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Development of a fish-based index of biotic integrity (FIBI) to assess the quality of Bandama River in Côte d'Ivoire*

B.R.D. Aboua[(1)**], E.P. Kouamélan[(1)], V. N'Douba[(1)]

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ABSTRACT

Key-words: *habitat quality, freshwater fish, biotic index, bandama River, Côte d'Ivoire*

The aim of this study was to develop effective tools based on fish assemblages, allowing the development of an effective assessment approach for the ecological status of running waters. Fish samples were collected using gill-nets with mesh sizes of 8, 10, 12, 14, 15, 18, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75 and 80 mm. Forty sites were visited from October 2008 to September 2009 in the Bandama River. A large part of the data set on fish descriptors associated with environmental parameters was compiled from regional databases. For each of the fish assemblage descriptors, stepwise multiple linear regressions with habitat variables were carried out. The residuals of the models obtained were used as candidate metrics independent of natural environmental factors. Student *t*-tests used to compare each metric in reference and disturbed samples indicated significant difference ($P < 0.05$) for six metrics. The standard residuals of metrics selected were added to constitute the final index. This multimetric index of fish assemblage integrity could serve as a practical technical reference for conducting cost-effective biological assessments of lotic systems.

RÉSUMÉ

Développement d'un indice d'intégrité biotique basé sur le poisson pour évaluer la qualité du fleuve Bandama en Côte d'Ivoire

Mots-clés : *qualité de l'habitat*, *poissons d'eau douce*, *indice biotique*, *fleuve Bandama*, *Côte d'Ivoire*

Le but de cette étude était de développer un outil basé sur le peuplement de poissons qui permettrait une évaluation effective du statut des cours d'eau. Les poissons ont été récoltés à l'aide de filets maillants de maille : 8, 10, 12, 14, 15, 18, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75 et 80 mm. 40 sites ont été visités durant un an (octobre 2008 à septembre 2009) sur le fleuve Bandama. Une grande partie des données sur les descripteurs de poissons, associée aux paramètres environnementaux, a été fournie à partir d'études déjà réalisées en Afrique. Pour chacun des descripteurs des peuplements de poissons, des relations ont été établies avec des variables environnementales, à partir de régressions linéaires multiples pas à pas. Les résidus de ces modèles ont été utilisés comme métriques susceptibles d'entrer dans la constitution d'un indice. Le test-*t* utilisé pour comparer les métriques entre prélèvements perturbés et prélèvement non perturbés indiquent une différence significative ($P < 0{,}05$) pour six métriques. Les résidus standards des métriques

(1) Laboratoire d'Hydrobiologie, UFR Biosciences, Université de Cocody, 22 BP 582, Abidjan, 25, Côte d'Ivoire.
**** The study was carried out by the Hydrobiology Laboratory of the Cocody – Abidjan University (Côte d'Ivoire)***
***** Corresponding author: abouabrd@yahoo.fr***

sélectionnées ont été additionnés pour constituer l'indice final. L'indice multi-paramétrique obtenu devrait être capable de fournir une évaluation pertinente de la qualité écologique des hydrosystèmes fluviaux.

INTRODUCTION

Human perturbations in river ecosystems lead to the deterioration of water quality and aquatic habitats (Allan and Flecker, 1993). Ivorian streams are subject to many disturbances. Indeed, the discharge of industrial effluents (Boubo, Sassandra, etc.), the use of fertilizers and pesticides in large plantations near running waters, the construction of hydro-agricultural and agro-pastoral dams (Go, Bandama, San Pedro, etc.) and hydroelectric dams (Bia, Bandama, Sassandra) have perturbed normal assessment of ecosystems (Gourène *et al*., 1999; Da Costa *et al*., 2000; Koné *et al*., 2003; Kouamélan *et al*., 2003; Kouamé *et al*., 2008). Moreover, the introduction of species to improve small-scale fisheries, develop fish farming or for biological control (Gooré Bi, 2009) can affect the biological functioning of ecosystems through food chains. Hocutt *et al*. (1994) summarized that all water resource development projects on the African continent have either failed to meet their stated objectives, and/or had socio-cultural and ecological impacts that were not predicted beforehand. In Côte d'Ivoire, deforestation estimated at 375 $km^2 \cdot million^{-1}$ capita (Lévêque and Paugy, 1999) resulted in the extinction of some fish species (Kamdem Toham and Teugels, 1999; Kouamélan, 1999). Given that these various threats affect aquatic environments, an assessment of water quality was necessary to preserve aquatic resources. It has been noted that the physical and chemical environment of a river is deeply influenced by the characteristics of the environment from which it flows; but the measurements in the water column refer to the conditions prevailing in the course at the time of collection. This led to the monitoring of river integrity using biological communities (fish) by Karr (1981). These reflect the usual or extreme events that have occurred in the past up until this moment in the studied areas. Fish assemblages are reckoned as indicators of aquatic ecosystem health, which has become key in water quality management (Karr, 1981; Karr *et al*., 1986; Oberdorff *et al*., 2002; Tejerina-Garro *et al*., 2006; etc.). In this context, guilds of fish are useful for both understanding aquatic community ecology and giving sound advice to decision-makers by means of metrics for indices of biotic integrity. The index of biotic integrity (IBI) could be a potentially useful management tool for the conservation of the species and their habitat. According to Kamdem Toham and Teugels (1999), development of a fish IBI for African rivers is favored by the naturally high species richness, compared with rivers of the temperate regions. However, the fish IBI application is made difficult because of the lack of biological community data and life-history information on most West African species, and the scarcity of information concerning fish community changes in response to environmental degradation in our streams. In the Bandama River, these statements hold true, but must be moderated. Generally, the biology, ecology and systematics of the species are not known as well as in temperate regions. Nonetheless, fish remains the best-known group of purely aquatic African animals (Daget and Iltis, 1965; Planquette and Lemasson, 1975; Mérona, 1981; Teugels *et al*., 1988; Traoré, 1996; Paugy *et al*., 2003a, 2003b; etc.). According to Hugueny *et al*. (1996), in West Africa, ecological and systematic knowledge are sufficient to meet the needs of an IBI based on fish assemblages. Good identification keys exist (Paugy *et al*., 2003a, 2003b). Fish biotopes and diets based on the index of preponderance of food items are generally known (Natajaran and Jhingran, 1961; Paugy, 1994; Fishbase, 2003).The objective of our work was to develop an index that would express system responses in Bandama River on a spatial scale that would help to target management of non-point sources of pollution. This approach consists of integrating environmental factors acting on fish assemblage structure under natural conditions, and distinguishing human-induced disturbances from natural variations. There are two possible approaches to establish the metrics of IBI. The first approach consists of using metrics or descriptors already defined in other studies (*e.g.* other Fish IBI studies) that have been proven to identify perturbations.

The second approach consists of selecting the metric for our data, which discriminate reference sites and disturbed sites. But in this latter case, the IBI must be validated on new independent data; which means that there are enough sites to select the metrics on a part of the data and test on another portion of the data. In this study, the first approach was chosen where metrics sensitive to perturbation were selected.

MATERIALS AND METHODS

> *STUDY AREA*

Bandama River, located entirely in Côte d'Ivoire, drains an area of 97500 km^2 between 3° 50 to 7° W and 5° to 10° 20 N. It is 1050 km long and rises in the north of the country between Korhogo and Boundiali and enters Grand-Lahou lagoon at sea level (Figure 1). Because of its north-south orientation, it covers different climatic and biogeographic areas. The Bandama river has a low slope gradient all over its course. It is characterized by alternating riffles and rocks (Mérona, 1981; Lévêque *et al*., 1983). The study zone comprises the main course of Bandama River with two man-made lakes (Kossou and Taabo), and the main tributaries, which are the Marahoué on the right bank (550 km) and the N'Zi on the left bank (725 km). The basin was chosen for the homogeneity of its ichthyofauna (Mérona, 1981; Aboua *et al*., 2010) and because of the existence of identified perturbations, which allows the IBI to be tested in situ. The sampling stations in this study were located on the main channels. They were chosen by considering access facilities and the presence of known human perturbations. At the Sucrivoire site (B34 and B35), in the Marahoué River, 213 km from the source, the river is characterized by relatively steep slopes and a rocky bottom, and receives discharges from Sucrivoire plant and runoff from sugar cane plantings. At the site B38 (Bouaflé), the river receives discharges from a brewery and lemonade plant. The sampling station B33 (N'Zianouan) on the N'Zi River is characterized by extensive fishing and by diffuse pollution from plantations of banana, papaya, palm tree, rice, etc. The sampling stations Pronoua (B29), Taniakro (B30) and Koyékro (B32) of the same river are located on the small reaches so that flows are interrupted during the dry season to form stagnant waters. On the main course of Bandama River, there are sampling stations located between the hydroelectric dam of Kossou and the hydroelectric dam of Taabo, representing a 95 km stretch. These hydroelectric dams influence water levels and produce electricity. Upstream of Bandama main channel, the river receives discharge from Sucaf plantations. These dams restrict fish movement, particularly between both dams, in the region upstream of Kossou dam, and in the region downstream of Taabo dam. Other potential inputs to this stretch of the river include tributaries; for example, a major tributary (Marahoué River) which flows into the Bandama river to Bozi (B10). Moreover, there is runoff from agricultural activities as well as smaller municipalities, artisanal gold-mining activities in the region downstream of Kossou dam, and extensive fishing to Zambakro (B11). In total, forty sites were classified a priori as reference or disturbed sites. The reference sites were those with no obvious signs of environmental disturbance or those with only minor signs of disturbance. The disturbed sites were those with obvious environmental disturbance from gold mining, dam construction, urbanization, and industrial, agricultural and fishery activities (Table I). The study zone was sampled between October 2008 and September 2009. The samples were collected during high and low water periods. However, due to the natural variability of the rains and the position of the hydroelectric dams on Bandama River, the water fluctuations were minimal and not considered in this study (Hugueny *et al*., 1996; Berté, 2009).

> *ENVIRONMENTAL VARIABLES*

At each sampling site, the following environmental variables were measured at the center of each reach. The physicochemical variables included pH and temperature (measured using a pH-meter pH 300/310), dissolved oxygen (oxymeter DO 330/310), conductivity and total dissolved solids (conductimeter CON 400/410), and water transparency (Secchi disk). These

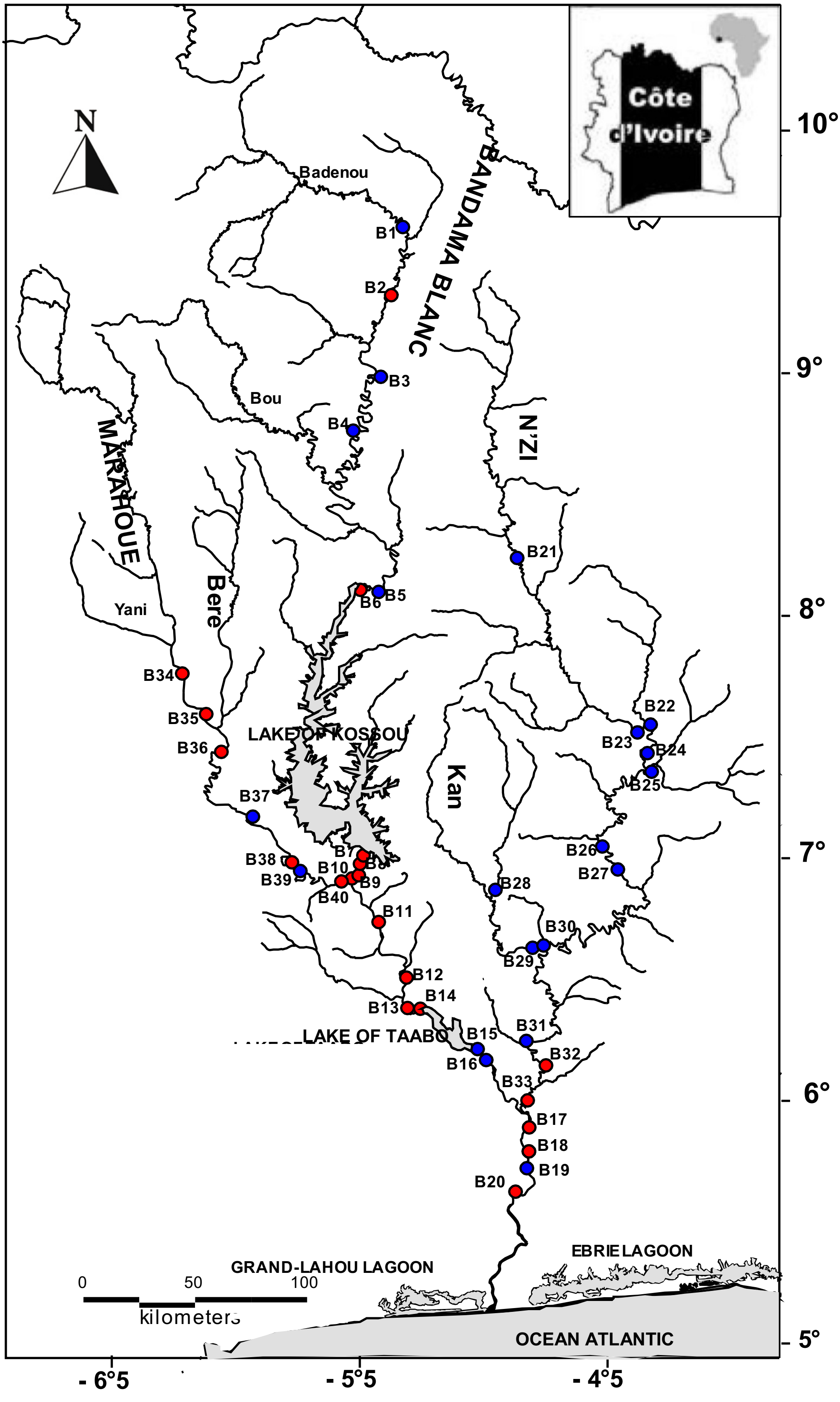

Figure 1
Map of the Bandama River and location of sampling sites. (•): a priori reference sites, (•): a priori disturbed sites.

Table I
Sites sampled in Bandama river basin. The known or supposed environmental disturbances are indicated. IW: industrial waste, D: dam, GM: gold mining, UR: urban and/or agricultural diffuse pollution.

Water course	Stations	Codes	Disturbances
Bandama blanc	Sinématiali	B1	
	Komborodougou	B2	IW
	Longo	B3	
	Nabédjakaha	B4	
	Marabadiassa	B5	
	Bouakaman	B6	UR
	Kossou	B7	D/GM
	Allai-Yaokro	B8	D/GM
	Toumbokro	B9	D/UR
	Bozi	B10	D/UR
	Zambakro	B11	D/UR
	Kimoukro	B12	D/UR
	Beriaboukro	B13	D/UR
	Bonikro	B14	D/UR
	Lamto	B15	
	N'Denou	B16	
	Tiassalé	B17	IW/UR
	Ahua	B18	UR
	Broubrou	B19	
	Bakanda	B20	UR
N'Zi	Yékolo	B21	
	Zaonkro	B22	
	YieraKro	B23	
	Ouokoukro	B24	
	Angouakro	B25	
	Bocanda	B26	
	Dimbokro (N'Zi)	B27	
	Dimbokro (Kan)	B28	
	Pronoua	B29	
	Taniakro	B30	
	Kalékoua	B31	
	Koyekro	B32	UR
	N'Zianoua	B33	UR
Marahoué	Sucrivoire (SR)	B34	UR
	Sucrivoire (SB)	B35	UR/IW
	Zuénoula	B36	UR
	Zoola Danagoro	B37	
	Bouaflé	B38	IW
	N'Gattakro	B39	
	Bozi	B40	D/UR

Table II
Quantitative and qualitative environmental variables considered for index development.

Variable	Code	Description	Range	Transformation
Flow velocity	VEL	mean of 3 measure, $m \cdot s^{-1}$	0–1.63	log(*x*)
Depth	DEP	m	0.5–6.5	log(*x*)
Width	WID	m	0.5–180	$\sqrt{x}$
Canopy closure	CAN	%	5–90	Rnd(*x*)+*c*
Altitude	ALT	m	27–984	none
Watershed area	WSA	km^2	1200–95 500	$\log(x)^2$
Distance to river source	DistS	km	100–947	none
Slope	SLO	‰	0.11–1.35	$\sqrt{x^3}$
Channel substrate				
Sand	SAN	%	0–60	log(*x*)
Gravel	GRA	%	0–60	log(*x*)
Mud	MUD	%	0–35	log(*x*)
Rock	ROC	%	0–90	log(*x*)
Clay-mud	CM	%	0–90	log(*x*)
pH	pH		6.27–10.45	Rnd(*x*)
Dissolved oxygen	DO	$mg \cdot L^{-1}$	2.99–7.5	none
Conductivity	Cnd	$\mu S \cdot cm^{-1}$	40.5–138.7	none
Water tranparency	Transp	cm	20–213	RndNormal(*x*)
Water temperature	Te	°C	24.1–32.55	none
Total dissolved solids	TDS	$mg \cdot L^{-1}$	21–119.6	$\arcsin(\sqrt{x}/100))$

variables were measured at 7.00 a.m and 1.00 p.m, except for water transparency, which was measured between 10.00 a.m and 15.00 p.m. Local physical and biological habitat variables were noted, as follows: the channel width (which was measured aboard a boat from one side to the other bank with rope), the channel depth (measured with a graduated weighted rope), the altitude, determined using a GPS (*Global Positioning System*) 12, Garmin, the current velocity, measured by observing the horizontal displacement of a float over a calibrated distance according to McMahon *et al*. (1996), mean canopy closure (expressed in % to the nearest m), and substrate type (sand, gravel, rock, mud and mixed clay-mud). Distance from sources and the watershed area were measured using a digital planimeter on a 1/200 000-scale map and slope derived from topographic maps. The average value of each variable was computed. These variables were subsequently transformed into a limited number of synthetic variables (Table II).

> *FISH SAMPLING AND FISH ASSEMBLAGE DESCRIPTORS*

Fish assemblages were sampled following a standardized sampling protocol. Two batteries of 19 gill-nets with mesh sizes of 8, 10, 12, 14, 15, 18, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75 and 80 mm were used. Each net measures 30 m long by 1.5 m deep. Gill-nets were set

Table III
Fish assemblage descriptors tested for relationships with environmental variables. (1: Hocutt et al., 1994; 2: Hay et al., 1996; 3: Hugueny et al., 1996; 4: Kamdem Toham and Teugels 1999; 5: Gooré Bi 2009).

Type	Name	Code	References	Transformation
Global	Number of native species	NE	1, 2, 3, 4, 5	none
	Catch per unit effort of natives	CPUE	1, 2, 3, 4	log(x)
	Shannon-Weaver diversity	Isha	5	$x^{1,8}$
	Biomass of natives	Biom	5	$\log(x)^2$
Taxonomic relative richness	Number of benthic species	NEB	1, 2	none
	Number of pelagic species	NEP	1	none
	Number of benthic Siluriform species	NEBS	3, 4	Rnd(x+c)
	Number of Mormyrid species	NEM	3	Rnd(x)
	Number of Cichlid species	NEC	1, 3,	none
	Number of Cyprinid species	NECy	4, 5	Rnd(x)+c
	Number of Alestid species	NEA	4	none
Trophic relative abundance	Percentage of individual omnivores	OMN	1, 2, 3, 4, 5	log(x)
	Percentage of individual piscivores	PIS	1, 2, 3, 4, 5	log(x)
	Percentage of individual invertivores	INV	1, 2, 3, 4	log(x)
	Percentage of individual herbivores	HER	1, 2,	arcsin(√x/100))
	Percentage of individual planktivores	PLA	1, 5	log(x)

parallel to the bank at 1.5 m depth during high and low water periods. Nets were set overnight (5.00 p.m–7.00 a.m) and during the following day (7.00 a.m–12.00 p.m). Indeed, gill-net selectivity depends on the probability that the fish meets the net and the probability that the fish was caught and retained in the net (a function of the circumference of the fish's head and of the mesh size of the gill-net) (Spangler and Collins, 1992).

Many fish assemblage descriptors were considered as possible index metrics. Each of them are biological indicators. These biological indicators were chosen from a wide variety of trophic levels and taxonomic groups in order to develop a measure of ecosystem health of the Bandama River. Fish assemblage metrics included in the study of Bandama river quality were generally chosen based on pre-existing fish IBI studies in Africa. These metrics were defined by Hocutt *et al*. (1994), Hay *et al*. (1996), Hugueny *et al*. (1996), Kamdem Toham and Teugels (1999), and Gooré Bi (2009) in different African rivers (Table III). Three types of descriptors were computed from the fish assemblage data: global, taxonomic and trophic ones.

The four global descriptors were: number of native species, Catch per unit effort of natives, Biomass of natives (in a defined sample) and The Shannon-Weaver index. These descriptors were supposed to decrease with human perturbations. Fish were identified according to Paugy *et al*. (2003a, 2003b) at species level. Each fish was counted, measured and weighed.

The taxonomic descriptors were the relative number of species of major fish families. Taxonomic classification is based on morphological characters and it is likely that form is linked to some aspects of the ecological role of species in the ecosystem (Matthews, 1998). The families considered in the analyses were the Mormyridae, which are sensitive species (Hugueny *et al*., 1996), the Alestidae, which are active pelagic swimmers (Kamdem Toham and Teugels, 1999), the Cyprinidae, which are species with either mid-water or benthic orientation (Kamdem Toham and Teugels, 1999) and the Cichlidae, species well suited to live in structured edge or vegetated habitats according to Winemiller *et al*. (1995). Their relatively high species richness and broad geographical distribution (Paugy *et al*., 2003a, 2003b) also make them useful indicators of ecosystem degradation over a wide range of conditions (Kamdem Toham and Teugels, 1999). The habitat descriptors included the number of benthic species, the number of benthic Siluriform species and the number of pelagic species. These descriptors were heavily influenced by the degradation of habitat components (substrate, width, depth, current, vegetation and general description of the environment) which, according to Bain *et al*. (2000), was due to the modification of natural flow by the discontinuous and erratic water releases from hydroelectric dams. Benthic Siluriform species unlike benthic species are large and long-lived species. These two habitat descriptors were used in this study because they were mentioned separately in different studies (Table III). The species number also decreases with human perturbation.

Trophic descriptors included specimens whose diet categories were determined from previous stomach content analysis for Bandama species caught in this study (Table III). The diet of species caught with an empty stomach was provided by other authors (Ngouda, 1997; Fishbase, 2003; Paugy and Lévêque, 2006). The trophic categories were piscivores, herbivores (higher plant), invertivores (regrouped insectivores and other benthic invertebrates), phytoplanktivores (algae, plankton) and omnivores (similar proportions of plants and animals). The latter four categories showed a sensitivity to water quality degradation and also habitat degradation (Karr *et al*., 1986; Kiblut, 2002). In this category, unlike other metrics, the number of omnivores was supposed to increase with human perturbation.

Biological descriptors and environmental variables were transformed to achieve a normal distribution as much as possible (Table II and III).

> SELECTION OF FISH ASSEMBLAGE METRICS AND INDEX DEVELOPMENT

The selection of fish assemblage metrics is based on Tejerina-Garro *et al*.'s (2006) method. It proceeded in two steps. Firstly, we computed multilinear regressions between fish assemblage descriptors and environmental variables. To reduce the cases of co-linearity (Oberdorff *et al*., 1995), we used a forward stepwise selection of the environmental variables combined with a ridge regression. Environmental variables likely to be modified by human disturbances typically encountered were excluded before modeling the relationships between fish descriptors and environment variables of reference samples. In practice, that means excluding the physicochemical parameters (water conductivity and total dissolved solids, dissolved oxygen, pH, water transparency, and temperature).

Secondly, we compared the residuals of preceding relation between a priori separation in the reference stations and disturbed ones using *t*-tests. Residual values of descriptors that displayed statistical differences between the two groups were selected as metrics for inclusion in the final index.

Thirdly, for each metric, we defined the upper and the lower anchors (Hering *et al*., 2006). The upper and lower anchors mark the indicative range of a metric. We used the standardized residuals as scores. We take a fictive example of an index composed of the metrics: specific richness and % of individual omnivores. The first metric was supposed to increase with area quality; it is the opposite for the second. So, we multiply the standardized residuals of % of individual omnivores by (–1). The final index score at each station is the sum of the standardized residuals of metrics selected which have the same weight (the same variance).

> INTERPRETATION OF THE INDEX

A tentative interpretation of the index values was made by computing a stepwise forward regression between the metrics selected and the environmental parameters supposed to be directly influenced by various disturbances and not included in the reference models (water conductivity and total dissolved solids, pH, water transparency, and water temperature).

All statistical analyses were performed with the software STATISTICA 7.1.

RESULTS

The biological characteristics used to calculate the IBI are shown in Table IV. A total of 70 fish species were collected with gill-nets. 16 fish descriptors were analyzed. The descriptors (7) that did not show any significant relationship with environmental variables were the number of native species, Catch per unit effort of natives, Number of Cichlid species, number of Cyprinid species, and the percentage of the omnivore, piscivore and phytoplanktivore individuals (Table V). Simple relationships were detected between environmental variables and other descriptors (9). However, a complex relationship was noted between the flow velocity, distance from source, canopy closure and mixed clay-mud, and the Shannon-Weaver index. The variables that most influenced fish assemblages were: the flow velocity, the distance from source and substrate type. The flow velocity had a positive effect on the number of benthic species, the percentage of herbivores and the Shannon-Weaver index, whereas the effect was negative on the percentage of individual invertivores. The number of benthic Siluriform species, the number of Mormyrids and the Shannon-Weaver index were negatively affected by distance from source.

For 6 fish assemblage descriptors, the mean residuals of the regression between descriptor and habitat were significantly different in the reference and disturbed stations (Table VI). Number of native species, the number of Cichlid species, the percentage of individual invertivores and the biomass were lower in the disturbed samples, whereas the number of benthic Siluriform species and percentage of individual herbivores were higher.

Table VII shows that the supposed disturbed stations exhibited values equal to or lower than 2.84 (mean = –2.58), with the exception of the site B12 (Kimoukro) and the site B18 (Ahua), which showed high values (respectively, 5.14 and 6.38). Although some samples from reference stations showed low index values at the sites B24 (Ouokoukro, –5.65), B25 (Angouakro, –3.40) and B37 (Zoola Danagoro, –6.39), the mean value for reference stations was significantly higher than that of disturbed stations (mean = 1.96; $t = 3.00$; $p < 0.05$).

Among the environmental variables related to water quality, the physicochemical parameters did not indicate significant change with perturbations (Table VIII). However, the changes observed were not uniform for the different types of perturbation. We noted low variability between the changes. Stations located between the man-made lakes of Kossou and Taabo and stations with gold mining were characterized by low dissolved oxygen. The stations disturbed by urban and/or agricultural diffuse pollution had high values of pH, conductivity, total dissolved solids and temperature. Stations with artisanal gold mining showed low pH and total dissolved solids, but had high transparency. Conductivity, temperature and transparency were low at stations with industrial effluent. Linear regressions of the sensitive metrics against the physicochemical variables generated few relationships (Table IX). Conductivity had a positive effect on the species and the percentage of individual invertivores. The biomass of natives increases with the pH, whereas the opposite effect was observed for number of benthic Siluriform species.

DISCUSSION

Monitoring the fish community is a viable alternative to physicochemical monitoring programs for assessment of biotic integrity (Karr, 1981).

Table IV
Number of fish species collected using gill-nets within Bandama River. 1= marine and/or brackish species; 2 = introduced species; 3 = hybrid.

Families	Species	Diet	Habitat
Protopteridae	*Protopterus annectens*	Piscivore	Benthic
Polypteridae	*Polypterus endlicheri*	Piscivore	Benthic
Elopidae	*Elops lacerta*[1]	Piscivore	Pelagic
Clupeidae	*Pellonula leonensis*	Invertivore	Pelagic
Osteoglossidae	*Heterotis niloticus*[2]	Herbivore	Benthic
Notopteridae	*Papyrocranus afer*	Invertivore	Benthic
Mormyridae	*Marcusenius furcidens*	Invertivore	Benthic
	Marcusenius senegalensis	Invertivore	Benthic
	Marcusenius ussheri	Invertivore	Benthic
	Marcusenius sp	Invertivore	Benthic
	Mormyrops anguilloides	Piscivore	Benthic
	Mormyrus rume	Invertivore	Benthic
	Pollimyrus isidori	Invertivore	Benthic
	Petrocephalus bovei	Invertivore	Benthic
Hepsetidae	*Hepsetus odoe*	Piscivore	Benthic
Alestidae	*Alestes baremoze*	Invertivore	Benthopelagic
	Brycinus imberi	Herbivore	Benthic
	Brycinus longipinnis	Invertivore	Pelagic
	Brycinus macrolepidotus	Herbivore	Pelagic
	Brycinus nurse	Invertivore	Pelagic
	Hydrocynus forskalii	Piscivore	Pelagic
	Micralestes elongatus	Invertivore	Pelagic
	Micralestes occidentalis	Invertivore	Pelagic
Distichodontidae	*Distichodus rostratus*	Herbivore	Benthic
Cyprinidae	*Barbus ablabes*	Invertivore	Benthopelagic
	Barbus macrops	Invertivore	Benthopelagic
	Barbus perince	Invertivore	Benthopelagic
	Barbus sublineatus	Invertivore	Benthopelagic
	Barbus sp	Invertivore	Benthopelagic
	Labeo coubie	Phytoplanktivore	Benthopelagic
	Labeo parvus	Phytoplanktivore	Benthopelagic
	Labeo sp	Phytoplanktivore	Benthopelagic
	Raiamas senegalensis	Invertivore	Benthic

Table IV
(Continued).

Families	Species	Diet	Habitat
Claroteidae	*Auchenoglanis occidentalis*	Invertivore	Benthic
	Chrysichthys maurus	Invertivore	Benthic
	Chrysichthys nigrodigitatus	Invertivore	Benthic
Schilbeidae	*Paraillia pelucida*	Invertivore	Benthic
	Schilbe intermedius	Piscivore	Pelagic
	Schilbe mandibularis	Herbivore	Benthic
Clariidae	*Clarias anguillaris*	Omnivore	Benthic
	Heterobranchus isopterus	Invertivore	Benthic
	Heterobranchus longifilis	Piscivore	Benthic
Malapteruridae	*Malapterurus electricus*	Piscivore	Benthopelagic
Mochokidae	*Synodontis bastiani*	Invertivore	Benthopelagic
	Synodontis punctifer	Herbivore	Benthopelagic
	Synodontis schall	Herbivore	Benthopelagic
Channidae	*Parachanna obscura*	Piscivore	Benthic
Centropomidae	*Lates niloticus*	Piscivore	Benthic
Carangidae	*Caranx hippos*[1]	Invertivore	Pelagic
	Trachinotus teraia[1]	Invertivore	Pelagic
Gerreidae	*Gerres melanopterus*[1]	Invertivore	Benthic
Cichlidae	*Chromidotilapia guntheri*	Invertivore	Benthopelagic
	Hemichromis bimaculatus	Invertivore	Benthopelagic
	Hemichromis fasciatus	Piscivore	Benthopelagic
	Oreochromis niloticus[2]	Phytoplanktivore	Benthic
	Sarotherodon galilaeus	Phytoplanktivore	Benthic
	Sarotherodon melanotheron	Phytoplanktivore	Benthic
	Thysochromis ansorgii	Invertivore	Benthopelagic
	Tilapia hybride[3]	Herbivore	Benthopelagic
	Tilapia guineensis	Herbivore	Benthopelagic
	Tilapia mariae	Herbivore	Benthic
	Tilapia zillii	Herbivore	Benthic
	Tylochromis jentinki	Invertivore	Benthopelagic
	Tilapia sp	Herbivore	Benthopelagic
Mugilidae	*Liza falcipinnis*[1]	Herbivore	Benthic
Polynemidae	*Polydactylus quadrifilis*[1]	Invertivore	Pelagic
Gobiidae	*Awaous lateristriga*	Invertivore	Benthic
Eleotridae	*Eleotris vittata*[1]	Invertivore	Benthic
Anabantidae	*Ctenopoma petherici*	Invertivore	Benthopelagic
Mastacembelidae	*mastacembelus nigromarginatus*	Invertivore	Benthopelagic
27	70		

Table V
Statistics of the linear regressions between descriptors and environmental variables. See Table II for variable codes and definitions.

Descriptor	Variable entered in model (sign of effect)	*p*
Global		
Number of native species		0.088
Catch per unit effort of natives		0.168
Shannon-Weaver diversity	VEL(+), DistS(–), CAN(–), CM(+)	0.003
Biomass of natives	ROC(–)	0.047
Taxonomic: relative richness		
Number of benthic species	VEL(+), ROC(–)	0.009
Number of pelagic species	ALT(–), GRA(+)	0.014
Number of benthic Siluriform species	DistS(–)	0.088
Number of Mormyrid species	DistS(–), WID(+)	0.081
Number of Cichlid species		0.229
Number of Cyprinid species		0.073
Number of Alestid species	ALT(–)	0.025
Trophic: relative abundance		
Percentage of individual omnivores		0.227
Percentage of individual piscivores		0.191
Percentage of individual invertivores	VEL(–)	0.097
Percentage of individual herbivores	VEL(+)	0.023
Percentage of individual planktivores		0.251

> *FISH-HABITAT RELATIONSHIPS*

Fish assemblages are subject to natural temporal and spatial variability, induced by aquatic habitat variability (Matthews, 1998). Using data from samples of Bandama River stations, relationships between fish assemblages and their habitats were established. The relations we found between fish assemblages and environmental variables were not complex. Indeed, each fish descriptor was associated with only one, two or no variables. We could explain this relation by the homogeneity of the ichthyofauna of Bandama basin, and the weak variations of environmental parameters of tropical rivers. In the downstream area of Konkouré River (Guinea), Hugueny *et al.* (1996) also noted the homogeneity of ichthyofauna and that no noticeable changes in the assemblages occurred relative to the width of the river. On the Ogun River (Nigeria), like Bandama River (Côte d'Ivoire) and African tropical rivers, the weak slope on a major part of courses could probably favor the homogeneity of fish fauna (Mérona, 1981; Lévêque *et al*., 1983).

The variables most frequently influenced in the multilinear regressions between habitat and fish assemblage descriptors were those related to river size (flow velocity and distance from source) and diversity of the substrate. The importance of current velocity, river size and substrate in determining fish assemblage composition has been documented by Gorman and Karr (1978) and Hugueny (1990).

Table VI
Statistics of the comparisons between disturbed and reference samples. Significant differences in bold.

	Reference		Disturbed		*p*
Metric	Mean	SD	Mean	SD	
Number of native species	3.156524	6.118075	–1.73440	6.250246	**0.042681**
Catch per unit effort of natives	0.631208	1.538141	–0.194153	1.150897	0.111843
Shannon-Weaver diversity	–2.32344	4.399150	–0.077737	3.550182	0.213441
Biomass of natives	8.890879	13.44844	–6.16783	13.10449	**0.005038**
Taxonomic: relative richness					
Number of benthic species	1.648617	3.204865	0.779410	4.482283	0.577013
Number of pelagic species	0.803368	2.528548	–0.888964	2.664577	0.109704
Number of benthic Siluriform species	–0.071763	1.011049	1.125617	1.532125	**0.031869**
Number of Mormyrid species	–0.017774	1.056152	–0.060687	1.093062	0.914266
Number of Cichlid species	0.734654	2.421787	–1.28950	2.245089	**0.012006**
Number of Cyprinid species	1.558474	3.860091	0.915689	2.351578	0.708696
Number of Alestid species	0.786495	1.855279	–0.898896	2.533686	0.064850
Trophic: relative abundance					
Percentage of individual omnivores	–0.268955	1.929246	1.893432	2.179941	0.080181
Percentage of individual piscivores	0.533955	0.850572	0.856133	1.128569	0.569119
Percentage of individual invertivores	–0.164716	0.562687	–0.672289	0.804846	**0.037091**
Percentage of individual herbivores	0.021813	0.243956	0.208491	0.273368	**0.037455**
Percentage of individual planktivores	0.623981	1.037231	1.083230	2.258313	0.600410

> *METRIC SELECTION*

Our metrics were a priori selected from other IBI studies (in Guinea, Cameroon, Namibia and Côte d'Ivoire) which have been proven to identify disturbances (Hocutt *et al*., 1994; Hay *et al*., 1996; Hugueny *et al*., 1996; Kamdem Toham and Teugels, 1999; Gooré Bi, 2009). So, Karr (1981) and Barbour *et al*. (1995) indicated that fish assemblage metrics including river quality indices were generally chosen on the basis of pre-existing detailed knowledge of fish species ecology in the considered region. For example, in the USA, the taxonomic descriptors of original metrics used by Karr (1981) differ from those used by Oberdorff and Hughes (1992) in France, which are also different from the taxonomic metrics used by Hugueny *et al*. (1996) in Guinea.

In this study, two general metrics (number of native species and biomass of natives), two taxonomic metrics (number of benthic Siluriform species and number of Cichlid species) and two trophic metrics (percentage of individual invertivores and herbivores) were sensitive to human-caused disturbances.

Number of native species is a common measure of species diversity that generally declines with environmental degradation. However, under certain circumstances (*e.g.* eutrophication) increasing productivity can lead to an increase in some species in species richness (Oberdorff *et al*., 2002). In this study, marine hybrid and introduced species were excluded from the total number of species. The observed decrease in richness scores with disturbance was expected. The biomass of natives in our study corresponds to catch per unit effort in weight

Table VII
Sample scores (standardized residuals) of individual metrics and total scores for the samples. Samples considered disturbed by human activities are in bold. See Table III for metric codes and definitions.

Stations	Metrics						Index value
	NE	NEBS	NEC	INV	HER	Biom	
B1	1.190584	1.744855	0.7762334	−2.373728	−0.6439469	1.159672	1.8536695
B2		−0.7021708	−2.001907	−2.468627	−0.7428331		−5.9155379
B3	2.786514	−1.170584	2.35395	−1.736491	1.542441	4.892959	8.668789
B4	1.918601	0.456188	1.906177	−1.186751	1.741005	4.015686	8.850906
B5	0.9092277	0.3390329	0.6813745	0.6008736	−0.6181985	−0.5779465	1.3343637
B6	**0.03081169**	**0.03101731**	**−0.5540792**	**−0.07278342**	**−0.4251382**	**0.1786152**	**−0.81155662**
B7	**−1.231009**	**4.653587**	**−1.558758**	**−3.985572**	**3.192274**	**−5.735866**	**−4.665344**
B8	**−0.3983835**	**0.04100229**	**−0.6929259**	**0.581777**	**−0.180327**	**1.490218**	**0.84136089**
B9	**1.205385**		**−0.6066576**	**−2.046142**	**2.355656**	**−3.315428**	**−2.4071866**
B10	**−0.261918**	**−0.3794027**	**0.1393906**	**−0.3502907**	**1.707444**	**−0.3877634**	**0.4674598**
B11	**1.817943**	**2.144261**	**−1.929868**	**−0.5309598**	**1.378809**	**−0.07131477**	**2.80887043**
B12	**1.737052**	**7.557501**	**0.02214076**	**−5.265246**	**−0.2734332**	**1.365959**	**5.14397356**
B13	**0.6296821**		**−1.084866**	**−9.055643**	**2.296748**	**0.684182**	**−6.5298969**
B14	**0.6634292**		**−0.9043868**	**−4.916448**	**1.576266**	**1.249109**	**−2.3320306**
B15	−0.4805373		1.125632	2.216768	−0.7407277	3.539117	5.660252
B16	1.068173		0.3316259	4.355395	−2.299216	5.36999	8.8259679
B17	**−1.461328**		**−2.566705**	**−5.5752**	**0.4121369**	**−0.669431**	**−9.8605271**
B18			**3.421859**	**2.70947**	**0.2521845**		**6.3835135**
B19	0.8948634		2.377535			0.4233131	3.6957115
B20		**4.609756**	**−0.7239074**	**−3.028802**	**0.1304202**		**0.9874668**
B21		−4.161023	1.036212	2.963035	−1.628987		−1.790763
B22			2.35395	0.8898765	−1.675803		1.5680235
B23	−0.3519365	0.02124356	−1.352706	−0.6424364	0.05635228	0.6081482	−1.66133486
B24			−2.516304	−6.152859	3.017434		−5.651729
B25			−1.298139	−2.295119	0.1918524		−3.4014056
B26	1.019166	0.4020934	1.548013	0.5140415	−1.130099	−0.6391588	1.7140561
B27	−0.152982	2.600667			2.919198	−0.9617008	4.4051822
B28	−0.00021242	−0.4898148	−0.3725538	−0.1167913	−0.03350415	0.08891997	−0.9239565
B29			3.485088				3.485088
B30	−2.595132	1.218322	1.607902	0.1520512	0.6946089	−1.591479	−0.5137269
B31	1.269469		1.360569	−3.077122	1.248601	1.668219	2.469736
B32		**1.865108**	**−4.634628**	**−4.100413**			**−6.869933**
B33	**−1.645346**	**4.858764**			**0.0515078**	**−0.4236446**	**2.8412812**
B34	**−2.635063**	**0.3050688**	**−1.161423**	**−2.942014**	**2.711485**	**−4.200542**	**−7.9224882**
B35	**−2.243878**	**−1.423249**	**−2.686967**	**−0.7755076**	**−0.09471405**	**−4.085454**	**−11.3097697**
B36	**−0.9467549**	**0.03482833**	**0.6034867**	**−0.5143904**	**0.6234705**	**−0.7610328**	**−0.96039257**
B37			−3.521949	−4.00689	1.129615		−6.399224
B38		−1.758446	0.1047063	−1.065727	−0.4884034		−3.2078701
B39	2.328032		1.524428			3.296029	7.148489
B40	**−1.032255**	**1.184121**	**−1.43618**	**−11.90315**	**6.002004**	**−1.143289**	**−8.328749**

Table VIII
Comparison of selected water quality parameters in reference and disturbed samples.

			Type of perturbation			
Sample variable	Reference (22)	Disturbed (18)	Between dams (9)	Gold mining (2)	Diffuse (15)	Indus. efflu (4)
	Mean (SD)		Range			
pH	7.40(0.75)	7.57(1.01)	6.89–8.14	6.89–7.13	6.71–10.45	6.92–9.84
Dissolved oxygen	5.58(1.23)	5.84(0.55)	4.84–6.14	4.84–6.4	5.3–6.73	5.69
Conductivity	95.51(26.47)	81.02(17.33)	73.66–91.75	75–79.7	40.05–123.42	40.5–74.05
Total dissolved solids	52.51(25.37)	44.44(20.52)	29.66–45.9	30–39.9	29.66–118	36.95–39.66
Water temperature	27.70(2.22)	28.38(1.72)	27–30.45	27.95	26.25–32.4	26.25–26.93
Water tranparency	62.32(52.25)	94.69(56.01)	50–213	130–148	22.5–213	38–65

No significant difference ($p > 0.05$).

Table IX
Statistics of the linear regressions between the metrics composing the index and physicochemical variables. See Table II for codes and definitions. Significant regressions at $p < 0.05$ are in bold.

Descriptor	Relation (sign of effect)	*p*
Number of native species	Cnd(+)	0,019
Biomass of natives	pH(+)	0,002
Number of benthic Siluriform species	pH(–)	0,036
Number of Cichlid species	(no variable in equation)	
Percentage of individual invertivores	Cnd(+)	0,025
Percentage of individual herbivores	pH(–)	0,062

of native fish species in each stretch. The difference in biomass of natives can result from differences in fish weight. Indeed, fish weight is high when the coefficient of condition which reflects the fish plumpness is high in areas with abundant food (Kartas and Quignard, 1984; Gooré Bi, 2009). But also, the difference in biomass could result in fish abundance and difference in fish composition. It could be explained by the behavior of fish reproduction, which may be altered by a reduction in spawning areas in a river. In the long term, the changes in the hydrological regime can influence the dynamics of fish populations by influencing the processes of reproduction and recruitment, leading to change in the relative abundance of species (de Lafontaine *et al*., 2002). This metric, not included in the original metric defined by Karr (1981), was sensitive to disturbance in our study and showed significant decrease with perturbation.

Concerning the two taxonomic metrics, we noted that the numbers of benthic Siluriform species showed a significant increase in relative species with perturbation, whereas the family of Cichlidae showed a significant decrease. The benthic Siluriform species was proposed by Oberdorff and Hughes (1992) and Hugueny *et al*. (1996) as a replacement for the original metric of Karr (1981), number of sucker species. In general, these benthic Siluriform species are large and long-lived species associated with the river bottom. They are opportunist predators in general, with trends to invertivory, eating aquatic insects (chironomids), mollusks, crustaceans and annelids, but also fish, aquatic plants and detritus (Lévêque and Paugy, 2006). This feeding habit favors this family in disturbed environments. Certain species of this taxonomic group (*e.g. Clarias*) are known for their varied tolerance to pollution and habitat degradation (Moreau, 1988; Lévêque and Paugy, 2006). The ability to use other food resources when available, and to take advantage of ambient oxygen when the dissolved oxygen supply becomes scarce, frees these species from prey scarcity and hypoxia conditions caused by water quality disturbances.

The Cichlidae family reacted to disturbances with a decrease in number of species. Fausch *et al*. (1984) suggested that in tropical zones, this metric replaces the number of sunfish species proposed by Karr (1981), keeping its intent of measuring the degree of degradation of submerged vegetation. The Cichlidae were used as a metric by Hocutt *et al*. (1994) and Hugueny *et al*. (1996) in African rivers.

The percentage of individual invertivores decreases significantly with perturbation. The diet of aquatic invertivores is based on benthic invertebrates, which are affected by human-induced disturbance such as substrate modification, flow regulation or sewage (Statzner *et al*., 2001). This metric is a surrogate for evaluating the degree that the invertebrate assemblage is degraded by environmental changes (Oberdorff *et al*., 2002). The percentage of individual herbivores is to assess the quality of the aquatic system food base at the primary level. Also, a large number of species prefer vegetated areas (Hocutt *et al*., 1994; Hay *et al*., 1996). Conversely, in our study, we found that the herbivores were reacting to disturbance with an increase in the percentage of individuals. In general, we noted that excessive intake of nutrients increases the production of algae and aquatic plants. This massive production of plants would also favor an increase in individuals which are herbivores in these disturbed environments. Indeed, direct observation in the field led us to suspect the existence of episodic pollution incidents. However, in the absence of any specific chemical analysis of the water, it was impossible to identify nutritive substances.

The percentage of individual herbivores was not included in the original metrics of Karr (1981). Due to the method we used to select metrics, separation of disturbed and reference samples should be good if not perfect. However, some samples called reference samples had values comparable with those called disturbed. There are various reasons for this result. Firstly, the index integrates 6 metrics, which should react differently to different disturbances. We also noted, among our metrics, the absence of an important metric: proportion of (in) tolerant species and/or individuals. This metric is often used and generally very efficient (Karr *et al*., 1986; Oberdorff and Hughes, 1992; Kamdem Toham and Teugels, 1999; Kestemont *et al*., 2000). Unfortunately, the necessary knowledge to identify all species and to integrate this metric is still limited in Africa, which would surely harm index quality. Secondly, the classification of our sites into disturbed and reference could have been erroneous in some cases. For example, the site B18, in the downstream area of the river, was considered disturbed because of the presence of many fishermen and agricultural diffuse pollution (hevea, cocoa, palm oil field), but it receives a high index score. The site B12 also receives a high score. Its location (between both man-made lakes, but a little further from the Taabo lake) makes it less sensitive to water level variation.

> *INTERPRETATION OF INDEX VARIABILITY WITH PHYSICOCHEMICAL PARAMETERS*

Although the small number of samples precludes a statistical analysis of the changes in physicochemical parameters, in the disturbed sites relative to the origin of the perturbation, some trends were revealed by the data. Artisanal gold mining on stations located between both dams (Kossou and Taabo) could be the cause of the low dissolved oxygen. According to Marteau (2001), the technique to extract gold consists of removing large amounts of soil for separation of the precious metal which, in turn, lowers endogenous oxygen production. The high pH, conductivity, total dissolved solids, transparency and temperature at urban and/or agricultural diffuse pollution stations were probably related to their particular hydrodynamics because these flows were possibly affected by the transit of persons and merchandise, and also by extensive fisheries. Consequently, the flow is considerably reduced in the mid-course, a situation which favors sedimentation according to Tejerina-Garro *et al*. (2006). Stations disturbed by industrial effluents had low conductivity, temperature and transparency. Direct information in the field led us to suspect the existence of episodic pollution incidents. The result is the incorporation of large quantities of suspended material in the rivers, which decreases transparency (Tejerina-Garro *et al*., 2006) and increases pH (Hugueny *et al*., 1996).

The number of relative species and percentage of individual invertivores were positively related to conductivity. Da Costa *et al*. (2000) found that conductivity was also amongst the main discriminant factors in both Agnebi and Bia rivers. However, we did not detect any difference in this parameter between disturbed and reference samples, but the conductivity was higher in stations affected by urban and/or agricultural diffuse pollution.

Benthic Siluriform species were negatively related to pH, and the biomass of natives was positively related to pH, while its influence on individual herbivores was not significant. pH was higher in stations affected by industrial effluents and urban and/or agricultural diffuse pollution, and it also did not show any difference between disturbed and reference samples. However, we noted that Yao *et al.* (2005) found a significant relationship between species number and pH in the Comoé River, but Da Costa *et al*. (2000) noted that the pH had the slightest influence on the ordination of samples in both Agnebi and Bia rivers.

The last relationship observed was that no physicochemical variable was influenced by Cichlid species. Indeed, a number of Cichlid genera are widespread in Africa, *e.g.* Tilapia species are continuously found throughout Africa from the eastern Cape in South Africa to Senegal in the west and the Nile and beyond to the Middle East in the east (Skelton, 1988).

However, additional research is needed to determine if FIBI scores only generated by one gear type can be used interchangeably with those generated by another gear type (*e.g.*, electrofishing boat versus paired fyke nets). A fish-based index is a tool that can be used for water course condition assessment, and while it can produce rapid assessments, it should also be used in the man-made lakes of Bandama Basin in order to measure strong responses to human disturbance. It should also be noted that FIBI scores are not a measure of the intensity of pressures. However, it is necessary to determine a pressure gradient in the basin. Nevertheless, the Fish Index should prove to be an effective tool to aid in the management and protection of important fish habitats in the riverine ecosystem of the Bandama River.

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REFERENCES

Aboua B.R.D., N'Zi K.G., Kouamélan E.P., Berté S. and Bamba M., 2010. Organisation spatiale du peuplement de poissons dans le Bandama. *International Journal of Biological and Chemical Sciences*, *4*, 1480–1493.

Allan J.D. and Flecker A.S., 1993. Biodiversity conservation in running waters: identifying the major factors that threaten destruction of riverine species and ecosystems. *BioScience*, *43*, 32–43.

Bain M.B., Harigb A.L., Loucksc D.P., Goforthd R.R. and Millsa K.E., 2000. Aquatic ecosystem protection and restoration: advances in methods for assessment and evaluation. *Environ. Sci. Pol.*, *3*, 589–598.

Barbour M.T., Stribling J.B. and Karr J.R., 1995. Multimetric approach for establishing biocriteria and measuring biological condition. *In*: Davis W.S. and Simon T.P. (eds.), Biological assessment and criteria, Tools for water resource planning and decision making, Lewis Publ., London, 63–77.

Berté S., 2009. Biologie et écologie de *Distichodus rostratus* (Günther, 1864) dans un hydrosystème particulier en Côte d'Ivoire, Thèse de Doctorat à l'Université de Cocody-Abidjan, Côte d'Ivoire, 180 p.

Da Costa K.S., Gourène G., Tito De Morais L. and Thys Van Den Audenaerde D.F.E., 2000. Caractérisation des peuplements ichtyologiques de deux fleuves côtiers Ouest-Africains soumis à des aménagements hydroagricoles et hydroélectriques. *Vie et Milieu*, *50*, 65–77.

Daget J. and Iltis A., 1965. Poissons de Côte d'Ivoire (eaux douces et saumâtres), Mémoires de l'Institut Fondamental de l'Afrique Noire, 74, 385 p.

de Lafontaine Y., Marchand F., Labonté D. and Lagacé M., 2002. The Hydrological Regime and Fish Distribution and Abundance in the St. Lawrence River: Are Experimental Trap Data a Valid Indicator? Environnement Canada – Région du Québec, Conservation de l'environnement, Centre Saint-Laurent, Rapport scientifique remis à la Commission mixte internationale, 33 p.

Fausch K.D., Karr J.R. and Yant P.R., 1984. Regional application of an index of biotic integrity based on stream fish communities, *Trans. Am. Fish. Soc.*, *112*, 39–55.

Fishbase, 2003. Fish species in Bandama River rises as the white Bandama in the Northern highlands and flows southward to enter the gulf of Guinea and the Tagba Lagoon near Grand-Lahou. Its majors tributaries are the Red Bandama (Marahoué) and the N'Zi, Fishbase.org. http://fish.mongabay.com/data/ecosystems/Bandama River.htm.

Gooré Bi G., 2009. Impact des activités humaines sur les communautés de poisson dans les systèmes aquatiques de la zone côtière ivoirienne (Côte d'Ivoire) : Établissement d'un indice d'intégrité biotique (IIB), Thèse de doctorat, Université de Cocody-Abidjan, Côte d'Ivoire.

Gorman O.T. and Karr J.R., 1978. Habitat structure and stream fish communities. *Ecology*, *59*, 507–515.

Gourène G., Teugels G.G., Hugueny B. and Thys Van Den Audenaerde D.F.E., 1999. Évaluation de la diversité ichtyologique d'un bassin ouest-africain après la construction d'un barrage. *Cybium*, *23*, 147–160.

Hay C.J., Van Zyl B.J. and Steyn G.J., 1996. A quantitative assessment of the biotic integrity of the Okavongo river, Namibia, based on fish. *Water South Africa*, *22*, 263–284.

Hering D., Feld C.K., Moog O. and Ofenbock T., 2006. Cook book for the development of a Multimetric Index for biological condition of aquatic ecosystems: Experiences from the European AQEM and STAR projects and related initiatives. *Hydrobiologia*, *566*, 311–324.

Hocutt C.H., Johnson P.N., Hay C. and Van Zyl B.J., 1994. Biological basis of water quality assessment: the Kavango River, Namibia. *Revue d'Hydrobiologie Tropicale*, *27*, 361–384.

Hugueny B., 1990. Richesse des peuplements de poissons dans le Niandan (Haut Niger, Afrique) en fonction de la taille de la rivière et de la diversité du milieu. *Revue d'Hydrobiologie Tropicale*, *23*, 351–364.

Hugueny B., Camara S., Samoura B. and Magassouba M., 1996. Applying an index of biotic integrity based on fish assemblages in a West African river. *Hydrobiologia*, *331*, 71–78.

Kamdem Toham A. and Teugels G.G., 1999. First data on an index of biotic integrity (IBI) based on fish assemblages for the assessment of the impact of deforestation in a tropical West African river system. *Hydrobiologia*, *397*, 29–38.

Karr J.R., 1981. Assessing of biotic integrity using fish communities. *Fisheries*, *6*, 21–27.

Karr J.R., Fausch K.D., Angermeier P.L., Yant P.R. and Schlosser I.J., 1986. Assessing biological integrity in running waters. A method and its rationale. *Illinois Natural History Survey*, *Special Publication 5*, 1–28.

Kartas F. and Quignard J.P., 1984. La fécondité des poissons téléostéens, Masson, Collection biologique des milieux marins 5, 117 p.

Kestemont P., Didier J., Depiereux E. and Micha J.C., 2000. Selecting ichtyological metrics to assess river bassin ecological quality. *Arch. Hydrobiol.*, *121*, 673–687.

Kiblut K., 2002. Les communautés ichtyologiques et mesure de l'indice d'intégrité biotique du bassin versant de la rivière Kamouraska, Diplôme d'études supérieures spécialisées « ingénierie des hydrosystèmes continentaux en Europe », Université François Rabelais, Tours, France, 64 p.

Koné T., Teugels G.G., N'Douba V., Gooré Bi G. and Kouamélan E.P., 2003. Premières données sur l'inventaire et la distribution de l'ichtyofaune d'un petit bassin côtier ouest-africain : Rivière Gô (Côte d'Ivoire). *Cybium*, *27*, 101–106.

Kouamé K.A., Yao S.S., Gooré Bi G., Kouamélan E.P., N'Douba V. and Kouassi N.J., 2008. Influential environmental gradients and patterns of fish assemblages in a West African basin. *Hydrobiologia*, *603*, 159–169.

Kouamélan E.P., 1999. L'effet du lac de barrage d'Ayamé (Côte d'Ivoire) sur la distribution et l'écologie alimentaire des poissons Mormyridae (Teleostei, Osteoglossiformes), Thèse de Doctorat. Katholieke Universiteit Leuven, Belgique, 221 p.

Kouamélan E.P., Teugels G.G., N'Douba V., Gooré Bi G. and Koné T., 2003. Fish diversity and its relationship with environment variables in West African basin. *Hydrobiologia*, *505*, 139–146.

Lévêque C. and Paugy D., 1999. Les poissons des eaux continentales africaines : diversité, écologie, utilisation par l'homme, IRD, Éditions, Paris, 521 p.

Lévêque C., Dejoux C. and Iltis A., 1983. Limnologie du fleuve Bandama, Côte d'Ivoire. *Hydrobiologia*, *100*, 113–141.

Marteau P., 2001. Mines et Carrières. *In*: Barret J. (ed.), Atlas illustré de la Guyane, CNES, IESG, IRD, Région Guyane Publ., 90–93.

Matthews W.J., 1998. Patterns in freshwater fish ecology, Chapman & Hall, New York.

McMahon T.E., Zale A.V. and Orth D.J., 1996. Aquatic habitat measurements. *In*: Murphy B.R. and Willis D.W. (eds.), Fisheries Techniques, American Fisheries Society, Bethesda, Maryland, USA, 83–120.

Mérona B. de, 1981. Zonation ichtyologique du bassin du Bandama. *Revue d'Hydrobiologie Tropicale*, *14*, 63–75.

Moreau Y., 1988. Physiologie de la respiration. *In*: Lévêque C., Bruton M.N. and Ssenlengo G.W (eds.), Biologie et écologie des poissons d'eau douce africains, Paris, France, 113–135.

Natajaran A.V. and Jhingran A.G., 1961. Index of preponderance – a method of grading the food elements in the stomach of fishes. *Indian Journal of Fisheries*, *8*, 54–59.

Ngouda S., 1997. Contribution à l'étude qualitative du régime alimentaire de quelques espèces de poisons dans l'estuaire du Sine-Saloum (Sénégal), Centre de recherche océanographique de Dakar-Thiaroye, Sénégal, 38 p.

Oberdorff T. and Hughes R.M., 1992. Modification of an index of biotic integrity based on fish assemblages to characterize rivers of the Seine Basin, France. *Hydrobiologia*, *228*, 117–130.

Oberdorff T., Guégan J.-F. and Hugueny B., 1995. Global scale patterns of fish species richness in rivers. *Ecography*, *18*, 345–352.

Oberdorff T., Pont D., Hugueny B. and Porcher J.-P., 2002. Development and validation of a fish-based index (FBI) for the assessment of "river health" in France. *Freshw. Biol.*, *47*, 1720–1734.

Paugy D., 1994. Écologie des poisons tropicaux d'un cours d'eau temporaire (Baoulé, Haut bassin du Sénégal au Mali) : adaptation au milieu et plasticité du régime alimentaire. *Revue d'Hydrobiologie Tropicale*, *27*, 157–172.

Paugy D. and Lévêque C., 2006. Régimes alimentaires et réseaux trophiques. *In*: Lévêque C., Paugy D. (eds.), Les poissons des eaux continentales africaines: diversité, écologie, utilisation par l'homme, IRD, Paris, 191–215.

Paugy D., Lévêque C. and Teugels G.G., 2003a. The fresh and brackish water fishes of West Africa, Collection tropical Fauna and Flora, Tome I, IRD Editions, MRAC, Tervuren.

Paugy D., Lévêque C. and Teugels G.G., 2003b. The fresh and brackish water fishes of West Africa, Collection tropical Fauna and Flora, Tome II, IRD Editions, MRAC, Tervuren.

Planquette R. and Lemasson J., 1975. Le peuplement de poissons du Bandama blanc en pays Baoulé. *Annales de l'Université Abidjan E* 8, 77–121.

Skelton P.H., 1988. Répartition des poissons d'eau douce africains. *In*: Lévêque C., Bruton M.N. and Ssentongo G.W. (eds.), Biologie et écologie des poissons d'eau douce africains, Travaux et Documents ORSTOM, 216, 65–91.

Spangler G.R. and Collins J.J., 1992. Lake Huron fish community structure based on gill-net catches corrected for selectivity and encounter probability. *N. Amer. J. Fish. Manage.*, *12*, 585–597.

Statzner B., Bis B., Doledec S. and Usseglio-Polatera P., 2001. Perspectives for biomonitoring at large spatial scales: a unified measure for the functional composition on invertebrate communities in European running waters. *Bas. Appl. Ecol.*, *2*, 73–85.

Tachet H., Richoux P., Bournaud M. and Usseglio-Polatera P., 2006. Invertébrés d'eau douce : systématique, biologie, écologie, CNRS 2[e] éditions, Paris.

Tejerina-Garro F.L., de Mérona B., Oberdorff T. and Hugueny B., 2006. A fish-based index of large river quality for French Guiana (South America): method and preliminary results. *Aquat. Living Resour.*, *19*, 31–46.

Teugels G.G., Lévêque C., Paugy D. and Traoré K., 1988. Etat des connaissances sur la faune ichtyologique des bassins côtiers de Côte d'Ivoire et de l'ouest du Ghana. *Revue d'Hydrobiologie Tropicale*, *21*, 221–237.

Traoré K., 1996. État des connaissances sur les pêcheries continentales ivoiriennes, Rapport de consultation, Projet FAO TCP/IVC/4553, IDESSA, Bouaké, Côte d'Ivoire.

Winemiller K.O., Kelso-Winemiller L.C. and Brenkert A., 1995. Ecomorphological diversification and convergence in fluvial cichlid fishes. *Environ. Biol. Fish.*, *44*, 235–261.

Yao S.S., Kouamélan E.P., Kone T., N'Douba V., Gooré Bi G., Ollevier F. and Thys Van Den Audenaerde D.F.E., 2005. Fish communities along environment gradients within the Comoé River basin, Côte d'Ivoire. *African Journal of Aquatic Science*, *30*, 195–204.