

Influential environmental gradients and patterns of fish assemblages in a West African basin

Kouakou Augustin Kouamé · Stanislas Silvain Yao · Gouli Gooré Bi ·
Essetchi Paul Kouamélan · Valentin N'Douba · N'Guessan Joël Kouassi

Received: 4 September 2007 / Revised: 27 November 2007 / Accepted: 11 December 2007 / Published online: 29 December 2007
© Springer Science+Business Media B.V. 2007

Abstract Twenty-two sites were monitored in the Lower Sassandra River Basin (Côte d'Ivoire, West Africa) to examine patterns in fish species assemblage structure along environmental gradients. Hierarchical clustering of the species presence–absence data identified four types of assemblages corresponding to the man-made Lake Buyo, the main channel, and the two major tributaries. Canonical Correspondence Analysis (CCA) indicated that canopy closure, leaves-wood, aquatic plants, temperature, width, total dissolved solids and depth were the environmental factors most strongly correlated with variation in the fish assemblages. Five species: *Papyrocranus afer*, *Micralestes elongatus*, *Parailia pellucida*, *Tilapia busumana* and *T. mariae* were reported from the basin for the first time. The investigation of the variation in species richness led to the assessment of a major anthropogenic disturbance induced by a palm oil factory. In conjunction with the fact that the Sassandra River hosts an

endemic species, *Synodontis koensis*, it was concluded that this basin is of high conservation priority.

Keywords Côte d'Ivoire · Sassandra River basin · Freshwater species · Environmental variables · Human impact · Species distribution

Introduction

In many African countries, where the economy is strongly dependent upon biological resources, the exploitation of natural resources and their conservation are ambiguous (Kamdem Toham & Teugels, 1999; Economic Commission for Africa, 2001). In fact, conservation of resources and development of countries are mutually dependent. Indeed, unless living resources and in particular aquatic ones are used and managed rationally, natural production faces the risk of collapse (Yapi-Gnaoré et al., 2000). Despite their economic, social and ecological importance, Africa's freshwater systems are being degraded at an alarming rate (Thieme et al., 2005). The multitude of threats (overfishing, land and forest degradation, pollution from burgeoning populations and industries, introduction of exotic species, dams and water withdrawals) suggests that conservation measures are long overdue.

To ensure a sound management and sustainable exploitation of freshwater biodiversity, it is vital to develop a deeper understanding of the factors and processes that determine aquatic diversity at different

Handling editor: J. A. Cambray

K. A. Kouamé · S. S. Yao (✉) · G. Gooré Bi ·
E. P. Kouamélan · V. N'Douba · N. J. Kouassi
Laboratoire d'Hydrobiologie, UFR Biosciences,
Université de Cocody-Abidjan, 22 B.P. 582, Abidjan,
Côte d'Ivoire
e-mail: yao_stan@yahoo.fr

N. J. Kouassi
Centre de Recherches Océanologiques, BP V18, Abidjan,
Côte d'Ivoire

spatial scales (Ibanez et al., 2007). The examination of variation in fish assemblage composition according to environmental gradients may help to clarify the role of biotic and abiotic factors for community organization, a major issue in aquatic ecology. Thus, scientific interest is increasingly focusing on the assessment of the relationships between species and the environment (Angermeier & Davideanu, 2004; Tejerina-Garro et al., 2005), yet in this field of research, few studies have been conducted on the tropics' aquatic systems (Lévêque, 2006).

In Côte d'Ivoire (West Africa), recent years have seen an emphasis on research to identify correlations between structural changes in the fish assemblages and environmental variables (Da Costa et al., 2000; Koné et al., 2003; Kouamélan et al., 2003; Yao et al., 2005; Kouadio et al., 2006; Konan et al., 2006). However, no investigation has been undertaken in the Sassandra River basin to detect patterns in fish communities and their possible environmental basis. Previous surveys conducted on this basin dealt mainly with taxonomic and biological aspects (Teugels et al., 1988; Kouamé et al., 2006), and stock assessment and management (Traoré, 1996).

As part of a project entitled "Characterization, utilization and conservation of freshwater fish biodiversity in Côte d'Ivoire", the present article aims to describe distribution patterns in the Lower Sassandra ichthyofauna and to identify correlations between structural changes in the assemblages and environmental variables.

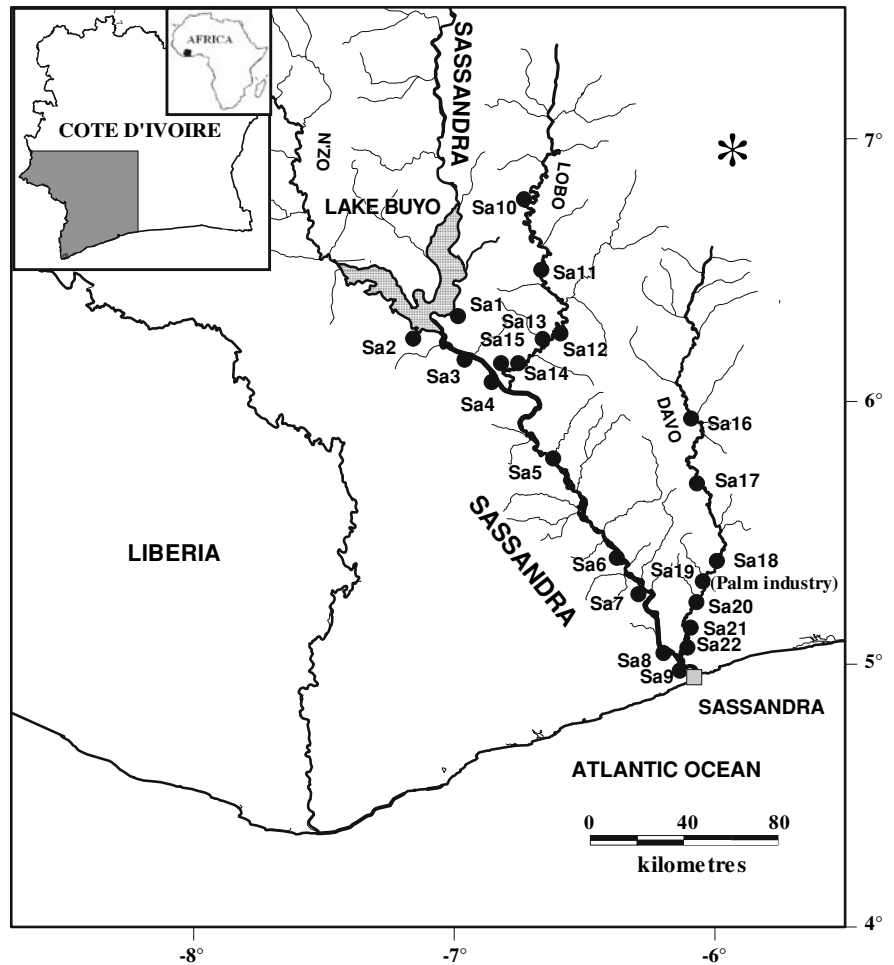
Material and methods

The Sassandra River basin rises in Bela region in Guinea and enters Atlantic Ocean in Côte d'Ivoire, close to the city of the same name (Fig. 1). It is 840 km long and encompasses an area catchment of 75,000 km², with a mean annual discharge estimated at 513 m³ s⁻¹ (Traoré, 1996; Lemoalle, 1999). The present study was restricted to the lower course of the basin because an ongoing armed conflict has prevented field work in northern Côte d'Ivoire since September 2002. The studied area includes four sectors: (1) the man-made Lake Buyo (drainage area: 920 km²) originated from the building of a hydroelectric dam on the main course of the Sassandra River in 1981 (Traoré, 1989). It is a deep and open

water. Aquatic vegetation is abundant and consists mostly of *Eichhornia crassipes* and *Echinochloa pyramidalis*; (2) the main channel with a mean slope estimated at 0.85 m km⁻¹, is bordered by gallery forests. The hydrological regime depends on both discharge from the dam and rainfall; (3) the Lobo tributary is shaded by overhanging canopy of riparian vegetation and (4) the Davo tributary receives a discharge of waste of palm oil from a factory. As a result, the water is characterized by high levels of organic pollution. The climate of the studied areas is typical of equatorial rainforest, comprising two dry (July–September and December–March) and two wet (September–November and April–July) seasons (Girard et al., 1971). Surveys occurred at 22 sampling sites of which 2 (Sa1 and Sa2) are located on the Lake Buyo, 7 (Sa3–Sa9) on the main channel, 6 (Sa10–Sa15) on the Lobo tributary and 7 (Sa16–Sa22) on the Davo tributary (Fig. 1). Each site was sampled at three-month intervals from October 2004 to September 2005. Fishes were collected with a fleet of 17 weighted monofilament gill nets (bar mesh sizes 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 80 and 90 mm), each measuring 30 m long by 2.5 m deep. Nets were set overnight (17–7 H) and during the following day (7–12 H). All fishes collected were identified following Paugy et al. (2003a, b). Each specimen was measured to the nearest mm and weighted to nearest 0.1 g.

A total of 19 variables were used to describe environmental conditions at each sampling site. Six physical and chemical features were considered: pH (measured with a pH-metre WTW-pH 330), temperature of water (measured in °C with a thermometer built into the pH-metre), dissolved oxygen (measured in mg l⁻¹ with an oxymeter WTW DIGI 330), water transparency (measured to the nearest cm with a Secchi disc), conductivity and total dissolved solids (measured in µS cm⁻¹ and mg l⁻¹, respectively, using a conductimeter WTW-LF 340). All these variables were measured at 7 H, 12 H and 17 H, and at 50 cm depth, except for water transparency. The habitat variables included are: current speed (measured in m s⁻¹ using a propeller-driven current metre Valeport BF 008), depth (m), width (m), mean canopy closure and height (visually estimated and expressed in % and to the nearest m), aquatic plants (measured as % of stream surface overlain by this shelter category) and substrate type (mud, sand, clay,

Fig. 1 Map of the Lower Sassandra River Basin with indication of the sampling sites (Sa1–Sa22)



gravel, rock, mixed clay-mud and leaves-wood, measured as % of stream bottom surface overlain by each substrate type). These 19 environmental variables were used to interpret the variation in species at each sampling site following Kamdem Toham & Teugels (1997, 1998).

Cluster analysis was applied to identify grouping of sampling sites with similar fish assemblages. This analysis is a multivariate technique that sorts objects (such as sampling units) into groups or clusters based upon their overall resemblance to one another (Ludwig & Reynolds, 1988). It was performed with the software Statistica version 6.0, using Euclidean distances and Ward's method (Pielou, 1984). Associations between fish assemblages and environmental variables were examined, using Canonical Correspondence Analysis (CCA), an ordination technique designed for direct analysis of the relationships between multivariate ecological data sets (Ter Braak & Smilauer, 2002).

Significance tests for the general model relating assemblage structure to environmental variables were based on Monte Carlo permutation tests (1000 permutations, $P < 0.05$). Environmental variables and fish data were $\log_{10}(x + 1)$ transformed prior analysis. Only species captured at least in five sampling sites were included in the analysis, because rare species have a minor influence on results of multivariate statistics (Gauch, 1982). The ordination was performed using the computer program Canoco version 4.5.

Results

Composition of the fish fauna

A total of 64 fish species, from 43 genera and 26 families, were collected in the sampling sites (Table 1). Eleven marine and/or brackish water

Table 1 Fish distribution in the Lower Sassandra River Basin

Family	Species	Codes	Lake Buyo	Main channel	Lobo tributary	Davo tributary
Polypteridae	<i>Polypterus endlicheri</i> Heckel, 1849				+	
Elopidae	<i>Elops lacerta</i> ^a Valenciennes, 1846			+		+
Clupeidae	<i>Pellonula leonensis</i> Boulenger, 1916	<i>Ple</i>	+	+	+	
Osteoglossidae	<i>Heterotis niloticus</i> ^b (Cuvier, 1829)		+	+	+	
Notopteridae	<i>Papyrocranus afer</i> (Günther, 1868)	<i>Paf</i>		+		+
Mormyridae	<i>Marcusenius furcidens</i> (Pellegrin, 1920)	<i>Mfu</i>		+	+	
	<i>Marcusenius senegalensis</i> (Steindachner, 1870)	<i>Mse</i>		+	+	+
	<i>Marcusenius ussheri</i> (Günther, 1867)	<i>Mus</i>		+	+	+
	<i>Mormyrops anguilloides</i> (Linnaeus, 1758)	<i>Man</i>		+	+	+
	<i>Mormyrus rume</i> (Valenciennes, 1846)	<i>Mru</i>	+	+	+	+
	<i>Petrocephalus bovei</i> (Valenciennes, 1846)	<i>Pbo</i>	+	+	+	+
	<i>Pollimyrus isidori</i> (Valenciennes, 1846)	<i>Pisi</i>		+	+	+
Hepsetidae	<i>Hepsetus odoe</i> (Bloch, 1794)	<i>Hod</i>	+	+	+	+
Alestidae	<i>Alestes baremoze</i> (Joannis, 1835)	<i>Aba</i>	+	+	+	+
	<i>Brycinus imberi</i> (Peters, 1852)	<i>Bim</i>	+	+	+	+
	<i>Brycinus longipinnis</i> (Günther, 1864)	<i>Blon</i>	+	+	+	+
	<i>Brycinus macrolepidotus</i> Valenciennes, 1849	<i>Bma</i>	+	+	+	+
	<i>Brycinus nurse</i> (Rüppel, 1832)	<i>Bnu</i>		+	+	+
	<i>Micralestes elongatus</i> Daget, 1957			+		
	<i>Hydrocynus forskalii</i> (Cuvier, 1819)	<i>Hfor</i>		+	+	+
Distichodontidae	<i>Distichodus rostratus</i> Günther, 1864	<i>Dro</i>	+	+	+	
Cyprinidae	<i>Barbus ablabe</i> (Bleeker, 1863)	<i>Bab</i>	+	+	+	
	<i>Barbus macrops</i> Boulenger, 1911	<i>Bmap</i>	+	+	+	
	<i>Barbus sublineatus</i> Daget, 1954				+	
	<i>Barbus trispilos</i> (Bleeker, 1863)				+	
	<i>Barbus wurtzi</i> Pellegrin, 1908				+	+
	<i>Labeo coubie</i> Rüppel, 1832	<i>Lcou</i>	+	+	+	+
	<i>Labeo parvus</i> Boulenger, 1902	<i>Lpar</i>	+	+	+	+
	<i>Raiamas senegalensis</i> (Steindachner, 1870)	<i>Rsen</i>		+	+	+
Claroteidae	<i>Chrysichthys maurus</i> (Valenciennes, 1839)	<i>Cma</i>	+	+	+	+
	<i>Chrysichthys nigrodigitatus</i> (Lacépède, 1803)	<i>Cnig</i>	+	+	+	+
Schilbeidae	<i>Parailia pellucida</i> (Boulenger, 1901)					+
	<i>Schilbe intermedius</i> (Rüppel, 1832)	<i>Sin</i>		+	+	
	<i>Schilbe mandibularis</i> (Günther, 1867)	<i>Sma</i>	+	+	+	+
Clariidae	<i>Clarias anguillaris</i> (Linnaeus, 1822)	<i>Can</i>	+	+	+	+
	<i>Heterobranchus isopterus</i> Bleeker, 1863	<i>His</i>	+	+	+	+
	<i>Heterobranchus longifilis</i> (Valenciennes, 1840)	<i>Hlo</i>	+	+	+	+
Malapteruridae	<i>Malapterurus electricus</i> (Gmelin, 1789)		+	+	+	
Mochokidae	<i>Synodontis bastiani</i> Daget, 1948	<i>Sba</i>	+	+	+	
	<i>Synodontis koensis</i> Pellegrin, 1933	<i>Sko</i>	+	+	+	+
	<i>Synodontis punctifer</i> Daget, 1964	<i>Spu</i>	+	+	+	+

Table 1 continued

Family	Species	Codes	Lake Buyo	Main channel	Lobo tributary	Davo tributary
Channidae	<i>Parachanna obscura</i> (Günther, 1861)	<i>Pob</i>	+	+	+	+
Centropomidae	<i>Lates niloticus</i> (Linnaeus, 1762)	<i>Lnil</i>	+	+	+	
Carangidae	<i>Caranx hyppos</i> ^a (Linnaeus, 1766)			+		
Lutjanidae	<i>Lutjanus goreensis</i> ^a (Valenciennes, 1830)			+		
Haemulidae	<i>Pomadasys jubelini</i> ^a (Cuvier, 1830)			+		
Cichlidae	<i>Chromidotilapia guntheri</i> (Sauvage, 1882)	<i>Cgu</i>		+	+	+
	<i>Hemichromis bimaculatus</i> Gill, 1862	<i>Hbi</i>	+	+	+	+
	<i>Hemichromis fasciatus</i> Peters, 1852	<i>Hfa</i>	+	+	+	+
	<i>Oreochromis niloticus</i> ^b (Lineaus, 1758)	<i>Onil</i>	+	+	+	+
	<i>Sarotherodon galilaeus</i> ^a (Linnaeus, 1758)	<i>Sga</i>		+	+	
	<i>Sarotherodon melanotheron</i> ^a Rüppel, 1852	<i>Sme</i>	+	+		
	<i>Tilapia busumana</i> (Günther, 1903)			+	+	
	<i>Tilapia guineensis</i> ^a (Bleeker in Günther, 1862)	<i>Tgu</i>	+	+	+	
	<i>Tilapia guineensis</i> × <i>Tilapia zillii</i> ^c		+	+	+	
	<i>Tilapia mariae</i> (Boulenger, 1899)			+		
	<i>Tilapia zillii</i> (Gervais, 1848)	<i>Tzi</i>	+	+	+	+
	<i>Tylochromis jentinki</i> ^a (Steindachner, 1895)			+		
Mugilidae	<i>Liza falcipinnis</i> ^a (Valenciennes, 1836)			+		
Gobiidae	<i>Awaous lateristriga</i> ^a (Duméril, 1861)			+		
Eleotridae	<i>Eleotris vittata</i> ^a (Duméril, 1858)			+		
	<i>Kribia nana</i> (Boulenger, 1901)			+		
Anabantidae	<i>Ctenopoma petherici</i> Günther, 1864					+
Mastacembelidae	<i>Mastacembelus nigromarginatus</i> Boulenger, 1898				+	
26	64		33	57	49	35

+ = Presence

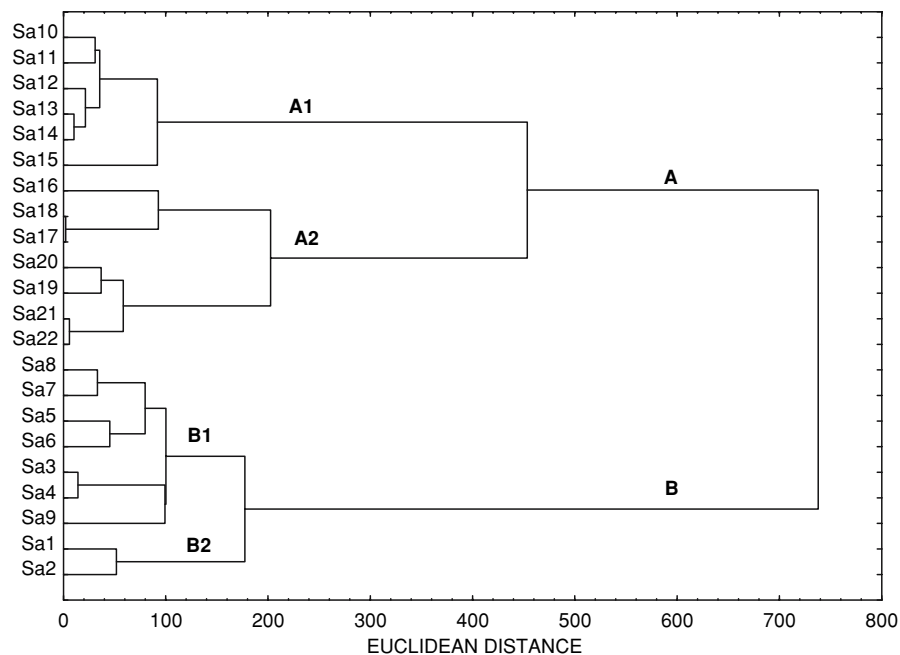
^a Fishes with marine and/or brackish water affinities^b Introduced species^c Hybrid species

species (*Elops lacerta*, *Caranx hyppos*, *Lutjanus goreensis*, *Pomadasys jubelini*, *Sarotherodon galilaeus*, *S. melanotheron*, *T. guineensis*, *Tylochromis jentinki*, *Liza falcipinnis*, *Awaous lateristriga* and *Eleotris vittata*), two introduced species (*Heterotis niloticus* and *Oreochromis niloticus*), one hybrid (*T. guineensis* × *T. zillii*) and one endemic species (*Synodontis koensis*) were reported. Cichlids was the most diverse group, represented by 12 species and amounting to 19% of the total number of fish species, followed by Cyprinids (13%), Mormyrids and Alestiids (11% each). The other families were poorly represented with less than four species.

Patterns of fish species assemblages

Hierarchical cluster analysis (Fig. 2) allowed to discriminate the sampling sites located on the tributaries (sites Sa10–Sa22: cluster A) from the others (sites Sa1–Sa9: cluster B). Within the cluster A, the subgroup A1 gathered the sites of the Lobo tributary (sites Sa10–Sa15) and the subgroup A2 consisted of those prospected on the Davo tributary (sites Sa16–Sa22). The cluster B included the sampling sites of the Lake Buyo (sites Sa1 and Sa2: subgroup B2) and those located on the main channel (sites Sa3–Sa9: subgroup B1).

Fig. 2 Cluster dendrogram summarizing similarity among sampling sites based on their fish assemblages. A1 (Sa10–Sa15) = Lobo tributary sites, A2 (Sa16–Sa22) = Davo tributary sites, B1 (Sa3–Sa9) = main channel sites and B2 (Sa1–Sa2) = Lake Buyo sites



The Lake Buyo ichthyofauna ($n = 33$) was distinguishable from those of other catchment areas by a lower proportion of Mormyrid species and the absence of most of marine and/or brackish water species (Table 1). The main channel exhibited the greater species richness ($n = 57$) and the higher number of marine and/or brackish water species ($n = 11$). Within the Lobo tributary ($n = 49$), fish assemblages were mostly characterized by the presence of more *Barbus* species than found in the other parts of the basin. On the other hand, the sampling sites of the Davo tributary ($n = 35$) were distinguished by a low proportion of both *Barbus* and cichlid species.

Quantitative aspects of fish distribution

Fish community comparisons based on the relative abundance of fish families showed that in the Lake Buyo, the dominant family was Cichlidae (40% of the total number of fishes sampled in this catchment area), followed by Claroteidae (15%), Alestidae (12%) and Cyprinidae (11%). In the main channel, Alestiids were the most abundant (34%), followed by Mormyrids (18%) and Clupeids (12%). In the Lobo tributary, the dominant families were Mormyridae (30%), Schilbeidae (22%) and Alestidae (21%). In

the Davo tributary, Alestidae were the most abundant (28%), followed by Claroteidae (17%), Schilbeidae (15%) and Mormyridae (8%).

Patterns of species richness

The fluctuations in the species richness within each catchment area were summarized in Fig. 3. In the main channel (Fig. 3a) and the Lobo tributary (Fig. 3b), the number of species increased progressively from upstream to downstream sampling sites. In contrast, an irregular distribution of fishes was observed in the Davo tributary (Fig. 3c), where the species richness varied from 16 species (Sa16) to 22 species (Sa17), before it decreased greatly, reaching the minimum value ($n = 7$ species) at the sampling site Sa19. Then, the number of species increased up to 19 at the sampling site Sa22.

Patterns of species composition in relation to environmental variables

The CCA showed the overall relationships between species distribution and environmental variables (Fig. 4). Among the 19 environmental variables initially included in the analysis, only seven were

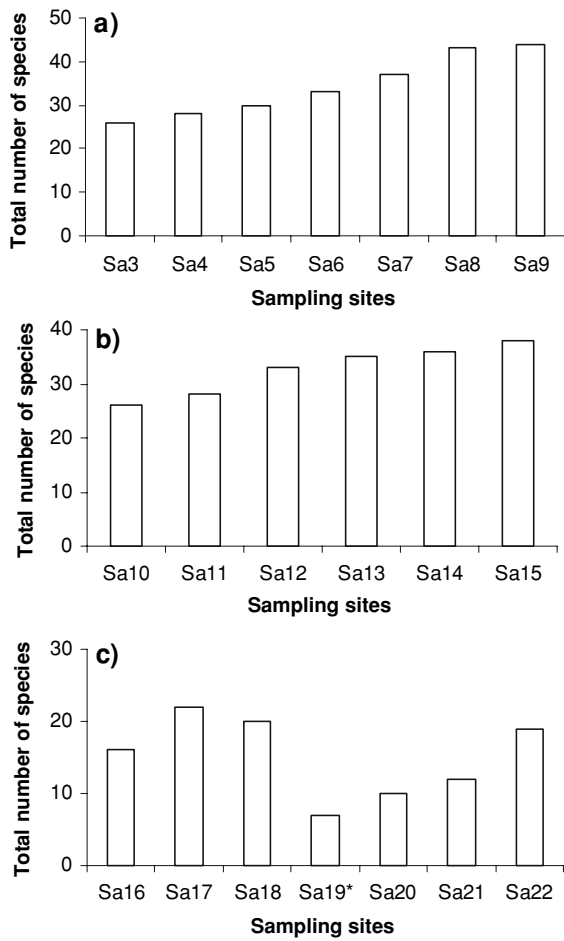


Fig. 3 Spatial evolution of the species richness within the Lower Sassandra River Basin. (a) main channel, (b) Lobo tributary, (c) Davo tributary, and * = Palm industry

significantly ($P < 0.05$) related to assemblage structure and accounted for 56.78% of the variance explained by all the original variables: canopy closure (9.74%), leaves-wood (9.63%), aquatic plants (8.75%), temperature (8.98%), width (7.05%), total dissolved solids (6.61%) and depth (6.02%). Among the ordination axes extracted from the analysis, the first two axes (with, respectively, eigenvalue $\lambda_1 = 0.57$ and eigenvalue $\lambda_2 = 0.32$), explained 54.4% of the cumulative variance in the species data. Monte Carlo permutation attested that both axes were significant ($P < 0.05$). Therefore our interpretation will be limited to these two axes which displayed four groups of sampling sites:

Group A1 was representative of the Lobo tributary sampling sites (Sa10–Sa15) having a maximal canopy

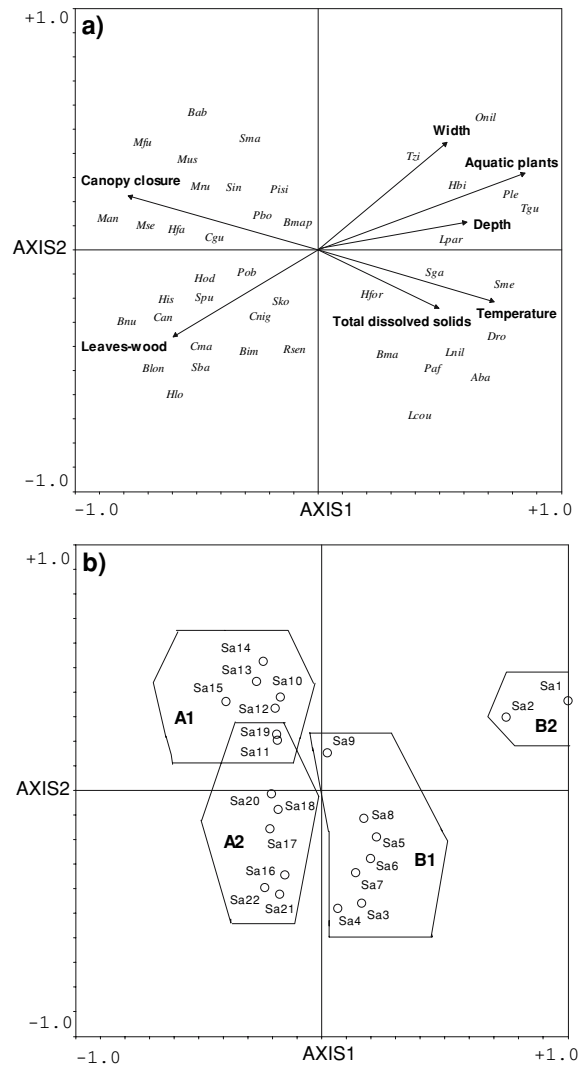


Fig. 4 Canonical correspondence analysis (CCA) plots showing species (a) and sites (b) distribution in relation to significant environmental variables. See Table 1 for species codes. A1 (Sa10–Sa15) = Lobo tributary sites, A2 (Sa16–Sa22) = Davo tributary sites, B1 (Sa3–Sa9) = main channel sites and B2 (Sa1–Sa2) = Lake Buyo sites

closure. The fish species correlated to this variable were *Barbus ablabes*, *B. macrops*, *Chromidotilapia guntheri*, *Hemichromis fasciatus*, *Marcusenius furcoidens*, *M. senegalensis*, *M. ussheri*, *Mormyrops anguilloides*, *Mormyrus rume*, *Petrocephalus bovei*, *Pollimyrus isidori*, *Schilbe intermedius* and *S. mandibularis*, which were negatively correlated with axis 1 and positively correlated with axis 2.

Group A2 comprised the sampling sites of the Davo tributary (Sa16–Sa22). This area was

distinguished by fish assemblage including *Brycinus imberi*, *B. longipinnis*, *B. nurse*, *Chrysichthys maurus*, *C. nigrodigitatus*, *Clarias anguillaris*, *Hepsetus odoe*, *Heterobranchus isopterus*, *H. longifilis*, *Parachanna obscura*, *S. bastiani*, *S. koensis*, *S. punctifer* and *Raiamas senegalensis* with negative scores and associated to a high mean % of leaves-wood in the substrate.

Group B1 represented the sampling sites of the main channel (Sa3–Sa9). This area was distinguished by fish assemblage including *Alestes baremoze*, *B. macrolepidotus*, *Distichodus rostratus*, *Hydrocynus forskalii*, *Labeo coubie*, *Lates niloticus*, *Papyrocranus afer*, *S. galilaeus* and *S. melanotheron* which were positively correlated with axis 1 and negatively correlated with axis 2. The main channel was characterized by low canopy closure and high temperature and total dissolved solids.

Group B2 included the sampling sites of the Lake Buyo (Sa1 and Sa2). The main fish species found in this area were *H. bimaculatus*, *L. parvus*, *O. niloticus*, *Pellonula leonensis*, *T. guineensis* and *T. zillii* with positive scores. Sites in the Lake were characterized by aquatic plants, and wider and deeper habitats.

Discussion

During the present survey, a total of 53 freshwater fish species were identified in the Sassandra River Basin, versus 72 species previously recorded by Teugels et al. (1988). The differences between these data were mainly related to the lack of monitoring both upstream and in the small tributaries. Nevertheless, five species were reported from the Sassandra River for the first time: *P. afer* (Notopteridae), *Micralestes elongatus* (Alestidae), *Parailia pellucida* (Schilbeidae), *Tilapia busumana* and *T. mariae* (Cichlidae), suggesting that the number of species known from this basin may be far from complete.

In general, the damming of a river generates numerous changes in aquatic habitats through the transformation of the ecosystem from the fluvial (lotic environment) to the lacustrine (lentic environment), the modifications in physical and chemical features of water, the habitat fragmentation and the alteration of both the natural hydrology and the hydrographic integrity (Jackson et al., 1988; World Commission on Dams, 2000). Additionally, dams may disrupt fish migrations, affecting the ability of

fish to move upstream and onto the floodplains to spawn. It is thus to be expected that an impoundment would have a profound effect upon the composition of the original fish fauna of the basin. In the present study, it appeared that within the Lake Buyo, the Cichlidae made up the greatest part of the catches. The predominance of the Cichlids in lacustrine fish faunas has been observed in several other man-made lakes, including Faé (Koné et al., 2003) in Côte d'Ivoire, and Kainji (Ita, 1984) in Nigeria. These findings underlined the adaptability of this fish family to lacustrine systems. One of the factors favourable to the expansion of the Cichlids in these lentic biotopes is the high production of plankton (Laë & Lévêque, 1999; Ouattara et al., 2001) on which they feed. Another point of similarity in the reservoirs ichthyofauna is the low proportion of Mormyrids, probably due to the inundating of the riverine habitat of these benthic-feeding fishes to anoxic depths. It is a pity that the scarcity of data on the fish distribution before the closure of the dam precludes accurate analysis of the evolution of fish fauna diversity in the Lake Buyo.

Our results revealed a general increase in species richness from upstream to downstream areas in the main channel and the Lobo tributary. This increase is generally attributed to a downstream increase in available habitat, habitat size, habitat heterogeneity and a decrease in environmental fluctuations (Grenouillet et al., 2004; Tejerina-Garro et al., 2005). The irregular fish distribution observed within the Davo tributary is mostly due to the activities of the palm oils industry located at the sampling site 19. The major concern is the discharge of the waste water and waste of palm oils into the stream. In addition, the water is extracted for cooling, washing or as a solvent as part of the production process. The degradation of the forest along the river for creating palm tree farms and pest control in these exploitations also constitute a threat for the aquatic biodiversity. As a result, the fish assemblage within the Davo tributary exhibited a low proportion of Mormyrids (8%) while the Siluriformes (Claroteidae, Schilbeidae and Mochokidae) are relatively abundant (41%). Indeed, Mormyrids are known to be very sensitive to water quality or habitat degradation (Kouamélan et al., 2005). Conversely, the Siluriformes are more tolerant to poor environmental conditions. Furthermore, during the fieldwork, local fishermen reported that they have suspended their activities at and around the sampling sites Sa19 and Sa20 because of the catches decline.

According to the CCA, the main environmental factors that determined the patterns of fish distribution and assemblage structure were width, aquatic plants, depth, temperature, total dissolved solids, leaves-wood and canopy closure. Surveys undertaken in other basins of Côte d'Ivoire such as the Boubo (Kouamélan et al., 2003), Comoé (Yao et al., 2005) and Mé (Kouadio et al., 2006) have also pointed to leaves-wood, canopy closure, width and temperature as major determinants of fish structure.

The importance of watershed size as a determinant of species diversity and distribution is largely documented for tropical rivers (Hugueny, 1990; Edds, 1993) as well as for temperate ones (Maret, 1997; Taylor et al., 2004). According to Angermeier & Schlosser (1989), three factors can explain the relation between numbers of fish species and stream size. An increase in stream size (1) results in an increase in diversity of habitat types, (2) provides a larger area that can support more individuals and that enables the pool of available species to be sampled more completely and (3) results in different rates of immigration and extinction.

In the Sassandra River, the watershed covered by the invasive plants is equivalent to more than 40% of the whole of the water. The impact of weed infestation should be discussed from two angles. From the point of view of the fish community, we hypothesize with Jackson et al. (1988) that the advent of macrophytes in a man-made lake is beneficial, as the vegetation improved the habitat by increasing food availability, spawning facilities and shelter from predators. Furthermore, the plants take up a large quantity of nutrients from the water, so that these are locked up within the dam basin rather than being lost by downstream discharge. Later, these nutrients are released to the food cycle when the plants themselves die and decay. From the point of view of riparian human populations, weed infestation is a problem, resulting in mounting economic, social and ecological costs. It disrupts navigation and fishing activities and is a health hazard as it offers a suitable habitat for the snail vectors of Schistosomiasis (N'Goran et al., 1997). For example, in the Sassandra River Basin, following the invasion of the macrophytes, the fish capture decreased from 142 tons in 1990 to 32 tons in 1994 (Etien & Arfi, 1996).

Several surveys have highlighted the contribution of depth in shaping of fish communities (Tunési et al., 2006; Chandra & Terry, 2007). The effect of

depth on assemblage structure is probably mediated by fish feeding habits, size and tolerance levels to anoxic conditions.

The role of both instream and outstream covers in the physical, chemical and biological processes in rivers has been stressed by several studies. Dead leaves and woody debris influence habitat characteristics such as depth and current (Angermeier & Karr, 1984). They also ensure food availability for fishes and protection from current and predators. The overhanging vegetation plays a key role in the determination of temperature, the primary production, the physico-chemistry, the hydrological regime and the trophic guild distribution within watershed (Welcomme & Mérona, 1988).

Conclusion

From a conservation standpoint, these results highlighted the need to prioritize conservation actions for the Sassandra basin. This conservation goal is all the more crucial since this basin shelters an endemic species, *S. koensis*. Specially, the minimization of the impacts of forestry operation, agricultural practices, industrial activities and damming are required. Stream width, stream depth, temperature, total dissolved solids and both instream (presence of wood and leaves, and aquatic plants) and bankside (canopy closure) cover appear to be the most influential factors in shaping species assemblages, and should be taken into consideration when defining aquatic habitat types for conservation planning and integrated river basin management. Furthermore, the report of several species for the first time in the basin, added to the current lack of adequate policing of the ecosystems in the north of Côte d'Ivoire because of civil war, requires us to update the ichthyofauna biodiversity as soon as possible.

Acknowledgements Authors wish to express their sincere thanks to the staff of Hydrobiology Laboratory of the Cocody-Abidjan University (Côte d'Ivoire) for fieldwork assistance, and to the Belgian Technical Cooperation for providing financial support.

References

- Angermeier, P. L. & G. Davideanu, 2004. Using fish community to assess streams in Romania: initial development of an index of biotic integrity. *Hydrobiologia* 511: 65–78.

- Angermeier, P. L. & J. R. Karr, 1984. Relationships between woody debris and fish habitat in a small warmwater stream. *Transactions of the American Fisheries Society* 113: 716–726.
- Angermeier, P. L. & I. J. Schlosser, 1989. Species-area relationships for stream fishes. *Ecology* 70: 1450–1462.
- Chandra, A. C. & A. D. Terry, 2007. Using environmental variables to predict the structure of deep-sea arctic fish communities: implications for food web construction. *Arctic Antarctic Alpine Research* 39: 2–8.
- Da Costa, K. S., G. Gourène, L. Tito De Morais & D. F. E. Thys Van Den Audenarde, 2000. Caractérisation des peuplements ichtologiques de deux fleuves côtiers Ouest-Africains soumis à des aménagements hydroagricoles et hydroélectriques. *Vie et milieu* 50: 65–77.
- Economic Commission for Africa, 2001. The state of demographic transition in Africa. ECA, Addis Ababa, Ethiopia.
- Edds, D. R., 1993. Fish assemblage structure and environmental correlates in Nepal's Gandaki River. *Copeia* 1: 48–60.
- Etien, N. & R. Arfi, 1996. Macrophytes aquatiques dans les eaux «continentales» ivoiriennes. *Archives Scientifiques Centre Recherche Océanologiques*, Abidjan 15:1–14.
- Gauch H. G. Jr., 1982. *Multivariate Analysis in Assemblage Ecology*. Cambridge University Press, New York.
- Girard, G., J. Sircoulon & P. Touchebeuf, 1971. Aperçu sur les régimes hydrologiques. In Avenard, J. M., M. Eldin, J. L. Guillaumet, E. Adjahoun & A. Perraud (eds), *Milieu naturel de la Côte d'Ivoire*. Mémoire ORSTOM 50: 109–155.
- Grenouillet G., D. Pont & C. Hérisse, 2004. Within-basin fish assemblage structure: the relative influence of habitat versus stream spatial position on local species richness. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 93–102.
- 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.
- Ibanez, C., T. Oberdorff, G. Teugels, V. Mamononekene, S. Lavoué, Y. Fermon, D. Paugy & A. K. Toham, 2007. Fish assemblages structure and function along environmental gradients in rivers of Gabon (Africa). *Ecology of Freshwater Fish* 16: 315–334.
- Ita, E. O., 1984. Kainji (Nigeria). In Kapetsky, J. M. & T. Petr (eds), *Status of African reservoirs fisheries*. FAO, Rome. CIFA Technical Paper 10: 43–103.
- Jackson, P. B. N., B. E. Marshall & D. Paugy, 1988. Fish communities in made-lakes. In: Lévêque C., M. N. Bruton & G. W. Ssentongo (eds), *Biology and Ecology of African Freshwater Fishes*. Editions de l'ORSTOM, Paris: 325–350.
- Kamdem Toham, A. & G. G. Teugels, 1997. Patterns of micro-climat use among fourteen fishes of the Lower Ntem River Basin (Cameroon). *Aquatic Living Resources* 10: 289–298.
- Kamdem Toham, A. & G. G. Teugels, 1998. Diversity patterns of fish assemblages in the Lower Ntem River Basin (Cameroon), with notes on potential effect of deforestation. *Archiv für Hydrobiologie* 141: 421–446.
- Kamdem Toham, A. & G. G. Teugels, 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.
- Konan F. K., F. Leprieur, A. Ouattara, S. Brosse, G. Grenouillet, G. Gourène, P. Winterton & S. Lek, 2006. Spatio-temporal patterns of fish assemblages in coastal West African rivers: a self-organizing map approach. *Aquatic Living Resources* 19: 361–370.
- Koné T., G. G. Teugels, V. N'Douba, G. Gooché Bi & E. P. Kouamélan, 2003. Fish assemblages in relation to environmental gradients along a small West African coastal basin, the San Pedro River, Ivory Coast. *African Journal of Aquatic Science* 28: 163–168.
- Kouadio N. F., E. P. Kouamélan, V. N'Douba, T. Koné, J. Snoeks & F. Ollevier, 2006. Update of fish biodiversity and impact of human activities on the community structure, Mé River (Ivory Coast). *Journal of Biological Sciences* 6: 805–814.
- Kouamé M. K., A. Ouattara, M. Y. Dieto & G. Gourène, 2006. Alimentation du Clupeidae *Pellonula leonensis* dans le lac de barrage de Buyo (Côte d'Ivoire). *Cybiurn* 30: 145–150.
- Kouamélan E. P., V. N'Douba & F. Ollevier, 2005. L'effet d'un lac de barrage hydroélectrique sur la distribution des poissons Mormyridae dans le bassin de la Bia en Côte d'Ivoire. *Annales de l'Université Marien N'GOUABI* 6: 120–128.
- Kouamélan E. P., G. G. Teugels, V. N'Douba, G. Gooché Bi & T. Koné, 2003. Fish diversity and its relationship with environment variables in West African basin. *Hydrobiologia* 505: 139–146.
- Laë R. & C. Lévêque, 1999. La pêche. In Lévêque C., D. Paugy (eds), *Les poissons des eaux continentales africaines: diversité, écologie, utilisation par l'homme*. Editions de l'IRD, Paris: 385–423.
- Lemoalle J., 1999. La diversité des milieux aquatiques. In Lévêque C. & D. Paugy (eds), *Les poissons des eaux continentales africaines: diversité, écologie, utilisation par l'homme*. Editions de l'IRD, Paris: 11–30.
- Lévêque, C., 2006. River and stream ecosystems of the north western Africa. In Cushing, C. E., K. W. Cummins & G. W. Minshall (eds), *River and stream ecosystems of the world*. CA, USA: University of California Press: 519–536.
- Ludwig J. A. & J. F. Reynolds, 1988. *Statistical ecology*. John Wiley & Sons, New York.
- Maret, T. R., 1997. Characteristics of fish assemblages and related environmental variables for streams of the Upper Snake River Basin, Idaho and western Wyoming, 1993–1995: U.S. Geological Survey Water Resources Investigation Report 97-4087: 1–46.
- N'Goran, E.K., S. Diabate, J. Utzinger & B. Sellin, 1997. Changes in human Schistosomiasis levels after the construction of two large hydroelectric dams in central Côte d'Ivoire. *Bull World Health Organ* 75: 541–545.
- Ouattara, A., N. Podoor & G. Gourène, 2001. Etudes préliminaires de la distribution spatio-temporelle du phytoplancton dans un système fluvio-lacustre africain (bassin Bia, Côte d'Ivoire). *Hydroécologie Appliquée* 13: 113–132.

- Paugy D., C. Lévêque & G. G. Teugels (eds), 2003a. Faune des Poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Editions IRD, Paris.
- Paugy D., Lévêque C. & G. G. Teugels (eds), 2003b. Faune des Poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Editions IRD, Paris.
- Pielou, E. C., 1984. The Interpretation of Ecological Data. John Wiley & Sons, New York.
- Taylor, C. M., L. R. Williams, R. A. Fiorillo, R. B. Thomas & M. L. Warren Jr., 2004. Fish assemblage structure under variable environmental conditions in the Ouachita Mountains. In J. M. Guldin (ed), Ouachita and Ozark Mountains Symposium: Ecosystem Management Research. General Technical Report SRS-74: U.S. Department of Agriculture, Forest Service, Southern Research Station, NC Asheville: 239–245.
- Tejerina-Garro F. L., M. Maldonado, C. Ibanez, D. Pont, N. Roset & T. Oberdroff, 2005. Effects of natural and anthropogenic environmental changes on riverine fish assemblages: a framework for ecological assessment of rivers. *Brazilian Archives of Biology and Technology* 48: 91–108.
- Ter Braak, C. J. F. & P. Smilauer, 2002. CANOCO reference manual and Canodraw for Windows user's guide: software for canonical community ordination (version 4.5). Microcomputer Power, New York.
- Teugels G. G., C. Lévêque, D. Paugy & K. Traoré, 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.
- Thieme M. L., R. Abell, M. L. J. Stiassny, P. Skelton, B. Lehner, G. G. Teugels, E. Dinerstein, A. Kamdem Toham, N. Burgess & D. Olson (eds), 2005. Freshwater Ecoregions of Africa and Madagascar: A Conservation Assessment. Island Press, Washington, DC, USA.
- Traoré, K., 1996. Etat des connaissances sur les pêcheries continentales ivoiriennes. Rapport de consultation. PROJET FAO TCP/IVC/4553, IDESSA, Bouaké, Côte d'Ivoire.
- Traoré, K. L., 1989. Caractéristiques physico-chimiques du Lac de Buyo. Rapport de Recherche, Institut d'Ecologie Tropicale (IET), Côte d'Ivoire.
- Tunesi, L., A. Molinari, E. Salvati & M. Mori, 2006. Depth and substrate type driven patterns in the infralittoral fish assemblage of the NW Mediterranean Sea. *Cybium* 30: 151–159.
- Welcomme, R. L. & B. de Mérona, 1988. Fish communities of rivers. In Lévêque C., M. N. Bruton & G. W. Ssentongo (eds), *Biology and Ecology of African Freshwater Fishes*. Editions de l'ORSTOM, Paris: 251–276.
- World Commission on Dams, 2000. Dams and development. Earthscan Publications, London, UK.
- Yao, S. S., E. P. Kouamélan, T. Koné, V. N'Douba, G. Gooré Bi, F. Ollevier & D. F. E. Thys Van Den Audenaerde, 2005. Fish communities along environment gradients within the Comoé River basin, Côte d'Ivoire. *African journal of Aquatic Science* 30: 195–204.
- Yapi-Gnaoré, C. V., K. S. Da Costa, N. C. Kouassi & I. Dembelé, 2000. Opportunities and strategies for conservation of fish genetic resources in Côte d'Ivoire. In Abban, E. K., C. M. V. Casal, T. M. Falk & R. S. V Pullin (eds), *Biodiversity and Sustainable Use of Fish in the Coastal Zone*. ICLARM Conference Proceedings 63: 28–31.