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Shrimp Assemblages in Relation to Environmental Characteristics of Four Shallow Rivers in South East Côte d'Ivoire

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Abstract

Shrimps are essential components of freshwater ecosystems where they contribute to detritivorous roles and can comprise the majority of macro-invertebrate biomass. However, changes in some environmental characteristics strongly influence their diversity and abundance. Patterns of their community structure in relation to environmental characteristics were investigated in four shallow rivers in South East Côte d'Ivoire. Shrimp samples were taken monthly using a long-handled net. Three species (*Desmocaris trispinosa, Macrobrachium thysi* and *M. raridens*) were caught in this study. Overall, species diversity and abundance were lower in rivers receiving palm oil mill effluents (POME) in their catchment area. Highest abundances for the latter rivers were recorded downstream, farther to POME release point. Analysis of the correlation between community structure and environmental variables showed that conductivity, water temperature, dissolved oxygen, percentage of mud, and pH were the environmental factors that strongly influenced spatial variation in shrimp abundance. *D. trispinosa* seemed to tolerate a wide range of environmental conditions, while *M. thysi* appeared more sensitive to disturbance of its environment.

Keywords: Decapoda, diversity, abundance, palm oil mill effluents, West Africa.

Introduction

Caridean shrimps play a central role in many freshwater ecosystems throughout the world because they influence the distribution of algae (Pringle, 1996) and the composition of benthic invertebrate communities (March *et al*., 2002). They are an important component of river invertebrate assemblages in tropical and subtropical zones, where they play the same detritivorous role as Amphipoda and Isopoda in temperate regions (Covich, 1988; Kumari de Silva and de Silva, 1989; March *et al*., 2001) and can, at times, comprise the majority of macro-invertebrate biomass (Boulton and Lloyd, 1991; Sheldon and Walker, 1998). In this regard, they may even be considered keystone species (Pringle *et al*., 1993), particularly in shallow rivers.

Based on this importance of aquatic invertebrate communities, freshwater ecologists are interested in processes that influence spatial distribution and structures of their faunal assemblages. Previous studies indicated that factors influencing shrimp communities were many and varied depending on the scale and methods applied. Physical and chemical parameters, the type of substrate and the presence or absence of aquatic vegetation, significantly influenced diversity, spatial and temporal distribution of shrimp communities (Fossati *et al*., 2002; Richardson and Cook, 2006; N'zi *et al*., 2008; Camara *et al*., 2009; Rashed-Un-Nabi *et al*., 2011; Tchakonté *et al*., 2014).

In Côte d'Ivoire, studies dealing with the influence of environmental conditions on shrimp communities were those of N'zi *et al*. (2003, 2008) and Camara *et al*. (2009). Only, the research of Camara *et al*. (2009) focused on a shallow river. Because of the fragility of this type of aquatic ecosystems, due to the consequence of runoff processes and/or effluent release from agricultural land and agro-industrial units (Li *et al*., 2013), knowledge of the structure of their fauna is necessary. Four of these shallow rivers, located in South East Côte d'Ivoire, were considered in this study. The region is an important agricultural zone with many industrial palm oil, cocoa, coco nuts, and rubber tree plantations. Two out of the four small rivers under study regularly received palm oil mill effluent (POME) in the upper part of their catchment area from an agro-industrial palm oil production unit. The aims of the study were to provide baseline information on shrimp diversity and sound out

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possible impacts of environmental characteristics on species richness, abundance, and distribution in this area.

Materials and Methods

Study Area

Four small rivers (Ehania, Bodoua, Boulo 1, and Boulo 2) located in South East Côte d'Ivoire were surveyed (Figure 1). This area is characterized by four seasons: a long rainy season (May to July), a short dry season (August to September), a short rainy season (October to November), and a long dry season (December to March). The upper zones of the studied rivers are surrounded by an industrial plantation of palm oil. Two of the studied rivers (Ehania and Boulo 1) received regularly POME in the upper zone of their catchment area from an important industrial palm oil production unit. Three to four sampling sites were chosen on each river along a longitudinal gradient. For River Boulo 1, in addition to these four sites, a fifth site (C5) was chosen on a small tributary which is free of POME release.

Environmental Conditions

Environmental parameters (water depth, temperature, pH, conductivity, dissolved oxygen, canopy, current velocity, mud level, vegetal debris occurrence, aquatic plant proportion, and gravel-sand mixture percent) were monthly measured *in situ* at each site from April 2012 through March 2013. Canopy cover (%) and substrate type (mud, gravel-sand mixture) were estimated visually as described by Gordon *et al*. (1994), and Rios and Bailey (2006). Current velocity ($m.s^{-1}$) was measured as implemented by Camara *et al*. (2009) and it was taken in mid-channel on five occasions by timing a floating object (polystyrene cube) over a five meter stretch of the river. Current velocity value recorded was the average of the five trials. Water depth (m) and width (m) were measured (average of five measures) to the nearest centimeter. Physical and chemical characteristics in different sampling sites are presented in Table 1.

Shrimp Samples Collection and Identification

Shrimps were collected monthly from April 2012 through March 2013 using a long-handled net (25 cm diameter, and 2 mm mesh size). Sampling was conducted by a single operator during five minutes at each sampling site. The material retained in the net was transferred into a white tray. Shrimps were then sorted and kept in plastic bottles containing a 70% ethanol solution. The shrimps caught were identified under a microscope following Monod (1966, 1980), and Powell (1980).

Data Analysis

The number of individuals per species, sites and sampling period was determined. The occurrence percentage (%OF) was calculated using the following formula:

$$\%OF = (Ni/Nts) \times 100,$$

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 Dajoz (2000): %OF>50: very frequent species;

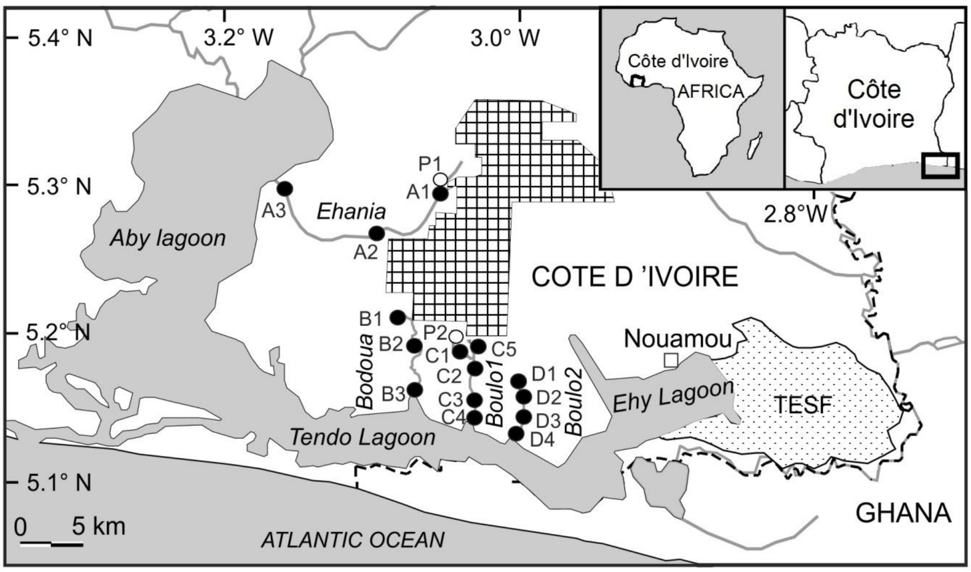

Figure 1. Sampling sites (●) in South East Côte d'Ivoire.○: Palm oil mill effluent release sites; TESF: Tano-Ehy Swamp Forest; gridded area: palm oil industrial plantation.

Table 1. Environmental variables (mean±SD) measured at different sites in four small coastal rivers (A: Ehania, B: Bodoua, C: Boulo 1, D: Boulo 2) in South East Côte d'Ivoire from April 2012 through March 2013

Rivers	Sites	Seasons	Environmental Variables										
			WT	DO (%)	Cond	WD	pH	GSM	Mud	VD	AP	Can	Vel
A	A1	RS	26.88±1.13	21.89±7.18	227.83±165.85	0.36±0.04	5.70±0.45	85	0	15	0	0	0.69
		DS	28.90±1.51	31.34±21.82	406.45±345.09	0.31±0.03	4.98±0.56						
	A2	RS	26.42±1.28	22.30±4.90	83.93±37.88	0.88±0.29	5.79±0.29	10	45	30	15	0	0.58
		DS	26.08±0.47	24.03±2.43	78.74±50.52	0.63±0.09	5.19±1.08						
	A3	RS	25.48±0.58	22.5±9.336	54.20±20.79	1.62±0.43	5.86±0.98	20	20	50	5	90	0.37
		DS	25.79±0.69	28.39±13.92	58.34±20.13	1.73±0.24	5.58±0.96						
B	B1	RS	25.73±1.16	42.44±6.11	40.50±29.24	0.42±0.05	5.51±0.75	20	35	45	0	50	0.00
		DS	26.28±0.81	45.60±7.97	25.33±1.75	0.42±0.11	5.92±1.23						
	B2	RS	25.47±0.37	46.04±4.07	34.32±12.88	1.31±0.28	5.36±0.62	40	10	50	5	5	0.57
		DS	26.10±0.72	52.03±6.56	28.94±2.28	1.23±0.72	5.93±0.89						
	B3	RS	26.12±0.45	37.98±18.38	58.66±6.33	0.41±0.06	5.42±0.46	20	15	65	0	25	0.00
		DS	27.09±0.14	21.53±7.52	45.18±2.91	0.43±0.01	5.71±0.26						
C	C1	RS	27.75±1.92	31.73±5.59	226.06±139.60	0.21±0.07	5.07±0.56	60	5	40	0	33	0.44
		DS	27.82±1.89	39.87±5.32	62.68±18.83	0.16±0.03	5.30±0.97						
	C2	RS	26.58±1.23	26.27±9.45	194.10±123.28	0.21±0.08	4.99±0.53	40	20	40	0	45	0.52
		DS	26.98±0.75	33.94±6.03	62.63±16.00	0.42±0.32	5.15±0.94						
	C3	RS	25.50±0.46	30.50±14.46	68.06±10.72	1.12±0.05	5.42±0.63	10	35	50	5	5	0.40
		DS	25.58±0.67	25.51±7.90	46.53±13.00	1.22±0.11	5.49±0.34						
	C4	RS	25.72±0.47	22.37±6.97	67.91±6.71	0.52±0.14	5.64±0.73	0	40	55	5	63	0.10
		DS	26.08±1.16	21.06±0.39	44.70±9.27	0.63±0.23	5.95±0.36						
	C5	RS	25.63±0.44	33.88±10.17	34.02±2.28	0.53±0.19	5.05±0.35	40	10	30	30	15	0.97
		DS	25.83±0.44	46.78±15.38	30.21±5.08	0.59±0.27	5.02±0.69						
D	D1	RS	25.99±0.47	17.55±5.91	35.89±5.36	0.86±0.22	5.57±0.65	30	35	35	0	70	0.00
		DS	25.85±0.52	37.34±17.18	58.26±24?35	0.77±0.27	5.99±0.39						
	D2	RS	26.02±0.36	17.00±4.13	30.38±3.78	0.56±0.07	5.37±0.54	60	10	30	0	5	0.12
		DS	25.93±0.95	31.70±16.66	29.13±9.46	0.40±0.05	5.34±0.71						
	D3	RS	26.22±0.35	32.67±6.29	30.80±2.87	0.76±0.23	5.28±0.69	0	20	80	0	80	0.16
		DS	26.05±041	34.49±6.38	25.24±2.55	0.60±0.15	5.55±0.30						
	D4	RS	25.85±0.79	19.34±6.94	36.07±5.47	1.41±0.38	5.90±0.39	70	0	30	0	10	0.16
		DS	27.15±1.83	24.41±15.13	39.03±5.28	1.65±0.15	5.88±0.62						

WT: water temperature; DO: dissolved oxygen; Cond: conductivity; WD: water depth; GSM: gravel-sand mixture, VD: vegetal debris, AP: aquatic plant; Can: canopy; and Vel: current velocity

25<%OF ≤50: common species; %OF≤25: rare species.

Before performing comparison analyses, data normality and homogeneity were checked using the Kolmogorov-Smirnov test (P>0.05) and the Levene test (Sokal and Rohlf, 1995), respectively. Seasonal variation in shrimp abundance was evaluated using the Student t test. A significance level of P<0.05 was considered**.**

Species abundance in relation to environmental variables was analyzed using Spearman's correlation test (Sokal and Rohlf, 1995) and the ReDundancy Analysis (RDA). The RDA method was used to detect patterns of species association related to environmental variables (ter Braak and Verdonschot, 1995). Environmental variables and shrimp data were log10(x+1) transformed prior to analysis. Monte Carlo permutations (500) were done so as to identify a subset of measured environmental variables which exerted significant and independent influences on shrimp distribution at P<0.05. RDA was performed using CANOCO 4.5 (ter Braak and Smilauer, 2002) whereas STATISTICA 7.1 computer package was used for the other tests. In the ordination diagram produced by CANOCO, the importance of environmental factors is indicated by the relative length of vectors, i.e. the longer the vector, the greater the influence on species distribution (ter Braak and Verdonschot, 1995).

Results

Species Composition and Distribution

Occurrence Data

From all the 15 sampling sites visited three species were collected: *Desmocaris trispinosa* (Desmocarididae), *Macrobrachium thysi*, and *M. raridens* (Palaemonidae). The species diversity varied with sampling rivers. It was highest in River Boulo 2 with the three species. Two species (*Desmocaris trispinosa* and *M. raridens*) were collected in rivers Bodoua and Boulo 1, while only *D. trispinosa* was caught in river Ehania.

Species occurrence percentage at each river level and species classification (very frequent, common, and rare) as well varied with sampling rivers. *D. trispinosa* was common in Rivers Ehania (%OF=31.03) and Boulo 1 (%OF=40) but very frequent in River Bodoua (%OF=90) and River Boulo 2 (%OF=82.50). *M. thysi* was common in River Bodoua (%OF=40) and River Boulo 2 (%OF=25) but rare in River Boulo 1 (%OF=14). *M. raridens*, which was only collected in River Boulo 2 appeared rarely (%OF=5) in the samples. At the level of all samples collected in this study in all four rivers, *D. trispinosa* appeared also very frequent (%OF=59.73), while *M. thysi* (%OF=20.13) and *M. raridens* (%OF=1.34) were rare.

When the analysis is done only considering the sampling season (dry or rainy seasons), *D. trispinosa* appeared very frequent in each sampling season (with %OF data of 61.33 and 59.46, respectively for dry and rainy seasons), while other species remained rare during these seasons (0-24 %OF).

Abundance Data

Overall, based on all samples collected during this study, *D. trispinosa* was the most abundant species with 6,130 individuals out of 6,398. It was followed by *M. thysi* and *M. raridens* with 265 and 3 individuals respectively. When the studied rivers were considered separately, *D. trispinosa* appeared also as the most abundant species for each of them. Figure 2 showed marked shrimp abundance variation both within sampling rivers as well as sampling sites. In Rivers Ehania and Boulo 1 where POME was released in the upstream area, shrimp abundance was noticeable only in the downstream section of the river (in sites A3 for River Ehania and C4 in River Boulo 1) with the exception of site C5 which is an upstream site of River Boulo 1 but located on a small tributary with no POME input. In two others rivers (Bodoua and Boulo 2) shrimps were caught in all different sites (from upstream to downstream), and abundance data did not seem to follow any particular gradient. The highest abundance was recorded at sites B1 and D3, respectively in Rivers Bodoua and Boulo 2.

Highest total shrimp abundances were observed during dry season for Rivers Ehania and Bodoua, while they mainly occurred in rainy season in Rivers Boulo 1 and Boulo 2 (Figure 3). But the student tests performed showed significant variation between seasons only for Boulo 1 (P<0.05).

Correlations Between Shrimps Abundance and Environmental Variables

The spearman correlation analysis results performed on species with important specimens number (*Desmocaris trispinosa* and *Macrobrachium thysi*) revealed that dissolved oxygen, conductivity, water temperature, and water velocity strongly influenced the abundance of shrimp species (Table 2). The abundance of *D. trispinosa* was negatively correlated with conductivity, water temperature and current velocity, while abundance of *M. thysi* was positively correlated with dissolved oxygen and

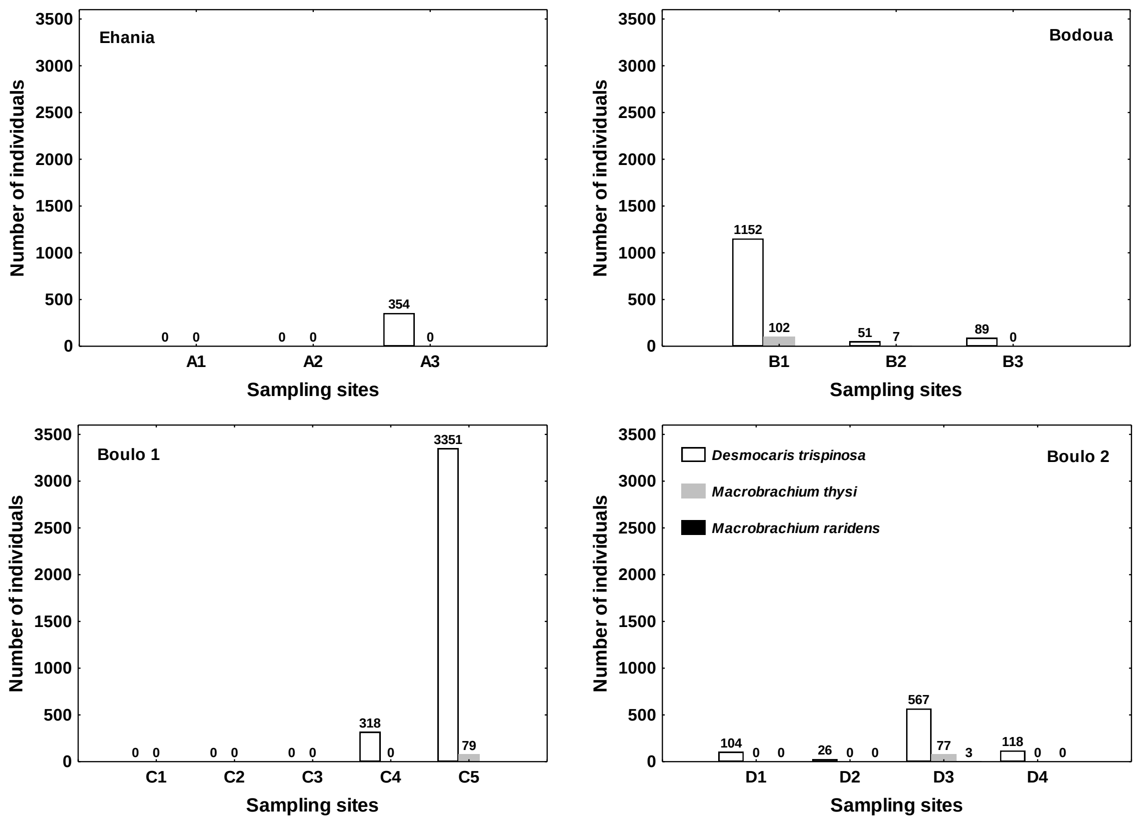

Figure 2. Shrimp' mean abundances for different sampling sites of four small coastal rivers in South East Côte d'Ivoire.

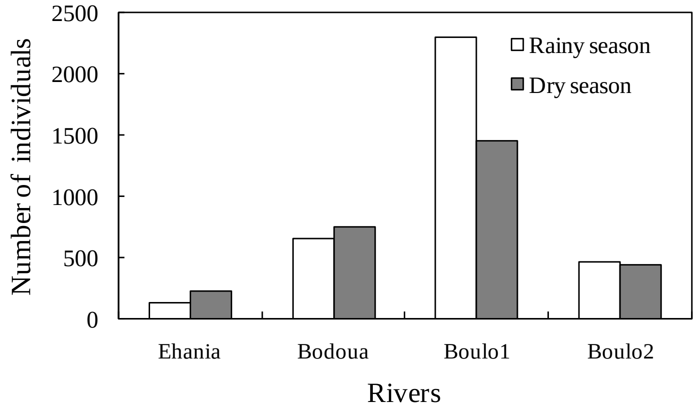

Figure 3. Number of shrimp individuals caught during dry and rainy seasons in four shallow coastal rivers (A: Ehania; B: Bodoua; C: Boulo 1; and D: Boulo 2) in South East Côte d'Ivoire from April 2012 through March 2013.

negatively with conductivity.

Results of the Redundancy Analysis (RDA) showed that the correlation between environmental factors and shrimp species was mainly explained by the first two axes (95.60% of total variance). Conductivity, water temperature, percentage of mud, pH, dissolved oxygen, and water velocity were the best at explaining shrimp fauna distribution in the explored rivers (Figure 4). *Desmocaris trispinosa* was more abundant in sites where pH was higher and water temperature, conductivity and percentage of mud displayed the lowest values. High abundances of *M. thysi* were mainly influenced by a good oxygenation level. The distribution of *M. raridens* did not seem to be influenced by any of the environmental variables considered in this study. Overall, axis 1 successfully separated sites receiving POME release from those that were free of it: sites receiving POME were mainly located in the positive part of axis 1 and were characterized by highest values of conductivity, water temperature, proportion of mud, and an absence of shrimps; sites that were free of POME release were located in the negative part of axis 1 and had lowest values of conductivity, water temperature, mud proportion, and included shrimps presence.

Discussion

Three species (*Desmocaris trispinosa*, *Macrobrachium thysi*, and *M. raridens*) were collected in the four small coastal rivers under study. The species diversity varied with sampling river. One or two species were collected in sites without POME, with a third species collected only in one site without POME. No shrimps were collected in the sites close to the POME releases (less than 3 km). The overall species diversity for these shallow coastal rivers is comparable to findings of Camara *et al*. (2009) in another small coastal river in the south of Côte d'Ivoire. These authors sampled 3 species (*D. trispinosa*, *Macrobrachium thysi*, and *M. dux*) in River Banco. However, species diversity in present study is lower than those mentioned in River Mé (n=10 species) (N'zi *et al*., 2003) and River Boubo (n=9 species) (N'zi *et al*., 2008) in Côte d'Ivoire. Many reasons such as longitudinal zonation of river abiotic conditions (Graça *et al*., 2004), river size (Camara *et al*., 2009), discharge (Cortes *et al*., 2002), sampling sites' (habitats) physical and chemical characteristics (Cumberlidge, 2005; Tchakonté *et al*., 2014), and sampling gear characteristics (Rashed-Un-Nabi *et al*., 2011) could explain species diversity variation along and within basins. For instance some shrimp species are collected only through electrofishing (N'zi *et al*., 2008; Rashed-Un-Nabi *et al*., 2011). The four small rivers sampled in this study were located in an important agricultural zone while the Banco River, in the Banco forest, is partly surrounded by the capital city Abidjan (Côte d'Ivoire). Water quality in these two rivers could have been impaired by human activities (agriculture, and uncontrolled discharge of domestic, urban and industrial wastes and sewages in the rivers) as mentionned by Tchakonté *et al*. (2014). However, the Banco River (9 km long) (Camara *et al*., 2009) and the four rivers studied in the present study (6, 7, 8.5, and 20 km long, respectively for Rivers Boulo 2, Boulo 1, Bodoua, and Ehania) are relatively small, while River Boubo (130 km long) (N'zi *et al*., 2008) and Mé (140 km long) (N'zi *et al*., 2003) are bigger. The ability of bigger rivers to support higher species diversity is explained by the fact that they have large range of various microhabitats being able to host more species (Graça *et al*., 2004). Additionally the sampling gear used could also have induced differences between data presented above. The present investigation was based on handled net fishing while N'zi *et al*. (2003, 2008) used an electrofishing gear in Boubo and Mé rivers.

Species richness was found to vary among rivers. In Rivers Ehania and Boulo 1, where POME was released in upper stream, few species (1 and 2) were collected and shrimp abundance seemed to follow an upstream-downstream gradient, with

Table 2. Results of the Spearman correlation analysis (*p*-values) between shrimp species and environmental factors

	Environmental variables										
Species	pH	DO	Cond	WD	WT	GSM	M	VD	AP	Can	Vel
Desmocaris tripinosa	0.26	0.03	-0.64	0.26	-0.41	0.06	-0.25	-0.19	0.09	-0.16	-0.41
Macrobrachium thysi	-0.05	0.46	-0.62	-0.06	-0.15	-0.02	-0.09	-0.28	0.15	-0.06	0.003

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.

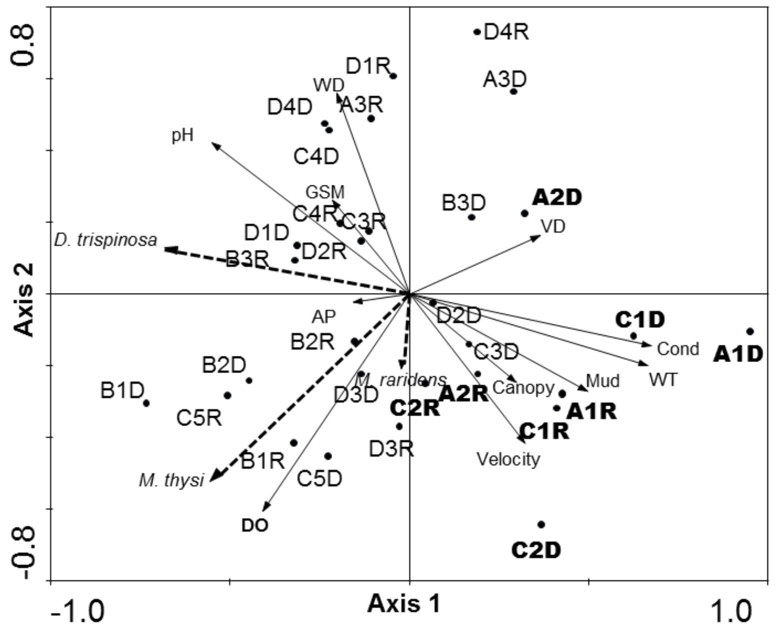

Figure 4. Redundancy analysis triplots showing relationships between sampling sites and shrimp species and environmental variables in the four shallow coastal rivers in South East Côte d'Ivoire.

Sample codes: A1-A3 from river Ehania, B1-B3 from river Bodoua, C1-C5 from river Boulo 1, and D1-D4 from river Boulo 2; Environmental variables: WT= water temperature, DO=dissolved oxygen, Cond=conductivity, WD=water depth, GSM= gravel-sand mixture, VD=vegetal debris, AP=aquatic plant, Can=canopy, and Vel=current velocity ; in bold samples with POME.

significant data only in downstream, further from the POME release point. Adversely in remaining rivers, species diversity was higher (2 to 3) and shrimp appeared in upstream, as well as middle stream, and downstream. These data are evidence that POME release in a river catchment area is a possible factor that may influence shrimp species diversity, as previously mentioned by Kouamé *et al.* (2012). At a stream reach scale, invertebrates have, in general, a clumped distribution, which is assumed to be related to the mosaic of interchanging conditions in substratum, flow conditions, depth and many others (Cortes *et al*., 2002). These conditions are likely to change at a scale of only a few metres or centimetres (Arunachalam *et al*., 1991; Graça *et al*., 2004). These data do not match with abundance variation in Rivers Ehania and Boulo 1, but they further explain the type of abundance variation of shrimp species collected in the present study rivers that were free of POME release in their catchment area.

Physical and chemical data analyzed in this study showed variations along and between the rivers. Canonical correspondence analysis performed further separated sites located on rivers with POME release in their catchment area from those which do not receive it. Sites of the first group were distinguished by high conductivity, water temperature, mud proportion and absence of shrimp, while those of the second group had low conductivity, water temperature, mud proportion and hosted more shrimp species. POME are known to contain soluble material such as gases (CH_4, SO_2, NH_3, halogens…), soluble liquids or solids which comprise ions and either organic or inorganic material and with their concentration above the threshold value (Igwe and Onyegbado, 2007). Thus without proper treatment POME may spoil aquatic ecosystems (Zhang *et al*., 2011). While evaluating the impact of effluents from an agro-industrial palm oil production unit on a small coastal river in Côte d'Ivoire) Kouamé *et al.* (2012) showed that conductivity, turbidity, pH, nitrites and orthophosphates were significantly higher in sites receiving effluents. The biotic structure and water quality of streams and rivers reflect an integration of the physical, chemical and anthropogenic processes occurring in a catchment area. Human induced hydrological changes, physical disturbances (habitat alteration, urban land use) and point and nonpoint sources of pollution (chemical contamination, surface runoff, intensive agriculture) are examples of processes responsible for a broad-scale deterioration of lotic ecosystems (Chatzinikolaou *et al*., 2006; Sharma and Chowdhary, 2011). The present study clearly showed a possible impact of POME release on environmental characteristics.

Analysis of the correlation between shrimp diversity and environmental characteristics showed that water temperature, conductivity, dissolved oxygen, pH, mud occurrence, and current velocity are the environmental characteristics that shape species diversity and abundance. It is almost a consensus among researchers that the main abiotic agents acting on the distribution and abundance of decapods are temperature, salinity, dissolved oxygen, depth, and substrate organic-matter content and texture (Tchakonté *et al*., 2014). Moreover, these parameters were key factors in the distribution of shrimps *Atyoida pilipes* and *Caridina weberi* in the rivers of Nuku-Hiva Island (Fossati *et al*., 2002), and *Pleoticus muelleri* in Southeastern Brazil (Costa *et al*., 2004). Data of the present study showed that the abundance of *D. trispinosa* decreased with increasing temperature, conductivity and current velocity. Adversely, previous studies on this species (Camara *et al*., 2009) mentioned that the highest densities were associated with high conductivities. The weakness of *D. trispinosa* to withstand in habitat with higher current velocity was already recorded in other shrimp species *Caridina waberi* (Atyidae) (Fossati *et al*., 2002). The abundance of *M. thysi* decreased with increasing water temperature and conductivity and increased with increasing dissolved oxygen level. The same trends were observed for this species in the Banco River (Camara *et al*., 2009). The high and positive correlation between *D. thysi* and the oxygen level of habitats makes this species more sensitive to environmental disturbances.

Conclusion

Three shrimp species (*Desmocaris trispinosa*, *Macrobrachium thysi* and *M. raridens*) were recorded in the four shallow rivers investigated in this study. Environmental variables such as water conductivity, temperature, dissolved oxygen, percentage of mud, and pH were the factors that strongly influenced spatial variation in shrimp diversity and abundance as shown in previous studies. More specifically, data of the present investigation showed that POME releases in some rivers catchment areas were important factors that caused environmental characteristics variations and, subsequently, induced species diversity and abundance reductions.

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