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PREDICTING FACTORS THAT INFLUENCE FISH GUILD COMPOSITION IN FOUR COASTAL RIVERS (SOUTHEAST IVORY COAST) USING ARTIFICIAL NEURAL NETWORKS

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ABSTRACT

The present study is focused on small coastal rivers in southeast Ivory Coast, aimed to predict species richness of fish guilds and to test contribution of environmental variables for explaining guild structure with Self-Organizing Map (SOM) and Backpropagation (BP) algorithms. The former method was applied to pattern the samples based on the richness of six major fish guilds observed (benthivores, invertivores, detritivores, piscivores, herbivores and omnivores). Four clusters were identified: cluster I was characterised by benthivores, cluster II was distinguished by invertivores, detritivores, piscivores and omnivores, cluster III had high richness of benthivores, invertivores and herbivores, and cluster IV had high numbers of omnivore, detritivore and piscivore species. The BP showed high predictability (0.89 for benthivores, 0.85 for omnivores and Odonata, 0.84 for herbivores). There was high correlation between observed and estimated values for piscivores (0.77) and detritivores (0.72); the poorest fit was for invertivores (0.63). The frequency histogram of residuals showed that most residuals lie around zero for all guilds. The most contributing variables in predicting the six fish trophic guilds were water temperature, conductivity, total dissolved solids, dissolved oxygen, depth, width, canopy and distance from source. This underlines the crucial influence of both instream characteristics and riparian environment.

How to Cite

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INTRODUCTION

In river systems, biological assemblages are organised along longitudinal gradient (source to mouth) of environmental condition. Generally, there is an increase in species richness from upstream to downstream (Oberdorff et al., 1993; Oberdorff et al., 2001*a*). This longitudinal modification in the organization of the assemblage richness has habitually been attributed to the following phenomena: biotic zonation or continual addition of species downstream. Species structure depends on the diversity and stability of stream habitats which provide ecological niches for the development of species (Malmqvist and Otto, 1987). Thus, understanding community patterns is important to manage target ecosystems. In the case of freshwater environmental management, a greater worldwide concern is being given to aquatic ecosystem health as a key feature of water quality. This health can be reflected in organisms such as fish, which are considered as indices of aquatic quality (Karr, 1981; Karr et al., 1986; Oberdorff et al., 2001*b*). Indeed, because of

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their longevity, mobility and sensitivity to habitat modification, fish are good bioindicators and they are often used for the assessment of the ecological integrity of rivers (Karr, 1981; Oberdorff et al., 2002; Barella and Petere, 2003; Pont et al., 2006; Lasne et al., 2007). Moreover, characterizing spatial and temporal patterns of fish assemblages remains an important tool for ecological assessment of rivers as the longitudinal nature of stream ecosystems has long been recognized as a major force in structuring lotic communities in both temperate and tropical regions (Tejerina-Garro et al., 2005). These variations lead to non-linear relationships between the fish assemblage structure and environmental variables (flow regime, temperature, food availability, substrate conditions, etc.) which characterize the river (Gevrey et al., 2005). Indeed, the species richness measures were sensitive to anthropogenic disturbances of the stream ecosystems (Resh and Jackson, 1993), particularly fish assemblage, which can be considered as good biological indicators of disturbance in stream (Karr, 1981; Adite and Van Thielen, 1995; Hugueny et al., 1996; Kamdem-Toham and Teugels, 1998, Oberdorff et al., 2001b; Oberdorff et al., 2002).

The present study is focused on four small coastal rivers in southeast Ivory Coast which play an essential role for local human populations, like most coastal rivers of Ivory Coast where water is used for domestic activities (drinking, cooking, bathing, etc.), fisheries and agriculture (irrigation, cattle drinking). In order to preserve water quality and the diversity of biological communities, it appears therefore necessary to manage these hydrosystems. Such management requires the knowledge of how environmental variables affect the richness, taxonomic and trophic guild structure of these communities (Smogor and Angermeier, 1999; Edia et al., 2010).

Although tropical hydrosystems in West Africa are important habitats, only a few studies have been carried out on trophic organization of the ecosystems (Villanueva, 2004; Da Costa and Tito De Moraïs, 2007; Traoré et al., 2008). However, analysis of feeding habits and guild structure can help to understand the functioning of a complex ecosystem and the possible impacts of different ecological changes on the system as a whole (Hajisamae et al., 2003; Villanueva, 2004; Christensen et al., 2005; Da Costa and Tito De Moraïs, 2007; Traoré et al., 2008). In this study, the trophic structure based on Paugy et al. (1994), Da Costa (2003), Da Costa and Tito De Moraïs (2007), Konan et al. (2013) classification was chosen. This classification reflects the feeding ecology and trophic organization types encountered in the geographical area studied. We considered these guilds of interest to resource managers due to their implications in community ecology and for landscape planning (Jackson et al., 2001). To visualize the organization and structure of fish assemblages, several multivariate techniques have been used depending on the aim of the studies (Park et al., 2005). During the last decade, an increasing number of studies in ecology, biogeography and conservation biology have tried to build predictive models of species distribution aimed at a better protection and management of natural resources and ecosystems (Gevrey et al., 2003; Lek et al., 2005; Konan et al., 2006; Konan et al., 2007; Lasne et al., 2007; Aliko et al., 2010; Grenouillet et al., 2011). Due to their efficiency, artifical neural networks (ANN) with the self-organizing map (SOM) and backpropagation (BP) algorithm are appropriate methods to model non-linear data (Rumelhart et al., 1986) and have demonstrated their utility in environmental decision-making (Lek et al., 1996; Lek et al., 2000; Cheng et al., 2012). This method is classified as a data-driven technique, which implies that their learning improves as more and more training data are presented (Singh, 2009). Indeed, modelling the composition of fish assemblages on the basis of biotic and abiotic environmental descriptors is an important aspect of the management of aquatic ecosystems.

The aim of this paper is to present an application of SOM (unsupervised ANN) and BP (supervised ANN) for learning and modelling lotic fish assemblages in southeast Ivory Coast with two objectives: (a) to predict species richness of fish guilds; and (b) to test the contribution of environmental variables for explaining guild structure.

MATERIALS AND METHODS

Study area and sampling sites

Located in the southeast of Ivory Coast, the four coastal rivers studied (Fig. 1) belong to the Western Guinean ichthyoregion, sector Eburneo-Ghanaian (Daget and Iltis 1965). These small rivers are located in lowland rainforest.

A site was retained in the upstream and downstream areas of each stream (Fig. 1). The basic characteristics of these rivers and their sampling sites are summarized in Table 1.

Fish sampling and environmental variables

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 of total length. These gill nets were 30 m long and 1.5 m high. At each sampling occasion, fishing was done overnight (17.00 - 7.00) and during the day (7.00 - 13.00).

All fish specimens were identified according to the identification keys of Paugy et al. (2003). A database of fish diet composition was constructed from bibliographic references and FishBase (Froese and Pauly 2014) to the trophic guild of species recorded.

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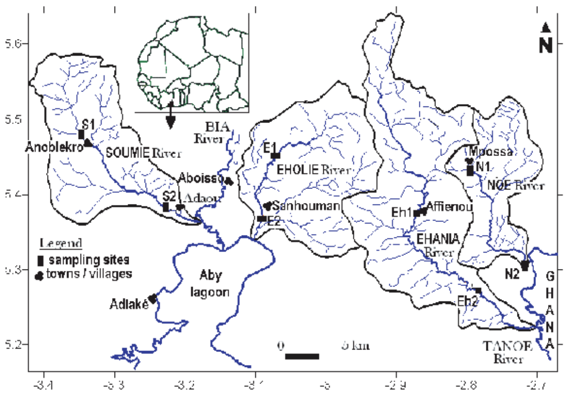

Fig 1. Study area and locations of the sampling sites. S: Soumié River, E: Eholié River, Eh: Ehania River; N: Noé River; 1: upstream, 2: downstream (Konan et al., 2006)

Twelve environmental variables were measured at each site and at each sampling period: water temperature (Tw), pH, conductivity (cond), total dissolved solids (tds), transparency (Trans), dissolved oxygen (do), canopy, flow, nitrate (NO_3^-), width, depth and distance to source (ds).

Data analysis

In this study, 64 samples were classified according to the number of fish guilds per site and per campaign using the SOM. The species were classified into different trophic guilds based on their main food items using available information. Six fish guilds (benthivores, invertivores, detritivores, piscivores, herbivores and omnivores) were retained because they were major components of the ichtyofauna of the studied rivers.

Self-Organizing Map (SOM)

The Self-Organizing Map (SOM) (Kohonen, 1982; 1995) was used to classify the samples according to fish guild composition. The species occurrence data set was arranged as a matrix of 64 rows (i.e., the 8 sites sampled on 8 campaigns) and 6 columns (i.e., the fish guild composition). For more details concerning the SOM algorithm and its applications, we refer the readers to Kiviluoto (1996), Kohonen (2001), Tison et al. (2004), Konan et al. (2006), Gevrey et al. (2009), Medlin and Jungclaus (2012).

The SOM toolbox (version 2) for Matlab® developed by the Laboratory of Information and Computer Science at the Helsinki University of Technology (http://www.cis.hut.fi/projects/somtoolbox/) was used, and the initialization and training methods suggested by the authors allowing the algorithm to converge faster were adopted (Vesanto et al., 1999).

To assess whether fish guilds associated with each cluster were related to spatial factor (i.e., undisturbed and disturbed areas), a proportion test based on $\aleph^2$ likelihood ratio statistics was applied (i.e., G-test with Yates' correction (Zar, 1999)).

Backpropagation algorithm

A multilayer perceptron (MLP) using backpropagation (BP) algorithm (Rumelhart et al., 1986) was used to predict the fish guild composition (output variables) depending on environmental data (12 input variables). The construction of the BP was based on Lek et al. (1996; 2000) method and made in a Matlab® platform. The BP structure was made up of a three-layered feed-forward network with information flowing from the input to the output layer. The input nodes comprised the environmental variables recorded per site and per campaign (64 samples) and the output node corresponded to the species richness of each fish guild. For the model evaluation, we determined the relative contribution (i.e. explanatory importance) of each predictive variable with partial derivatives (PaD) algorithm (Dimopoulos et al., 1995, Gevrey et al., 2003). For more details concerning the BP algorithm and its applications, see Rumelhart et al. (1986), Lek and Guégan (1999), Lek et al. (2000), Gevrey et

Table 1. Characteristics of the study area

Study area	Soumié Rivers		Eholié Rivers		Ehania Rivers		Noé Rivers	
Catchment area (km^2)	645		615		1050		400	
Length (km)	66		58		140		50	
Slope (m.km^{-1})	3.31		2.96		2.36		1.45	
Mean annual flow (m^3.s^{-1})	11.76		11.40		15.74		9.56	
Sampling sites	**S1**	**S2**	**E1**	**E2**	**Eh1**	**Eh2**	**N1**	**N2**
Localization	05° 29'N 03° 22'W	05° 24'N 03° 17'W	05° 28' N 03° 08' W	05° 23' N 03° 08' W	05° 24' N 02° 55' W	05° 17' N 02° 50' W	05° 28' N 02° 51' W	05° 18' N 02° 46' W
Mean width (m)	14.34	16.92	22.28	22.18	15.58	29.93	11.11	15.00
Mean depth (m)	0.84	1.41	1.27	1.88	1.44	2.29	0.69	2.38
Current velocity (m.s^{-1})	0.48	0.42	0.37	0.26	0.36	0.26	0.39	0.21
Canopy closure (%)	90	55	95	65	60	45	70	25

S = Soumié River, E = Eholié River, Eh = Ehania River, N = Noé River, 1 = upstream, 2 = downstream

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al. (2003), Park et al. (2003), Edia et al. (2010).
An environmental descriptor was regarded as significant to the model when its contribution was higher than 10% (Brosse and Lek, 2002).

RESULTS

Patterning sites using SOM

The samples were classified by the SOM according to the fish guild composition in the 20 output nodes so that each node included samples with similar guild composition (Fig. 2). The units of the SOM map were classified into four different groups (I, II, III and IV) based on the cluster analysis with Ward algorithm (Fig. 2). The bold contours display different clusters on the SOM map (Fig. 2).

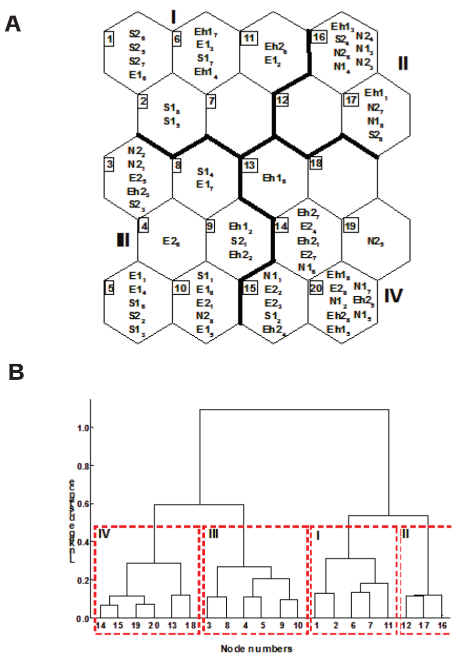

Fig 2. A) Sample classification according to fish guild species richness using the SOM. S: Soumié River, E: Eholié River, Eh: Ehania River; N: Noé River; 1: upstream, 2: downstream. The Latin numbers (I-IV) represent different clusters. The Arabic numbers (1-20) represent the SOM units. B) Hierarchical classification of SOM units using Ward's algorithm. The numbers correspond to the cell numbers of the map in Figure 2A.

Clusters II and IV were significantly (respectively, G = 4.61, df = 1, $p < 0.05$ and G = 19.30, df = 1, $p < 0.001$) associated with samples from the Ehania (Eh1, Eh2) and Noé (N1, N2) upstream and downstream sites, and the Eholié (E2) downstream site, which are most disturbed by anthropogenic activities such as agricultural and domestic activities as they are located close to populated areas. For the two clusters I and III, the proportion of samples of relatively undisturbed sites (Soumié River upstream and downstream (S1, S2) and Eholié downstream (E1)) is higher, however, this predominance is not significant (respectively, G = 3.01, df = 1, $p > 0.05$ and G = 0.42, df = 1, $p > 0.05$).
In general, bottom areas of the SOM map showed the highest richness, whereas top areas had low richness (Fig. 3). Cluster I was characterised by moderate benthivore richness with low richness for other groups. Then, cluster II was distinguished by moderate species richness of invertivores, detritivores, piscivores and omnivores, and low species richness of herbivores. Cluster III had high richness of benthivores, invertivores and herbivores with moderate richness for omnivores and low richness for detritivores and piscivores. Last, sites in cluster IV had high numbers of omnivores, detritivores and piscivores species, along with moderate richness for benthivores and invertivores and low richness for herbivores.

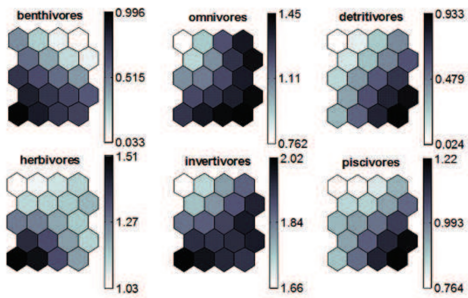

Fig 3. Visualization of each fish guild richness calculated in the trained SOM in grey scale. Dark represents high value richness, while light is low value richness.

Prediction of guild composition

After the learning process with 6 trophic guilds (invertivores, detritivores, piscivores, benthivores, herbivores and omnivores), the correlation coefficients obtained for the training set between estimated and observed values were greater than 0.63 for all trophic guilds (Fig. 4). On the basis of high correlation coefficient between observed and estimated values, the best performance among BP models was obtained for the benthivore (0.89), omnivore (0.85) and herbivore (0.84) guilds. There was also a high correlation between observed and estimated values (0.77 and 0.72), respectively, for piscivores and detritivores. The poorest fit was for invertivores (0.63). The frequency histogram of residuals showed that most residuals lie around zero for all guilds.
In terms of ecological information extracted from the BP model, the result of the PaD algorithm stresses the importance of environmental variables in the prediction of the six guilds. The results of the sensitivity analysis with PaD algorithm for the trophic guild models showed a relative importance of contribution of each environmental variable to each

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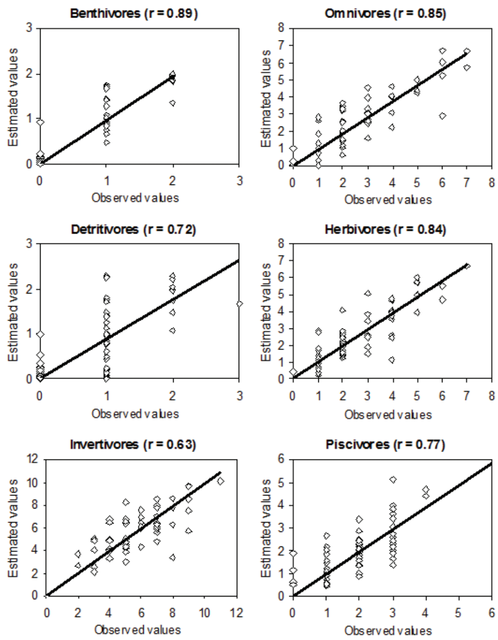

Fig 4. Training results of the model to predict trophic guilds richness with environmental variables: scatter plots of correlations between observed and estimated values by the trained BP

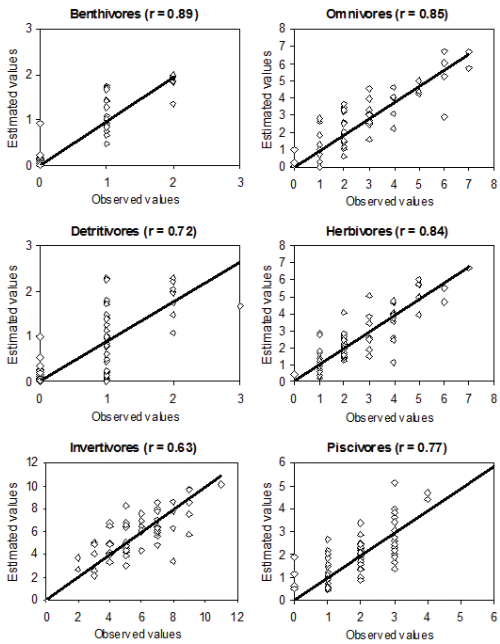

Fig 5. Contribution of explanatory variables (percentage) for each trophic guild. The dotted line represents the significance level (i.e. 10%). Tw = water temperature, cond = conductivity, tds = total dissolved solids, trans = transparency, NO3 = nitrate, do = dissolved oxygen, ds = distance to source

trophic guild. Different trophic guilds were differently influenced by diverse parameters. Figure 5 showed the importance of contribution in percentage for each descriptor after applying the method of partial derivatives.

Benthivores were most strongly influenced by the conductivity (cond), total dissolved solids (tds), dissolved oxygen (DO), depth and percentage of canopy. Water temperature (Tw), nitrates (NO_3^-), width and distance from source (ds) were meaningful in omnivore prediction. Only free descriptors were significant among herbivores (conductivity, distance from source and canopy) and detritivores (water temperature, nitrate and depth). The main variables which determine the piscivore guild were total dissolved solids (tds), width, distance from source (ds) and canopy. Concerning the invertivore guild, width, depth, distance to source (ds), canopy, flow and dissolved oxygen (do) were the most contributing variables. Transparency (trans) and pH were not meaningful in any BP model.

DISCUSSION

The significant human presence and the induced anthropogenic activities can largely explain the classification made by the SOM. Indeed, the samples gathered in clusters II and IV are mainly from the Ehania (Eh1, Eh2) and Noé (N1, N2) upstream and downstream sites and the Eholié (E2) downstream site, which are most disturbed by anthropogenic activities such as domestic and agricultural activities as they are located close to populated areas. For clusters I and III, the proportion of samples which are relatively exempt from disturbance (the Soumié River upstream and downstream (S1, S2) and the Eholié downstream (E1)) is higher, however, this predominance is not significant. According to Lévêque and Paugy (1999), the aquatic ecosystems are particularly affected by the anthropogenic activities as well as in the aquatic environment and in the catchment area. Indeed, human efforts to meet rapidly growing demands (for food, fresh water, timber, fibber and fuel) have resulted in an array of extensive changes to terrestrial and hydrosystems (Roux et al., 2008). The living conditions which result from these changes could be unfavourable according to Matthews & Styron (1981) and Wootton (1992) for fish species. For Karr et al. (1986), Lemoalle (1999) and Oberdorff et al. (2001b), the fish populations react quickly to the disturbances of their mediums which thus involve modifications of the specific composition, abundance and trophic structure.

The use of the supervised artificial neural network, a multilayer perceptron (MLP) models, on the basis of environmental variables for predicting fish species richness in groups of guilds, showed high accuracy. Overall, most error values lay around zero. This accuracy was probably due to ability of the MLP to deal with complex and non-linear data such as ecological data (Lek et al., 1996; Gevrey et al., 2005). Moreover, it is known that the community structure is changed by disturbances in the environment and the level of the structure

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change is used to assess the intensity of environmental stress (Hellawell, 1986).

Furthermore, with the help of sensitivity analysis, the MLP approach showed a relative importance of each environmental parameter in structuring fish assemblages. The mainly contributing parameters in predicting fish trophic guilds can be grouped into physical variables (water temperature, depth, width, flow, distance to source, canopy) and chemical parameters (conductivity, total dissolved solids, dissolved oxygen and nitrate). The pH, conductivity and the total of dissolved solids which express water mineralization level are linked to nutrient accumulation (Galdean and Staicu, 1997). Mainly related to the landscape disturbance according to Freeman et al. (2007), nutrient accumulation is known to regulate the dissolved oxygen ratio through the algal growth (Turner and Rabalais, 1994; Justic et al,. 1995). The high nutrient accumulation in hrydrosystems improves acidity, conductivity and total dissolved solids and reduces dissolved oxygen. According to Bayley (1995), dissolved oxygen is influenced by wind, water velocity, thermal effects and organic matter decomposition throughout the hydrological cycle. Moreover, according to Wiederholm (1984) and Schindler (1990), this accumulation affects the energy flow of aquatic systems and causes the decline of biodiversity.

The major parameters which determine the omnivore and detritivore guild were temperature, nitrate, width and distance to source. According to Cowx and Van Zyll De Jong (2004), the species composition of fish communities has been found to change when environments are modified by anthropogenic pressures. Thus, biodiversity decreases and the proportion of omnivorous and detritivorous fish increases in a river system (Karr, 1981; Roth et al., 1996; Xie and Chen, 1999; Schleiger, 2000; Fang et al., 2008). The Rivers Noé, Ehania, Eholié and Soumié cover a region where intensive agricultural activities are developed (palm oil, banana, pineapple, coffee, rubber and cocoa). Seasonal drainage inflows associated with these agricultural activities (fertilizer and phytosanitary products, industrial effluents) constitute sources of pollution to aquatic ecosystems. Some studies have established that when eutrophication condition increases, the species richness of piscivorous fish decreases (Persson et al., 1988; Jeppesen et al., 2000), while invertivorous, herbivorous (Yurk and Ney, 1989; Bachmann et al., 1996), benthivorous and detritivorous fish have been observed to increase (Persson et al., 1988; Jeppesen et al., 2000). Total dissolved solids (tds), width, distance from source (ds) and canopy were the most important variables which influenced the piscivores. Changes in the river channel morphology (depth and width) are related to oscillations of the hydrological cycle due to regional seasonality (Thomaz et al., 2007; de Melo et al., 2009). Piscivores inhabit the main river channel where they can prey on fish that enter or leave the flooded region (Petry et al., 2003; de Melo et al., 2009). In addition, water temperature appears as an important, indicator of watershed vitality because of its affecting metabolism, development, activity and assemblage composition of aquatic organisms (Naiman et al., 1992; Lasne et al., 2007). Moreover, it is recognized that the riparian plant occupies a major rule in food availability in tropical stream systems (Benstead et al., 2003). Riparian vegetation helps determine what, how much and when materials from upland areas enter the hydrosystem. These conditions could favor the presence of refuges (tree branch and trunk, and roots) in the flooded vegetation and food prey (invertebrates, algae fixed to the substrate, arthropods and fruits) falling from the flooded vegetation (Casatti et al., 2003; de Melo et al., 2009; Edia et al., 2010). Leaves incorporated into the channel substrate help the establishment of a varied fauna that can be used as food by fish (Uieda and Uieda, 2001). In addition, the presence of species guilds in a particular habitat has been widely discussed as a possible strategy for avoiding trophic competition or for optimizing available resources (Angel and Ojeda, 2001). These conditions seem to explain the association of the herbivores, invertivores, benthivores and piscivores with the riparian vegetation cover parameter in this study.

Thus, the conservation of aquatic communities in general, and particularly of fish diversity, may be preceded by the surrounding landscape preservation.

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Sažetak

PREDVIĐANJE ČIMBENIKA KOJI UTJEČU NA SASTAV STRUKTURA RIBA U ČETIRI OBALNE RIJEKE (JUGOISTOČNA OBALA BJELOKOSTI) POMOĆU UMJETNIH NEURONSKIH MREŽA

Ovo je istraživanje usmjereno prema malim obalnim rijekama na jugoistočnoj Obali Bjelokosti s ciljem predviđanja bogatstva vrsta riba i testiranjem doprinosa varijabli iz okolice kako bi se objasnila struktura populacija pomoću samoorganiziranih karata (SOM) i povratnih (BP) algoritama. Metoda je primijenjena na uzorku temeljenim na bogatstvu šest glavnih zabilježenih tipova ishrane (bentivori, invertivori, detrivori, piscivori, herbivori i omnivori). Identificirane su četiri skupine: klaster I je karakteriziran bentivorima, klaster II se odlikuje invertivorima, detrivorima, piscivorima i omnivorima, klaster III je bogat bentivorima, invertivorima i herbivorima, a klaster IV je imao visok broj omnivora, detrivora i piscivora. BP je pokazao visoku predvidljivost (0,89 za bentivore, 0,85 za omnivore i Odonata, 0,84 za herbivore). Visoka korelacija je zamijećena između promatranih i procijenjenih vrijednosti

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za piscivore (0,77) i detrivore (0,72), a najmanja za invertivore (0,63). Histogram pokazuje da se većina ostataka kreće oko nule za sve osobine. Varijable koje su najviše doprinijele predviđanju šest trofičkih ribljih struktura su temperatura vode, provodljivost, ukupno otopljene tvari, otopljeni kisik, dubina, širina, zasjenjenost i udaljenost od izvora. To naglašava presudan utjecaj karakteristika vodotoka i priobalnog okoliša.

Ključne riječi: sastav struktura riba, umjetne neuronske mreže, predviđanje, zapadna Afrika

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