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Spatio-temporal patterns of fish assemblages in coastal West African rivers: a self-organizing map approach

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Abstract – We investigated spatio-temporal patterns of fish assemblages in four small coastal rivers in South-East Ivory Coast. The samples were collected between July 2003 and March 2005 at 8 sampling sites (2 per river: 1 upstream and 1 downstream). A total of 59 fish species belonging to 39 genera, 23 families and 11 orders were captured. Perciforms (30% of the families and 33% of the species), followed by Siluriforms (22% and 22%), Osteoglossiforms (13% and 17%), Characiforms (9% and 10%) and Pleuronectiforms (9% and 3%) were the most abundant orders. Among the families sampled, Cichlidae (20% of the species), Mormyridae (13%), Clariidae (10%), Cyprinidae (10%) and Characidae (8%) were largely represented. Among the 59 fish species captured, we identified fifteen marine/brackish species and two introduced species. To analyse patterns of fish assemblages, we used a non-linear clustering technique, the self-organizing map (SOM). Using SOM, samples were classified into 4 clusters, mainly related to the spatial location of the sampling sites. Except for the distance from the source of the river, environmental variables (width, depth, current velocity) did not show a clear distribution gradient on the SOM map. This pattern was explained by the abundance of estuarine/marine species (i.e. 25% of the species) characterizing the lower course of the rivers studied. Such a distribution of estuarine/marine species colonizing the lower and middle course of the rivers was explained by the absence of dams and contrasts with the patterns observed in more fragmented rivers of Ivory Coast. Therefore, we suggest that these small streams should be preserved in order to permit estuarine/marine species to migrate between streams and the Aby lagoon, thus allowing their large distribution and their reproduction in favourable habitats. We suggest particular attention be given to the Soumié River basin which represents the only preserved stream ecosystem within the Bia River basin.

Key words: ichthyofauna / coastal rivers / hierarchical clustering / self-organizing map / Western Africa

Résumé – Distribution spatio-temporelle des assemblages de poissons des cours d'eau de la côte ouest africaine : une approche basée sur les cartes de Kohonen. Nous étudions les types de distribution spatio-temporelles d'assemblages de poissons de quatre cours d'eau du sud-est de la Côte d'Ivoire. Les échantillonnages de 8 sites (2 sites par rivière : un amont et un aval) sont effectués entre juillet 2003 et mars 2005. Au total, 59 espèces de poisson appartenant à 39 genres, 23 familles et 11 ordres sont capturées. Les Perciformes sont les plus abondants (30 % des familles et 33 % des espèces), suivis des Siluriformes (22 % des familles), des Ostéoglossiformes (13 % et 17 %), des Characiformes (9 % et 10 %) et des Pleuronectiformes (9 % et 3 %). Les familles les plus largement représentées sont les Cichlidés (20 % des espèces), Mormyridés (13 %), Clariidés (10 %), Cyprinidés (10 %) et les Characidés (8 %). Des 59 espèces de poissons capturés, quinze espèces de milieu marin-saumâtre et deux espèces introduites sont identifiées. Pour analyser les distributions des assemblages de poissons, nous utilisons une technique de classification non-linéaire : la carte de Kohonen (basée sur un algorithme de groupage non dirigé *: self-organizing map*, SOM). À l'aide de cette carte, les échantillons sont classés en quatre groupes, principalement liés à la position spatiale des sites d'étude. À l'exception de la distance à l'embouchure du cours d'eau, les variables environnementales (largeur, profondeur, vitesse du courant) ne montrent pas clairement de gradient sur la carte de Kohonen. Le modèle observé est caractérisé par l'abondance des espèces estuariennes/marines (25 % des espèces) caractéristiques de la partie aval des cours d'eau étudiés. Une telle distribution des espèces estuariennes/marines colonisant les parties intermédiaires et aval des cours d'eau s'explique par l'absence de barrage, et contraste avec les modèles observés sur les cours d'eau

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plus fragmentés de Côte d'Ivoire. Ainsi, nous proposons que ces petits cours d'eau soient préservés afin de permettre aux espèces estuariennes/marines de migrer entre les rivières et la lagune Aby, permettant ainsi leur large répartition et leur reproduction dans les habitats favorables. Une attention particulière doit être portée à la rivière Soumié qui représente le seul écosystème lotique préservé dans le bassin du fleuve Bia.

1 Introduction

Because of its high level of diversity and endemism, the study of freshwater fish of African inland waters has a long history (e.g. Daget and Iltis 1965; Teugels et al. 1988; Lévêque et al. 1998; Crisman et al. 2003). In West Africa, although a large amount of information is available on the fish fauna of large river basins, only a few studies have been undertaken in coastal rivers (Hugueny et al. 1996; Gourène et al. 1999; Koné et al. 2003a,b; Kouamélan et al. 2003). In this work, we focussed on four small coastal rivers in the South-East of Ivory Coast. Despite the lack of ecological information on these systems, they play an important role for human populations. These rivers, like other coastal rivers of Ivory Coast are used for domestic activities (drinking, cooking, bathing...), agriculture (irrigation, cattle drinking), and fish constitute an important food resource for local people. However, compared to other Ivory Coast rivers (e.g. San Pedro, Bia and Agnébi rivers), these aquatic systems face few anthropogenic impacts (no dams or large cities), and can therefore be considered as reference zones. It is therefore important to preserve the water resource and maintain the biotic integrity of these ecosystems to ensure the sustainability of the fish populations. With this aim, characterisation of the present state of the fish fauna is needed to be able to identify future potential anthropogenic disturbances (Bengen et al. 1992; Adite and Van Thielen 1995; Hugueny et al. 1996; Lévêque 1996; Kamdem-Toham and Teugels 1998; Koné et al. 2003b). Particularly, characterizing spatial and temporal patterns of fish assemblages remains an important tool for ecological assessment of rivers as (i) the longitudinal nature of stream ecosystems has long been recognized as a major force in structuring lotic communities in both temperate and tropical regions (reviewed by Tejerina-Garro et al. 2005) and (ii) changes in fish assemblages between dry and rainy seasons in tropical regions has been linked to seasonal variations in stream hydrology (Lowe-McConnell 1987).

To study the spatial and temporal organization of fish assemblages, we used an unsupervised artificial neural network, the self-organizing map (SOM), which is a clustering technique capable of displaying patterns in complex data sets (Kohonen 2001). This method has proved to be effective in characterizing distribution patterns in community ecology analysis (e.g. Park et al. 2003; Tison et al. 2004) with the advantage of representing non-linear relationships (Lek et al. 2000). Moreover, SOM handles species with low frequency of occurrence (i.e., rare species) contained in many ecological data sets (Brosse et al. 2001, Ibarra et al. 2005), unlike conventional methods such as multivariate analysis (e.g. PCA). In fact, we consider that rare species are important to accurately describe fish assemblage structure (Przybylski 1993) and to determine their biological integrity and conservation value (Cao et al. 1998; Lenat and Resh 2001). In addition, large species are usually rare, but constitute a large biomass in the fish captures and therefore constitute an important food resource for local people.

This study aimed (i) to characterize the diversity of the fish fauna of four small coastal streams belonging to the Bia-Tanoe rivers and Aby lagoon complex; (ii) to assess whether the fish assemblages are influenced by seasonal and habitat gradients; and (iii) to discuss conservation implications.

2 Materials and methods

Study area and sampling sites

Located in the South-East of Ivory Coast, the four coastal rivers studied (Fig. 1) belong to the Western Guinean ichthyoregion, sector Eburnéo-Ghanaian (Daget and Iltis, 1965). These small rivers are located in lowland rainforest. The Noé River (05°19' – 05°35' N and 02°55' – 02°47' W) and the Ehania River (05°17' – 05°43' N and 02°46' – 03°03' W) are tributaries of the Tanoé River and encompass an area of 238 and 585 km^2 respectively. With 70 km length, the Ehania River has a general slope of 2.36 $m\,km^{-1}$ and mean annual flow of 15.7 $m^3\,s^{-1}$ (dry season: 14.3 $m^3\,s^{-1}$; rainy season: 19.8 $m^3\,s^{-1}$). The Noé River has a main-channel total length of 30 km, a slope of 1.45 m km^{-1} and a mean annual flow of 9.5 $m^3\,s^{-1}$ (dry season: 5.3 $m^3\,s^{-1}$; rainy season: 16 7 $m^3\,s^{-1}$). The Soumié River (05°23' – 05°39' N and 03° 15' – 03°29' W), tributary of the Bia River, has a catchment area of 395 km^2, a main-channel total length of 41 km and a slope of 3.31 m km^{-1}. Its mean annual flow corresponds to 11.7 $m^3\,s^{-1}$ (dry season: 9.7 $m^3\,s^{-1}$; rainy season: 12.3 $m^3\,s^{-1}$). The Eholié River (05°21' – 05°36' N and 03°10' – 02°59' W) has a catchment area of 373 km^2, a main-channel total length of 35 km and a slope of 2.96 m km^{-1}. It runs into the Aby lagoon with a mean annual flow of 11.4 $m^3\,s^{-1}$ (dry season: 10.0 $m^3\,s^{-1}$; rainy season: 12.3 $m^3\,s^{-1}$).

A site was retained in the upstream and the downstream areas of each stream (Fig. 1). Canopy closure was relatively high in upstream sites (60–90%) and medium in downstream sites (35–65%). Human activities occurred mostly in downstream courses of each basin.

Fish sampling

Samples were collected during 8 sampling surveys from July 2003 to March 2005 (i.e. 4 during the rainy season and 4 during the dry season). The 8 sites were sampled during each survey. The sampling sites covered a river section of approximately 1.5 km in length (i.e. reach scale). This river section length was selected to cover a fair degree of habitat heterogeneity. Fish populations were collected with two sets of 8 gillnets (mesh sizes 12, 15, 17, 22, 25, 30, 40 and 45 mm), allowing the capture of almost all the fish longer than 80 mm total

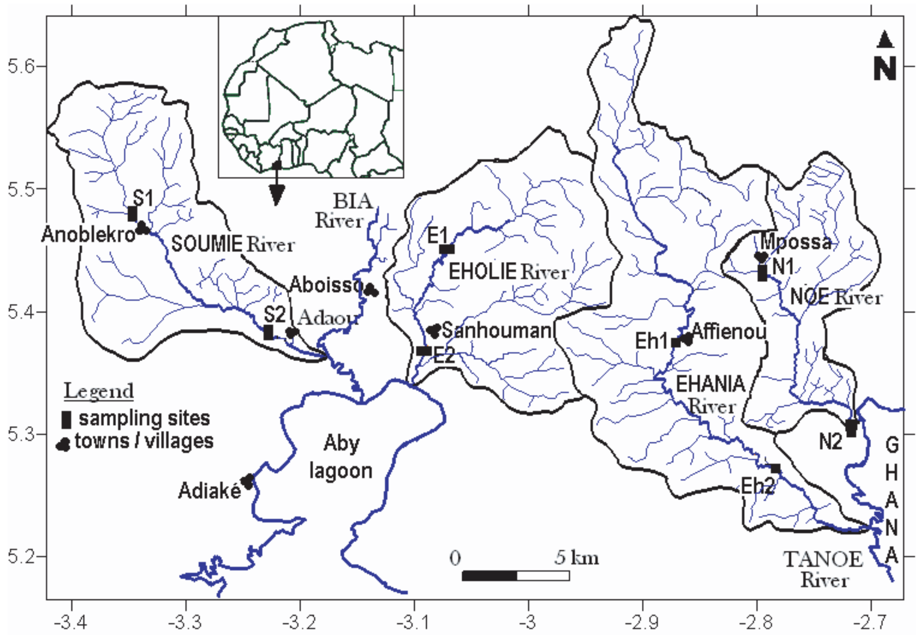

Fig. 1. Study area and locations of the sampling sites. S: Soumié River, E: Eholié River, Eh: Ehania River; N: Noé River; 1: upstream, 2: downstream.

length. These gill nets were 30 m long and 1.5 m high. At each sampling occasion, fishing was done overnight (17.00 to 7.00) and during the day (7.00 to 13.00). All fish specimens were identified according to the identification keys of Lévêque et al. (1990, 1992). Each specimen was measured (standard length) to the nearest mm and weighed to the nearest gram.

Environmental variables

At each sampling period, three environmental variables (i.e. current velocity, mean width and mean depth) were quantified at the reach scale by applying the transect method (Hugueny 1990). This method consists of delimiting each reach by equidistant cross-stream transects; along which each variable was measured at regularly spaced intervals (see Hugueny 1990). Current velocity was measured by observing the horizontal displacement of a float over a calibrated distance. Each site was also characterized spatially by its distance from the source.

3 Data analysis

Basic statistics applied to species composition analysis

First, we established a list of species sampled in the upstream and downstream sites of each basin. Then, the similarity between the upstream and downstream sites was quantified using the Jaccard similarity index ranging from 0 to 1 (Legendre and Legendre 1998). Last, the Mann-Whitney test was applied to test for differences in species richness found in the upstream and downstream sites of each basin.

Self-Organizing Map (SOM)

First, a species occurrence data set was arranged as a matrix of 64 rows (i.e., the 8 sites sampled on 8 occasions) and 59 columns (i.e., the species). Each of the 64 samples of the data set can be considered as a vector of 59 dimensions. Species occurrence was preferred to fish abundance because of the selectivity of gill net sampling techniques, which can bias the calculation of species abundance (Hugueny et al. 1996). Then, the species occurrence data set was patterned by training the SOM. The architecture of the SOM consisted of two layers of neurons (or nodes): (i) the input layer that was composed of 59 neurons connected to each vector of the data set and (ii) the two-dimensional output layer was composed of 20 neurons (i.e. a rectangular grid with 5 by 4 neurons laid out on a hexagonal lattice). We chose a 20-neuron grid because this configuration presented minimum values of both quantization and topographic errors, which are used to assess classification quality (e.g. Park et al. 2003). The SOM algorithm calculates the connection intensities (i.e. vector weights) between input and output layers using an unsupervised competitive learning procedure (Kohonen 2001), which iteratively classifies samples in each node according to their similarity in species composition. Thus, the SOM preserves the neighborhood so that samples with close species occurrences are grouped together on the map, whereas samples with very different species occurrences are far from each other. The connection intensity of the SOM corresponds to the probability of occurrence of a species in a group of samples, and can be displayed on the map as shades of grey: the darker the color, the higher the probability (e.g., black means a species occurred in >90% of the samples) (Lek et al. 2000). Last, mean values of each environmental variable were calculated in each node of the trained SOM map to understand the relationships between the biological and environmental variables. These mean values assigned to the SOM map were visualised using a grey scale, and then compared with maps of sampling sites as well as biological attributes.

For more details concerning the SOM algorithm and its applications, we refer the readers to Kohonen (2001), Giraudel and Lek (2001), Park et al. (2003) and Reyjol et al. (2005). The analysis was carried out using the SOM Toolbox© (Alhoniemi et al. 2005) for Matlab© in a PC platform.

Definition of SOM clusters

We checked whether relevant groups of samples characterized distinct fish assemblages by performing a hierarchical cluster analysis (Ward's linkage and Euclidean distance). To do so, we used a new matrix (20×60, output neurons × species) of the connection intensity values estimated by the SOM. The number of clusters was defined by applying the Davies-Bouldin index (DBI), in which minimum values indicate low variance within clusters and high variance between clusters (Vesanto and Alhoniemi 2000). Between-cluster differences in species richness were evaluated using the Kruskal-Wallis test, a non-parametric analysis of variance, followed by Mann-Whitney test to identify specific differences. Then, we assessed whether fish assemblages associated with each cluster were related to seasonal and spatial factors (i.e. rainy and dry seasons; upstream and downstream areas) by applying a proportion test based on χ^2 likelihood ratio statistics (i.e. *G*-test with Yates' correction; Zar 1999).

4 Results

The composition of the ichthyofauna (species, genera, families) collected during this study is shown (Table 1). A total of 59 fish species belonging to 39 genera, 23 families and 10 orders were captured from the various samples. Perciform (30% of families and 32% of species) was the most abundant order, followed by Siluriform (22% and 22%), Osteoglossiform (13% and 15%), Characiform (9% and 10%) and Pleuronectiform (9% and 3%). A single family belonging to Cypriniform, accounted for 10% of species. Among the families sampled, Cichlidae (20% of species), Mormyridae (14%), Clariidae (10%), Cyprinidae (10%) and Characidae (8%) were largely represented.

Among the 59 fish species collected, 11 species appeared at least with 50% of occurrence (i.e. *Brycinus longipinnis, Petrocephalus bovei, Chromidotilapia guntheri, Marcusenius ussheri, Schilbe mandibularis, Hemichromis fasciatus, Hepsetus odoe, Papyrocranus afer, Chrysichthys nigridigitatus, Raiamas senegalensis* and *Barbus trispilos*). Then, 6 species were caught only once (i.e. *Trachinotus teraia, Citharichthys stampflii, Pomadasys jubelini, Elops lacerta, Gymnallabes* sp. and *Sarotherodon galilaeus*) and 15 marine/brackish species inhabiting the Aby lagoon were collected (i.e. *Liza falcipinnis, Raiamas senegalensis, Sarotherodon melanotheron, S. galilaeus, Tilapia mariae, Pellonula leonensis, Eleotris senegalensis, Chonophorus lateristriga, Trachinotus teraia, Citharichthys stampflii, Pomadasys jubelini, Elops lacerta, Tilapia guineensis, Brienomyrus brachyistius, Hemichromis*

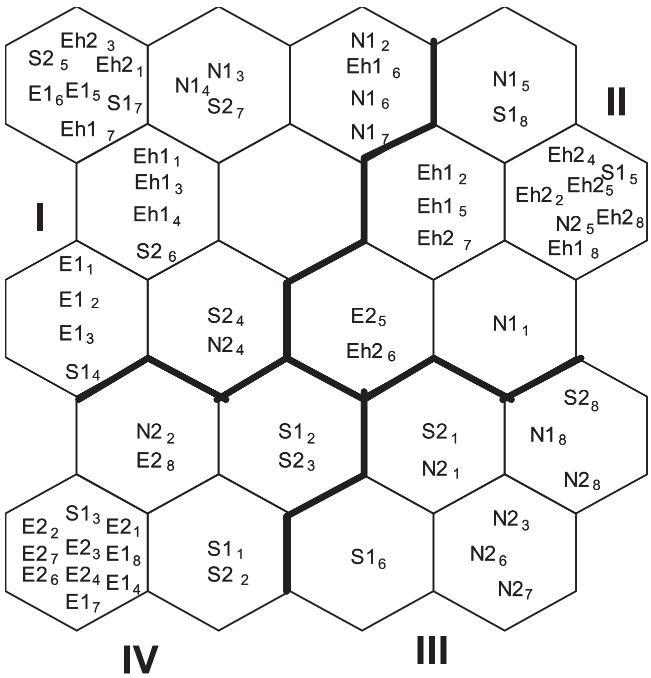

Fig. 2. Classification of samples using presence-absence data through the learning process of the self-organizing map. S: Soumié River, E: Eholié River, Eh: Ehania River; N: Noé River; 1: upstream, 2: downstream. Index 1 to 8 = number of samples.

fasciatus), as well as two introduced species (*Oreochromis niloticus* and *Heterotis niloticus*). Last, 26 species are common to the 4 basins, i.e. with high occurrence; 6 species appeared only in the downstream area of the Eholié river (*Citharichthys stampflii, Trachinotus teraia, Pomadasys jubelini, Elops lacerta, Sarotherodon galilaeus, Tilapia guineensis*), and 2 species (*Gymnallabes sp., Clarias buettikoferi*) occurred only in the downstream area of the Ehania river.

For Eholié, Ehania and Noé rivers, the upstream area (12.5 ± 3.1 mean ± SD, 11.2 ± 3.2, 11.5 ± 2.4, respectively) was less rich in species than the downstream area (19.3 ± 4.6, 18.4 ± 4.3, 18.7 ± 4.1, respectively) (Mann-Whitney test, p = 0.012; p = 0.023; p = 0.010, respectively), while we found no significant differences between the upper and lower courses of the Soumié River (Mann-Whitney test, $p = 0.11$); upper course: 11.3 ± 4.5, lower course: 14.4 ± 4.2. The Jaccard index calculated between the upstream and downstream sites remained generally rather high (i.e. between 0.4 and 0.7). The strongest similarities between the upper and lower courses were observed in the Noé (0.67), Soumié (0.64), Eholié (0.63) rivers and the lowest in the Ehania River (0.51).

The samples were classified by the SOM according to their species composition in the 20 output nodes, so that each node included samples with similar species. Most samples from downstream courses of Eholié (E2), Noé (N2) and Soumié (S2) rivers were located in the lower part of the SOM map, whereas samples from the downstream course of Ehania were classified mostly in the upper-right part (Fig. 2). The samples collected in upstream areas were mainly grouped in the upper and the upper-left areas of the map. The hierarchical cluster analysis (Fig. 3b), applied to the output matrix extracted from

Table 1. Fish species collected in the Soumié, Eholié, Ehania and Noé Rivers during this study: upstream and downstream; x = presence; - = absence.

	Rivers	SOUMIE		EHOLIE		EHANIA		NOE	
Families	**Species**	**Up**	**Down**	**Up**	**Down**	**Up**	**Down**	**Up**	**Down**
	Clarias anguillaris	-	-	x	-	-	x	x	x
	Clarias ebriensis	-	-	-	-	-	x	-	x
CLARIIDAE	*Clarias buettikoferi*	-	-	-	-	-	x	-	-
	Gymnallabes sp.	-	-	-	-	-	x	-	-
	Heterobranchus isopterus	x	x	x	x	-	-	x	x
	Heterobranchus longifilis	x	x	x	x	x	-	x	x
	Parailia pellucida	x	x	x	x	-	-	x	x
SCHILBEIDAE	*Schilbe intermedius*	-	-	-	-	-	x	-	x
	Schilbe mandibularis	x	x	x	x	x	x	x	x
MOCHOKIDAE	*Synodontis bastiani*	-	-	-	-	-	x	-	x
MALAPTERURUDAE	*Malapterurus electricus*	-	x	-	x	-	-	x	-
CLAROTEIDAE	*Chrysichthys maurus*	x	x	x	x	x	x	x	x
	Chrysichthys nigrodigitatus	x	x	x	x	x	x	x	x
MASTACEMBELIDAE	*Aetiomastacembelus*	x	-	-	-	x	x	-	x
	nigromarginatus								
NOTOPTERIDAE	*Papyrocranus afer*	x	x	x	x	x	x	x	x
CHANNIDAE	*Parachanna obscura*	x	-	-	x	x	x	x	x
ELEOTRIDAE	*Eleotris senegalensis*	-	-	x	x	-	x	-	-
GOBIIDAE	*Chonophorus lateristriga*	x	-	-	x	-	-	-	-
BOTHIDAE	*Citharichthys stampflii*	-	-	-	x	-	-	-	-
CARANGIDAE	*Trachinotus teraia*	-	-	-	x	-	-	-	-
HAEMULIDAE	*Pomadasys jubelini*	-	-	-	x	-	-	-	-
ELOPIDAE	*Elops lacerta*	-	-	-	x	-	-	-	-
MUGILIDAE	*Liza falcipinnis*	x	x	x	x	x	-	-	x
	Chromidotilapia guntheri	x	x	x	x	x	x	x	x
	Hemichromis fasciatus	x	x	x	x	x	x	x	x
	Orechromis niloticus	-	x	-	x	-	-	-	x
	Sarotherodon galilaeus	-	-	-	x	-	-	-	-
	Sarotherodon melanotheron	x	x	x	x	x	x	x	x
CICHLIDAE	*Tilapia busumana*	-	x	-	x	x	x	x	-
	Tilapia dageti	-	-	-	x	-	-	-	x
	Tilapia mariae	x	x	-	x	x	x	x	x
	Tilapia guineensis	-	-	-	x	-	-	-	-
	Tilapia zillii	x	x	x	x	-	x	x	x
	Tylochromis intermedius	-	x	-	-	-	x	-	-
	Tylochromis jentenki	x	-	x	x	-	x	-	x
ANABANTIDAE	*Ctenopoma kingsleyae*	-	x	-	-	x	x	-	x
	Ctenopoma petherici	x	x	x	x	x	x	x	x
HEPSETIDAE	*Hepsetus odoe*	x	x	x	x	x	x	x	x
	Brycinus imberi	x	-	-	-	x	x	x	x
	Brycinus longipinnis	x	x	x	x	x	x	x	x
CHARACIDAE	*Brycinus macrolepidotus*	x	x	x	x	-	x	x	x
	Brycinus nurse	-	-	-	-	-	x	x	x
	Micralestes occidentalis	x	-	-	-	x	x	x	x
CLUPEIDAE	*Pellonula leonensis*	-	-	x	x	-	-	x	x
	Barbus ablabes	x	x	x	x	x	x	x	x
	Barbus trispilos	x	x	x	x	x	x	x	-
CYPRINIDAE	*Barbus wurtzi*	x	x	x	x	-	x	-	-
	Labeo coubie	-	-	-	x	x	x	x	x
	Labeo parvus	-	-	-	-	x	x	x	x
	Raiamas senegalensis	x	x	x	x	x	x	-	x
	Brienomyrus brachyistius	-	-	-	x	x	-	x	x
	Marcusenius furcidens	x	x	x	x	-	x	x	x
	Marcusenius ussheri	x	x	x	x	x	x	x	x
MORMYRIDAE	*Marcusenius senegalensis*	x	x	x	x	x	x	x	x
	Mormyrops anguilloides	x	-	x	x	-	x	-	x
	Mormyrus rume	x	x	-	-	-	x	x	x
	Petrocephalus bovei	x	x	x	x	x	x	x	x
	Pollimyrus isidori	-	-	x	x	x	x	x	x
OSTEOGLOSSIDAE	*Heterotis niloticus*	-	-	-	x	-	-	-	x

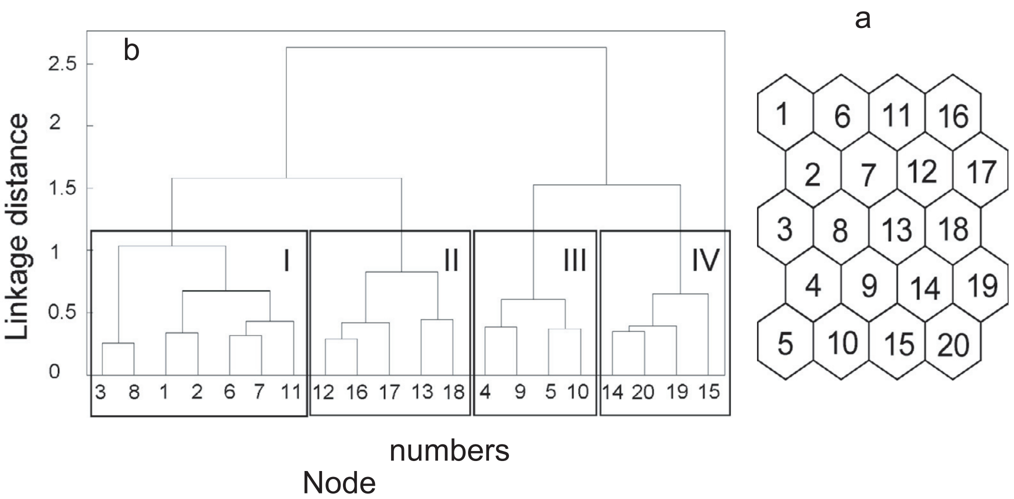

Fig. 3. a) Self-organizing map (SOM) (20 nodes) b) Hierarchical clustering of the SOM nodes with a Ward linkage method and a Euclidean distance: the numbers (i.e. ranging from 1 to 20) correspond to those assigned on each node of the SOM. The four boxes correspond to the clusters selected from the Davies-Bouldin index (DBI, see material and methods for more details).

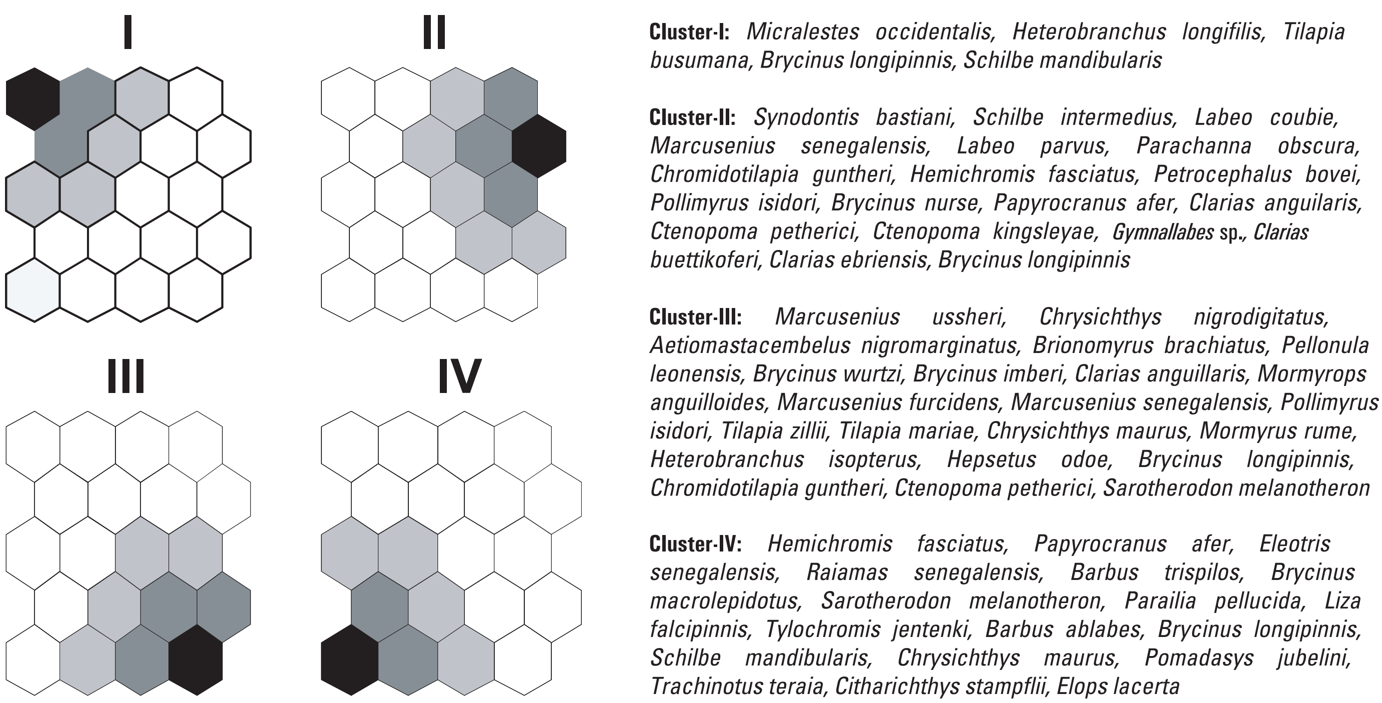

Fig. 4. Distribution patterns of fish species in each cluster defined by the hierarchical clustering applied on the self-organizing map (SOM) units. Dark represents high probability of occurrence, and light indicates lower probability.

the SOM, classified the samples into four clusters according to the minimum Davis-Bouldin index (DBI), i.e. DBI = 1 for 4 clusters and DB I = 1.63 for 2 clusters.

The fish assemblage pattern in the SOM map is presented (Fig. 4). Cluster-I was mainly associated with two co-occurring species (i.e. *Micralestes occidentalis* and *Tilapia busumana*), and cluster-II was characterised by Clariidae species such as *Gymnallabes* sp., *Clarias buettikoferi, Clarias ebriensis*, *Clarias anguilaris*. Then, cluster-III was distinguished by fish belonging to Mormyridae (i.e. *Marcusenius ussheri, Mormyrops anguilloides, Marcusenius furcidens, Mormyrus rume, Brionomyrus brachiatus*). Last, cluster-IV was mainly characterised by marine/brackish species such as *Pomadasys jubelini, Trachinotus teraia, Citharichthys stampflii, Elops lacerta*, *Chonophorus lateristriga, Hemichromis fasciatus, Eleotris senegalensis, Raiamas senegalensis, Pellonula leonensis, Liza falcipinnis,* and *Tylochromis jentenki*.

The mean values of each environmental variable were calculated and visualized in the SOM map trained with the biological dataset. Except for the distance from the source, environmental variables (i.e. width, depth, current velocity) did not

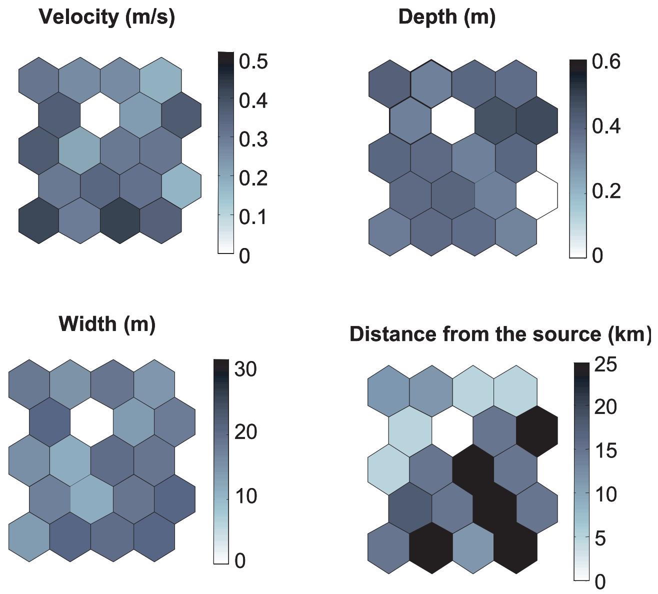

Fig. 5. Visualization of environmental variables on the self-organizing map (SOM) trained with fish assemblages. Dark represents high values and light represents low ones.

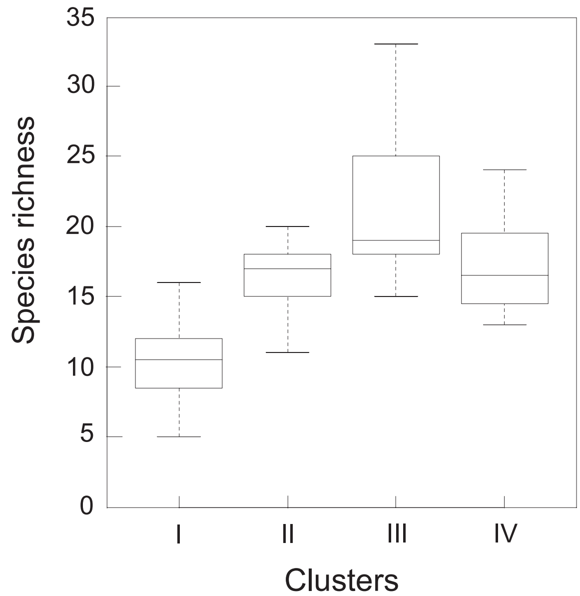

Fig. 6. Boxplot comparing fish species richness in the four clusters defined by the self-organizing map.

show a clear gradient distribution on the SOM map (Fig. 5). The distance from the source displayed the highest values in the lower right part of the SOM map (cluster-III) whereas lowest values appeared in the upper left part (cluster-I). The tests for proportions confirmed this last result. Samples from cluster-I were significantly related to upstream areas ($G = 4.29$, $df = 1$, $p < 0.05$), whereas those from cluster-III were significantly related to downstream areas ($G = 3.94$, $df = 1$, $p < 0.05$). Concerning the seasonal factor, only cluster-II was related to it ($G = 4.85$, $df = 1$, $p < 0.05$). Most of the samples belonging to cluster-II were collected in the dry season.

The Kruskal-Wallis test showed highly significant differences in species richness between clusters ($p < 0.001$, Fig. 6). Cluster-I displayed the lowest species richness and was significantly different from clusters II, III and IV (Mann-Whitney test, $p < 0.001$). Cluster-II comprised fewer species than cluster-III ($p < 0.05$), whereas there were no significant differences ($p > 0.1$) between clusters II and IV or between clusters III and IV.

5 Discussion

Comparing the fish fauna from the rivers studied showed that Perciforms, Siluriforms and Osteoglossiforms are the orders containing the most families and species as also observed by Teugels et al. (1988), Froese and Pauly (2006) and Da Costa (2003) in the Bia and Tanoé rivers in the same region. Concerning families, five of them dominate by their number of species (i.e. Cichlidae, Mormyridae, Cyprinidae, Characidae, Clariidae), as also mentioned by Da Costa (2003) in the Bia and Agnébi rivers.

Our inventory in the Noé and Ehania rivers indicated species richness lower than those reported by Teugels et al. (1988) and Froese and Pauly (2006) in the Tanoé River. This difference could be related to the sampling procedure and the types of habitats prospected (Gourène et al. 1999; Paugy and Lévêque 1999; Koné et al. 2003b). Moreover, these two rivers are tributaries of the Tanoé River. Therefore, it is also expected that some species occurring in the main channel of the Tanoé River basin did not inhabit tributaries such as the Ehania and Noé rivers. Then, in the present study, 18 species were reported for the first time in the Tanoé river basin (i.e. *H. niloticus, O. niloticus, T. dageti, T. intermedius, C. anguillaris, C. ebriensis, Clarias buettikoferi, Gymnallabes* sp.*, S. intermedius, Synodontis bastiani, H. odoe, L. falcipinnis, Brycinus nurse, Labeo coubie, Barbus wurtzi, Brienomyrus brachyistius, Mormyrops anguilloides, Pollimyrus isidori*). Thus, its species richness increased from 61 (Teugels et al. 1988; Froese and Pauly 2006) to 78 species. Among these newly occurring species, two introduced species appeared *Heterotis niloticus* and *Oreochromis niloticus*, whose presence in Noé may be related to the many farm ponds established along this river. Because exotic species can have harmful impacts on native species (e.g. Clavero and García-Berthou 2005; Leprieur et al. 2006), attention should be paid to their spread in the Tanoé River basin.

In this study, fish assemblages were patterned through an adaptive learning algorithm, the self-organizing map (SOM), according to the distribution similarities of each species. The suitability of this tool is known to provide more relevant classifications and ordinations than conventional multivariate analysis due to the ability of SOM to consider rare species without overfitting bias (Chon et al. 1996; Foody 1999; Giraudel and Lek 2001). Overall the SOM showed four clusters of fish assemblages, related to the longitudinal river gradient. Indeed, cluster I mainly gathers samples from upstream while the three others are associated to downstream sections of the rivers. Broadly, the species richness of the downstream course of Ehania, Eholié and Noé rivers is higher than in the upstream one, as also observed by Hugueny (1990), Tito de Morais and Lauzanne (1994), Da Coasta et al. (2000) and Koné et al. (2003a) in other tropical river systems. The successive addition of species along the longitudinal gradient of stream ecosystems is known to be related to the increase of the heterogeneity and volume of habitats and the depth of the river (Vannote et al. 1980; Hugueny 1990, Matthews 1998). This increase in the number of species in the lower course is, according to Lévêque et al. (1990, 1992), also related to the increase of species with estuarine/marine affinities. Thus, our results did not show a clear relationship between species assemblages and river size such as width and depth, which is not surprising given the small size of the tributaries studied. Cluster-III is distinguished from the others by the presence of species with low resilience such as Mormyridae, a family indicating good ecological conditions (Bénech et al. 1983; Lowe-McConnell 1987; Lévêque et al. 1991; Hugueny et al. 1996). This cluster is primarily associated with the samples of Soumié and Noé especially the downstream part of river Noé. Cluster II was characterised by species with high resilience (*Clarias buettikoferi, C. anguillaris, C. ebriensis, Synodontis bastiani, Hemichromis fasciatus, Ctenopoma petherici, C. kingsleyae*.) This cluster was characterized by the samples from the Ehania River especially from its downstream part. Considering anthropic activities, the basin of Ehania is occupied by extensive palm plantations especially in its downstream part, and a gold mine (Mines of Afema) was located between the two stations on this river. Pollution related to these activities, could generate unfavourable living conditions where only the most resilient species can survive. Cluster-IV was also distinguished from the others by the presence of numerous brackish and marine species. This cluster includes almost all the samples of Eholié (7 out of 8): the only one of the four rivers studied which flows directly into the Aby lagoon. Moreover, the downstream station of this river is closest to this brackish water. According to Lévêque et al. (1990, 1992), Diouf et al. (1991), Pouyaud (1994), Lévêque and Paugy (1999), a number of brackish and/or marine water species can go upstream in the rivers. Overall, a quarter of the species collected during this study are estuarine/marine species and characterize the lower course of Ehania, Eholié, Soumié and Noé rivers. Several authors such as Konan (2002), Koné et al. (2003a), Da Costa (2003), and Kouamélan et al. (2003) already reported the presence of estuarine/marine species in Western African river basins. These fish can penetrate rivers rather high (Albaret 1994). For example *Liza falcipinnis,* which is perfectly euryhaline according to Albaret (1994), was captured at most of the stations. Bruslé (1981) and Albaret and Legendre (1985) explained this wide distribution directly by its hypereuryhalinity and its broad food spectrum. Like *Liza falcipinnis*, the various species with both estuarine and marine affinities, adapted to these various ecosystems, would be better suited for using additional food resources and hence optimizing the energy costs of the reproduction, which can occur in lagoon the (Albaret and Legendre 1985), or in brackish or freshwater sytems (Bruslé 1981), and sometimes in the sea (Pillay 1965). In the Bia river, Da Costa et al. (2000) observed that estuarine/marine species (i.e. *Liza falcipinnis, Pellonula leonensis, Raiamas senegalensis, Tilapia mariae and Tylochromis jentenki*) previously observed in the upper course of the Bia River were restricted to the downstream part after the construction of two dams, which have been recognized as a major threat to aquatic fauna (Allan 1995). In the streams studied, there were no dams that could impede fish migration and these species were sampled in both upstream and dowstream sites of the Soumié River, a tributary of the Bia River in its downstream part. Then, *Chonophorus lateristriga* absent from the Bia River (Teugels et al. 1988; Da Costa et al. 2000; Froese and Pauly 2006) was also recorded in the upstream site of the Soumié river during this study. This species was also sampled in neighboring streams such as the Eholié river (i.e. present study), the Agnéby River (Da Costa et al. 2000) and the Tanoé River (Teugels et al. 1988; Froese and Pauly 2006). It was reported by Diouf et al. (1991), Pouyaud (1994) and Lévêque and Paugy (1999), that dams impede estuarine/marine fish from migrating upstream during floods, which disturbs their life cycle, especially reproduction in favourable habitats. Another major impact is also the reduction of the distributional range of these species (Lévêque and Paugy 1999). Therefore, we suggest that the small streams investigated during this study should be preserved to permit estuarine/marine species to migrate from the Aby lagoon. Moreover, the Soumié River basin is the only preserved stream ecosystem within the Bia River basin that can be colonized by migratory species. We therefore suggest setting conservation measures to protect this basin and to prevent future construction of dams. Indeed, this stream could constitute a reference system that could be used to measure the impact of anthropogenic disturbances in surrounding rivers.

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References

Adite A., Van Thielen R., 1995, Ecology and fish catches in natural lakes of Benin, West Africa. Environ. Biol. Fish. 43, 381–391.

Albaret J.J., Legendre M., 1985, Biologie et écologie des Mugilidae en lagune Ebrié (Côte d'Ivoire) : Intérêt potentiel pour l'aquaculture lagunaire. Rev. Hydrobiol. Trop. 18, 281–303.

Albaret J.J., 1994, Les poissons : biologie et peuplements. In: Durand J.R., Dufour P., Zabi, S. G.F. (Eds.) Environnement et ressources aquatiques de Côte d'ivoire, Tome II Les milieux lagunaires. Abidjan, ORSTOM, pp. 239–279.

Alhoniemi E., Himberg J., Parhankangas J., Vesanto J., 2005, SOM Toolbox, version 2.0 beta, a software library for Matlab 5 implementing the Self-Organizing Map algorithm. [oneline] http://www.cis.hut.fi/projects/somtoolbox/

Allan J.D., 1995, Stream ecology: structure and function of running water. Chapman and Hall, London.

Bénech V., Durand J. R., Quensière J., 1983, Fish communities of Lake Chad and associated rivers and floodplains. *In*: Carmouze J.P., Durand J.R., Lévêque C. (Eds.) Lake Chad. Ecology and productivity of a shallow tropical ecosystem, Monographiae Biologicae (53), La Haye, W. Junk, pp. 293–356.

Bengen D., Lim P., Beland A., 1992, Qualité des eaux de trois bras morts de la Garonne : variabilité spatio-temporelle. Rev. Sci. Eau 5, 131–156.

Brosse S., Giraudel J.L., Lek S., 2001, Utilisation of non-supervised neural networks and principal component analysis to study fish assemblages. Ecol. Model. 146, 159–166.

Bruslé J., 1981, Sexuality and biology of reproduction in grey mullets. In: Oren O. H. (Ed.) Aquaculture of grey mullets, New York, Cambridge Univ. Press, pp. 99–154.

Cao Y., Williams D.D., Williams N.E., 1998, How important are rare species in aquatic community ecology and bioassessment. Limnol. Oceanogr. 43, 1403–1409.

Chon T.S., Park Y.S., Moon M.H., Cha E.Y., 1996, Patternizing communities by using an artificial neural network. Ecol. Model. 90, 69–78.

Clavero M., García-Berthou, E., 2005, Invasive species are a leading cause of animal extinctions. Trends Ecol. Evol. 20, 110.

Crisman T.L., Chapman T.L., Chapman C.A, Kaufman L.S., 2003, Conservation, ecology and management of African freshwaters. Gainesville, Florida, University Press of Florida.

Da Costa K.S., 2003, Structure des peuplements, déterminisme de la diversité spécifique de l'ichtyofaune et pratique durable de la pêche dans quelques hydrosystèmes africains : cas des bassins Agnébi et Bia, et de 13 petits barrages du Nord de la Côte d'Ivoire. Thèse de doctorat, Université d'Abobo-Adjamé, Côte d'Ivoire.

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

Daget J., Iltis A., 1965, Poissons de Côte d'Ivoire (eaux douces et saumâtres). Dakar, Édition IFAN Inst. Fr.Afr. Noire.

Diouf P.S., Kebe M., Le Reste L., Bousso T., Diadhiou H.D., Gaye A.B., 1991, Plan d'action forestier. Pêche et aquaculture continentales. CRODT, FAO, ministère du développement et de l'hydraulique, Vol. I.

Foofy G.M., 1999, Applications of self-organizing feature map neural net work in community data analysis. Ecol. Model. 120, 97–107.

Froese R., Pauly D. (Eds.), 2006, FishBase. World Wide Web electronic publication. www.fishbase.org, version (11/2005).

Giraudel J.L., Lek S., 2001, A comparison of self-organizing map algorithm and some conventional statistical methods for ecological community ordination. Ecol. Model. 146, 329–339.

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

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. Rev. Hydrobiol. Trop. 23, 351–364.

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

Ibarra A.A., Park Y.S., Brosse S., Reyjol Y., Lim P., Lek S., 2005, Nested patterns of spatial diversity relealed for fish assemblages in a west European river. Ecol. Freshw. Fish. 14, 233–242.

Kamdem-Toham A., Teugels G.G., 1998, Diversity of fish assemblages in the Lower Ntem River Basin (Cameroon), with notes on potential effect of deforestation. Arch. Hydrobiol. 141, 421–446.

Kenkel N.C., Orloci L., 1986, Applying metric and nonmetric multidimensional scaling to ecological studies: some new results. Ecology 67, 919–928.

Kohonen T., 2001, Self-Organizing Maps. 3rd edition, Berlin, Germany, Springer-Verlag.

Konan K.F., 2002, Variation spatio-temporelle des populations et peuplements de poissons de trois bassins du Sud-Est ivoirien (Tanoé-Ehania-Soumié). Pre-doctoral report, Abobo-Adjamé University, Ivory Coast.

Koné T., Teugels G.G., N'Douba V., Gooré Bi G., Kouamelan, E.P., 2003a, 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.

Koné T., Teugels G.G., N'Douba V., Kouamelan E.P., Gooré Bi G., 2003b, Fish assemblages in relation to environmental gradients along a small west African coastal bassin, the San Pedro River, Ivory Coast. Afr. J. Aquat. Sci. 28, 163–168.

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

Legendre P., Legendre L., 1998, Numerical ecology. 2nd English edition. Elsevier Science BV, Amsterdam.

Lek S., Giraudel J.L., Guégan J.F., 2000, Neuronal networks: algorithms and architectures for ecologists and evolutionary ecologists. *In*: Lek, S., Guégan J.F. (Eds.) Artificial Neuronal Networks: Application to Ecology and Evolution. Berlin, Springer-Verlag, pp. 3–27.

Lenat D.R., Resh V.H., 2001, Taxonomy and stream ecology – the benefits of genus-and species-level identifications. J. North Am. Benthol. Soc. 20, 287–298.

Leprieur F., Hickey M., Arbuckle C.J., Closs P.G., Brosse S., Townsend C.R., 2006, Hydrological disturbance benefits a native fish at the expense of an exotic fish in a New Zealand stream. J. Appl. Ecol. 43, 930–939.

Lévêque C., Paguy D., Teugels G.G. (Eds.), 1990, Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome I. Faune tropicale, XXVIII, MRAC-Tervuren / ORSTOM-Paris.

Lévêque C., Paugy D., Teugels G.G., 1991, Annotated checklist of the freshwater fishes of the Nilo-Sudan river bassin in Africa. Rev. Hydrobiol. Trop. 24, 131–154.

Lévêque C., Paguy D., Teugels G.G. (Eds.), 1992, Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'ouest. Tome II. Faune tropicale, XXVIII, MRAC-Tervuren / ORSTOM-Paris, pp. 385–902.

Lévêque C., 1996, Ecosystèmes aquatiques. Paris, Éditions Hachette, 158p.

Lévêque C., Bruton M.N., Ssentongo G.W. (Eds.), 1998, Biology and ecology of African freshwater fishes. Bondy, ORSTOM.

Lévêque C., Paugy D. (Eds), 1999, Peuplement des cours d'eau et des biotopes associés. *In*: Les poissons des eaux continentales africaines : Diversité, écologie, utilisation par l'homme, Paris, IRD, pp. 283–294.

Lowe-McConnell R.H., 1987, Ecological study in tropical fish communities. Cambridge University Press, Tropical Biology series.

Matthews W.J., 1998, Patterns in freshwater fish ecology. New York, Chapman and Hall, Second Printing by Kluwer Academic Press.

Park Y.S., Cereghino R., Compin A., Lek S., 2003, Applications of artificial neural networks for patterning and predicting aquatic insect species richness in running waters. Ecol. Model. 160, 265–280.

Paugy D., Lévêque C., 1999, L'échantillonnage des peuplements de poissons. In: Lévêque C., Paugy D. (Eds.) Les poissons des eaux continentales africaines : diversité, écologie, utilisation par l'homme, Paris, Editions de l'IRD, pp. 227–236.

Pillay T.V.R., 1965, Report to the Government of Nigeria on investigations of the possibility of brackish water fish culture in the Niger Delta. FOA/UN Rep. FAO/EPTA.

Pouyaud L., 1994, Génétique des populations de tilapias d'intérêt aquacole en Afrique de l'Ouest. Relations phylogénétiques et structurations populationnelles. Univ. Montpellier, Ph.D. dissertation.

Przybylski M., 1993, Longitudinal pattern in fish assemblages in the upper Warta river, Polsk. Arch. Hydrobiol. 126, 499–512.

Reyjol Y., Fischer P., Lek S., Rösch R., Eckmann R., 2005, Studying the spatiotemporal variation of the littoral fish community in a large prealpine lake, using self-organizing map. Can. J. Fish. Aquat. Sci. 62, 2294–2302.

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

Tejerina-Garro F.L., Maldonado M., Ibanez C., Pont D., Roset N., Oberdorff, 2005, Effects of natural and anthropogenic environmental changes on riverine fish assemblages: a framework for ecological assessment of rivers. Braz. Arch. Biol. Technol. 48, 91–108.

Tison J., Park Y.S., Coste M., Delmas F., Giraudel J.L., 2004, Use of unsupervised neural networks for eco-regional zonation of hydrosystems through diatom communities: case study of Adour-Garonne watershed (France). Arch. Hydrobiol. 159, 409–422.

Tito de Morais L., Lauzanne L., 1994, Zonation longitudinale des peuplements ichtyologiques avant la mise en eau de la retenue de Petit-Saut (Guyane française). Rev. Hydrobiol. Trop. 27, 467–483.

Vannote R.L., Minshall G.W., Cummins K.W., Sedell J.R., Cushing C.E., 1980, The river continuum concept. Can. J. Fish. Aquat. Sci. 37, 130–137.

Vesanto J., Alhoniemi E., 2000, Clustering of the self-organizing map. IEEE Trans.Neural Networks 11, 586–600.

Zar J.H., 1999, Biostatistical Analysis. 4nd Edition, NJ Prentice Hall.