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Biodiversity and influence of the living environment of brachyuran crabs (Decapods) in the mangroves of the Cameroon coast

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Abstract: A study was conducted between November 2019 and November 2020 in several mangroves of the Cameroon coast in order to contribute to the knowledge and conservation of crab biodiversity in mangrove ecosystems. The physico-chemistry revealed a low basic water pH, high salinity, high mineralization, high temperature, characteristic of coastal tropical areas and medium to low water oxygenation. The sediments obtained were predominantly silty and sandy. Burrow densities per m² were higher in mangroves located in brackish water. Concerning the crab fauna, high abundance and species richness were obtained. The species belonging to the genera *Parasesarma*, *Perisesarma*, *Pachygrapsus* and *Uca* were the most predominant. This predominance is linked to their strong capacity to resist long periods of mangrove exodus, their varied diet, their high basal metabolism and their great osmoregulatory capacity. The impact of tides on the physico-chemistry of mangrove waters was revealed by correlation tests. The abundance of crabs within the mangrove and the density of burrows are significantly positively correlated. This study revealed a low specific diversity of crabs within mangroves located in fresh water compared to those in brackish water.

Keywords: mangrove; osmoregulation; crab; ecological indices; canonical correspondence analysis; physic-chemistry; freshwater; brackish water.

INTRODUCTION

Mangroves are among the most representative tropical ecosystems, yet they are also among those most impacted by climatic changes (sea level rise, deforestation, etc.). They comprise a significant fauna, with crabs being the most significant member. Due to their mode of nutrition and habitats, crabs do in fact play a significant part in the structure and overall functioning of the mangrove (Koo et al. 2007, Krishnan et al. 2007, Kristensen 2008). As they are in charge of element transfer and maintain functional variety and biochemical variability in the sediments, they are a true member of the engineer species within the mangrove ecosystem (Jones et al. 1994, Coleman and Williams 2002, Kristensen 2008). Their bioturbatory activity related to burrow construction modifies the structure of the sediment and influences the nutrient fluxes themselves (Cadamuro 1999). By determining its macroporosity, they aerate the hydromorphic sediment of mangroves, thus promoting aerobic processes such as nitrification (Herteman 2010). The volume released by burrowing increases the infiltration capacity of water and thus promotes the possibilities of exchange between pore water and sediment (Stefano et al. 2009). Furthermore, by burying and ingesting fallen mangrove leaves, crabs participate in the decomposition of organic matter and contribute to the enrichment of the sediment with nutrients (Stefano et al. 2009). Finally, the strong predation exerted by crabs on propagules is an important pressure factor in the recruitment of young mangroves, and thus contributes to the structuring of the vegetation. Despite these functions, mangroves are increasingly subject to strong anthropogenic pressures (fishing, logging, various types of pollution, etc.), to which are added the effects of climate change and coastal erosion (PANGIRE 2009). In addition, the ever-increasing demographic pressure, coupled with difficult living conditions, pushes coastal populations towards abusive exploitation of mangrove areas, which leads to habitat loss. According to Sinsin et al. (2018), the loss of mangrove habitats is the main threat for the crab fauna. This loss of habitat and the various pressures exerted on it, lead to a degradation of water quality and consequently an imbalance in the distribution of the carcinological fauna of mangroves. Several studies on the mangrove crab fauna have been carried out in Africa and in the world. These include the work of Gillikin et al. (2004) and Cannicci et al. (2009) in Kenya, Ashton (2002, 2003) in Malaysia and Esenowo et al. (2010) in Nigeria. These works showed that the mangrove is an ecosystem that is rich in crab biodiversity and that the families Sesarmidae, Grapsidae and Ocypodidae were the most represented in this ecosystem. To our knowledge, the only existing study of the genus in Cameroon, to our knowledge, is that of Ngo-Massou et al. (2014). This study was

carried out only in the mangroves of the Wouri River (freshwater mangroves) and revealed a low specific richness of crabs. In order to understand the impact of abiotic factors on the structuring of the crab fauna within the mangrove, the current study aims to assess the general biodiversity of crabs within several types of unstudied mangroves along the Cameroon coast. The aim is to evaluate the variation of the crab fauna according to the type of mangrove and its intrinsic properties.

MATERIALS AND METHODS

STUDY OF THE ENVIRONMENT

Among the three major mangrove areas of Cameroon, the mangrove of the Cameroon estuary was chosen for this study due to its large surface area and its heterogeneity. Sampling was carried out in the locality of Manoka and on Mouanko Island (Fig. 1). This coastal region has a tropical coastal climate with two seasons, a long wet season from March to October and a short dry season from November to February (Suchel 1972, Sighomnou 2004). The soils are ferralitic and hydromorphic in nature with vegetation mainly dominated by *Rizophora racemosa* and *Avicenia germinans* (Ndongo 2001). Fourteen (14) sampling stations were selected based on criteria such as the aquatic environment in which the mangrove is found, the presence of a possible source of pollution and the distance between the stations (Fig. 1). These various criteria are responsible for the heterogeneity of stations. Depending on the aquatic environment, the sampling stations were partitioned into two groups. The first group consists of stations located in freshwater influenced zones, especially in the Kwa-Kwa and Sanaga Rivers, named ED1 to ED4. The second group concerns stations located in marine water influenced zones, located in the Cameroon estuary and indexed from ES1 to ES10.

SAMPLING METHODS AND PARAMETERS OF INTEREST

Sampling was carried out over 13 months from November 2019 to November 2020 at high and low tides. Several environmental parameters were studied, including physico-chemical and granulometric parameters, burrows and crab fauna. With regard to the physico-chemical parameters of the water, the pH, temperature (°C), salinity (PSU) and dissolved oxygen (%) were measured and tested following APHA (1998) and Rodier et al. (2009). The particle size

distribution of the sediment was carried out using the Robinson Kohn pipette method and a 200 μm mesh size sieve. The density, opening diameter and depth of the burrows were evaluated over an area of 100 m^2 . For this purpose, at each station an area of 1 m^2 was marked out using a graduated string.

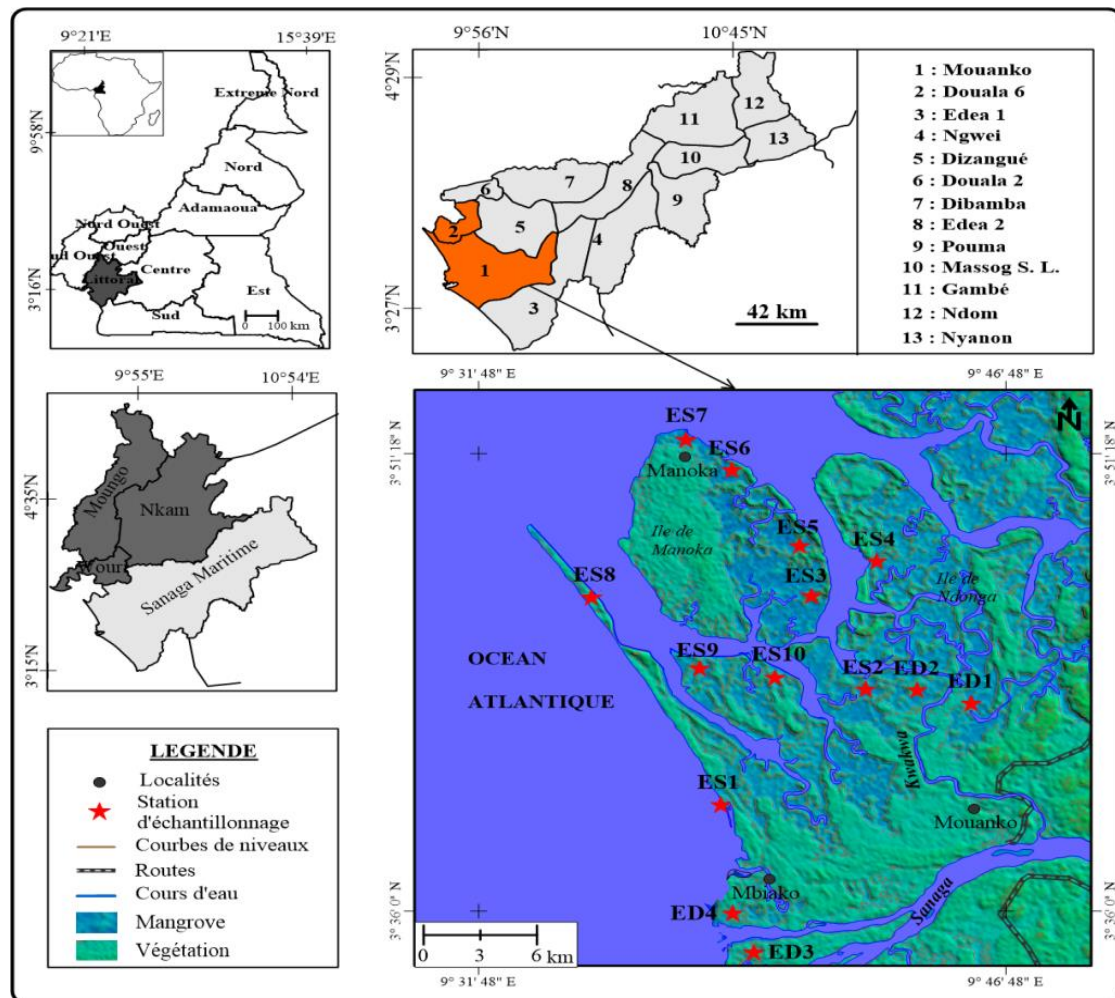


Fig. 1 : Distribution map of sampling stations.

Each present burrow was then counted, and its diameter and depth were measured. Crabs sampling was carried out using the multi-habitat approach proposed by Stark et al. (2001), adapted from Barbour et al. (1999), which consists of carrying out a total of 20 net shots in different micro-habitats at each station. In this case, the equipment used for the sampling of crabs was a streamer-type sampler. Sampling was completed by burrow excavations (Mouton and Felder 1996) and hand-captures (Monteforte 1987) wherever possible. Excavations were done when the substrate was soft, while hand-catching was done for tree crabs (Skov and Hartnoll 2001). The crab fauna that was obtained was fixed and then preserved in 95° alcohol,

whereas identifications were made under a stereoscopic microscope using the keys and works of Monod (1980), De Moor and Day (2002), and Poupin et al. (2010).

STATISTICAL ANALYSIS

The occurrence frequency (F) of species expressed as a percentage was calculated according to the formula of Leclercq (2001):

$$F = \frac{P_i \times 100}{P_t},$$

where P_t is the total number of samples and P_i is the number of samples where species i is present. The frequency of occurrence (F) provides information on the constancy of a species in a given habitat without any indication of its quantitative importance (Dajoz 2000). A distinction is made between omnipresent species, which appear in all the surveys (100%); regular species, present in 75 to <100% of the surveys; constant species, present in 50 to <75% of the surveys; accessory species present in 25 to <50% of the surveys and rare species present in less than 25% of the surveys (Dufrene and Legendre 1997). The specific richness (S) indicates the number of species recorded in a given environment at a given time and provides information on the variability of the ecological niches of a station (Alliaume et al. 1990). The Shannon Weaver (1963) diversity index (H') was calculated as follows:

$H' = -\sum_{i=1}^S P_i \log_2 P_i$; It was used to highlight the overall diversity of the stand. This index measures the degree of organization of the stand (Krebs 1989, Tonkin et al. 2013). The equitability index (J) (Pielou 1969) was calculated as follows: $J = H' / \log_2(S)$; It allowed us to study the regularity of species distribution. This index varies between 0 and 1 and reflects the quality of organization of a stand (Amanieu and Lasserre 1982). To determine if the values of the environmental parameters, specific richness, Shannon Weaver diversity index and Pielou equitability index differ between sampling sites and between seasons, the non-parametric statistical test of Kruskal-Wallis was used. When the Kruskal-Wallis test was significant, the Mann Whitney U test was applied to compare two by two the sampling site values and seasonal values to understand where the parameters differ significantly. The Spearman's rank non parametric correlation coefficient (Lehman 2005), was used to quantify the relationship between the physico-chemical parameters and fauna of crabs. For all statistical test a significance level of $\alpha=0.05$ was used. Canonical Correspondence Analysis (CCA) was applied to relate the abundances of the main crab taxa to environmental variables

after undergoing a logarithmic transformation [$\log(X + 1)$] (Ter Braak and Smilauer 2002). This enabled the identification of abiotic factors influencing the abundance of taxa. The analysis was performed using CANOCO for Windows version 4.5 (Ter Braak and Smilauer 2002).

RESULTS

PHYSICO-CHEMISTRY OF MANGROVE WATERS

The temperature in the mangroves varied between 25.4 and 32.8°C, values obtained respectively at stations ES4 in August (high rainfall season) and ES1 in April (low rainfall season) with an average of 28.60 \pm 1.58°C (Fig. 2A). Couple of stations have been compared in terms of their mean temperatures over the 13 months by means of the Mann Whitney U test. The test revealed statistically significant differences between the stations: ED1 and ES7 (p-value=0.01), ED4 and ES2 (p-value=0.002), ED2 and ES8 (p-value=0.01), and between ES4 and ES7 (p-value=0.03). Comparing the mean temperatures observed in all the stations between the two seasons (high rainfall and low rainfall), no significant difference was observed (p-value=0.53).

The values of the pH varied between 5.85 and 9.87, with an average of 7.59 \pm 0.65. The patterns of pH variation in both fresh and brackish water were similar (Fig. 2B). Within the freshwater mangroves, the pH varied between 5.85 and 9.55 (Fig. 2B), values obtained at the station ED2 in November 2019 during high tide, and at the station ED1 in October 2020 during low tide, respectively. These values fluctuated around a mean of 7.10 \pm 0.77. However, there is no significant difference between the mean values obtained at the different couple of stations in freshwater mangroves (p-value=0.57). For mangroves located in brackish water, the values varied between 6.94 and 9.87, with an average of 7.71 \pm 0.52. The highest pH value was obtained at station ES3 in October (rainy season) during low tide. The Kruskal-Wallis test did not show any statistically significant difference between stations (p-value=0.48). However, significant differences were obtained between sampling months (p-value=2.32 $\times 10^{-17}$). The values of dissolved oxygen saturation varied between 8.3 and 97.6%. The lowest percentages of dissolved oxygen saturation were obtained in November 2020 at stations ED3, ED4 and ES1 (O₂<17%), while station ED3 (September 2020) recorded the highest percentage of dissolved oxygen saturation (Fig. 2C). No significant differences were found between stations (p-value=0.07). However, significant differences were found between

several months (p-value=0.00001). The salinity values were low in the stations located in freshwater mangroves (from 9.6 to 703 PSU) (Fig. 2D1), in contrast to the values obtained in brackish water (from 102 to 14600 PSU) (Fig. 2D2), with averages between 27.85 ± 18.28 PSU and 5570.44 ± 4103.77 PSU for freshwater and brackish water, respectively.

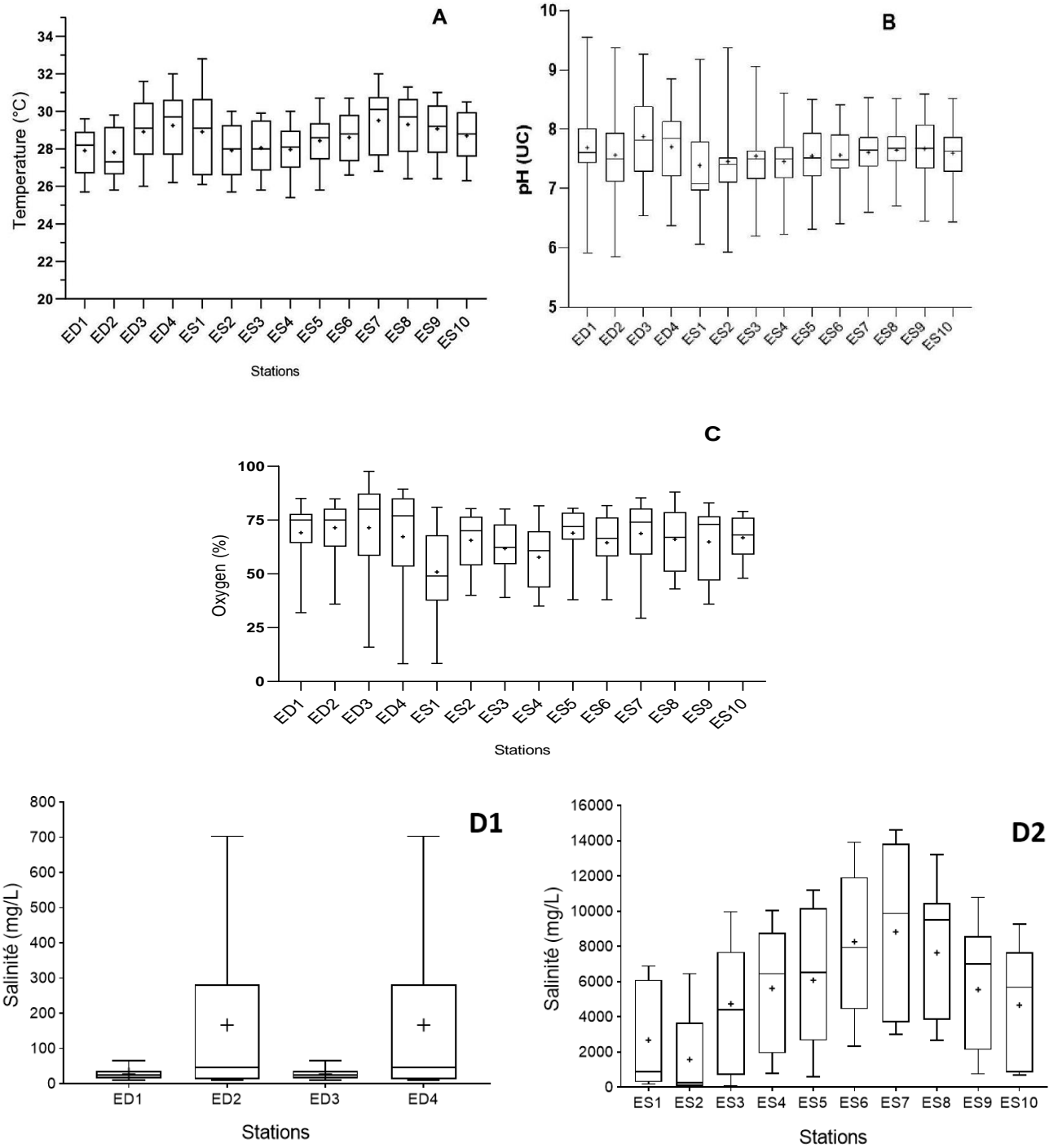


Fig. 2 : Spatial variations of temperature (A), pH (B), oxygen below (C) and salinity (D) (D1=freshwater mangrove and D2=brackish water mangrove).

There was no significant difference between freshwater stations (p-value=0.69), however several significant differences were obtained between the salinity values within the mangroves located in brackish water (Table 1).

Table 1 : Significant differences in salinity observed between sampling stations.

	ES1	ES2	ES3	ES6	ES7	ES8
ES3		0,0089				
ES4	0,01	0,0012				
ES5	0,013	0,0014				
ES6	0,0017	0,00027	0,04			
ES7	0,0029	0,00027	0,04			
ES8	0,004	0,0004				
ES9	0,01	0,0017				
ES10	0,04	0,0034		0,027	0,031	0,035

GRANULOMETRY

The nature of the sediments varied according to the stations and the proximity or otherwise of the Atlantic Ocean. Two types of substrates, sandy and silty, predominated in the brackish and freshwater mangroves. Stations ES1, ES2, ES8, ES9, ES10, located in Mouanko and stations ES6 and ES7 located on Manoka Island had a sandy substrate, while stations ED1, ED2, ED3, ED4, located in Mouanko and stations ES3, ES4, ES5, located in Manoka had a silty substrate (Table 2). All the freshwater mangrove stations had silty substrates (Table 2).

MANGROVE CRAB FAUNA

A total of 883 specimens of brachyuran crabs were collected during the study period. Twenty-six species belonging to six families and fourteen genera were identified (Table 3). The three most abundant families are the Sesarmidae (498 individuals, representing 56.40% of the total crab abundance) (Fig. 3A), the Grapsidae (238 individuals, accounting for 26.95%), and the Ocypodidae (102 individuals, 11.55% of the overall crab fauna). The families Portunidae, Geryonidae and Xanthidae were the less abundant, with 2.38%, 1.59 % and 1.13% of the overall crab biodiversity respectively. The genera *Parasesarma* (26.73%) (Family Sesarmidae), *Pachygrapsus* (19.48%) (Family Grapsidae), *Uca* (10.64%) (Family

Ocypodidae) and *Perisesrama* (10.42%) (Family Sesarmidae) constitute the most representative crab fauna within the studied mangroves (Fig. 3B). On the other hand, individuals belonging to the genera *Metagrapsus*, *Minuca*, *Metopograpsus* and *Tubuca* were the less abundant with 0.8%, 0.68, 0.56% and 0.23% of the total abundance of the fauna collected, respectively.

Table 2 : Particle size analysis in the different stations of interest.

Stations	Grain size (%)					Nature of substrate
	Sg	Sf	Ar	Lf	Lg	
ED1	4.05	1.11	20.54	52.57	21.73	Silty
ED2	11.27	3.67	31.43	48.45	5.18	Silty
ED3	3.45	9.32	42.15	39.01	6.07	Silty
ED4	2.76	10.43	26.10	43.98	16.73	Silty
ES1	75.61	3.10	8.72	11.20	1.37	Sandy
ES2	45.36	14.85	13.00	21.35	5.44	Sandy
ES3	1.76	1.08	27.52	47.93	21.72	Silty
ES4	2.97	6.18	23.31	37.95	29.59	Silty
ES5	3.17	1.98	21.19	51.09	22.57	Silty
ES6	38.34	29.78	2.11	11.45	18.32	Sandy
ES7	56.25	40.80	1.52	1.30	0.15	Sandy
ES8	59.75	30.47	5.08	4.00	0.70	Sandy
ES9	51.09	11.09	5.40	23.11	9.31	Sandy
ES10	40.73	13.82	6.23	20.50	18.72	Sandy

Ar= Clay (element with a diameter less than 2 μm) ; Lf = Fine silt (element with a diameter between 2 and 10 μm) ; Lg = Coarse silt (element with a diameter between 10 and 20 μm) ; Sf = Fine sand (element with a diameter between 20 μm and 0.2 mm) ; Sg = Coarse sand (element with a diameter between 0.2 mm and 2 mm).

DENSITY, DIAMETER AND DEPTH OF CRAB BURROWS

The burrow density obtained varies between 7 and 103 T/m² around an average of 62.21±33.19 T/m². In freshwater mangroves it oscillates around 9.25±15.03 T/m² while in brackish water it varies around 39.85±30.28 T/m². The lowest burrow densities were obtained at stations ED1 and ED3 (7 T/m²) in the freshwater mangroves. On the other hand, stations ES2 (103 T/m²) and ES7 (95 T/m²) located in brackish water mangroves (Cameroon estuary) were the most densely populated in terms of number of burrows per m². Nevertheless, no significant difference exists between the densities obtained in freshwater and those obtained in brackish water (p-value=0.21).

Table 3 : Biodiversity of brachyuran crabs obtained in the mangroves studied. T = total workforce. Each item represents the number of species.

Order	Family	Genus/Species	ED1	ED2	ED3	ED4	ES1	ES2	ES3	ES4	ES5	ES6	ES7	ES8	ES9	ES10	T
		<i>Geograpsus</i> sp.	3	10	5	3	2	18	7	0	0	0	0	5	0	1	54
		<i>Pachygrapsus propinquus</i>	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2
		<i>Pachygrapsus gracilis</i>	0	0	0	0	0	0	2	1	0	18	0	0	20	11	52
		<i>Pachygrapsus</i> sp.	0	0	0	0	0	29	0	9	6	38	0	33	1	2	118
		<i>Metagrapsus</i> sp.	0	0	0	0	0	0	7	0	0	0	0	0	0	0	7
	Grapsidae	<i>Metopograpsus</i> sp.	3	0	0	1	0	0	0	0	0	0	1	0	0	0	5
		<i>Sesarma rubinofforum</i>	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2
		<i>Sesarma reticulatum</i>	0	0	0	0	0	0	3	0	0	0	0	0	0	0	3
		<i>Guinearma</i> sp.	0	0	5	0	10	0	38	0	0	0	0	0	0	0	53
		<i>Guinearma alberti</i>	0	0	0	0	0	23	0	10	0	0	0	0	0	0	33
		<i>Sesarma</i> sp.	0	2	0	0	0	18	2	4	21	0	3	0	18	11	79
		<i>Parasesarma plicatum</i>	0	0	0	3	14	0	8	47	0	4	0	0	0	0	76
		<i>Parasesarma longicristatum</i>	0	0	0	0	0	0	0	0	0	0	0	7	0	0	7
		<i>Parasesarma samawati</i>	0	0	0	0	0	0	0	0	0	0	0	7	0	0	7
		<i>Parasesarma asperum</i>	0	0	9	0	0	0	0	0	0	0	0	0	0	0	9
		<i>Parasesarma</i> sp.	0	2	1	5	43	5	12	6	23	7	0	7	9	17	137
		<i>Perisesarma indiarum</i>	0	0	0	0	0	0	0	4	0	0	0	24	0	0	28
	Sesarmidae	<i>Perisesarma</i> sp.	6	3	0	0	21	22	0	9	3	0	0	0	0	0	64
	Portunidae	<i>Callinectes sapidus</i>	0	0	0	0	0	0	0	0	0	0	21	0	0	0	21
		<i>Uca</i> sp.	0	0	0	0	0	2	0	0	0	0	6	0	0	0	8
		<i>Uca major</i>	0	0	0	0	0	0	0	0	0	0	80	0	0	0	80
		<i>Uca neocultrimana</i>	0	0	0	0	0	0	0	0	0	6	0	0	0	0	6
		<i>Tubuca</i> sp.	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2
	Ocypodidae	<i>Minuca</i> sp.	0	0	0	0	0	2	0	0	0	4	0	0	0	0	6
	Xanthidae	<i>Leptodus</i> sp.	0	0	0	0	0	0	0	0	0	10	0	0	0	0	10
Decapods	Geryonidae	<i>Geryon</i> sp.	4	0	0	0	0	0	0	0	0	0	9	1	0	0	14

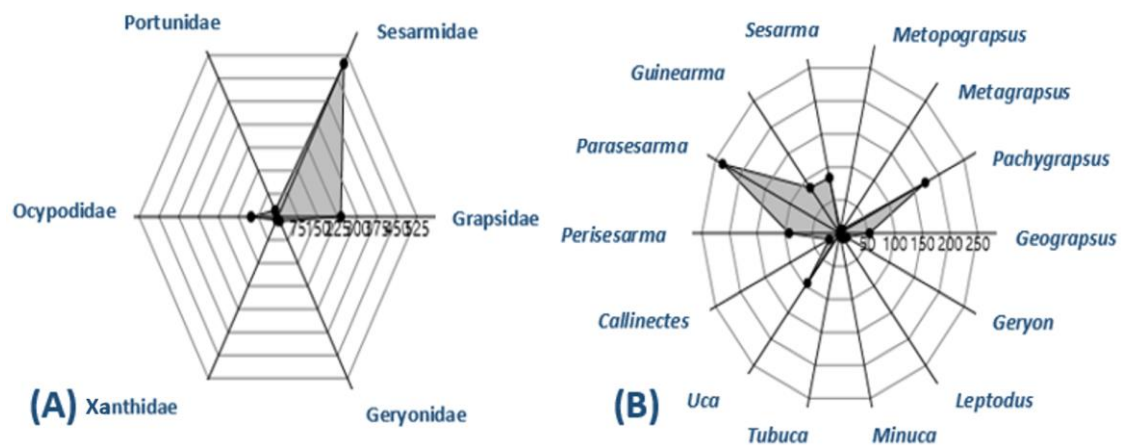


Fig. 3 : Abundance of crab families (A) and genera (B) in the mangroves studied.

Three classes of burrows could be distinguished according to the diameter of their opening; small burrows ($\phi \leq 5$ mm), medium burrows ($5 \text{ mm} \leq \phi \leq 2 \text{ cm}$) and large burrows ($\phi \geq 2 \text{ cm}$) (Table 4). Most burrows within the surveyed mangroves are large burrows. There is a significant difference in density between small and medium burrows (p-value=0.01), and between small and large burrows (p-value=0.002). Average burrow depths ranged from 4.5 ± 2.12 cm to 19.5 ± 3.53 cm. Stations ED1, ED3 and ED4, located in freshwater mangroves, had the lowest depths (smaller than 5.5 cm). In contrast, all burrows located in brackish water mangroves in both Mouanko and Manoka had mean depths greater than or equal to 10 cm, except for station ES8 whose mean depth is 9.75 ± 1.06 cm. The burrow diameter and depth are not significantly different at all stations (p-value=0.51).

Table 4 : Burrow morphology and density. These figures represent the number of burrows obtained.

	Diameter (ϕ)			Density (m^2)	Depth (cm)
	$\phi \leq 5 \text{ mm}$	$5 \text{ mm} \leq \phi \leq 2 \text{ cm}$	$\phi \geq 2 \text{ cm}$		
ED1	1	2	4	7	5.5 ± 0.70
ED2	0	6	44	50	11 ± 0.00
ED3	2	4	1	7	4.5 ± 2.12
ED4	3	6	1	10	5 ± 1.41
ES1	7	20	55	82	19.5 ± 3.53
ES2	2	21	80	103	12.75 ± 2.47
ES3	26	4	51	81	13.75 ± 0.35
ES4	11	63	19	93	18 ± 0.00
ES5	2	19	33	54	10.75 ± 1.06
ES6	14	35	22	71	15 ± 0.00
ES7	10	45	40	95	17.5 ± 2.12
ES8	8	21	27	56	9.75 ± 1.06
ES9	12	41	32	85	15.16 ± 1.04
ES10	1	12	64	77	12.60 ± 3.51
Total	99	299	473		

No ubiquitous species were obtained in the mangroves studied, except species *Geograpsus* sp. in freshwater mangrove area (Fig. 4). The species *Parasesarma* sp. was the only regular species, as it was present at 85.71% of the stations investigated. *Geograpsus* sp., *Sesarma* sp. and *Pachygrapsus* sp. are constant species as they are present at 50 to 75% of the stations. *Pachygrapsus gracilis*, *Parasesarma plicatum* and *Perisesarma* sp. are accessory species as they are present at 25 to 49% of the surveyed stations (Fig. 4).

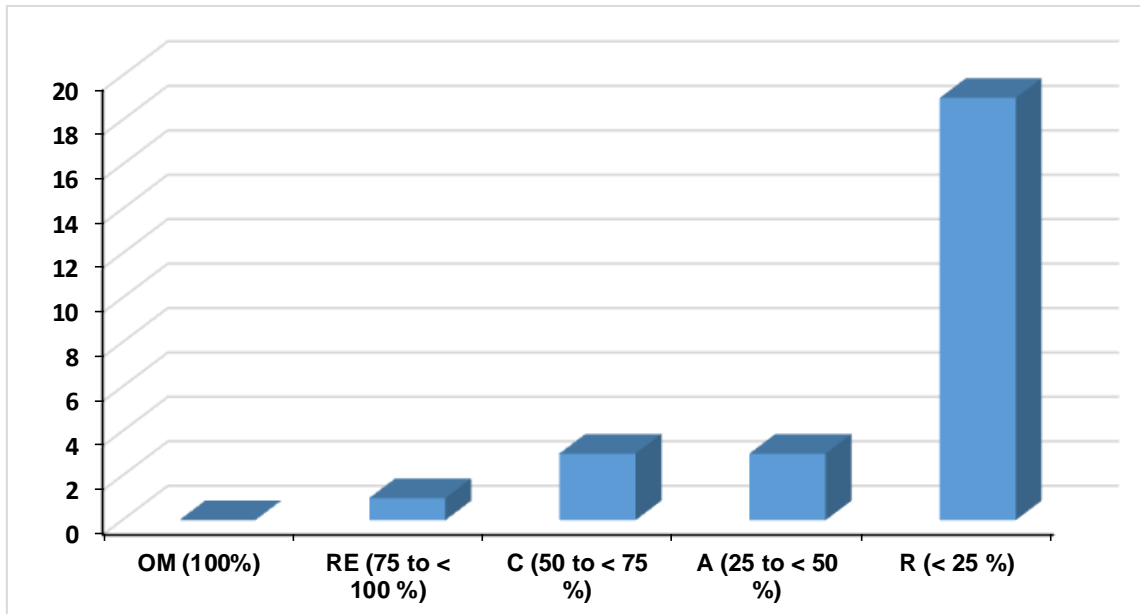


Fig. 4 : Frequency of occurrence of crab species (A=Accessory species ; C=Constant species ; OM=Omnipresent species ; R=Rare species ; RE=Regular species).

The remaining 19 species, representing 75% of the observed crab biodiversity, belong to the category of rare species since they are present in less than 25% of the stations.

ECOLOGICAL INDICES

The calculation of specific richness (Table 5) reveals that the spatial distribution of the 26 species obtained during the study period is very heterogeneous. The stations with the highest specific richness are located in the brackish water mangroves (ES2, ES3 and ES4 with 9, 8 and 8 species, respectively). The first four stations located in freshwater were the poorest (4 species each). Despite the dissimilarity between the specific richness obtained in the two types of environment, no significant difference was recorded between values of specific richness within the stations (p -value=0.061). The Shannon Weaver species diversity index varied between 1.61 and 2.70 bits/ind. In freshwater the average diversity was 1.76 bits/ind compared to 2.05 in brackish water mangroves. Stations ES2, ES3 and ES6 located in brackish water mangroves were the most diversified with 2.70, 2.32 and 2.31 bits/ind, respectively. However, station ED2 located in freshwater, stations ES7 and ES9 located in brackish water were the least diversified. Nevertheless, no significant difference was obtained between the different values of the Shannon Weaver diversity index within the stations (p -value=0.11).

Pielou's equitability index (J) indicates that the crab fauna within the mangroves is inequitably distributed as the values obtained within the study stations tend towards 0, except for station ES2 (Table 5). The equitability index presents no significant differences between stations (p-value=0.40).

Table 5 : Specific richness, Shannon-Weaver diversity and Pielou equitability indices.

	ED1	ED2	ED3	ED4	ES1	ES2	ES3	ES4	ES5	ES6	ES7	ES8	ES9	ES10
Specific richness (S)	4	4	4	4	6	9	8	8	4	7	7	7	4	5
Shannon and Weaver diversity index (H')	1.93	1.61	1.7	1.82	2	2.7	2.32	2.23	1.64	2.31	1.61	2.26	1.62	1.87
Pielou equitability indices (J)	0.41	0.34	0.4	0.38	0.42	0.6	0.49	0.47	0.34	0.49	0.34	0.48	0.34	0.39

RELATION OF THE ENVIRONMENT ON THE BIOLOGY AND DISTRIBUTION OF CRABS

Results of Canonical Correspondence Analysis showed four groups with a total inertia of 71.40% (Fig. 5). The positive part of axis 1 is composed of the genera *Callinectes*, *Uca* and *Leptodus*. These are taxa that dig medium-sized burrows (5 mm-2 cm) and are mainly influenced by high salinity and temperature. These genera are characteristic of stations ES6 and ES7. The negative part of axis 1 consists of stations ES3, ES4 and ES5 characterised by coarse silty substrates (Lg), and are mainly home to species belonging to the genera *Geograpsus*, *Metagrapsus* and *Guinearma*.

Concerning axis 2, its negative part is dominated by species belonging to the genera *Metopograpsus* and *Geryon*. These taxa would be influenced mainly by high pH, dissolved oxygen, clay (Ar) and fine silty (Lf) substrates. These characteristics were observed at stations ED1, ED2, ED3 and ED4. Finally, the positive part of axis 2 is dominated by species belonging to the genera *Pachygrapsus*, *Tubuca*, *Sesarma*, *Parasesarma*, *Perisesarma* and *Minuca*. They are positively correlated with high burrow densities and depths, small (<5 mm) and large (>2 cm) burrow opening diameters and sandy substrates. These characteristics were mainly observed at stations ES1, ES2, ES8 and ES9 (Fig. 5).

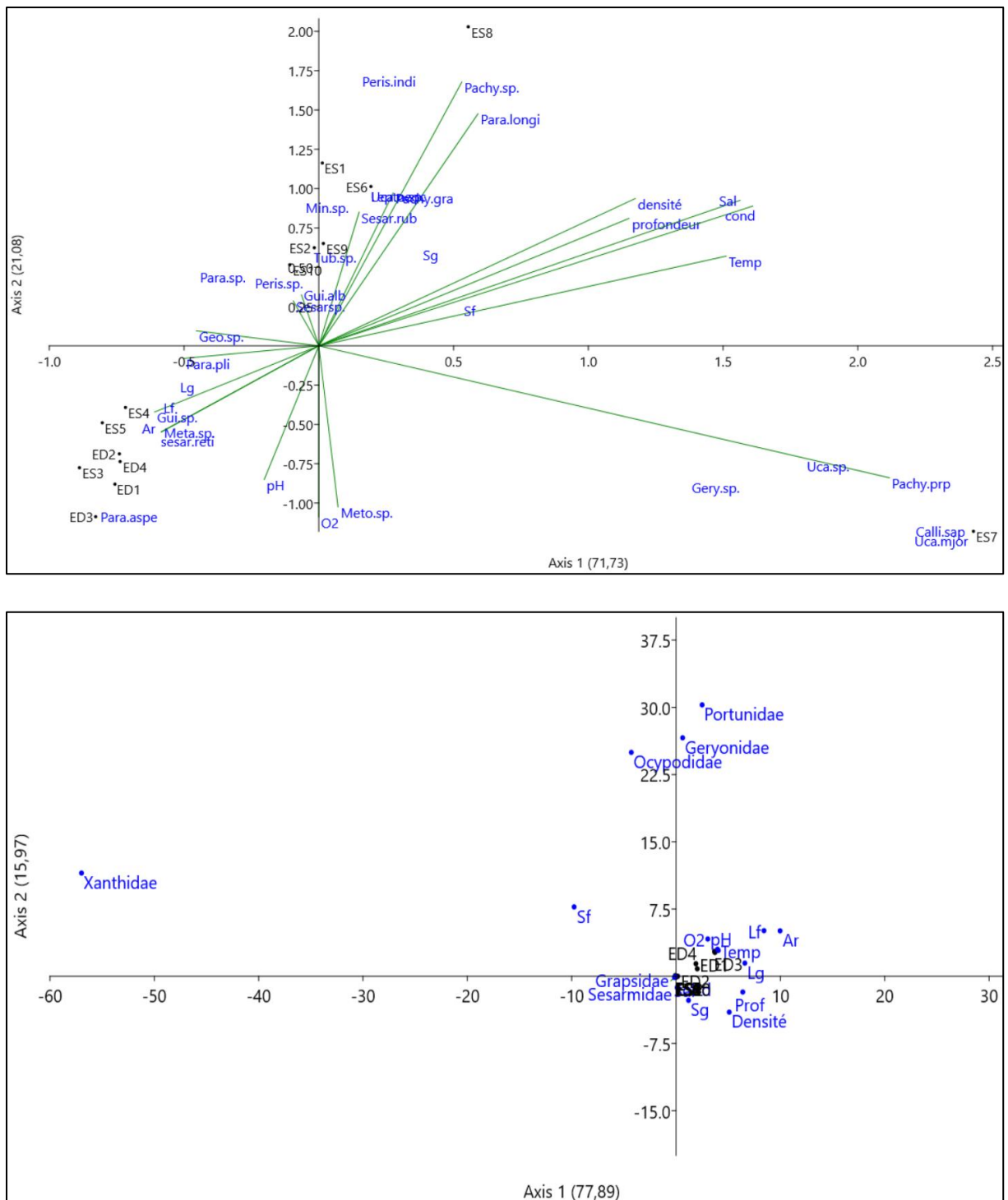


Fig. 5 : Canonical Correspondence Analysis between biotic and abiotic parameters of the mangrove (Ar=clay ; Lf=fine silt ; Lg=coarse silt ; Sal=salinity ; Sf=fine sand ; Sg=coarse sand ; Temp=temperature).

Positive and statistically significant Spearman correlations were obtained between the species *Callinectes sapidus* and sandy substrates ($r=0.209$; $p<0.01$), between species of the genus *Pachygrapsus* and salinity ($r=0.156$; $p<0.05$), between species of the genus *Leptodus* and salinity ($r=0.256$; $p<0.05$) and between the genus *Uca* and salinity ($r=0.450$; $p<0.05$). A weak negative correlation was obtained between species of the genus *Perisesarma* and high burrow depths ($r=-0.146$; $p<0.01$).

DISCUSSION

PHYSICO-CHEMISTRY OF MANGROVE WATERS

Globally, the temperatures of the mangrove waters were high during the study period. These high temperature values are features of the climate of tropical coastal regions, and could also be due to the contribution of warm water by the tides within the mangroves. According to Peltre (1983), tropical marine waters have high temperatures compared to other aquatic environments. However, the temperature differences between the different sites are due to the sampling periods. This could be explained by the fact that water temperatures are also a function of room temperatures. The water in the mangroves surveyed showed a slightly basic average pH. This basicity would be due to the constant input of water rich in alkaline ions by the tides. According to Renaudin (2001), water from the marine environment has a basic pH that is between 7.5 and 8.4. Furthermore, the lowest values obtained in freshwater confirm the low impact of tides at stations located in freshwater mangroves. These values are higher than those obtained by Ngo-Massou et al. (2014) in the mangroves of the Wouri River.

Salinity is very high within the mangroves compared to those obtained by Ngo Massou et al. (2014) in the Douala mangroves. However, significant differences between the stations located in fresh water and those located in brackish water (depending on the distance from the Atlantic Ocean) were found. These differences are in agreement with the classification of Renaudin (2001), according to which salinity in freshwater is below 1000 PSU and above this value in brackish water. The high concentrations of mineral salts can be explained by the proximity of the stations to the Atlantic Ocean. Indeed, distance calculations revealed that stations ED1 to ED2 are located approximately 17 km from the Atlantic Ocean, while stations ES1 to ES10 are in average located approximately 7.5 km from the Atlantic Ocean. The low dissolved oxygen saturation levels obtained in this study are similar to those revealed within the mangroves of the Bijagos Archipelago (25-60% oxygenation) by Gallois et al. (2006). This characteristic of low oxygenation could be explained on one hand by the low

photosynthetic activity due to the presence of mangrove foliage which reduces the incidence of light. Moreover, the decline or poverty of oxygen in mangroves may be due to the decomposition of organic matter and the arrival of oxygen-poor water through the tides (Villanueva 2004). On the other hand, it could be strengthened by the fact that the weak mixing of water within the mangrove (Marchand et al. 2004). Nevertheless, this phenomenon of mixing, induced by the tides, could provoke high percentages of dissolved oxygen saturation (97.60%) according to the periods of the day and the year, which would explain the significant difference between the sampling periods.

GRANULOMETRY

The silty and sandy nature of the sediment within the mangroves studied is similar to that obtained by Herteman (2010) in three mangrove facies on the island of Mayotte (France). This sediment texture is different from that generally encountered in aquatic environments located on land (Ngon Ngon et al. 2005) where clayey sediments (size < 2 μm) are encountered. Within the mangrove, sediments play an important role in biogeochemical processes. Indeed, sands and silts, which are generally larger in size than clay, have better infiltration and permeability capacities (Saenger 2002). These processes of infiltration and high permeability of silts and sands, combined with the bioturbatory activities of crabs, are responsible for the circulation of oxygen and nutrients within the sediments in the mangrove (Nordhaus et al. 2009). The silty nature of the sediments in all freshwater mangroves and the sandy nature of the sediments in brackish water mangroves is mainly due to the impact of land erosion. This phenomenon explains the granulometric gradient from the land to the lagoon (Herteman 2010).

BURROWS

The values obtained in the present study are higher than those revealed by Herteman (2010) in some mangroves of Mayotte (mean = 32.16 T/m^2 , sd = 9 T/m^2). This disparity could be explained by the activities taking place in the study area. Indeed, the work of Herteman (2010) focused on mangroves heavily impacted by domestic wastewater, which would thus reduce crab populations at the origin of the burrows. The comparative analysis between the results obtained in Mayotte and those from the Cameroon coastline encourages the idea that the number of burrow holes per m^2 is correlated with the density of crabs (Warren 1990). The burrow hole depths measured in this work are shallow (< 20 cm) compared to those obtained by Herteman (2010) (30-50 cm). According to Stieglitz et al. (2000), Koo et al. (2007),

Kristensen and Thorup-Kristensen (2007), most burrows are between 50 and 1 m deep. Such a large discrepancy could be due to the fact that the burrows do not have an absolutely vertical orientation, and thus could have underground branches. This is an aspect that would have been overlooked in this assessment. It would therefore be desirable to think of more sophisticated depth assessment methods, which would take into account the different ramifications of burrow holes in order to better assess their depths.

CRAB BIODIVERSITY

The present study reports a biodiversity of crabs grouped into 6 families, 14 genera and 26 species. These results are higher than those obtained by Ngo-Massou et al. (2014) in the mangroves of the Wouri River (Cameroon) and those of Herteman (2010) in the Malamani mangroves on the island of Mayotte in France. In general, these differences are due to several factors, including the duration of the study, the sampling times and methods, and the number of stations. In terms of duration, studies in the mangrove should be conducted over long periods of time, as it is a constantly changing environment. This was the case in the present study. Furthermore, crab sampling should also be done at night, as crabs emerge from their burrows at sunset. With regard to the stations, the multiplication of study stations and the consideration of the different aquatic environments (freshwater, brackish water and salt water) in the mangrove are determining factors in studies of crab biodiversity within the mangrove. This was not the case in the work of Ngo-Massou et al. (2014) that included 6 study stations in the middle of an urban area. According to the work of Nobbs and Blamires (2015), and Salgado-Kent and McGuinness (2010), the distribution and faunal richness of crabs in the mangrove is a function of the intrinsic characteristics of the mangrove studied, as well as the methodological approach of the study within this ecosystem. On the other hand, sampling techniques used at each station were also responsible for the variation in crab biodiversity. Indeed, at stations ES2, ES4, ES7 and ES8, all of the above-mentioned sampling techniques were used since these stations had habitats (banks, burrows and the presence of several branches on the ground) that allowed them to be used. This is the reason why these stations had the highest specific richness, unlike the stations located in the freshwater mangrove zone where the use of all sampling methods was not possible. This can justify their low specific richness.

The crab family Sesarmidae was the most represented. This group constitutes the densest, species-rich (over 250) crab fauna (Naruse and Ng 2012, Brösing et al. 2014) and with the highest biomass within the mangrove (Frusher et al. 1994, Emmerson 2001). This is mainly

due to their generally detritivorous diet, which recycles large quantities of primary products, especially mangrove leaves, throughout the year (Robertson and Daniel 1989), and their ability to withstand temporary anoxic conditions and fluctuations in water salinity.

Species belonging to the genera *Parasesarma* (De Man, 1895), *Perisesarma* (De Man, 1895), *Pachygrapsus* (Randall, 1840), were encountered in the majority of surveys. This significant presence could be linked to the fact that these are arboreal species, and therefore can escape aquatic predators and endure long periods of mangrove exodus. In addition, these are deep burrowing species (Nobbs and Blamires 2015). Such observations were also made by Herteman (2010) and Stefano et al. (2009). However, the work of Ngo-Massou et al. (2014) reveals a near absence of species of the genus *Parasesarma*. This difference could be explained by the taxonomic identifications of species belonging to the genera *Parasesarma* and *Perisesarma*. Indeed, these two genera are among the most complex and taxonomically problematic taxa (Guerao et al. 2004, Rahayu and Ng 2010, Davie and Pabriks 2010). They are very similar morphologically and differ only in the presence of an antero-lateral spine (epibranchial) on the carapace of species of the genus *Perisesarma* (Guerao et al. 2004, Rahayu and Ng 2010, Davie and Pabriks 2010). Species belonging to the genus *Uca* are also abundant, but were mainly encountered at a mangrove station located on a beach and characterized by the highest dissolved salt concentrations (ES7). This position explains the positive correlations between the genus *Uca* with salinity and sandy substrate. In addition, this genus groups together species that have a branchiostegal system transformed into a lung, the efficiency of which varies according to the species, depending on the number of branches and their complexity (Theuerkauff 2018). For this reason, their degree of terrestrialization has been revised upwards, via cast visualization of the lung which revealed high complexity and efficiency (Paoli et al. 2015).

Spatially, stations located within freshwater mangroves harbour very few crabs, compared to those located in brackish water. This is reflected in their low observed specific richness and diversity. The results of Ngo Massou et al. (2014) who worked in freshwater mangroves of the Wouri River confirm this observation. This difference could be due to an advanced degradation of the environment of mangroves located in fresh water compared to mangroves located in brackish water. Also, decapods in general and crabs in particular are fundamentally marine organisms, and therefore thrive best in relatively high salinity conditions (brackish water mangroves). Indeed, the high salt concentrations in brackish water mangroves allow the

rapid renewal of crab shells and therefore their growth (multiplication) (Poupin and Juncker 2010), which is relatively slow in mangroves with a strong freshwater influence.

ENVIRONMENT AND BIODIVERSITY

Among the abiotic factors influencing the distribution of crab biodiversity, the species *Callinectes sapidus* proliferated best near large sediments, namely sands. Hence their presence mainly at stations was located near beaches. This preference is due to the fact that it's a loose substrate that allows them to easily dig burrows and hibernate in turbulent conditions. This preference was also observed by Dulcic et al. (2010). This is also related to their diet, since they are essentially carnivorous species which, because of their large claws at low tide, emerge from the water, burrows and hunt on sandy beaches.

The significant and positive correlation showed between the species of the genus *Pachygrapsus* and the species *Leptodus* sp. and abiotic parameters such as highly salty and mineralized waters underlines that these species are not only of marine origin but also prefer environments with low impact from anthropic activities. This is the reason why these species have not been observed in freshwater mangroves. Concerning the species *Perisesarma* sp., the negative correlation obtained with large burrow depths is due to the fact that these species do not usually dig large burrows. In order to escape from predators and to search for food, these species generally walk along the large branches of mangroves as arboreal species. Furthermore, the negative correlation between these species and temperature is explained by the fact that these species live essentially in environments with a strong canopy, where sun rays are not sufficiently strong.

CONCLUSION

The maintenance of the balance and structure of the crab fauna within the mangrove depends on multiple environmental factors. These factors include the physico-chemical quality of the water, the nature of the sediment, tidal regimes and the bioturbation activities of the crabs. Significant correlations were obtained between these different parameters. However, it should be noted that the methods used to evaluate burrow densities and depths, as well as sampling frequencies and techniques, are sources of divergence in the results and should therefore be taken into account in the comparative analyses of biodiversity studies within mangroves. The results could eventually be improved if more explanatory variables are used or polynomial regression approaches are adopted.

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