and by the different natural climatic parameters that the we can record. The colonization of a carcass by necrophagous insects depends on the combination of environmental parameters (temperature, air humidity, precipitation, light) as well as the innate capacity of a given species to detect and reach the resource at the same time using mainly olfactory cues. Trapping operations for necrophagous insects carried out over an entire year showed that there was no correlation between variations in the populations of these Diptera, those in temperature and precipitation. However, there was correlation between the number of these same Diptera and the variations of relative humidity.

In sum, although the weekly population levels of these Diptera varied considerably throughout the year, these experiments showed that the main necrophagous Diptera, belonging to the families Calliphoridae, Muscidae and Sarcophagidae, were present throughout the year. Apart from relative humidity, these results show that other climatic parameters have a weak influence on the activity of the main necrophagous Diptera in the Sub-Sudanese zone of Côte d'Ivoire. Throughout the year, a carcass exposed to the open air, in the sub-Sudanese zone, is likely to be colonized by these necrophagous Diptera. This work opens up prospects for other work to understand the behavior of these Diptera when the carcass is stored in an enclosed place. The identification of competition and interspecific predation phenomena of Diptera larvae on pig carcasses exposed to the open air would allow us to better understand the abundance of *Chrysomya albiceps*.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest with respect to this article.

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