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Fish biodiversity and community structure of Okpara stream, Oueme River, Benin, West Africa: Risk of high predation and food-web alteration

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Abstract

Despite their economic and commercial importance for grassroots, and the high degradation pressure of their habitat, the fishes of most African riverine ecosystems are unknown. The current study aimed to document the diversity and community structure of the Okpara stream (Oueme River) fishes in order to contribute for habitat protection, species conservation and valorization. From December 2015 to May 2017, fish samplings were made monthly on five collecting sites with gill net, hooks and cast net. Overall, 53 fish species belonging to 30 genera and 14 families were inventoried with Mormyridae (9 species) and Cichlidae (8 species) the most speciose taxa. Numerically, 15 species aggregating 92.14% dominated the fish community with *Hemichromis fasciatus* (29.20%), the most dominant species. The high abundance of *Hemichromis fasciatus*, a top piscivorous cichlid, suggested a high predation that may affect the food web and the ecosystem balance. The multiple degradation factors recorded require a holistic management scheme including ecotoxicological studies, water hyacinth biocontrol, habitat protection, species conservation/ valorization and ecosystem follow-up.

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Introduction

In African freshwaters, the number of described fishes reached 10500 species that constitute about 25% of presently known living vertebrates (Lévêque and Paugy, 2006). However, in most African fresh and brackish waters, fish populations and communities are threatened and stocks have drastically depleted because of severe environmental disturbances. In Benin, the hydrographic network consists of lotic ecosystems (rivers, streams etc.) and lacustrine habitats such as freshwater lakes, lagoons, floodplains, wetlands etc. that stands as potential sources of income for grassroots and fishermen usuallly involved in multi-species fishery activities (FAO, 2006; MAEP, 2014; Adite *et al.,* 2017). In particular, the Okpara stream (200km), the main tributary of the Ouémé River (510km), the longest running water in Benin, provides an important commercial fish resource to the northern region of Benin. Yet, the multiple uses of the Okpara stream engendered severe degradations to this riverine water along with profound modifications of environmental quality and fish community structure (Hounsou *et al.,* 2010; Elegbede, 2015).

Major causes of the degradation of Okpara stream were (1) the withdrawal of water by SONEB, a Benin Water Company that withdraws and treats the stream water for domestic uses (Zogo *et al.,* 2008), (2) the withdrawal of water for agriculture (irrigation), (3) the permanent use of chemical fertilizers and pesticides for agriculture, (4) the use of prohibited and controversial fishing methods, (5) the proliferation of invasive aquatic vegetation such as *Echhornia crassipes*, the water hyacinth, (6) the introduction of the invasive exotic fish species, *Oreochromis niloticus* (Cichlidae) and (7) the dumping of domestic wastes. These degradation factors negatively affect the water quality, the fish community structure and the fish production (Gourene *et al.,* 1999; Laleye *et al.,* 2004; Adite *et al.,* 2013). Thus, there is an urgent need to globally assess the "ecological health" of the Okpara stream and to evaluate the fish population status in order to design an ecological sound ecosystem management scheme that guaranty the conservation and the sustainable exploitation of the fish biodiversity.

The current ichtyological research was undertaken on the Okpara stream (Ouémé River) in Northern-Benin in order to document ecological data related to physical environment, fish species distribution, population structure and degradation impacts in order to improve fish resource management and conservation in Benin as well as in tropical Africa. Specific objectives were 1) to investigate fish assemblages, distribution and community structure; 2) to investigate relationships between environmental factors and fish community indices; 3) to evaluate ecosystem degradation and impacts on fish population and 4) to suggest management scheme for ecosystem restoration, biological resource conservation and valorization.

Material and methods

Study region description

The study region is the Okpara stream (200Km), the longest tributary of the Oueme River. In Benin, the Oueme river (510Km) sourced from the Southwest of Nikki Township at an altitude of 450m and constitutes the longest running water and the most important in term of fish species richness and fish production (Laleye *et al.,* 2004). Geographically, the Okpara stream is situated between 8°14'-9°45' North and 2°35'-3°25' East, and belongs to the northern hydrographic network. In the northern region of Benin, the climate is tropical with a dry season (November - April), a wet season (May - August) and a flood period (September - October). Annual ambient temperature averaged 26.6°C and lower temperatures, around 16°C, were recorded in December-January. Annual mean rainfall is about 1200mm with a peak (1300mm) recorded in July, August or September (Kora, 2006; INSAE, 2004). Soils are ferruginous and alluvial and covered by a wooded savanna of *Parkia biglobosa*, *Khaya senegalensis*, *Vitellaria paradoxa,* marshy meadows, bamboo and fallow bushes (Dossou-Yovo, 2009; Ogouwale, 2013). Commercial fisheries take place in the Okpara stream that was mainly exploited by the grassroots. In addition, the stream supplies the surrounding populations with drinking water from a dam built by the Benin water company, the SONEB. Furthermore, the Okpara stream provides water for irrigated agricultures.

Sampling sites

For this study, five (05) sampling locations were selected (Fig. 1). These sites were chosen according to localities, accessibility, fisheries importance and levels of sites degradation.

- Site 1: This site is situated in Perere Township at Okpara up stream;
- Site 2: It is localized in Parakou Township at Gadela village (Okpara up stream), at about 2Km from SONEB dam;
- Site 3: This site is located at Kpassa village where a dam was built to serve as a source of drinking water for the populations of Tchaourou and Parakou Townships and surrounding villages;
- Site 4: Site 4 is situated around Okpara downstream at Yarimarou village (Tchaourou Township) where the dam withdraws its water;
- Site 5: This site is also located around Okpara downstream at Sui village (Tchaourou Township).

At the five collecting sites, samplings were done in the "aquatic vegetation habitat" at the edge of the stream and in the "open water habitat" characterized by a high depth and exempt of vegetation.

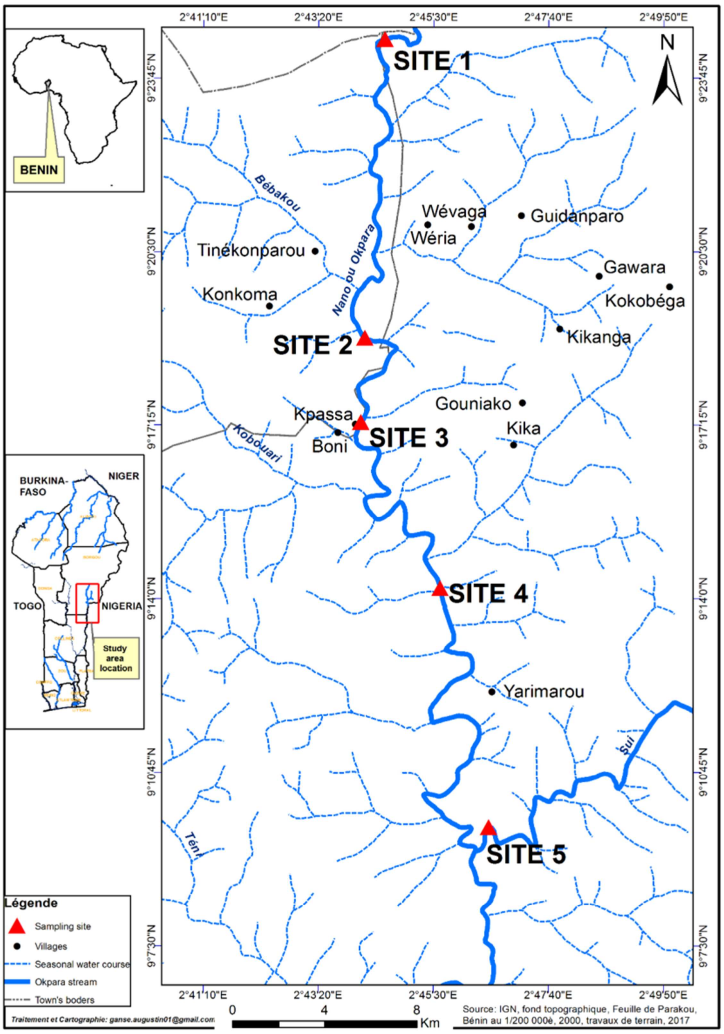

Fig. 1. Okpara stream and sampling sites. Site 1= Perere Township, Site 2 = Gadela village (Parakou Township), Site 3= Kpassa village (Tchaourou Township), Site 4= Yarimarou village (Tchaourou Township), Site 5 = Sui village (Tchaourou Township).

Evaluation of water characteristics

The quality of the different habitats (aquatic vegetation, open water) was assessed in situ at each sampling site. The depth was measured to the nearest 1cm using a graduated rope attached to a water sampler. The temperature and the dissolved oxygen were measured respectively to the nearest 0.1°C and 0.1mg.l^{-1} using a digital multi-probe (HANNA model 9150 waterproof). pHs were measured to the nearest 0.1 using a pH meter "model 3150 waterproof". Turbidities were measured to the nearest 1cm using a Secchi disc.

Fish collection

Fish samplings were done once a month for eighteen (18) months in all habitats. At each sampling site, experimental fishing have been done in the open water with an experimental gill net (25 m x 1.30m, 30mm-mesh; 25m x 1.30m, 15mm-mesh) and in marginal aquatic vegetation with a seine (4.20m-length, 2m – width, 5mm-mesh) (Adite *et al.,* 2013). In addition, fish samplings were directly made in the fishermen artisanal captures. Thus, one third of each fisherman catches was sampled, but including all uncommon or rare species (Okpeicha, 2011). Fishing gears such as gillnets, seines, cast nets, hooks, and traps were used by the fishermen to collect the fishes. After collection, the fish samples were first identified in situ using fish identification references such as Reed *et al.* (1967), Lowe McConnell (1975, 1987), Van Thielen *et al.* (1987), Skelton (1993), Paugy *et al.* (2004), Lévêque and Paugy (2006), Lévêque *et al.* (1990-1992). The fish assemblages were preserved in a cooler and then transported to the Laboratory of Ecology and Management of Aquatic Ecosystem (LEMEA) to confirm the identifications. The valid scientific names of the fish species have been confirmed on the website of www.Fishbase.org (Froese and Pauly, 2018). In the lab, each fish individual was measured, weighted and preserved in 10% formalin and latter in 70% ethanol to make easier other biological observations such stomach content analysis and aspects of reproductive biology (Schreck and Moyle, 1990; Murphy and Willis, 1996).

Data analysis

Values of water factors have been recorded in Excel 2017 spreadsheet and mean values have been computed to access variabilities between sites. Also, ichthyolgical data were recorded in Excel spreadsheet and fish community indices such as abundance, relative abundance, species richness, species diversity and evenness measure were calculated. Species richness was computed using Margalef (1968) index of species richness (d):

$$d = S - {}^{1}/_{\ln N}$$

where S is the number of species, N is the number of individuals in the sample.

Shannon &Weaver (1963) diversity index (H') were determined using the following formula:

$$H' = -\sum_{i=1}^{n}[Pi * \log_2(pi)]$$

where H' is the species diversity index, pi = ni/N, the proportion of total sample belonging to species i, ni the number of individuals of each species in the sample, N, the total number of individuals of all species in the sample.

Simpson index of diversity was calculated using the following formula:

$$Ds = \sum {}^{Ni(Ni-1)}/_{N(N-1)}$$

where Ds is the Simpson index, *Ni* is the number of individuals of each species and N is the total number of individuals of all species. The Simpson index varies from 0 to 1. This index had a value of 0 to indicate the maximum diversity, and a value of 1 to indicate the minimum diversity.

Also, the Hill diversity index (Hill, 1973; Peet, 1974; Routledge, 1979) was computed in order to have much more accurate idea of the species diversity. This diversity index integrates both Shannon and Simpson diversity indices. The diversity index of Hill (1973) is calculated according to the formula:

$$Hill = {}^{(1/Ds)}/_{e^{H'}}$$

with Ds, the Simpson's index of species diversity and H', the Shannon's diversity index. This index varies from 0 to 1. The more the values are close to 1, the more the diversity will be low and the maximum diversity will be observed for values close to 0 (Grall and Hily, 2003). The index of Hill is more relevant for the measure of diversity but does not exclude the use of the other two indices because their joint use makes possible to better understand the structure of the community (Grall and Hily, 2003).

The evenness measure of Shannon-Weaver (1963) (E) function was computed following the formula:

$$E' = {}^{H'}/_{\log_2 S}$$

with *H'* the species diversity index, *S* the number of species.

In order to determine the different assemblages and the spatial distribution of the fishes, the factorial correspondence analysis (AFC) and the hierarchical clustering analysis were performed using the FactoMineR package statistical analysis software, version R 3.2.4 (Husson *et al.,* 2016). The relationships between the relative abundance of the dominant fish species and the water physicochemical parameters were assessed through the spearman correlation coefficient using SPSS 21 (Morgan *et al.,* 2012) and the redundancy analysis (RDA) using CANOCO software, version 4.5 (Ter Braak and Smilauer, 2002). The trophic structure of the fish community was assessed by grouping the fishes in different trophic guilds (phytoplanctinovores, benthivores, macrophyte feedeers, detritus feeders, zooplanctinovores, intermediate carnivores and top-carnivores). Feeding studies by Halliday and Young (1996), Adite and Winemiller (1997), Hugueny and Pouilly (1999), and Adite *et al.* (2005) were used as basis to generate these feeding guilds.

Results

Water Characteristics

Means and ranges of physicochemical parameters from Okpara stream are shown in Table 1. Overall, water depths ranged between 10.10 and 1080cm (Mean: 255.24±38.18) and water transparencies ranged between 7.1 and 80cm (mean: 32.13±2.39). Water temperatures varied from 18.9 to 30.1°C and averaged 27.33±3.26°C. Dissolved oxygen ranged between 0.44 and 5.66mg/l (mean: 2.70±0.2) with percentages of saturation varying between 6.37 and 75.30% (mean: 34.40±2.18). pHs varied from 6.40 to 8.10 and averaged 7.11±0.31. Globally, the water quality of the Okpara was suitable for primary production and for the survival and growth of the fishes.

Table 1. Means (±SD) of physicochemical parameters measured in the Okpara stream (Oueme River) from December 2015 to May 2018.

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD
Ambient temperature (°C)	26.77±0.47	26.16±0.13	26.99±0.28	27.0±0.45	26.25±0.19
Water temperature(°C)	27.24±0.56	26.02±0.13	26.11±0.34	26.71±0.53	26.08±0.20
Depth (cm)	233.17±43.17	246.37±37.51	322.39±47.04	210.08±47.12	355.31±47.06
Transparency (cm)	37.36±3.65	17.86±2.95	25.21±2.74	55.88±5.43	15.14±0.47
Dissolved O_2 (mg/l)	3.06±0.22	3.33±0.95	3.66±0.16	2.37±0.34	2.44±0.13
% O_2	30.26±2.42	32.91±1.04	38.60±1.85	31.68±3.54	30.45±1.14
pH	7.06±0.06	7.07±0.041	7.12±0.033	7.20±0.06	7.08±0.02

Fish species composition and relative abundance

During the eighteen (18) months of sampling, a total of 9552 fish individuals were collected and 53 species belonging to 29 genera and 14 families (Table 2) were inventoried. Fish families such as Mormyridae and Cichlidae were the most represented families with nine (9) and eight (8) species, respectively, whereas the less speciose family was Hepsetidae with one (1) species, *Hepsetus odoe* (Table 2). Numerically, five (5) fish species dominated the Okpara stream fish community with cumulated abundance of 65.65%. These were the carnivorous cichlid, *Hemichromis fasciatus,* the dominant species making about 29.20% of the fish community followed by the mormyrid *Marcusenius senegalensis* (16,27%), *Schilbe intermedius* (10.34%), a Schilbeidae, the nile tilapia *Oreochromis niloticus* (Cichlidae) accounting for 9.84% and *Brycinus macrolepidotus* (Characidae) making about 9.14% of the community. The remaining 49 species made together about 34.35%, and none of them made individually more than 3% of the fish community. Among them, common species were *Synodontis schall* (2.86%), *Chromidotilapia guntheri* (2.36%), *Epiplatys bifasciatus* (2.14%), *Enteromius macrops* (1.85%), *Clarias gariepinus* (1.61%), *Coptodon guineensis* (1.43%), *Sarotherodon galileus multifasciatus* (1.37%), *Hepsetus odoe* (1.3%), *Ctenopoma petherici* (1.22%) and *Hyperopisius bebe* (1.21%) (Table 2). Also, cumulated abundance of fifteen (15) species, from *Hemichromis fasciatus* (29.49%) to Hepsetus odoe (1.14%) reached 92.18% and the remaining 38 fish species made together 7.82%. With regards to fish biomass, the 9552 individuals composing the fish assemblages weighted 334,322.67 g. Like the numeric abundances, species such as *Oreochromis niloticus* (28.14%), *Hemichromis fasciatus* (14.29%), *Brycinus macrolepidotus* (11.07%), *Marcusenius senegalensis* (10.52%) and *Schilbe intermedius* (7.36%) dominated the total biomass of the fish community.

Table 2. Fish species composition, abundance, standard length (SL) range and mean, weigth range and mean of the fishes inventoried in the Okpara stream (Oueme River) from December 2015 to May 2017.

Families	Species	N	Relative Abundance (%)	SL Mean (cm)	SL Range (cm)	Weight Mean (g)	Weight Range (g)	Total weight (g)
Alestidae	*Brycinus macrolepidotus*	882	9.23	11.45	5-27.5	41.94	3.22 -509	37002.9
	Brycinus longipinnis	26	0.27	6.21	4-7.3	6.78	1.58-10.1	176.2
	Brycinus leuciscus	8	0.08	8.88	8-11	16.82	11.38-33.16	134.5
	Micralestes occidentalis	1	0.01	5.3	-	3.44	-	3.4
Anabantidae	*Ctenopoma kingsleyae*	3	0.03	13.4	10-11.8	62.4	60.5-64	182.9
	Ctenopoma petherici	118	1.23	9.19	3.1-11.8	29.75	1.24-81.82	3505.8
Aplocheilidae	*Epiplatys bifasciatus*	207	2.17	2.06	1.2-3.1	0.19	0.02-0.62	39.4
Bagridae	*Bagrus bajad*	6	0.06	16.37	14.1-18.8	78.67	50.1-117.4	472.1
	Bagrus docmak	3	0.03	14.6	12.5-17.1	52.32	28.5-87.4	157
Cichlidae	*Oreochromis niloticus*	850	8.90	12.27	2.2-26	110.33	0.6-909	94080
	Hemichromis fasciatus	2818	29.49	7.92	1.1-12.9	16.95	0.06-88.2	47775.2
	Chromidotilapia guntheri	228	2.39	7.17	1.6-11.5	18.43	1.24-62.14	4201
	Sarotherodon galilaeus mutifasciatus	163	1.71	9.93	1-114.5	69.5	0.01-998	11328.7
	Coptodon guineensis	138	1.44	7.44	0.9-20	36.01	0.04-285.4	5888
	Coptodon zilli	80	0.84	9.42	4.8-15.8	43.14	5.1-203.4	3451.1
	Sarotherodon caudomarginatus	8	0.08	8.75	5.3-14.3	39.13	8.2-119.5	313
	Pelmatolapia mariae	3	0.03	4.43	2.1-7.7	5.87	0.38-15.38	17.6
Clariidae	*Clarias agboyiensis*	14	0.15	14.36	12-17	29.66	14.5-49.8	415.3
	Clarias ebriensis	40	0.42	17.19	11-33.7	62.93	13.28-485	2517
	Clarias gariepinus	155	1.62	17.53	6.1-40	72.74	3.02-676	11275.1
	Clarias pachymena	2	0.02	23.5	17-30	172.59	52.18-293	345.2
	Gymnalabes typus	3	0.03	12.8	11-14	20.13	14.88-23.3	60.4
	Heterobranchus longifilis	11	0.12	19.6	12-39	126.67	19-424	1393.4
Claroteidae	*Chrysischtys nigrodigitatus*	59	0.62	11.82	7-40.7	38.79	5.8-214.2	2288.6
	Chrysischtys auratus	21	0.22	13	7.2-17.5	54.09	6.6-140.7	1135
Cyprinidae	*Labeo parvus*	91	0.95	11.42	7.1-17	34.17	5.38-108.86	3041.5
	Labeo senegalensis	1	0.01	18	-	177.8	-	177.8
	Enteromius macrops	179	1.87	6.32	2.1-8.1	8.63	0.22-95.8	1544.8
	Enteromius callipterus	64	0.67	6.68	1.8-8.2	9.62	0.38-14.36	538.7
	Enteromius chlorotaenia	1	0.01	8	-	14.5	-	14.5
	Raiamas senegalensis	1	0.01	8.8	-	16.82	-	16.82
Hepsetidae	*Hepsetus odoe*	109	1.14	15.18	4.7-39	95.95	3.22-1346	10266.7
Malapteruridae	*Malapterurus beninensis*	11	0.12	13.78	12-15	77.96	56.8-103.9	857.5
	Malapterurus electricus	4	0.04	15.98	12.4-19	136.56	50.22-226	546.2
Mockokidae	*Synodontis macrophtalmus*	7	0.07	10.44	6.4-12.4	32.78	13.2-51.24	229.5
	Synodontis melanopterus	7	0.07	13.23	12.4-14.2	61.23	50-67.24	428.8
	Synodontis nigrita	43	0.45	9.9	5.7-14.7	34.43	5.42-96.3	1308.3
	Synodontis schall	276	2.89	10.62	5.3-20.3	38.12	4.52-257.1	10520.6
	Synogontis budgetti	35	0.37	15.16	5.7-23	114.47	6.18-258.7	4006.4
	Synodontis sorex	1	0.01	12.5	-	50.82	-	50.8

Families	Species	N	Relative Abundance (%)	SL Mean (cm)	SL Range (cm)	Weight Mean (g)	Weight Range (g)	Total weight (g)
Mormyridae	*Hyperopisius bebe*	117	1.22	15.96	5.2-29.7	39.7	4.6-233	4486.5
	Marcusenius senegalensis	1570	16.43	10.68	4.4-15.7	22.48	1.46-72.2	35164.1
	Mormyrops anguilloides	3	0.03	36.8	35.5-38.5	402.97	316.3-455	1288.9
	Mormyrus rume	53	0.55	18.06	7.9-39	88.86	4.3-696	4710.1
	Petrocephalus pallidomaculatus	28	0.29	7.44	7.2-7.9	9.82	8.8-12.1	275.2
	Petrocephalus soudannensis	6	0.06	6.2	4.1-8	6.6	1.68-10.36	39.6
	Petrocephelus pellegrini	2	0.02	6.73	6-7.2	6.38	4.94-76	19.1
	Petrocephelus bovei	81	0.85	7.03	6-8.1	7.56	4.52-12.2	604.4
	Brienomyrus niger	2	0.02	8.2	8-8.4	15.6	15.4-15.8	31.2
Polypteridae	*Polypterus ansorgii*	4	0.04	21.03	17.7-25.8	76.97	40.66-121.4	307.9
	Polypterus endlicheri endlicheri	12	0.13	20.42	17.7-24.9	86.46	52.1-140.1	951.1
Schileidae	*Schilbe intermedius*	998	10.44	11.5	5.9-20.3	24.69	6.66-184.7	24619.3
	Schilbe mystus	2	0.02	14.35	8.8-19.9	74.31	7.4-141.22	148.6

Size of fishes

In general, the mean standard length of the fishes varied from 2.06cm (*Epiplatys bifasciatus*) to 36.8cm (*Mormyrops anguiloides*), and the mean weight ranged between 0.19g for *Epiplatys bifasciatus* to 402.97g for *Mormyrops anguiloides* (Table 2). Large species collected were *Chrysischtys nigrodigitatus* (Claroteidae) reaching a maximum standard length SL_m= 40.7cm with a maximum weight W_m =214.2g, *Heterobranchus longifilis* (Clariidae) with SL_m= 39cm and W_m =414g, *Clarias gariepinus* (Clariidae) with SL_m= 40cm and W_m =676g, *Clarias ebriensis* (Clariidae) with SL_m= 33.7cm and W_m =485g, *Clarias pachymena* (Clariidae) with SL_m= 30cm and W_m =293g, *Mormyrus rume* (Mormyridae) with SL_m= 39cm and W_m =696g, *Mormyrops anguilloides* (Mormyridae) with SL_m= 38.5cm, W_m =455g and *Hepsetus odoe* (Hepsetidae) reaching a maximum SL_m= 39cm and a maximum weight W_m =1346g. Small fish species were *Epiplatys bifasciatus* (Aplocheilidae) reaching SL_m= 3.1cm, *Enteromius macrops* (Cyprinidae) with SL_m= 8.1cm and *Enteromius callipterus* (Cyprinidae) with SL_m= 8.2cm.

Diversity indices

In the Okpara stream, Margalef (1968) species richness varied from sites to sites and ranged between 24 (site 5) and 40 (site 2). The Shannon-Weaver index of species diversity (H') computed for the cumulated fish assemblages ranged between H'=2.98 (site 3) and H'=3.76 (site 4) and reached 3.56 for the whole stream. Simpson index for the whole fish community was 0.144 and ranged between 0.1094 (site 4) to 0.2159 (site3). The Hill diversity index integrates both the Shannon-Weaver index and the Simpson index and varied between 0.208 (site 2) to 0.235 (site 3) and reached 0.198 for the whole fish community. The evenness index (E) for the whole fish community was 0.62 and ranged between 0.57 (site 3) and 0.78 (site 4) (Table 3). With regards to fishing gears, the fish assmblages from gill net displayed the highest species richness d=49 and the lowest value d=8 was recorded from trap catches. Likewise, the highest Shannon-Weaver diversity index H'= 3. 43 was recorded from gill net and trap catches exhibited the lowest value H'= 2.38. The Simpson index value ranged between 0.16 (gill net) and 0.24 (trap), and the Hill diversity index varied from 0.21 for gill net to 0.38 for trap while the evenness ranged from 0.61 (gill net) to 0.80 (trap) (Table 3). In contrast with the flood season, the dry and wet periods exhibited the highest species richness d=46 and d=40 respectively. Likewise, the diversity indexes displayed nearly the same trends. Indeed, the Shannon-weaver indicated that the dry and wet seasons were the most diversified periods and showed H'= 3.59 and H'=3.19, respectively. Both the Simpson index and the Hill index recorded confirmed these seasonals models (Table 3).

Table 3. Species richness and diversity index by sampling site, fishing gear and season of the fishes collected in the Okpara stream (Oueme River) from December 2015 to May 2017.

		Species richness (d)	Shannon-weaver diversity index (H')	Simpson (Ds)	Hill	Evenness (E)
Sampling sites	Site1	35	3.59	0.1227	0.225	0.6997
	Site2	40	3.72	0.1168	0.208	0.6985
	Site3	37	2.98	0.2159	0.235	0.5723
	Site4	28	3.76	0.1094	0.212	0.7825
	Site5	24	3.47	0.1381	0.225	0.7569
Fishing gears	Trap	8	2.38	0.2403	0.385	0.79
	Gil net	49	3.43	0.1551	0.209	0.61
	Cast net	13	2.86	0.2049	0.279	0.80
	Seine	14	2.56	0.2307	0.335	0.69
Seasons	Wet	40	3.19	0.2146	0.192	0.6
	Flood	18	3.15	0.1751	0.245	0.76
	Dry	46	3.59	0.132	0.209	0.65
All stream	-	53	3.56	0.144	0.198	0.6209

Occurrence and distribution of the fishes in the stream

In the Okpara stream, 23 fish species occurred only in upstream and not recorded in downstream. In contrast, only five (5) species, *Enteromius chlorotaenia, Synodontis budgetti, Raiamas senegalensis, Bagrus bajad*, *Bagrus docmak* were recorded sonely in downstream and not present in upstream (Table 6). However, both habitats, upstream and downstream harbored in common 25 species (Table 6). With regards to the five (5) sampling sites, the percentage occurrence (PO) of the 53 fish species ranged between 20 and 100% (Table 6). Ten (10) fish species with restraint distribution were found only in one (1) site (PO: 20%), and fifteen (15) with large distribution (PO: 100%) were recorded in the 5 sampling sites of the study (Table 6).

Table 4. Fish guilds obtained from the Hierarchical Clustering Analysis of the Okpara stream (Oueme River) fish community. Fish samplings were performed from December 2015 to May 2017.

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
S. macrophtalmus	*C. kingsleyae*	*G. typus*	*H. bebe*	*S. budgetti*
M. occidentalis	*E. bifasciatus*	*P. pallidomaculatus*	*S. galilaeus m.*	*R. senegalensis*
S. mystus	*E.macrops*	*B.niger*	*C. pethericii*	*B. docmak*
S. sorex	*P. soudanensis*	*P. bovei*	*C. zillii*	*B. bajad*
	P. mariae	*E. callipterus*	*M. senegalensis*	*E. chlorotaneia*
	P. pellegrini	*S. caudomarginatus*	*S. intermedius*	*L. senegalensis*
	P. ansorgii	*M. electricus*	*S. schall*	
	C. agboyensis		*O. niloticus*	
	M. rume		*C. guineensis*	
	M. benineensis		*P. endlicheri*	
	H. fasciatus		*C. gariepinus*	
	C. pachymena		*B. macrolepidotus*	
	B. longipinnis		*C. nigrodigitatus*	
	B. leuciscus		*H. odoe*	
	S. melanopterus		*L. parvus*	
	C. ebriensis		*S. nigrita*	
			H. longifilis	
			C. auratus	
			M. anguilloides	
			C. guntheri	

Table 5. Matrix of correlation coefficients (*r*) obtained from the regression between water parameters and both species abundance and Margalef species richness of fishes captured in Okpara stream (Oueme river tributary). Number of observations (N): 18.

Water parameters	Numeric abundance	Species richness
Depth (cm)	0.56	0.50
Transparency (cm)	-0.76**	-0.60*
Dissolved oxygen (mg/l)	0.88**	0.56*
Dissolved oxygen Saturation (%)	0.63*	0.59*
Water temperature (°C)	0.28	-0.05
pH	-0.06	-0.09

**. Correlation is significant at the 0.01 level.

*. Correlation is significant at the 0.05 level.

Table 6. Trophic categories, relative abundance, and percentage occurrences of the fishes collected in the Okpara stream (Oueme River) from December 2015 to May 2017.

Trophic category	Relative abundance (%)	Total weight (%)	Up-stream	Lower stream	Occurrence (Number of sites)	% Occurrence
Detritivores	4.7	5.99				
Chrysichtys nigrodigitatus	0.62	0.69	+	+	5	100
Chrysichtys auratus	0.22	0.34	+	+	3	60
Synodontis shall	2.89	3.15	+	+	5	100
Synodontis nigrita	0.45	0.39	+	+	4	80
Synodontis melanopterus	0.07	0.13	+		2	40
Synodontis budgetti	0.37	1.20		+	2	40
Synodontis sorex	0.01	0.02	+		1	20
Synodontis macrophtalmus	0.07	0.07	+		1	20
Planktinovores/microcarnivores	15.28	31.65				
Oreochromis niloticus	8.90	28.14	+	+	5	100
Sarotherodon galilaeus m.	1.71	3.39	+	+	4	80
Sarotherodon caudomarginatus	0.08	0.09	+		3	60
Pelmatolapia mariae	0.03	0.01	+	+	4	80
Epiplatys bifasciatus	2.17	0.02	+		3	60
Herbivores / Macrophytophage	14.42	14.575				
Coptodon zillii	0.84	1.03	+	+	5	100
Coptodon guineensis	1.44	1.76	+	+	5	100
Brycinus longipinnis	0.27	0.05	+		2	40
Brycinus macrolepdotus	9.23	11.07	+	+	5	100
Brycinus leucisus	0.08	0.04	+		2	40
Micraletes occidentalis	0.01	0.001	+		1	20
Enteromius macrops	1.87	0.46	+		1	20
Enteromius callipterus	0.67	0.16	+	+	3	60
Enteromius chlorotaenia	0.01	0.004		+	2	40
Omnivores	3.33	5.75				
Clarias gariepinus	1.62	3.37	+	+	5	100
Clarias ebriensis	0.42	0.75	+		3	60
Clarias pachymena	0.02	0.1	+		2	40
Clarias agoyenesis	0.15	0.12	+		1	20
Heterobranchus longifilis	0.12	0.42	+	+	5	100
Gymnalabes typus	0.03	0.02	+		2	40
Labeo parvus	0.95	0.91	+	+	5	100
Labeo senegalensis	0.01	0.05	+		1	20
Raiamas senegalensis	0.01	0.01		+	1	20
Insectivores / Benthophages	19.44	13.555				
Hyperopisius bebe	1.22	1.34	+	+	5	100
Brienomyrus niger	0.02	0.005	+		2	40
Marcusenius senegalensis	16.43	10.52	+	+	5	100
Mormyrus rume	0.55	1.41	+		3	60
Petrocephalus bovei	0.85	0.18	+		2	40

Trophic category	Relative abundance (%)	Total weight (%)	Up-stream	Lower stream	Occurrence (Number of sites)	% Occurrence
Petrocephalus soudanensis	0.06	0.01	+		2	40
Petrocephalus pellegrini	0.02	0.01	+		3	60
Petrocephalus pallidomaculatus	0.29	0.08	+		1	20
Intermediate carnivores	14.53	10.76				
Chromidotilapia guntheri	2.39	1.26	+	+	4	80
Schilbe mystus	0.02	0.05	+		1	20
Schilbe intermedius	10.44	7.36	+	+	5	100
Polypterus endlicheri endlicheri	0.13	0.28	+	+	4	80
Polypterus ansorgii	0.04	0.09	+		3	60
Bagrus bajad	0.06	0.14		+	2	40
Bagrus docmak	0.03	0.05		+	2	40
Malapterurus electricus	0.04	0.16	+	+	3	60
Malapterurus beninensis	0.12	0.26	+		1	20
Ctenopoma petherici	1.23	1.05	+	+	5	100
Ctenopoma kingsleyae	0.03	0.06	+		2	40
Top carnivores	30.66	17.75				
Mormyrops anguiloides	0.03	0.39	+	+	4	80
Hemichromis fasciatus	29.49	14.29	+	+	4	80
Hepsetus odoe	1.14	3.07	+	+	5	100

In addition, the output from the Factoriel Correspondance Analysis (AFC) coupled with the Hierarchical Clustering Analysis indicated that the Okpara stream fish community was classified and distributed in five (5) groups or clusters composed of 4, 16, 7, 20 and 6 species, respectively according to their abundance and habitat (Fig 2 and 3). For example, uncommon species such as *S. macrophtalmus*, *M. occidentalis*, *S. mystus*, *S. sorex* of reduced relative abundances (≤ 0.07) in cluster1 were concentrated in Site1 only (Fig 3). Also, clusters 2 and 4 integrated dominant species from Sites 1, 2, 3 and from all Sites, respectively (Fig 3).

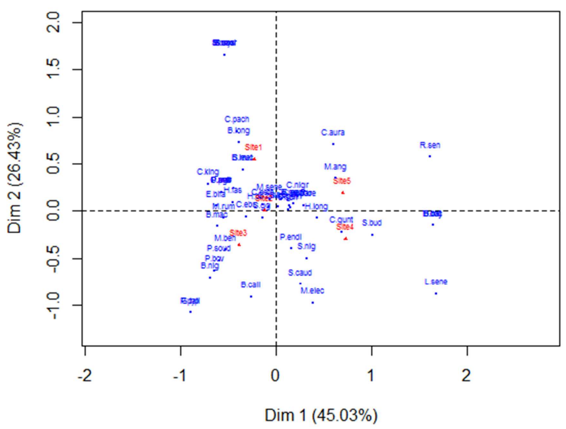

Fig. 2. Factoriel Correspondance Analysis (AFC) of the Okpara stream (Oueme River) fish community.

B.doc = *Bagrus docmak*; B.baj = *Bagrus bajad*; B.call = *Enteromius callipterus*; B.mac = *Enteromius macrops* ; B.leuc= *Brycinus leuciscus* ; B.long= *Brycinus longipinnis*; B.macro= *Brycinus macrolepidotus* ; C.gun = *Chromidotilapia guntheri* ; C.aura = *Chrysichthys auratus* ; C.nig = *Chrysichthys nigrodigitatus* ; C.agb = *Clarias agboyensis* ; C.ebr = *Clarias ebriensis* ; C.gari = *Clarias gariepinus* ; C.pach= *Clarias pachymena* ; C.gui= *Coptodon guineensis* ; C.zillii= Coptodon zillii ; C.king = *Ctenopoma kingsleyae* ; C.peth= *Ctenopoma petherici* ; E.bif= *Epyplatys bifasciatus* ; G.typ = *Gymnalabes typus* ; H.fas = *Hemichromis fasciatus* ; H.odoe= *Hepsetus odoe*; H.long= Heterobranchus *longifilis* ; H.bebe= *Hyperopisius bebe* ; L.par = *Labeo parvus* ; L.sene = *Labeo senegalensis* ; M.ben= *Malapterurus benineensis* ; M.elec = *Malapterurus electricus* ; M.sene= *Marcusenius senegalensis* ; M.occi= *Micralestes occidentalis* ; M.ang= *Mormyrops anguiloides* ; M.rum = *Mormyrus rume* ; O.nil= *Oreochromis niloticus* ; P.mar = *Pelmatolapia mariae* ; P.bov= *Petrocephalus bovei* ; P.pall= *Petrocephalus pallidomaculatus* ; P.pell= *Petrocephalus pellegrini* ; P.soud= *Petrocephalus soudanemsis* ; P.ans= *Polypterus ansorgii* ; P.end= *Polypterus endlicheri endlicheri* ; S.caud= *Sarotherodon caudomarginatus* ; S.gm= *Sarotherodon galileus multifasciatus* ; S.int = *Schilbe intermedius* ; S.mys= *Schilbe mystus* ; S.bud= *Synodontis budgetti* ; S.mac= *Synodontis macrophtalmus* ; S.mel= *Synodontis melanopterus*;

S.nig= *Synodontis nigrita* ; S.sch= *Synodontis schall* ; S.sor= *Synodontis sorex* ; R. sene= *Raiama senegalensis* ; B. nig= *Brienomyrus niger* ; B.chlo= *Enteromius chlorotaenia*.

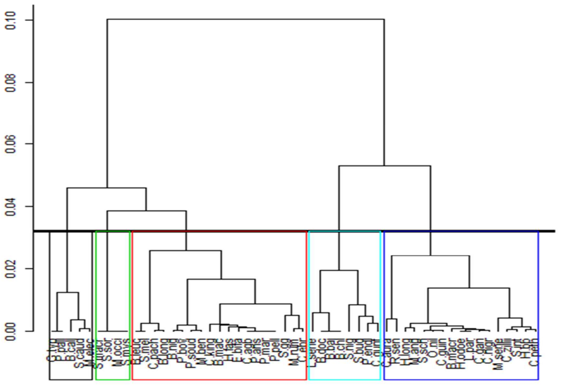

Fig. 3. Hierarchical Clustering Analysis of the Okpara stream fish community (see species names in legend of Fig 2).

Environmental correlates

To assess the relationships between the water quality and the fish community attributes, relative abundances of fishes and species richness were plotted against water features such as depth, transparency, dissolved oxygen,% of saturation, temperature and pH. Overall, regressions between the fish abundances and the water physicochemical parameters gave *r* values ranging between -0.76 and 0.88 (Table 5). Comparable trends were recorded for the regression between the species richness and the water characteristics with a matrix of correlation coefficients (*r*) varying between -0.60 and 0.59 (Table 5). Also, the redundancy analysis (RDA) performed on the physicochemical parameters and the fifteen (15) dominant species of the stream indicated that the first two axes expressed 80.7% (Axis 1=70.9%; Axis 2= 9.8%) of the observed correlations species abundance – physicochemical parameters along with significant (P<0.05) correlation coefficients r_1 =0.83 and r_2 =0.73, respectively. As results, the RDA output revealed the existence of two groups of species (Fig 4). The first included fishes such as *Enteromius macrops*, *Chromidotilapia guntheri*, *Coptodon guineensis* , Ctenopoma petherici, *Epyplatys bifasciatus* , *Hemichromis fasciatus* , *Hepsetus odoe*, *Hyperopisius bebe*, *Marcusenius senegalensis*, *Oreochromis niloticus*, *Sarotherodon galileus multifasciatus*, *Synodontis schall* that were positively correlated with dissolved oxygen, O_2 saturation percentage and depth, but negatively correlated with transparency, water temperature and pH. The second group was constituted of *Schilbe intermedius, Clarias gariepinus* and *Brycinus macrolepidotus* that were positively correlated with transparency, water temperature and pH, but negatively correlated with dissolved oxygen, O_2 saturation percentage and depth (Fig 4).

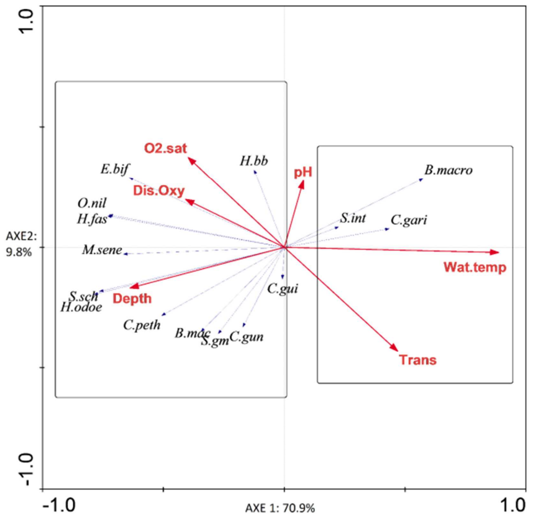

Fig. 4. Redundancy Analysis (RDA) of water features and the abundance of 15 donimant species of the Okpara stream fish community.

B.mac = *Enteromius macrops* ; B.macro = *Brycinus macrolepidotus* ; C.gun = *Chromidotilapia guntheri* ; C.gari = *Clarias gariepinus* ; C.gui = *Coptodon guineensis* ; C.peth = Ctenopoma petherici; E.bif = *Epyplatys bifasciatus* ; H.fas = *Hemichromis fasciatus* ; H.odoe = *Hepsetus odoe*; H.bb = *Hyperopisius bebe* ; M.sene = *Marcusenius senegalensis* ; O.nil = *Oreochromis niloticus* ; S.gm = *Sarotherodon galileus multifasciatus* ; S.int = *Schilbe intermedius* ; S.sch = *Synodontis schall*. Wat.temp = water temperature; Diss.oxy = Dissolve oxygen; O2.sat = Percentage of oxygen saturation; Trans = Transparency.

Trophic structure

The fish community of the Okpara stream was numerically dominated by the top-carnivores (terminal consumers), *Hemichromis fasciatus*, *Hepsetus Odoe* and *Mormyrops anguiloides* making together 30.66%. *H. fasciatus* was the most dominant top carnivore with a relative abundance of 29.49%. The next four (4) dominant trophic guilds were insectivores/benthivores (19.44%) dominated by *Marcusenius senegalensis* (16.43%), planctonivores/ microcarnivores (15.28%) dominated by *Oreochromis niloticus* (8.90%), herbivores/macrophytophage (14.42%) dominated by *Brycinus macrolepdotus* (9.23%) and intermediate carnivores (14.53%) dominated by *Schilbe intermedius* (10.44%). The least abundant trophic guilds were detritus feeders and omnivores accounting for 4.7% and 3.33%, respectively (Table 6). In terms of biomass, planktinovores were the proeminent trophic guilds making 31.65% of the fish community biomass due to the predominance of *Oreochromis niloticus* (28.14%). The least dominant feeding group was omnivores making 5.75% of the total biomass.

Discussion

Environmental quality, fish community structure and distribution

Successful management of aquatic ecosystems and fish resource conservation and valorization require a complete knowledge of the environmental quality and the fish community structure (Sossoukpe, 2011; Giorgio, 2016; Nsor and Obodai, 2016). Though the water quality of the Okpara stream was globally favorable for the survival and the growth of the fishes, the downstream sites (Site4, Site5) under degradation showed critical water features (mean dissolved oxygen: 2-3.2mg/l) that could jeopardize the optimal well-being of some fish species. As reported for most aquatic habitats in Benin, major degradation factors of the riverine waters were the withdrawal of water for domestic uses (Zogo *et al.,* 2008) and for irrigated agriculture, the use of chemical fertilizers and pesticides for agriculture, the dumping of domestic wastes and the proliferation of water hyacinth (*Echhornia crassipes*) (Tossou, 2004; Tejerina-garro *et al.,* 2005).

Despite these ecological disturbances, the current ichtyological research indicated that the Okpara stream dwelled relatively high fish species richness composed of 53 species belonging to 30 genera and 14 families that was also confirmed by the higher diversity indexes of Shannon-Weaver (H '= 3.56), Simpson (Ds = 0.144) and Hill (Dh=0.198) (Grall and Hily, 2003). The great diversity displayed by this lotic habitat was due to the fact that the Okpara stream is the largest tributary of the Oueme River that appears to be the greatest, the longuest and the more diversified running water in Benin (Laleye *et al.,* 2004). This finding is higher than those reported by Hazoume (2017) on the Sô stream and by Montchowui *et al.* (2007) on the Hlan stream, two riverine waters connected to the Oueme River, showing some species richnesses d = 48 and d = 43, respectively. In this study, sites at upstream exhibited higher species richness than those located at lower stream probably because of the influence of the dam built on the Okpara stream. The low species richnesses, d=28 and d=24 recorded for Sites 4 and 5, respectively, indicated that these habitats were subjected to severe environmental degradation due to the withdrawal of the stream water, the use of chemical fertilizers and pesticides in adjacent agricultures, the dumping of domestic wastes, the invasion of water hyacinth and the introduction and proliferation of an exotic cichlid, *Oreochromis niloticus*. The highest specific richness (d = 46) recorded during the dry season is the result of reduced water volume because of the scarcity of rain coupled with the withdrawal of water by SONEB, making most fish species vulnerable to fishing gears. With regards to fishing methods and gears, the highest species richness (d = 49) recorded for the gill net was the result of its multiple meshes leading to low selectivity of fishes.

The result consistently showed that cichlids dominated the fish community with nine (9) species aggregating a numeric relative abundance of 44.2%, corresponding to a biomass of 42.43%, with *Hemichromis fasciatus*, the dominant species making 29.49% of the fish community. These results agreed with the general trend reported in Southern-Benin inland waters where cichlids represented almost half (49.82%) of the country fish biomass, evidencing the great fishery and commercial importance of this family (Gbaguidi and Pfeifer, 2008; Gbaguidi *et al.,* 2016; Adite *et al.,* 2017).

Indeed, like the Okpara stream fish fauna, cichlids dominated Lagoon Toho-Todougba (Adite, 1995), the man made lake of Ahozon (Gbaguidi *et al.,* 2016) and Lake Toho (Adite *et al.,* 2017) of the Southern Benin where this taxa numerically made 84.8%, 93.89% and 88.26%, respectively. The current findings also agreed with those reported by Eyi *et al.* (2016) in the Ono Lagoon of Côte d'Ivoire, by Fryer and Iles (1972) in the Great Lakes of Africa and by Snoeks (2000) in the lakes of East Africa where cichlids were the foremost family in the fish community (Leveque 1997; Ikenweiwe *et al.,* 2007). In term of abundance, among the 53 fish species inventoried, only fifteen (15) species, *Hemichromis fasciatus*, *Marcusenius senegalensis*, *Schilbe intermedius*, *Brycinus macrolepidotus*, *Oreochromis niloticus*, *Synodontis schall, Epiplatys bifasciatus, Enteromius macrops, Sarotherodon galileus multifasciatus, Clarias gariepinus, Coptodon guineensis, Ctenopoma petherici, Hyperopisius bebe* and *Hepsetus odoe* dominated the fish assemblages with aggregated relative abundance of 92.18%. The 38 species remaining were of trivial importance making together 7.82% and none of them made individually more than 0.95% of the fish community.

In this study, the degradation factors depicted greatly affected the distribution of the fishes in the Okpara stream where the less disturbed sites at upstream (Sites 1, 2 and 3) harbored more fishes than downstream sites (Sites 4 and 5) under severe ecological desasters (Poff *et al.,* 1997; Tejerina-garro *et al.,* 2005). Though the species tolerance to abiotic factors is the main cause of the spatial organization of the fish community, habitat fragmentation and loss could greatly affect the distribution scheme of the fishes in the Okpara stream (Aguilar Ibarra, 2004; Attingli *et al.,* 2016). In addition, the high predation from the piscivorous cichlid, *Hemichromis fasciatus*, could also have impacted the distribution patterns (Wilson *et al.,* 2010; Trystram, 2016).

Environmental correlates

In the Okpara stream, the results indicated that the fish abundance and the species richness significantly (P < 0.01, P < 0.05, respectively) increased with dissolved oxygen. Except some tolerant species such as Clariidae, Malapteruridae, Polypteridae, Mochokidae etc. that possess an accessory organ for air breathing (Van Eer *et al.,* 2004), most of the species inventoried require a high concentration of dissolved oxygen for survival, growth and reproduction. Consequently, an increase in dissolved oxygen could boost the fish abundance. Inversely, the fish abundance and the species richness significantly (P < 0.01, P < 0.05, respectively) decreased with transparency. Although high water transparencies could be attributed to low suspended material, the reduced primary production may also cause high transparencies affecting negatively the fish. Depth was positively correlated with these two biological attributes, but not significant (P > 0.05).

With regards to species-environment relationships, the existence of the two correlations groups (Fig. 6) was due to differential physicochemical tolerance among the dominant fishes considered to perform the RDA analysis. In particular, the positive correlation recorded between dissolved oxygen and the abundance of most dominant fishes (12 species), *Enteromius macrops*, *Chromidotilapia guntheri*, *Coptodon guineensis*, *Ctenopoma petherici*, *Epyplatys bifasciatus*, *Hemichromis fasciatus*, *Hepsetus odoe*, *Hyperopisius bebe*, *Marcusenius senegalensis*, *Oreochromis niloticus*, *Sarotherodon galileus multifasciatus*, *Synodontis schall*, showed the great importance of this factor in fish survival and growth (Fan *et al.,* 2007). Indeed, metabolic and physiological functions in fishes require an appropriate concentration of dissolved oxygen (Bergheim *et al.,* 2006; Duan *et al.,* 2011; Abdel-Tawwab *et al.,* 2015). In addition, the aerobic degradation of organic matters in polluted sites requires dissolved oxygen (Kekacs *et al.,* 2015). Likewise, because of water withdrawal from Okpara stream, depths fluctuated and could control fish reproduction and abundance (Adaka *et al.,* 2016). The increase of *S. intermedius, C. gariepinus* and *B. macrolepidotus* with transparency, water temperature and pH suggested that these three species were sensitive to high turbidity, low temperature and acid pH.

Evidence of high predation in the stream fish community

In Okpara stream, unlike most freshwater lakes, the carnivorous species *Hemichromis fasciatus* dominated the fish community and made 29.49% of the fish assemblages. This abundance of top predators is much higher than those reported by Adite *et al.* (1995; 2013) in Toho-Todougba lagoon and in the mangrove ecosystem at the Benin coastal zone and by Tossavi (2012) in Lake Toho where top-carnivores including *H. fasciatus* accounted for 8.5%, 6.6% and 1.14%, respectively. This unusual high abundance of carnivorous species and mainly *H. fasciatus*, suggested a high predation in the Okpara stream. The prominence of *H. fasciatus* in this stream could be seen as an ecological disaster because may engender some negative effects on the fish community. As reported by Hammill *et al.* (2015), predation may alterate ecosystem composition and functioning and food web structure. According to Öhlund (2012), predation could drive ecological and evolutionary divergence among preys. The high predation depicted in the Okpara stream constituted a threat for the fish community and require a special management scheme to restore the ecosystem balance.

Conclusion

The current ecological study showed that the Okpara stream harbored a high ichthyological diversity with 53 species numerically dominated by Mormyrids and Cichlids. The high abundance of the piscivorous cichlid, *Hemichromis fasciatus* that made numerically 29.49% of the fish community suggested a high predation in the Okpara stream and constituted a risk for the equilibrium of the food web and the ecosystem. Also, the stream was under severe environmental degradation caused by the dam built to provide drinking water, the use of chemical fertilizers and pesticides for agricultures, the dumping of domestic wastes, the colonization of invasive floating plants and the proliferation of the exotic cichlid, *Oreochromis niloticus*. Sound ecological management scheme should include ecotoxicological studies, biocontrol of water hyacinth, habitat protection, species conservation and valorization and ecosystem follow-up.

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