Dynamics of shrimp fauna in the Aby-Tendo-Ehy Lagoon complex (southeast of Côte d'Ivoire), an hydrosystem under anthropic pressure

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World Journal of Advanced Research and Reviews, 2022, 16(01), 877–885

Publication history: Received on 01 September 2022; revised on 25 October 2022; accepted on 28 October 2022

Article DOI: https://doi.org/10.30574/wjarr.2022.16.1.0964

Abstract

In order to provide basic scientific data essential for the conservation and sustainable management of the Aby-Tendo-Ehy Lagoon complex in South East of Côte d'Ivoire, patterns of shrimps' community structure in relation to environmental characteristics has been studied in this ecosystem subject to intense anthropogenic pressures, particularly agro -industrial. Sampling was conducted monthly from April 2012 to March 2013 using a handled net and lobster pots. Eleven species of shrimp including three species (*Macrobrachium equidens*, *M. zariquieyi* and *Melicertus kerathurus*) adding to the list of shrimp fauna of Côte d'Ivoire were sampled during this study. Redundancy analysis (RDA) showed that environmental variables such as dissolved oxygen, conductivity, water temperature, transparency, plant debris and aquatic plants strongly diversity and abundance of shrimp fauna. This study has demonstrated the exceptional nature of this lagoon complex, and strongly recommends its preservation.

Keywords: Shrimps; Ecology; Anthropized ecosystem; Aby-Tendo-Ehy Lagoon complex; Côte d'Ivoire

1. Introduction

Threats to aquatic biodiversity from anthropogenic activities are increasing [16]. Despite the development of a national action plan on biodiversity [1], and the adoption of a biodiversity conservation policy [24] in response to these pressures, the southeast of Côte d'Ivoire remains a highly anthropized area [13]. Located in this part of Côte d'Ivoire, the Aby-Tendo-Ehy lagoon complex is contiguous with the Tanoe-Ehy Swamp Forest, which has been identified as a site of high conservation value [15]. In addition, it is the site of the most important fishing activity in the region [13]. Unfortunately, it is subject to intense anthropic pressures, especially agro-industrial likely to modify the quality of this hydrosystem, and harm its biological diversity [25]**.** Shrimp, like many other groups of organisms, are very sensitive to pollution-related environmental changes [7, 8]. In addition, they represent a highly diverse group of macroinvertebrates [6], many species of which are an important source of animal protein for the human diet. In addition, these organisms remain an important link in the food web in aquatic ecosystems [3]. Despite the growing number of works devoted to shrimps in Côte d'Ivoire, their data for the Aby-Tendo-Ehy Lagoon complex are scarce. Consequently, the present work

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aims at knowing the spatio-temporal dynamics of the shrimp fauna in this anthropized ecosystem in order to contribute to its safeguar.

2. Material and methods

2.1. Study area

The Aby-Tendo-Ehy lagoons system located between the latitudes 5°05'-5°22' N and the longitudes 2°51'- 3°21'W in South East Côte d'Ivoire was surveyed (Figure 1). It forms a natural border between Côte d'Ivoire and Ghana (Figure 1), and it's extends over 30 km of the coastline and covers an area of 424 km^2, with a mean depth of 3.5 m and width of 5.5 km [22]. This lagoon system includes Aby lagoon, Tendo lagoon and Ehy lagoon. The Aby lagoon covers 305 km^2, has a total shoreline of 24.5 km long, and has 15.5 km wide. The Tendo lagoon which is the median part of our study system has a length of 22 km and a width varying between 1.5 and 3.5 km. The Ehy lagoon is located in the eastern side of the lagoon system and has a surface area of 45 km^2 [22]. A total of twelve sampling sites were selected, distributed along the lagoon system in three areas (four sites per lagoon) according to different environmental characteristics related to longitudinal salinity range (Figure 1). Ehy lagoon sampling sites had no marine water influences, but were under a contribution of freshwater from the Tanoe Ehy Swamp Forest and Tanoe River. Tendo lagoon sampling sites were near the mouth of Tanoé River. Thus, they receive the bulk of freshwater inflow from Tanoe River. Aby lagoon sampling sites were the most influenced by marine waters.

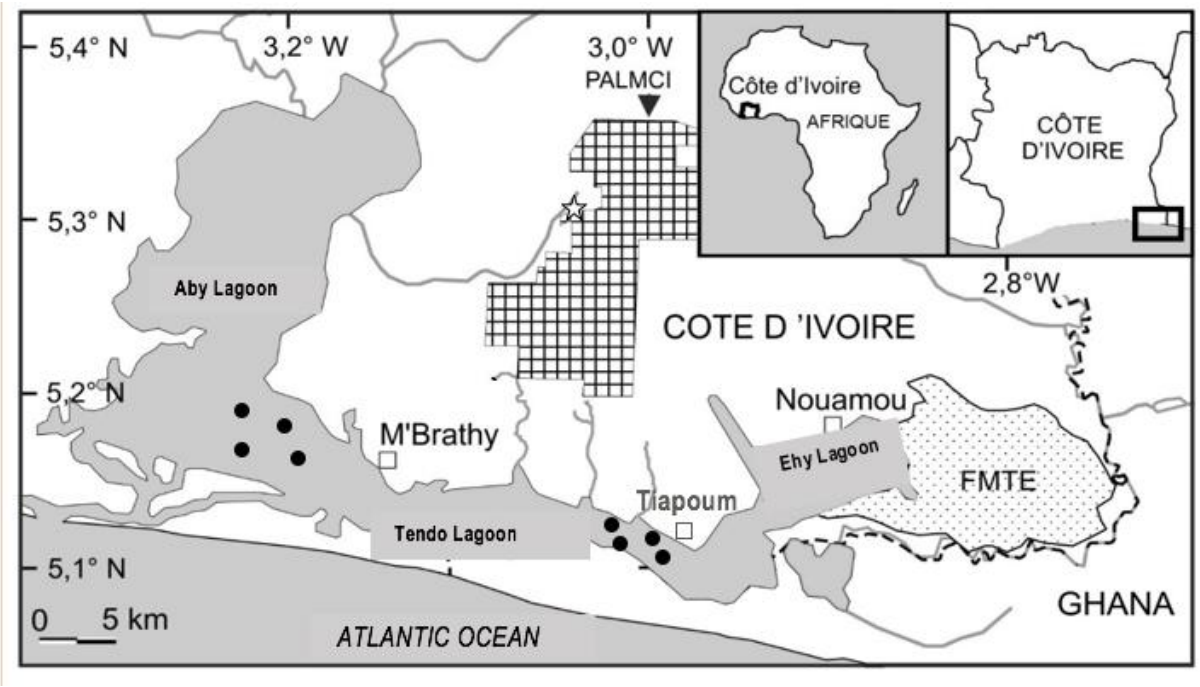


Figure 1 Sampling sites (●) in the Aby-Tendo-Ehy lagoons system from April 2012 through March 2013

2.2. Measurement of Environmental parameters

Environmental parameters (Table 1) were once monthly measured in situ at each sampling site from April 2012 through March 2013. Canopy cover and substrate type (mud, gravels and mixture) were estimated visually as described by [11] and [21]. Water depth and width were measured (average of five measures) to the nearest centimeter.

2.3. Shrimp Samples Collection and Identification

Shrimps were collected once monthly from April 2012 through March 2013 using lobster pots baited by the residues of coconut oils and the rests of food (pitch, meats). The material retained in the lobster pots was sorted and kept in jars containing a 10% formalin solution. The shrimps caught were identified following [10, 17, 18, 20, 23].

2.4. Data Analysis

The number of individuals per species, sites and sampling period was determined. The occurrence percentage (%OF) was calculated using the following formula: %OF = (Ni/Nts)×100, with Ni = number of samples containing a given species i, and Nts = total number of samples collected. The %OF was used to classify species following [4] : %OF>50: very frequent species; 25<%OF ≤50: common species; %OF≤25: rare species. Seasonal variation of spieces richness was evaluated using the Mann-Whitney *U*-test, and the Kruskall-Wallis test has been used to compare the different species abundance between the different lagoons. A significance level of $p<0.05$ was considered**.** Seasonal variation in shrimps' abundance and environmental variables were evaluated using the Anova test. Species abundance in relation to environmental variables was analyzed using Spearman's correlation test, and the ReDundancy Analysis (RDA). The RDA method was used to detect patterns of species association related to environmental variables. RDA was performed using CANOCO 4.5. STATISTICA 7.1 computer package was used for the other tests.

Table 1 Environmental variables (mean±SD) measured in the Aby-Tendo-Ehy lagoons system from April 2012 through March 2013. AP=aquatic plant, Can=canopy, Cond=conductivity, DO=dissolved oxygen, GSM=gravel-sand mixture, VD=vegetal debris, WD=water depth, WT= water temperature

Lagoons	Seasons	Environmental variables										
		Sal (ppt)	pH	DO (%)	Cond (µS/cm)	WD (m)	WT (°C)	GSM	Mud	VD	AP	Can
Aby	RS	0.43±0.98	6.86±0.68	69.57±7.06	161.72±109.01	1.81±0.64	28.16±1.63	85	15	0	0	0
	DS	0.47±0.98	6.29±1.08	76.44±15.72	347.49±197.92	1.75±0.67	28.82±0.98					
Tendo	RS	0	6.86±0.73	60.04±13.87	146.66±119.29	2.93±1.65	28.62±1.77	75	15	5	5	0
	DS	0	6.95±0.8	69.28±12.73	332.37±269.38	2.72±1.22	28.56±1.38					
Ehy	RS	0	7.08±0.65	58.08±16.54	63.36±16.21	1.51±0.7	27.97±2.18	70	20	5	5	5
	DS	0	7.48±0.9	69.61±18.86	69.02±13.68	1.35±0.58	30.51±3.24					

In the same station, the variables with values written in bold show significant differences between the seasons (ANOVA, $p < 0.05$)

3. Results

3.1. Species composition and distribution

Eleven species of shrimp were sampled in all three lagoons surveyed. These were Atya gabonensis (Atyidae), *Macrobrachium chevalieri, M. dux, M. equidens, M. felicinum, M. macrobrachion, M. vollenhovenii, M. raridens, M. zariquieyi* (Palaemonidae); *Farfantepenaeus notialis* and *Melicertus kerathurus* (Penaeidae). The diversity of these species varies from one lagoon to another (Table 2). The number of species follows a decreasing gradient from lagoon Aby (10 species or 90.91% of the total species richness) to lagoon Ehy (5 species). Five species (*M. dux, M. equidens, M. felicinum, M. macrobrachion and M. vollenhovenii*) are common to all three lagoons, four (*Farfantepenaeus notialis, Macrobrachium chevalieri, M. raridens and Melicertus kerathurus*) are specific to Aby Lagoon and one species (*Atya gabonensis*) is specific to Tendo Lagoon. When the analysis of the shrimp population is made taking into account the alternation of the rainy and dry seasons, a variation in the specific richness is also observed (Figure 2). It is expressed by the increase in the number of species during the flood than during the dry season in the Tendo and Ehy lagoons, while in the Aby lagoon, the specific richness increases from the rainy season to the dry season. The percentage of occurrence (Table 3) of species differs from one lagoon to another and from one season to another. *Macrobrachium dux, M. macrobrachion and M. vollenhoveni*i are constant in all three lagoons and in all seasons. *Macrobrachium equidens* is constant during the rainy season in Aby and Tendo lagoons but during the dry season it is incidental in Aby lagoon and rare in Tendo lagoon. In Ehy lagoon, it is incidental during both seasons. *Macrobrachium felicinum* is constant in the rainy season and incidental in the dry season in Aby; it is incidental in the rainy season and rare in the dry season in Tendo, but in Ehy lagoon it appears only incidentally in the rainy season. As for *Farfantepenaeus notialis,* it appears only in Aby lagoon and consistently during both seasons with respectively a frequency of 66.67% during the flood and 71.43% during the dry season. *Macrobrachium zariquieyi* is incidental during the wet season and rare during the dry season in Aby lagoon and appears during the wet season in Tendo lagoon rarely. *Melicertus kerathurus and Macrobrachium raridens* appear only during the dry season and rarely in Aby Lagoon.

Table 2 Species composition and distribution in the Aby-Tendo-Ehy lagoons system from April 2012 through March 2013

Hydrosystems			
Species	**Aby**	**Tendo**	**Ehy**
Farfantepenaeus notialis	+		
*Melicertus kerathurus**	+		
Atya gabonensis		+	
Macrobrachium chevalieri	+		
Macrobrachium dux	+	+	+
*Macrobrachium equidens**	+	+	+
Macrobrachium felicinum	+	+	+
Macrobrachium macrobrachion	+	+	+
Macrobrachium raridens	+		
Macrobrachium vollenhovenii	+	+	+
*Macrobrachium zariquieyi**	+	+	
Total: 11	10	7	5

*= species reported for the first time in Ivorian hydrosystems

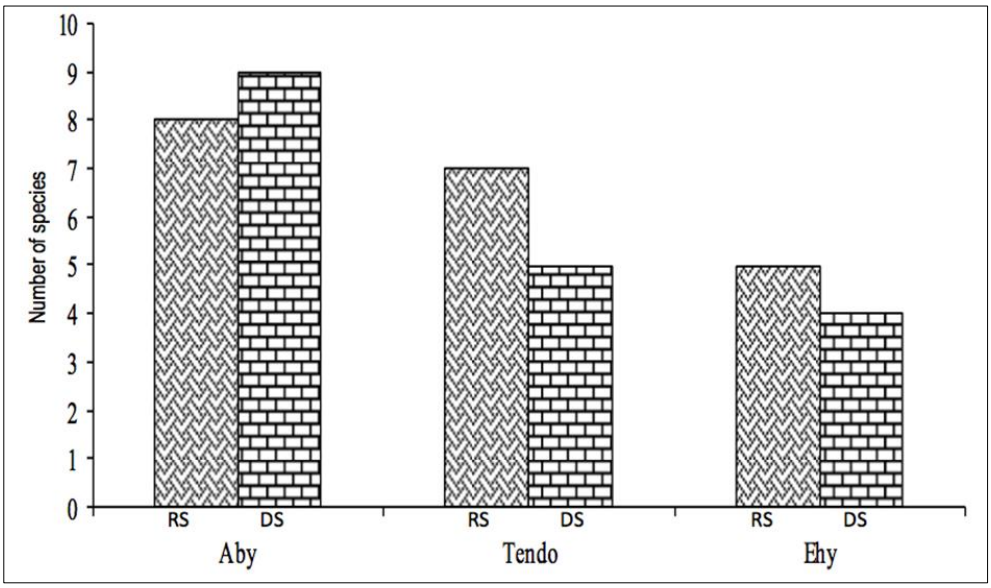


Figure 2 Seasonal variation in the Aby-Tendo-Ehy lagoons system (Côte d'Ivoire) from April 2012 to March 2013. RS= rainy season, DS= dry season

Table 3 Species occurrence percentage of shrimp species in the Aby-Tendo-Ehy lagoons system (Côte d'Ivoire) from April 2012 to March 2013

	Aby lagoon			Tendo lagoon			Ehy lagoon		
Species	**%AF**	**%F RS**	**%F DS**	**%AF**	**%F RS**	**%F DS**	**%AF**	**%F RS**	**%F DS**
Farfantepenaeus notialis	66.67***	71.43***	60***	-	-	-	-	-	-
Melicertus kerathurus	8.33*	-	20*	-	-	-	-	-	-
Atya gabonensis	-	-	-	16.67*	28.57**	-	-	-	-
Macrobrachium chevalieri	8.33*	14.29*	-	-	-	-	-	-	-
Macrobrachium dux	91.67***	85.71***	100***	83.33***	71.43***	100***	83.33***	85.71***	80***
Macrobrachium equidens	58.33***	71.43***	40**	25**	57.14***	20*	41.66**	42.86**	40**
Macrobrachium felicinum	58.33***	71.43***	40**	25**	28.57**	20*	25**	42.86**	-
Macrobrachium macrobrachion	100***	100***	100***	100***	100***	100***	100***	100***	100***
Macrobrachium raridens	8.33*	-	20*	-	-	-	-	-	-
Macrobrachium vollenhovenii	100***	100***	100***	83.33***	85.71***	80***	100***	100***	100***
Macrobrachium zariquieyi	16.67*	28.57**	20*	8.33*	8.33*	-	-	-	-

- = missed; * = rare species ; ** = accessory species; *** = constant species; AF = annual frequency; FRS = frequency in the rainy season; FDS = frequency in the dry season

3.2. Numerical abundance of species

A total of 13249 individuals were caught in all the lagoons. This cumulative number decreases from Aby Lagoon to Ehy Lagoon. *Macrobrachium vollenhovenii* and *M. macrobrachion* have the highest numerical percentages with 34.26% and 33.90% of the total number of individuals respectively. They are followed by *M. dux* (19.45%), *M. equidens* (5.50%) and *M. felicinum* (5.22%). The other species (*Farfantepenaeus notialis*, *M. raridens*, *M. zariquieyi*, *Atya gabonensis* and *Melicertus kerathurus*) together represent 1.66% of the total number of fish. When the lagoons studied are considered separately, *M. vollenhovenii* and *M. macrobrachion* also appear as the most abundant species. Of the species common to all three lagoons, two species (*M. dux*, *M. felicinum*) are more abundant in Aby Lagoon, two species (*M. vollenhovenii* and *M. macrobrachion*) are more abundant in Ehy Lagoon, and one species (*M. equidens*) is more abundant in Tendo Lagoon. Only *Farfantepenaeus notialis* is statistically different in abundance between Aby Lagoon and Tendo and Ehy Lagoons (Mann Whitney *U* test, $p < 0.05$). When the analysis is done by season, the highest abundances of shrimp were recorded during the rainy season in each lagoon (Figure 3). However, the difference is not significant between seasons (Mann Whitney *U* test, $p > 0.05$).

3.3. Correlations between species abundance and environmental variables

Table 4 Results of the Spearman correlation analysis (*p*-values) between shrimp species and environmental factors

	Environmental variables											
Species	**pH**	**DO**	**Cnd**	**WD**	**WT**	**Sal**	**WTr**	**GSM**	**M**	**Vv**	**AP**	**Can**
Macrobrachium dux	-0.37	-0.26	-0.09	0.60	-0.83	0.07	-0.03	0.36	-0.41	-0.21	-0.21	-0.41
M. equidens	0.14	-0.77	-0.54	0.49	-0.77	-0.51	-0.60	-0.24	0.00	0.41	0.41	0.00
M. felicinum	-0.54	-0.09	-0.03	0.49	-0.77	0.30	0.09	0.48	-0.41	-0.41	-0.41	-0.41
M. macrobrachion	0.14	-0.43	-0.71	-0.20	-0.77	-0.10	-0.26	-0.24	0.41	0.00	0.00	0.41
M. Vollenhovenii	0.14	-0.09	-0.60	-0.37	-0.54	0.07	-0.09	-0.12	0.41	-0.21	-0.21	0.41
M. zariquieyi	-0.88	0.64	0.52	0.33	-0.15	0.83	0.52	0.89	-0.66	-0.88	-0.88	-0.66
Farfantepenaeus notialis	-0.84	0.84	0.68	-0.03	0.10	1.00	0.84	0.85	-0.49	-0.98	-0.98	-0,49

Significant correlations are in bold; DO: dissolved oxygen; Cond: conductivity; WD: water depth; WT: water temperature; GSM: gravel-sand mixture; M: mud; VD: vegetal debris; AP: aquatic plant; Can: canopy; and Vel: current velocity.

The influence of environmental variables on the abundance of species was shown, on the one hand, by the Spearman correlation analysis (Table 4) and, on the other hand, by a redundancy analysis (RDA) (Figure 4). The results of the Spearman correlation analysis performed on the species with high numbers (*Macrobrachium dux*, *M. equidens*, *M. macrobrachion*, *M. vollenhovenii*, *M. zariquieyi*, and *Farfantepenaeus notialis*) showed that pH, dissolved oxygen level, salinity, water temperature, transparency, ravel-sand mixture, vegetal debris and aquatic plants strongly influenced shrimp species abundance ($p < 0.05$). *M. dux*'s abundance was negatively correlated with temperature while that of M. zariquieyi and *Farfantepenaeus notialis* were significantly negatively correlated with pH, percentage of plant debris and aquatic plants but positively correlated with dissolved oxygen, salinity, transparency and percentage of sand-gravel mixture. The RDA ordination along factorial axis 2, which expresses 35.90% of the variance, clearly separates Aby Lagoon from Tendo and Ehy Lagoons. Aby lagoon, positively correlated with axis 2, was characterized by high values of variables such as salinity, dissolved oxygen content, conductivity, transparency, and ravel-sand mixture.

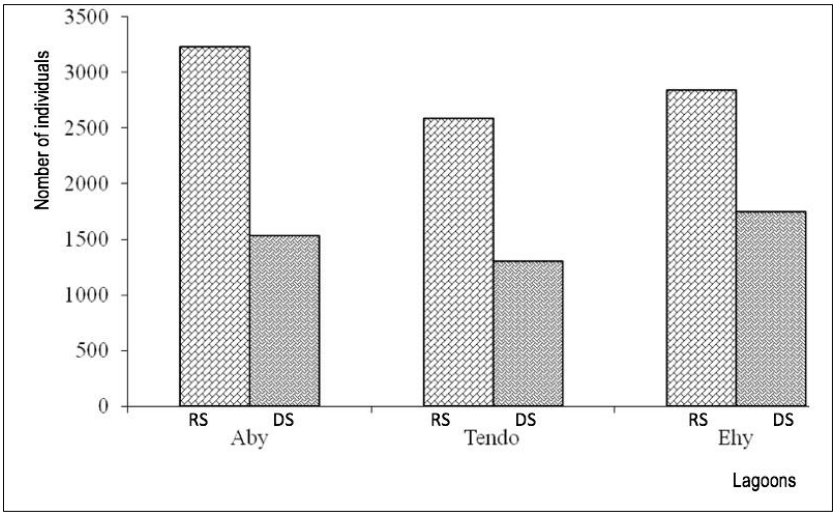
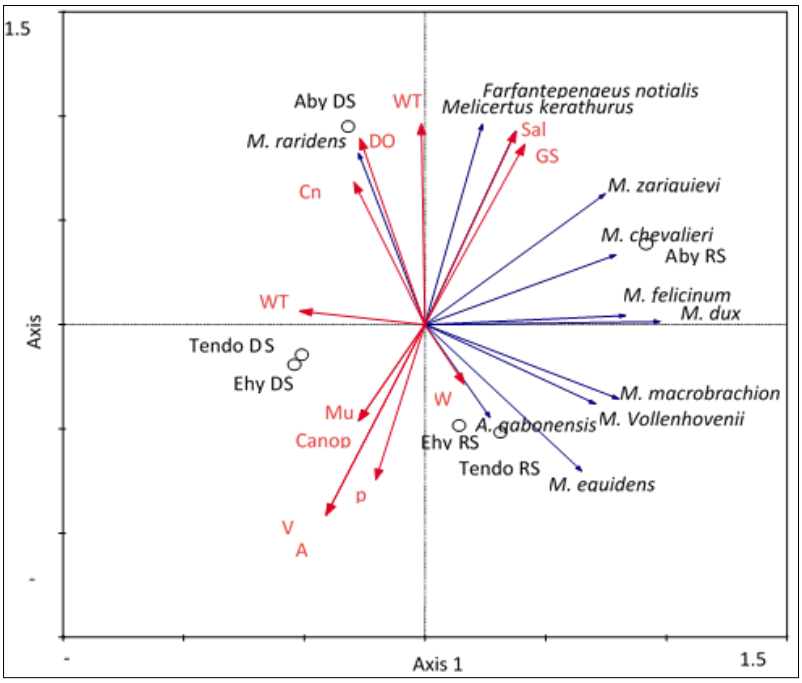


Figure 3 Number of shrimp individuals caught during dry and rainy seasons in the Aby-Tendo-Ehy lagoons system (Côte d'Ivoire) from April 2012 to March 2013. RS= rainy season, DS= dry season



RS= rainy saison ; Sample code : A= Atya, M= Macrobrachium ; Environmental variables : AP=aquatic plant, Cond=conductivity, DO=dissolved oxygen, GSM= gravel-sand mixture, VD=vegetal debris, Vel=current velocity, WD=water depth, WT= water temperature, WTr= water transparency

Figure 4 Redundancy analysis triplots showing relationships between sampling sites and shrimp species and environmental variables in the Aby-Tendo-Ehy lagoons system (Côte d'Ivoire). Saisons: DS= dry saison

It is specifically home to marine species (*F. notialis* and *M. kerathurus*), a freshwater species reported for the first time in Ivorian rivers (*M. zariquieyi*) as well as *M. chevalieri* and *M. raridens*. The Tendo and Ehy lagoons contain species such as *Atya gabonensis*, *Macrobrachium equidens*, *M. macrobrachion*, *M. raridens* and *M. vollenhovenii*. They are positively correlated to variables such as pH, depth, canopy closure rate, aquatic plants and substrate consisting of mud and plant debris.

4. Discussion

Sampling in the Aby-Tendo-Ehy lagoon complex (Côte d'Ivoire) yielded 13249 shrimp individuals grouped into 11 valid species. These taxa belong to two freshwater families (Atyidae and Palaemonidae) and one marine family (Penaeidae). The freshwater families are represented respectively by the genera *Atya* and *Macrobrachium*. The marine and/or brackish family is represented by the genera *Fartantepenaeus* and *Melicertus*. The genus *Macrobrachium* is represented by eight species while the other genera are mono-specific (one species). The species richness of the present study is significantly higher than those reported by [14] (9 species), [9] (7 species), [8] (6 species) and **Camara *et al*. (2009)** (3 species), but lower than the work of [19] (13 species). Several reasons could explain the differences in specific compositions between these works: the material and methodology used, the environmental characteristics of the biotopes sampled, the sampling periods and the migration of species. The variability of the habitats surveyed and the sampling periods could also explain the specific differences observed between these different ecosystems. The large study areas offer a diversity of habitats to exploit [12]. The present work recorded three species that are added to the list of the shrimp fauna of Côte d'Ivoire. These are two freshwater species *Macrobrachium equidens*, *M. zariquieyi* and a species with marine and/or brackish affinity *Melicertus kerathurus*. Analysis of spatial variation in species richness and numerical abundance showed that these two variables are higher in Aby lagoon with salinity above zero (the other lagoons have zero salinity during the entire sampling period). In addition, marine species were only found in this lagoon. These data reflect the absolute implication of salinity in the life history of shrimp. This importance of specific richness could be explained in part by the fact that this lagoon communicates directly with the marine environment. Therefore, it shelters species with marine and/or estuarine affinities during at least one stage of their reproduction cycle. The analysis of the seasonal variation of the specific richness showed that the greatest number of species was recorded during the rainy season in all the lagoons. These data reflect the more favorable living conditions for aquatic organisms during the flood period than during the low water period. Indeed, in addition to better oxygenation of the waters due to the agitation movements caused by the water current, the water bodies, during the flood period, also have a significant amount of food thanks to the flooding and/or rainfall regime through the fruits, plant debris and terrestrial invertebrates that fall into the water [4]. Ordination in RDA separated Aby Lagoon from Tendo and Ehy Lagoons. Aby Lagoon is characterized by high values of variables such as dissolved oxygen content, transparency, percentage of sand-gravel mixture, and conductivity but especially by variable salinity. It specifically supports the marine species *Fartantepenaeus notialis* and *Melicertus kerathurus*. Salinity is therefore a determining factor for the presence or absence of marine species.

5. Conclusion

A total of eleven shrimp species belonging to two freshwater families (Atyidae and Palaemonidae) and one marine water family (Penaeidae) were sampled during this study. pH, dissolved oxygen, salinity, water temperature, transparency, ravel-sand mixture, vegetal debris and aquatic plants significantly influenced the diversity and abundance of different species of shrimp. In addition, this work has recorded three species which are added to the list of shrimp fauna of Côte d'Ivoire. These are two freshwater species *Macrobrachium equidens*, *M. zariquieyi* and a species with marine and/or brackish affinity *Melicertus kerathurus*. Consequently, its preservation is highly recommended.

Compliance with ethical standards

Acknowledgments

This work is part of the research project entitled “Evaluation of refuge and nursery roles of the Tanoe- Ehy swamp forest for fishes of adjacent lagoon and marine ecosystems” and was funded by the Program d’Appui Stratégique à la Recherche Scientifique, Côte d’Ivoire (PASRES) and Centre Suisse de Recherches Scientifiques en Côte d'Ivoire (CSRS) through its RASAPCI program (Recherche et Action pour la Sauvegarde des Primates en Côte d’Ivoire, CSRS, Côte d’Ivoire). Authors are grateful Gnangny Aka Francis fisherman in M’Brathy for his availability throughout the sampling period. We are also grateful Konan Y. Aristide, Money A. Ida, and Simmou Y. Junior for their support during field sampling.

Disclosure of conflict of interest

There is no conflict of interest between the authors in respect of this manuscript.

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