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Evaluation of organic pollution at the Acadjas farms in sector V of the Ebrié lagoon and their impact on local benthic invertebrates

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Abstract

Although Acadjas farms contribute to increase fish production in Côte d'Ivoire, they are not without impact on the aquatic environment. This study aims at evaluating the organic pollution caused by the Acadjas fishing method practiced in the bay of Mopoyèm and study their consequences on benthic macroinvertebrates population. Four sampling investigations were carried out following the seasons between August 2016 and July 2017. After having measured, *in-situ*, certain physicochemical parameters (pH, temperature, salinity, dissolved oxygen and transparency), water samples and benthic macroinvertebrates were collected with a sterile bottle and a Van Veen grab at the level of Acadjas and at a reference station, respectively. In the laboratory, water samples were analyzed for BOD5, nitrite, ammonium, phosphate and suspended solids (SS) concentrations. Macroinvertebrates were identified using specialized keys guides. The results revealed that organic pollution is high at the level of Acadjas (OPI between 2.25 and 3). The consequences are characterized by a decrease in total abundance, diversity and growth of pollutant-tolerant organisms (Tubificidae and Chironomidae). Today, it is important to reorganize this method of fishing so that it can be practiced in a responsible and sustainable way with regard to the environment.

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Introduction

Acadja is a form of extensive fish farming practiced in West African lagoons (Anoh, 2012). The introduction of Acadjas in the Ivorian lagoons followed the need to increase the fishing productivity in these environments (Hem & Avit., 1994a), which tend to lose its productivity due to overfishing (Durand *et al.*, 1982).

In Ebrié lagoon, the first installations of Acadjas were made in the early 1980s (Albaret *et al.*, 1981, Doucet *et al.*, 1985). Since then, many installations of Acadjas have emerged in the lagoon. However, in Sector V of the Ebrié Lagoon, specifically in Mopoyèm Bay, the Acadjas technique is more intensively practiced (Anoh and Aboya, 2011). This activity, which is not stressful and very profitable (Anoh, 2012), is mostly adopted (Aboya, 2016) by young people at the expense of the traditional method of fishing. Thus, the number and the size of the Acadjas in this bay increase constantly. Unfortunately, this method of fish farming, although very productive (Hem and Avit, 1994a), has the disadvantage of polluting the waters and subsequently reducing the local biodiversity in the exploited areas (Bankole and Olou, 2000, Dedjiho *et al.*, 2014, Laleye, 2015). Regarding the environment, this technique gives a lot of concerns regarding the presence and the operating mode of these Acadjas parks in the waters of the Ebrié lagoon. In fact, the set-up of the Acadjas involves placing artificial substrates consisting of bundles of branches and foliage, fagots or bamboos in open water (Hem *et al.*, 1990, Anoh, 2012). These materials constitute a threat to biodiversity in that they contribute to the modification of current, sedimentology, suspended matter and particles in deep waters (Anoh, 2012). The degradation of its organic materials could also lead to anoxic conditions by the depletion of dissolved oxygen (Dedjiho *et al.*, 2014). In addition, the technique of Acadjas fishing make use of eutrophizing by-products such as banana peels, cassava peels and palm kernel cakes as nutritional supplement and to fertilize the environments. These organic compounds, get accumulated in the environment, thus leading to water nutrients' enrichment following the decomposition process and causing organic pollution and silt deposit at the bottoms of lagoon. Significant consequences could then be observed on the quality of the water and also on the biodiversity, especially on the local benthic fauna. The latter, however, is an essential link in the trophic chain of aquatic ecosystems and strongly contributes to the recycling of organic matter (Gnohossou, 2006).

In Côte d 'Ivoire, it is clear that no study has been carried out to understand the possible environmental problems that the Acadjas farms could cause. Work on the Acadjas generally deals only with questions related to their introduction (Albaret *et al.*, 1981, Konan, 1989), to their practice (Doucet *et al.*, 1985, Hem and Avit, 1991, Guiral *et al.*, 1993, Hem and Avit, 1994b, Anoh, 2012) and the social problems they sometimes cause (Anoh, 2012 ; Aboya, 2014). This study aim to evaluate the organic pollution near the Acadjas and to study the population of benthic macroinvertebrates exposed to their exploitation in the Bay of Mopoyèm (Sector V of the Ebrié Lagoon).

Material and methods

Description of the study environment and characteristics of the Acadjas

Mopoyèm Bay is located west of Ebrié Lagoon precisely in the Sector V on the Northern side of the shore between longitudes West 4°451 and 4°464 and latitudes North 5°306 and 5°318 (Figure 1). This bay, having area of 14.45 km² (Varlet, 1978, MINEF, 1999), is located in an area influenced by sub-equatorial Attiean climate with four seasons, two dry seasons (Short dry season: SDS and Long dry season: LDS) and two rainy seasons (Short rainy season: SRS and Long rainy season: LRS).

The waters of this bay are also influenced by the floods and decreases of a small coastal river (the Kpapkidje River). Described as oligohaline and not polluted by Pagano and Saint-Jean (1988), the waters in this bay are characterized by a relatively low salinity varying according to the seasons and with a temperature oscillating around 24.0 °C in the rainy season and 30.0 °C during the dry season (Iltis, 1984).

The Acadjas farms exploited in the Bay of Mopoyèm are built using bundles of branches thrown to the bottom of the lagoon and then surrounded by bamboo (*Bambusicola thoracica*) for sighting the location of the Acadja. The size and shape of the Acadjas parks are variable, but in general they are circular in shape with an average diameter of 35 meters. At least once a week, Acadjas farmers make a feed consisting of banana peels, cassava peels and palm seed cakes.

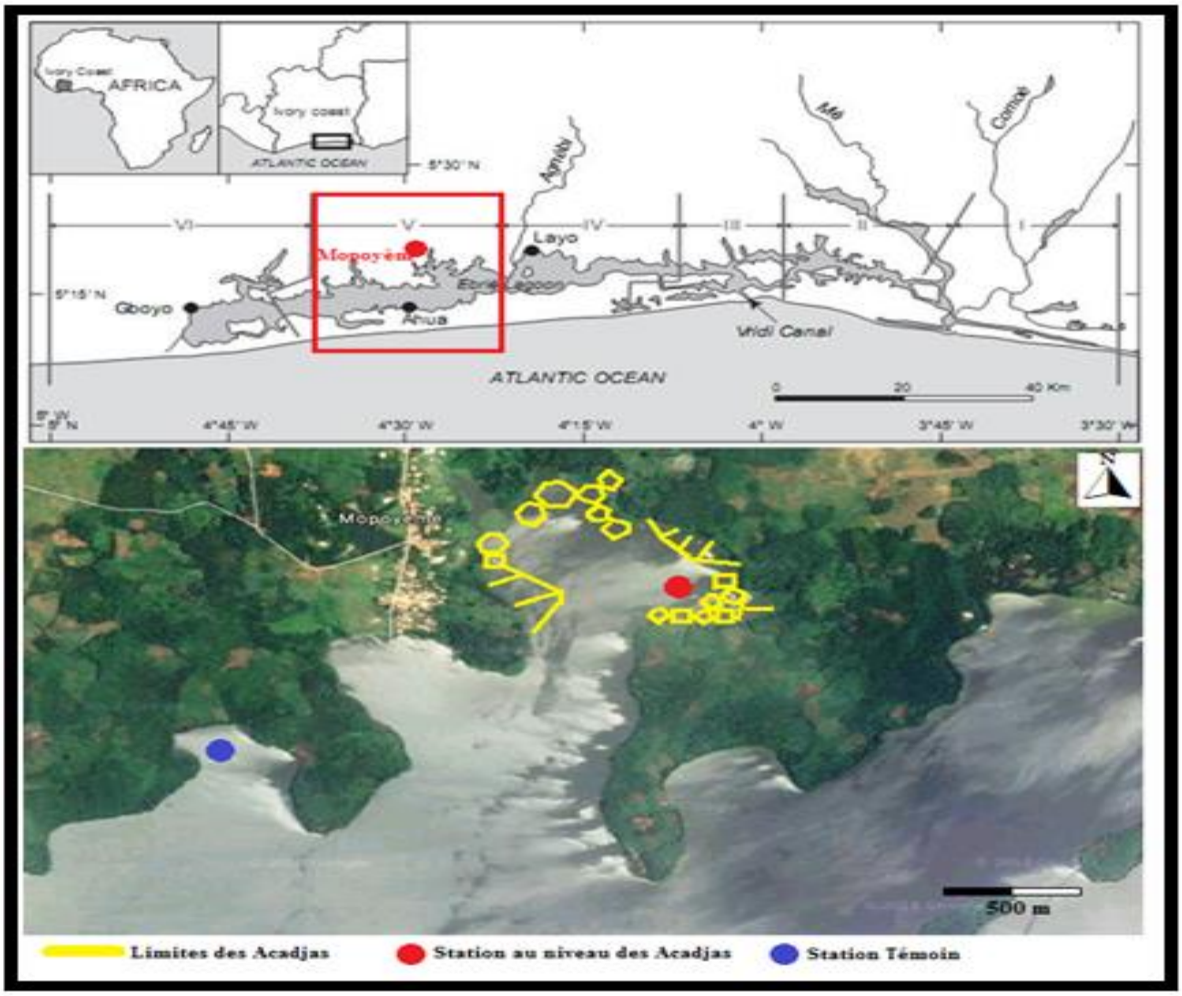

Fig. 1. Satellite view of the Acadjas facilities in Mopoyèm Bay (Sector V, Ebrié Lagoon). (Source: Dufour *et al.*, 1994 and Google map 2017).

Choice of stations and measurement of physicochemical parameters

Two sampling stations were chosen in Mopoyémé Bay : the first station (SA: 5°309896 N - 4°453956 W) is located at the level of Acadjas installation and the second station called reference (SR: 5°303318 N - 4°472102 W) is located in an area free of Acadjas installation, anthropogenic activities and contamination (Figure 1).

Four sampling compaigns were conducted from August 2016 to July 2017 taking into consideration seasonal variations in climate. In the field, physicochemical parameters such as temperature, pH, dissolved oxygen (DO) and salinity were measured using a multiparameter HANA Model HI98194. Transparency was measured with a Secchi disk. A 1 liter sterilized glass vial was used to collect water sample at each station for the determination of nutrient salts (nitrites, ammonium and phosphates), determination of biological oxygen demand (BOD5), and suspended solid matter (SS). The samples thus taken are placed in a cooler containing cold accumulators and sent to the Pastor Institute of Côte d'Ivoire for the various analyzes.

The determination of the nitrite, ammonium and phosphate ions was carried out according to the colorimetric method using a spectrophotometer and reagents as described by Murphy and Riley (1962). BOD5 was determined by the respirometric method using the Ox Itop manometric heads (APHA, 1998). The concentration of suspended solids (SS) was determined using the fiberglass filter filtration method (Rodier *et al.*, 2009).

Assessment of the organic pollution

The assessment of the organic pollution was done by calculating the organic pollution index (OPI) proposed by Leclercq (2001). The method consists of using the values obtained for the phosphates, nitrites, ammonium ions and BOD5 to find the class corresponding to the average value of each parameter. The OPI is obtained by finding the average of the four classes. The value of this index makes it possible to assess the state of organic pollution of the medium in which the sample was taken (Table 1).

Sampling and identification of benthic macroinvertebrates

The benthic organisms were collected using a Van Veen grab of 0.0250 m^2. Ten collections were made at each station.

The sediments were washed. The benthic organisms were subsequently sorted and stored in pill containers containing 10% formaldehyde. The observation of the organisms in the laboratory was done with a binocular magnifying glass and identification with the keys of Binder (1957), Dejoux *et al.* (1981) and Tachet *et al.* (2010). Macroinvertebrates were finally grouped according to their sensitivity to organic pollution (Anonymous, 2015).

Mathematical analysis of data

The Shannon diversity index (H') and the Equitability (E) were calculated, using PAST software (Paleontological Statistics), to measure and compare the species richness between the two stations.

The similarity between the two stations was studied by calculating the Jaccard index (I) expressed by the formula I = Nc/(Ns + Nr + Nc) with Nc, the taxon number common to the SA and SR stations, Ns, the number of taxon at the station SA and Nr, the number of taxon at the station SR.

The Mann-Whitney test allowed us to verify whether there is a significant difference between the composition of macroinvertebrates at the level of Acadjas and at the reference station.

Results

Physicochemical characteristics and organic pollution

The results concerning the physicochemical characteristics obtained at the two stations are recorded in Table 2. At the level of the Acadjas, we recorded 6.22 for the pH, 30.40 ° C for the temperature, 2.21 PSU for the salinity, 3.79 mg O_2/l for dissolved oxygen, 0.68 m for transparency and 78.75 mg/l for SS.

On the other hand, at the reference station, these same parameters have a value of 8.12 for the pH, 27.21 ° C for the temperature, 2.45 PSU for the salinity, 5.18 mg of O_2/l for the dissolved oxygen, 0.93 m for transparency and 43.97 mg/l for SS. The analyzes performed for the determination of BOD and the determination of nutrient salts gave us 83.8 mg/l for BDO5, 70 µg/l for nitrite, 0.82 mg/l for ammonium and 108.5 µg/l for phosphate precisely from the sample collected from the Acadjas. However, in the reference station sample, these values are 37.53 mg/l for BOD5, 12.75 µg /l for nitrite, 0.10 mg/l for ammonium and 40.75 µg/l for phosphate.

Table 1. Quality Grid (OPI) (Leclercq, 2001).

N° of class	BOD5 (mg/l)	Ammonim (mg/l)	Nitrites (µg/l)	Phosphates (µg/l)	OPI (class average)	Organic pollution
5	< 2	< 0,1	≤ 5	≤ 15	5.0 - 4.6	No
4	2 - 5	0.1 – 0.9	6 - 10	16 - 75	4.5 - 4.0	Weak
3	5.1 - 10	1 – 2.4	11 - 50	76 - 250	3.9 - 3.0	Moderate
2	10.1 - 15	2.5 - 6	51 - 150	251 - 900	2.9 - 2.0	High
1	> 15	> 6	> 150	> 900	1.9 - 1.0	Very High

The calculated OPI shows that water quality varies from one season to another at both stations (Figure 2). In the Acadjas the indices of organic pollution go from 2.75 in short raining season to 3.00 in the long raining season and of 2.50 in short dry season to 2.25 in long dry season. At the reference station, the indices are rather 3.00 in the short rainy season, 4.00 in the long rainy season, 3.25 in the short dry season and 3 in the long dry season.

The highest organic pollution was observed in dry seasons and the weakest in rainy seasons. However, organic pollution is relatively higher in the waters of the Acadjas than that of the reference station.

Table 2. Averages and standard deviations (SD) of the physicochemical parameters at the Acadjas (SA) and the reference station (SR) measured between August 2016 and July 2017 in the Ebrié lagoon.

Stations	SA				ST			
Parameters	Min	Max	Average	SD	Min	Max	Average	SD
pH	6.02	7.48	6.22	0.66	7.90	8.71	8.12	0.89
Temperature (°C)	29.4	31	30.40	1.72	26.5	28.3	27.21	2.59
Salinity (PSU)	1.75	3.15	2.21	0.64	2.07	2.89	2.45	0.42
DO (mg/L)	3.14	4.53	3.79	0.61	4.35	6.17	5.18	0.88
Transparency (m)	0.55	0.83	0.68	0.13	0.76	1.2	0.93	0.20
SS (mg/L)	54.83	84.62	78.75	13.94	21.73	69.86	43.97	19.84
BOD5 (mg d'O_2/L)	54.9	112	83.8	23.98	13.2	61.4	37.53	22.00
Nitrites (µg/L)	30	120	70	42.42	7	20	12.75	5.62
Ammonium (mg/L)	0.46	1.39	0.82	0.40	0.07	0.17	0.10	0.05
Phosphates (µg/L)	80	150	108.5	37.35	13	70	40.75	24.68

DO : Dissolved Oxygen and PSU : Practical Salinity Unit.

Composition of benthic macroinvertebrates

The organisms found are listed in Table 3. The benthic macroinvertebrates found from the Acadjas station are grouped into four classes, eight orders and eleven families. The families Thiaridae, Tubificidae and Chironomidae are the most abundant in this station. They represent more than 81% of the total population. On the other hand, in the reference station there are seven classes, fifteen orders and twenty-one families. Crustaceans, Bivalves and some insect families (Baetidae, Libellulidae, Lestidae and Veliidae) dominate with more than 80% of the total population. Considering their tolerance to organic pollution, near Acadjas we found 2.94% of highly sensitive organisms, 31.36% of medium sensitive organisms and 65.68% of tolerant organisms. On the other hand, at the reference station we found 12.60% of very sensitive organisms, for medium sensitive organisms 80.93% and 6.46% of organisms that are tolerant to organic pollution.

Equitability, Shannon and Jaccard Index

The table 4 show results about different index at the two stations. The Shannon index and Equitability are respectively 1.712 and 0.7141 in the Acadjas. Whereas for the reference station the Shannon index is 2.473 and the Equitability 0.8123. The values of these two parameters are low in the Acadjas compared to those of the reference station. The Jaccard Index with a value of 0.21875 indicates that there is little similarity between the two stations. The Mann-Whitney test with p = 0.01 also revealed that there is a significant difference between the two stations in terms of taxonomic composition.

Table 3. Taxonomic list of benthic macroinvertebrates collected between August 2016 and July 2017 at the level of Acadjas (SA) and at the reference station (SR) in the Ebrié lagoon.

Classes	Orders	Families	Sensitivity	Stations	
				SA	SR
Hydrozoa	Hydroid	Clavidae	M	0	1
Bivalvia	Veneroida	Donacidae	M	0	52
Gastropods	Caenogastropoda	Thiaridae	M	105	9
Arachnida	Araneae	Tetragnathidae	M	1	7
	Trombidiformes	Hydrachnidae	M	0	4
Annelida	Oligochaeta	Tubificidae	T	117	0
		Lumbricidae	T	7	0
	Polychaeta	Nereididae	T	19	19
		Nephtyidae	T	13	0
		Lysaretidae	T	0	8
		Sigalionidae	T	7	0
Insecta	Diptera	Chironomidae	T	82	13
		Nymph	M	0	3
	Dermaptera	Forficulidae	M	0	8
	Hemiptera	Veliidae	M	8	17
		Belostomatidae	M	0	13
	Ephemeroptera	Baetidae	S	11	78
	Odonata	Libellulidae	M	0	34
		Lestidae	M	3	23
	Coleoptera	Dytiscidae	M	0	6
Malacostraca	Amphipoda	Gammaridae	M	0	148
		Corophidae	M	0	82
		Crangonyctidae	M	0	5
	Decapoda	Palaemonidae	M	0	27
	Isopoda	Sphaeromatidae	M	0	62
7 Classes	16 Orders	25 Families		373	619

Influences of organic pollution on the composition of macroinvertebrates

The graphs in Figure 3 show the influence of organic pollution on the composition of benthic macroinvertebrates according to the seasons. In the Acadjas, where organic pollution is relatively high, there is a dominance of tolerant organisms and a small proportion of sensitive organisms. On the other hand, at the reference station where the organic pollution is less, we observed that the organisms of medium sensitivity (Gastropoda, Arachnida, Malacostraca and other Insecta such as Odonata, Coleoptera, Hemiptera and Dermaptera) are the most abundant. In addition, a relatively larger proportion of sensitive organisms are found in the reference station. Moreover, it can be seen that in the two stations, the proportion of organisms tolerant to organic pollution is greater in dry seasons when the organic load is very high. Sensitive organisms, on the contrary, abound mostly during the rainy seasons with the reduction of organic pollution.

Discussion

The physicochemical characteristics of the water samples showed that the quality of the water at the level of Acadjas is less than that of the water in the reference station. The concentrations of BOD5, ammonium, nitrites and phosphate, which are organic pollution indicator parameters (BE, 2011), are relatively high in Acadjas waters. Temperature and suspended solid matter are also high at these facilities.

Table 4. Equitability, Shannon and Jaccard index of two sampling stations.

	Acadjas station	Reference station
Equitability	0.7416	0.7977
Shannon index	1.778	2.429
Jaccard index	0.21875	

On the other hand, the pH, the dissolved oxygen and the transparency are weak compared to those of the reference station. The different values of the physicochemical parameters would be related to the pollutant nature of the materials (cluster of branches) used for the construction of the Acadjas and also to the agricultural byproducts (banana peels, cassava peels and palm seed cakes) used as nutrient and fertilizer during Acadjas setting up.

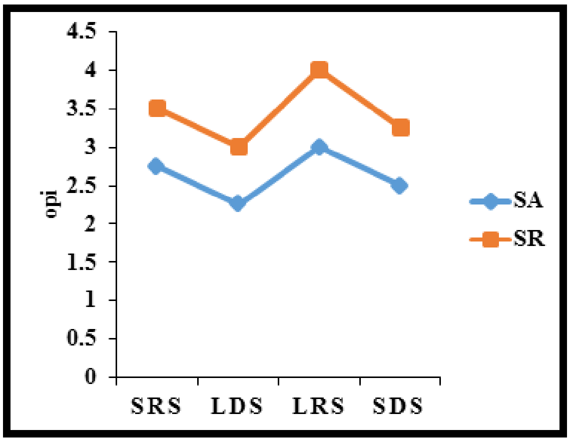

Fig. 2. Seasonal variation of the Organic Pollution Index (OPI) at the Acadjas (SA) and the reference Station (SR) between August 2016 and July 2017 in the Ebrié lagoon.

Indeed, the decomposition of these organic compounds is accompanied by a strong bacterial activity responsible for the reduction of dissolved oxygen (Villeneuve *et al.*, 2006) and also chemical reactions favoring the formation and accumulation of nitrogenous nutrients and phosphorus in the environment (Gulis and Suberkropp, 2002, Najla, 2015, Human *et al.*, 2018). In addition, the decomposition of organic matter is a phenomenon that facilitates the release of organic fine particles (Laignel, 2009) into the water column. This results in increasing the level of suspended solids and therefore reducing the transparency of the water. The values obtained regarding the Acadjas facilities for BDO5, ammonium, nitrate and phosphate have led to the suspicion of organic pollution. The assessment of water quality by the determination of the organic pollution index confirmed this observation. The waters of the Acadjas environment have an OPI which varies between 2.25 and 3 while in the reference station the OPI varies between 3 and 4. These values indicate that the organic pollution is, in general, high in the Acadjas except during the rainy season when it becomes moderate. Organic pollution is rather moderate in all seasons in the control station except during the long rainy season when it is very low because of the inflow of water from the rains and floods of the Kpapkidje River. The reason for the lower organic pollution during the long rainy season would be due largely as a result of the dilution effect of abundant freshwater inflow (river and runoff) from the mainland according to Makhoukh *et al.* (2011), Zinsou *et al.* (2016), and Amon *et al.* (2017).

The torrential rains would therefore play a major role in the phenomenon of self-purification of surface water during these periods.

The values for diversity index Shannon and Equitability were low in Acadjas station (H '= 1.712 and E = 0.7141) compared to those of the reference station (H' = 2.473 and E = 0.8123). These values indicate that the Acadjas station is less diversified than the reference station. It is also observed that the number of taxa noted at the Acadjas (373 organisms) was almost two times lower than that obtained at the reference station (619 organisms). The Mann-Whitney test revealed a significant difference (p = 0.01) between the two stations with respect to taxonomic richness.

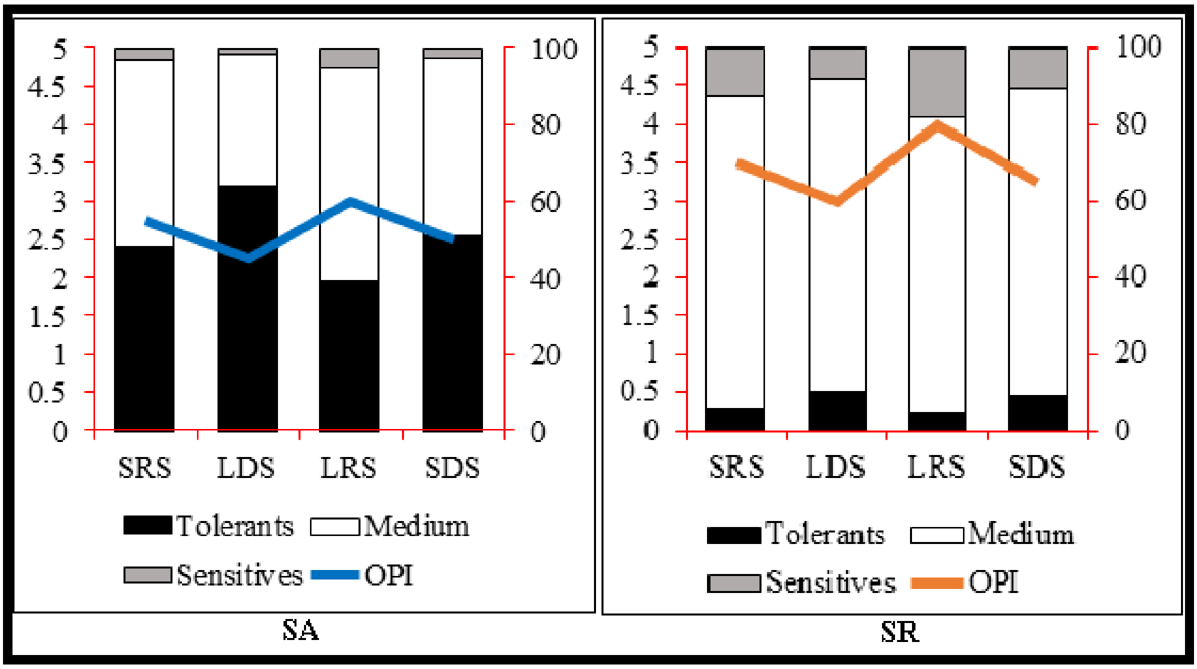

Fig. 3. Seasonal variation of the group of polluo-sensitivity benthic macroinvertebrates according to the degree of organic pollution in the Acadjas (SA) and the reference station (SR) between August 2016 and July 2017 in the Ebrié lagoon.

This difference is due to the particular ecological conditions at each of the two stations. The installation of Acadjas make use of branches for construction and agricultural by-products for food, have the effect of enriching sediments with organic matter. The degradation of organic matter by bacteria causes anoxia of the environment while accumulating nitrogen and phosphorus nutrients. This results in a eutrophic environment that is generally unfavorable for the survival of highly sensitive benthic macroinvertebrates such as Ephemeroptera and some Coleoptera. On the other hand, organisms that are more tolerant to organic pollution and less demanding in oxygen such as Annelids and Chironomidae are able to survive under this particular environmental conditions of the Acadjas. The latter are recognized as organisms capable of proliferating in eutrophic environments (Olomukoro and Ezemonye, 2006). The change in the composition of the benthic fauna following an accumulation of organic matter in the environment was observed by Simmou *et al.* (2015) and Yoboué *et al.* (2018). Several studies have also shown that the distribution of the different taxonomic groups of macroinvertebrates is closely related to the conditions of the environment, namely the availability of food (Peeters *et al.*, 2004), the composition of the substrate (Gnohossou, 2006), the increase in nutrient load (Buss *et al.*, 2002), competition and predation (Haddaway *et al.*, 2014).

Therefore Thiaridae, Tubificidae and Chironomidae, which are scavenger and omnivorous organisms, abound in the Acadjas where they find their food. On the other hand, taxa belonging to certain groups of Insects (Dermaptera, Hemiptera, Odonata and Coleoptera) and Crustaceans (Gammaridae, Corophidae, Palaemonidae and Sphaeromatidae) are only found in the reference station. Some taxa among Insects and Crustaceans are predators and move in the water column in search of their prey. They would be thwarted in their movement by the physical clumsy that is the presence of branches in the water. In addition, the value of Jaccard's similarity index revealed a low similarity between the two stations. Indeed, out of the 25 families surveyed in all the two stations, only 7 families are common to both stations. 14 families were found exclusively at the reference station against 4 families at the Acadjas facilities. The practice of the Acadjas would be responsible for the reduction in the diversity of the local benthic fauna.
Seasonal variations in the composition of benthic macroinvertebrates based on the degree of organic pollution revealed that pollutant-tolerant organisms (Tubificidae and Chironomidae) proliferate in dry seasons when the organic load in the environment is particularly high at the expense of pollutant-sensitive organisms (Ephemeroptera).

In rainy seasons the distribution of macroinvertebrates is modified with the decrease of pollutant-tolerant organisms and the marked appearance of pollo-sensitive organisms. During dry seasons the decomposition of organic matter, the reduction of water currents and evaporation lead to high organic pollution in the Acadjas. This leads to the disappearance of sensitive organisms for the benefit of the most tolerant. In the rainy season, abundant inflow of continental water (rivers and runoff) and strong water currents contribute to the dilution of water and the dispersion of organic matter, thus reducing organic pollution. This change brings about favorable environmental conditions and a biological equilibrium is established with a relatively high proportion of sensitive organisms.

In general, the disruption on aquatic organisms and particularly on benthic macroinvertebrates, caused by the practice of Acadjas are manifested by the reduction of species diversity and abundance. The overall results are in line with the study done by Bankole and Olou (2000), Onyema (2013) and Dedjiho (2014) on the disruption caused by the practice of Acadjas on the quality of waters of lake Nokoué and the Estuarine lagoon of Lagos and also on the specific diversity of the organisms of lake Ahémé in Benin.

Conclusion

Our study has shown that the practice of the Acadjas has pronounced consequences on the quality of waters and on the composition of the benthic macroinvertebrates.

The organic pollution caused by these practice is manifested by anoxic conditions, enrichment of the water with nutrients, by the increase of the BOD5 and the level of suspended matter. These poor environmental conditions are amplified during the dry seasons and improved during the rainy seasons. However, degradation of water quality has a significant impact on benthic fauna. The practice of the Acadjas is responsible for reduction in the number of population and the taxonomic richness of the benthic organisms. There is a proliferation of organic pollution indicator organisms such as molluscs, annelids and some insects belonging to the family Chironomidae.

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