FISH DIVERSITY ALONG THE LONGITUDINAL GRADIENT IN A MAN–MADE LAKE OF WEST AFRICA, TAABO HYDROELECTRIC RESERVOIR, IVORY COAST

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Summary

Fish assemblage patterns in Taabo Reservoir, a hydroelectric lake of Ivory Coast, were studied and related to the longitudinal gradient (river–dam gradient) composed of riverine, transitional, and lacustrine zones. Data were collected at 5 stations and each one was sampled during 5 surveys. Fish community structure was analysed using alpha and beta diversity indices. In total, 53 fish species were obtained in the whole ecosystem. Total species richness recorded at each ecological zone was 42, 43 and 45 species respectively in the riverine, transitional and lacustrine zones. Alpha diversity did not differed significantly along the longitudinal gradient but reached the highest value (33 species) in the transitional zone and the lowest (18 species) occurred in both the riverine and lacustrine zones. Temporal variability of Alpha diversity according to the hydrological regime of the lake differed with the zone. Beta diversity showed that fish assemblages similarity was higher between the transitional and the riverine zones ($\beta_w = 0.43$) and lower between the riverine and the lacustrine zones ($\beta_w = 0.79$).

Key words: Fish diversity, longitudinal gradient, man–made lake, Taabo Reservoir, West Africa

INTRODUCTION

Species are the fundamental particles of biodiversity. Therefore, species number in local communities present an abiding interest (Bisby, 1995). In reser-

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voirs, dams alter spatio–temporal patterns of discharge that are important in structuring stream fish assemblages (Poff and Allan, 1995). Unnatural patterns in stream flow variability below dams can reduce diversity of lotic fishes (Cushman, 1985; Bain et al., 1988) and facilitate the establishment of introduced species (Marchetti and Moyle, 2001; Propst and Gido, 2004). Reservoirs also can affect structure of upstream fish assemblages.

On a regional scale, the longitudinal gradient (river–dam) has been recognized as important in reservoirs (Thornton, 1990; Carvalho et al., 1998; Agostinho et al., 1999). The longitudinal gradient fall along the main reservoir axis due to changes in basin geomorphology and hydrology and, consequently, in physical, chemical, and biological variables. Along such gradient, fish assemblages may vary widely in composition (Matthews et al., 1989; Da Costa et al., 2000). This gradient may be divided in three zones: riverine zone, transitional zone, and lacustrine zone (Thornton, 1990). The riverine zone is a typical lotic environment, with intense flow. The transitional zone is an ecotone between the riverine zone and the lacustrine zone of the reservoir. The lacustrine zone is close to the dam.

Moreover, reservoirs in tropical and subtropical regions have been studied extensively since dam completion (Arcifa and Meschiatti, 1993; Agostinho et al., 1994, 1997a; Carvalho et al., 1998; Gourène et al., 1999; Da Costa et al., 2000). The early years of a new reservoir are marked by high variability in population abundance and patchy distribution of fish due to colonization and adjustment to the new conditions. Studies performed after this period, when populations tend to have stabilized in the new environment, are needed for a full understanding of assemblage structure.

Taabo Reservoir is one of the four hydroelectric lakes of Ivory Coast and it is used for important fisheries. Studies on the fish community are useful for a durable management of fishing activities.

In this study, we analyzed the patterns of fish assemblage diversity through the longitudinal gradient, three decades after impoundment of the Taabo Reservoir.

MATERIALS AND METHODS

Study area

The study was carried out on Taabo hydroelectric reservoir (06°20'N — 06°40'N and 5°W — 5°30'W). It was established in 1978 by the impoundment of the Bandama River, one of the four important rivers of Ivory Coast (Fig. 1). This reservoir has a main–channel total length of 16 Km and an area of 69 km^2 at the average operating level of the dam (124 m). At this level, average water volume is around 625 10^6 m^3. It encompasses a catchments area about 58 700 km^2 and a mean annual flow of about 128.7 m^3/s (Kouassi et al., 2007). The monthly fluctuations of the mean water level, during the period

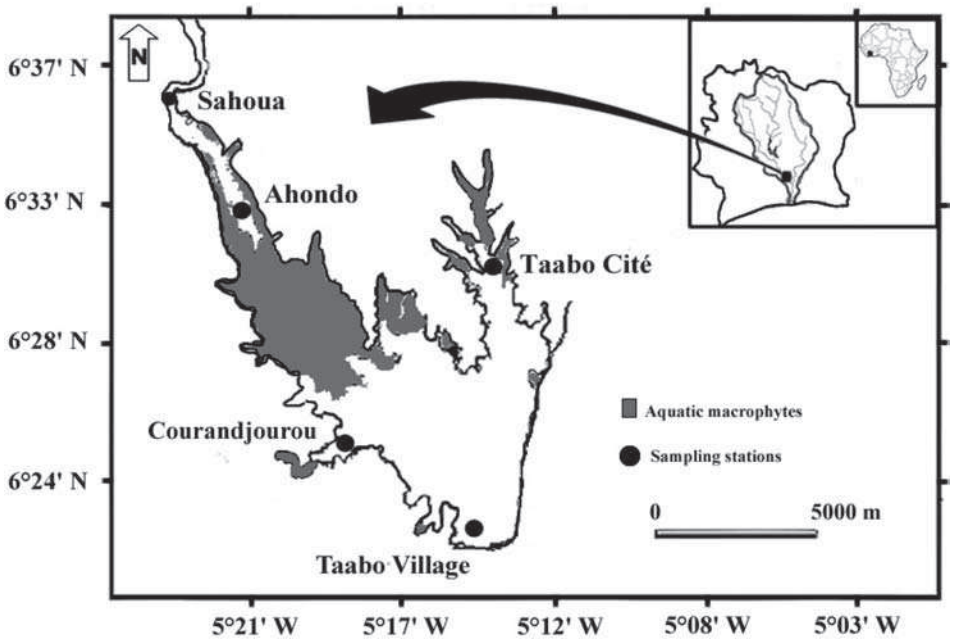

Figure 1. Taabo Reservoir map with sampling stations
Slika 1. Rezervoar Taabo s mjestima uzorkovanja

2006 — 2007, are illustrated on Figure 2. Data were provided by the operator of the hydroelectric energy. The maximum reached 123.84 m and occurred in October 2006, while the minimum (119.36 m) was recorded in May 2007. Macrophytes are very abundant in this reservoir particularly in the transitional zone.

Five sampling stations were retained in the Taabo Reservoir: one site in the riverine zone at Sahoua locality, another in the transitional zone at Ahondo locality and three sites in the lacustrine zone at Taabo cité, Taabo village and Courandjourou localities (Fig. 1). More sampling sites were retained in the lacustrine zone because of its relative extensive surface. Some others characters of the study sites are presented in Table 1.

Sampling

Fish populations were sampled during five surveys: July, October and December in 2006, and March and June in 2007. Data were collected through experimental and commercial fishing in order to obtain a greater number of species as possible. Concerning the experimental fishing, gill nets were usually set during the afternoon at about 16:00 h and lifted the following morning at about 07:00 h. Fish specimens were identified according to P a u g y et al. (2003).

Table 1. Characteristics of the five study sites including the geographical positions and water physico–chemical properties (Mean ± S.D values)
Tablica 1. Značajke pet lokacija, uključujući geografsku poziciju i fizikalno–kemijske parametre vode (srednja vrijednost ± stand. devijacija)

Study sites — Istraživane lokacije					
Characteristics–značajke	Sahoua	Ahondo	Taabo cité	Taabo village	Courandjourou
Geographical positions–geografski položaj	06°19'38.60''N 05°10'34.90''W	06°17'20.80''N 05°09'37.20''W	06°16'03.90''N 05°05'03''W	06°12'40.90''N 05°06'22''W	06°13'47.20''N 05°08'14''W
Temperature (°C)	28.87±1.21	28.81±1.07	28.76±0.63	28.51±0.65	29.10±0.05
Dissolved Oxygen — O_2 (mg/L)	4.58±1.03	3.89±1.90	5.304±2.33	4.70±1.36	4.15±0.74
pH	7.04±0.48	6.77±1.85	7.23±0.60	6.29±1.41	6.70±0.04
Secchi depth (m) –prozirnost	0.91±0.41	0.92±0.36	0.92±0.08	1.17±0.52	1.43±0.70
Conductivity (μS/cm) –provodljivost	86.24±24.88	85.16±20.40	87.03±13.34	85.89±15.88	90.45±61.64
Turbidity (NTU) — turbiditet	23.52±11.84	21.30±10.58	18.84±4.78	13.59±5.45	12.07±1.27
PO_4^{3-} (μmol/L)	7.43±4.58	7.28±5.56	9.46±11.10	9.37±7.83	6.12±6.64
NO_3^- (mg/L)	0.39±0.31	0.44±0.46	0.59±0.74	0.79±0.91	1.17±0.06
NO_2^- (μmol/L)	0.61±0.37	0.6±0.41	0.54±0.30	0.82±0.59	0.72±0.52
SiO_2^- (mg/L)	26.55±21.79	26.49±22.26	23.35±18.53	28.28±21.04	40.88±6.48

Data analysis

Occurrence frequency of fish species (F) was determined through the following formula: $F = (n_i \times 100)/N$, where n_i is the number of samples in which species i appeared and N the total number of samples.

In order to investigate the organization of the fish community, alpha and beta diversity were used. Alpha diversity (α–diversity) was assessed using species richness. At each site, α–diversity is the number of taxa collected during a sampling survey. The spatial (along the longitudinal gradient) and temporal (within each ecological zone) variations of this index were analysed. Temporal dynamic was studied according to the hydrological regime of the lake (spate and drop of water level illustrated by Figure 2). So, the sampling months of October 2006 and June 2007 were located in spate while those of July and December 2006 and March 2007 were located in drop. Kruskal–Wallis test was used to assess differences between the three zones according to this index.

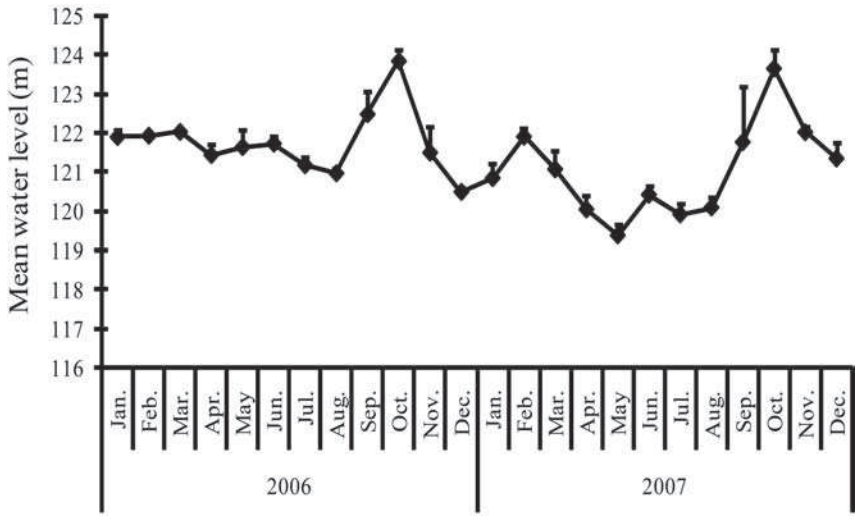

Figure 2. Monthly variations of the mean water levels of Taabo Reservoir during the period 2006 — 2007
Slika 2. Mjesečna kolebanja srednjih vrijednosti razine vode rezervoara Taabo u razdoblju 2006. — 2007. godine

Beta diversity (β–diversity) index was applied to quantify turnover in species composition along the longitudinal gradient (Wilson and Shmida, 1984; Blackburn and Gaston, 1996). We used Whittaker's index (β_w) (Whittaker, 1972) calculated as: $\beta_w = (S_R/\alpha_{mean}) - 1$. β_w was computed for each pair of zones (transitional — riverine, transitional — lacustrine and riverine — lacustrine). Total richness (S_R) and mean richness (α_{mean}) were calculated per zone.

RESULTS

Fish community composition and species frequency of occurrence

A total of 14 294 individuals belonging to 18 families and 53 species were collected (Table 2). The family of Cichlidae had the highest species richness (10 species). It was followed by Mormyridae (8 species) and Alestidae (6 species). Ten families were represented with only one species: Anabantidae, Centropomidae, Channidae, Clupeidae, Distichodontidae, Hepsetidae, Notopteridae, Osteoglossidae, Polypteridae and Protopteridae.

Analysis of occurrences indicated that 27 species had frequency comprised between 20 and 100% in each ecological zone. The others species were at least absents in one zone. Only 3 species (*Chrysichthys nigrodigitatus*, *Synodontis*

Table 2. List of fish species along the longitudinal gradient in Taabo Reservoir and their percentage of occurrence
Tablica 2. Lista ribljih vrsta uz longitudinalni gradijent u rezervoaru Taabo i njihov postotak

		Zones of the longitudinal gradient — zona long. gradienta		
Families — porodice	Species — vrste	Riverine	Transitional	Lacustrine
ALESTIDAE	*Alestes baremoze*	20	40	40
	Brycinus imberi	100	60	40
	Brycinus longipinnis	40	100	0
	Brycinus macrolepidotus	40	20	20
	Brycinus nurse	80	20	40
	Hydrocynus forskalii	80	60	40
ANABANTIDAE	*Ctenopoma petherici*	60	80	40
CENTROPOMIDAE	*Lates niloticus*	60	60	0
CHANNIDAE	*Parachanna obscura*	60	20	40
CICHLIDAE	*Chromidotilapia guntheri*	80	20	80
	Hemichromis bimaculatus	0	40	40
	Hemichromis fasciatus	40	20	100
	Oreochromis niloticus	60	100	100
	Sarotherodon galilaeus	40	20	100
	Tilapia dagetii	0	20	20
	Tilapia guineensis	0	20	60
	Tilapia mariae	0	0	20
	Tilapia sp.	0	0	40
	Tilapia zillii	80	60	100
CLARIIDAE	*Clarias anguillaris*	100	80	40
	Clarias gariepinus	40	20	20
	Heterobranchus longifilis	20	20	0
CLAROTEIDAE	*Auchenoglanis occidentalis*	80	40	80

	Auchenoglanis sp.	0	0	40
	Chrysichthys maurus	20	40	100
	Chrysichthys nigrodigitatus	100	100	100
CLUPEIDAE	*Pellonula leonensis*	0	20	80
CYPRINIDAE	*Barbus bynni waldroni*	0	0	20
	Barbus macrops	0	0	80
	Labeo coubie	60	80	100
	Labeo parvus	40	0	100
	Labeo senegalensis	20	0	0
DISTICHODONTIDAE	*Distichodus rostratus*	100	100	80
HEPSETIDAE	*Hepsetus odoe*	60	20	40
MOCHOKIDAE	*Chiloglanis occidentalis*	20	0	0
	Synodontis bastiani	100	100	100
	Synodontis punctifer	100	80	100
	Synodontis schall	100	100	80
MORMYRIDAE	*Marcusenius fursidens*	20	40	0
	Marcusenius senegalensis	60	100	100
	Marcusenius sp.	40	20	20
	Marcusenius ussheri	60	20	40
	Micralestes occidentalis	0	0	20
	Mormyrops anguilloides	60	60	60
	Mormyrus rume	40	40	20
	Petrocephalus bovei	40	40	20
NOTOPTERIDAE	*Papyrocranus afer*	40	60	0
OSTEOGLOSSIDAE	*Heterotis niloticus*	60	60	60
POLYPTERIDAE	*Polypterus endlicheri*	40	60	0
PROTOPTERIDAE	*Protopterus annectens*	40	100	20
SCHILBEIDAE	*Parailia pellucida*	0	0	20
	Schilbe intermedius	100	80	40
	Schilbe mandibularis	100	100	100
	Total — Ukupno	42	43	45

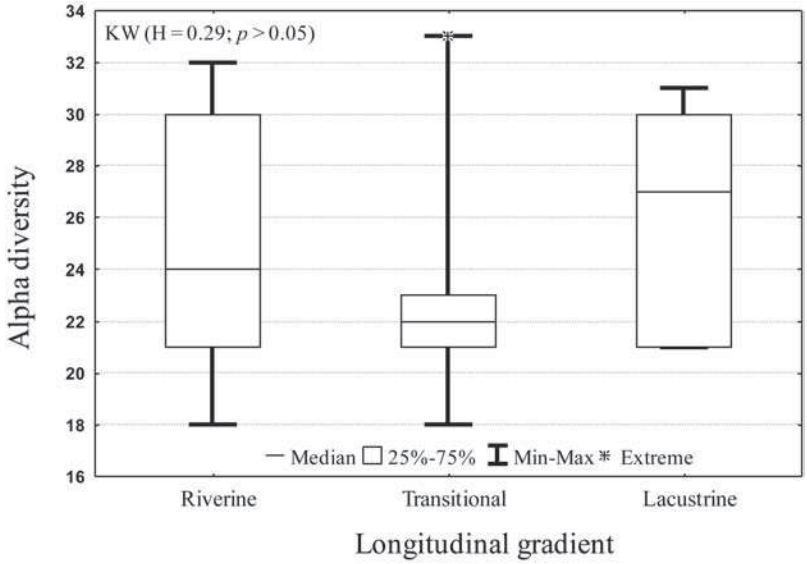

Figure 3. Spatial variations of alpha diversity along the longitudinal gradient of Taabo Reservoir; KW: Kruskal–Wallis test
Slika 3. Prostorne varijacije alfa–gustoće uzduž longitudinalnoga gradijenta rezervoara Taabo; KW: Kruskal–Wallisov test

bastiani and *Schilbe mandibularis*) had 100% of frequency in both riverine, transitional and lacustrine zones.

Alpha diversity

Total species richness recorded at each zone was 42 for the riverine, 43 for the transitional and 45 for the lacustrine. Along the longitudinal gradient, α–diversity index presented variations within and between ecological zones.

The highest value of α–diversity (33 species) was recorded in the transitional zone and the lowest (18 species) was obtained in the riverine and lacustrine zones (Fig. 3). This index was not significantly different between the three ecological zones (Kruskal–Wallis: $H = 0.29$; $p > 0.05$).

Concerning the temporal fluctuations, α–diversity indicated the maximum (32 species) and minimum (18 species) values in spate (June 2007) and drop (December 2006) periods respectively, at the riverine zone (Fig. 4). The transitional zone presented the maximum (33 species) and the minimum (18 species) values in drop periods (March 2007 and July 2006). In the lacustrine zone, the highest (31 species) value of á–diversity was recorded in a spate time (June 2007) while the lowest (21 species) was obtained in drop (July 2006) and spate (October 2006) times.

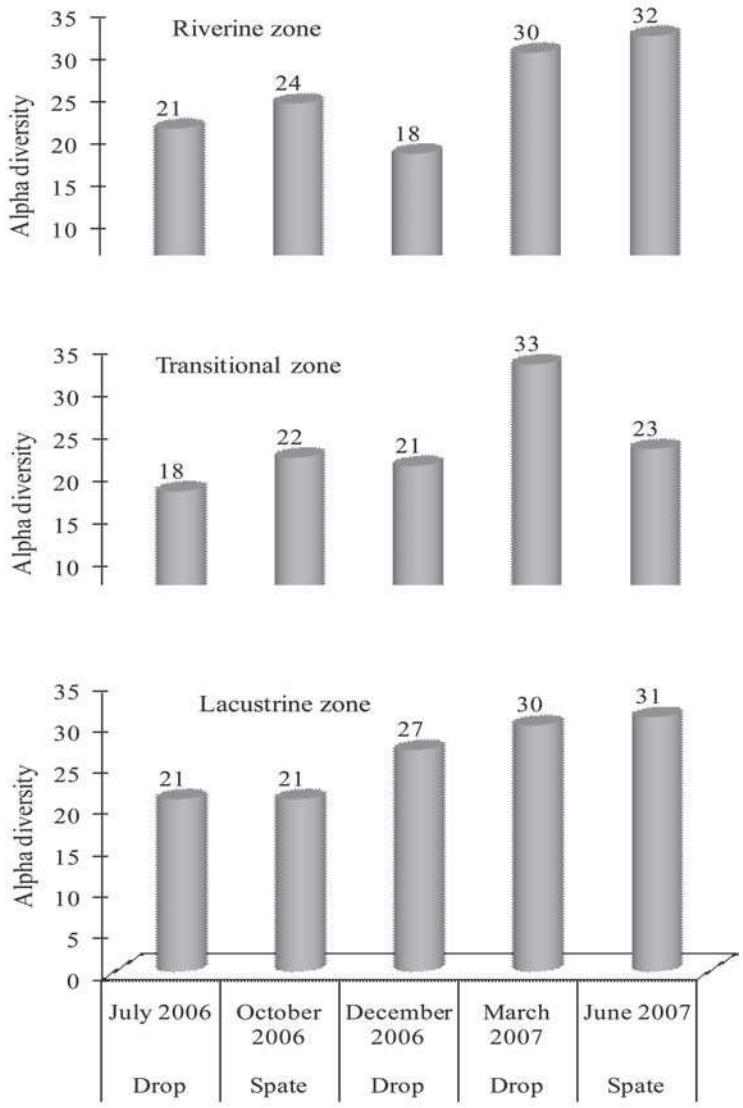

Figure 4. Variations of alpha diversity within ecological zones of the longitudinal gradient of Taabo Reservoir

Slika 4. Varijacije alfa gustoće unutar ekoloških zona longitudinalnoga gradijenta rezervoara Taabo

Beta diversity

Beta diversity was 0.43 between the transitional and the riverine zones, 0.73 between the transitional and the lacustrine zones, and 0.79 between the riverine the lacustrine zones. The highest α–diversity registered between the

riverine and lacustrine zones showed the lowest similarity between these sites. The highest similarity of fish community occurred between the transitional and riverine zones.

Along the longitudinal gradient, many species were common to the three ecological zones (Table 2). However, some species were found typical to zones. These included *Labeo senegalensis* and *Chiloglanis occidentalis* in the riverine zone and *Tilapia mariae*, *Tilapia* sp., *Auchenoglanis* sp., *Barbus bynni waldroni*, *Barbus macrops*, *Micralestes occidentalis* and *Parailia pellucida* in the lacustrine zone. None species was typical to the transitional zone.

DISCUSSION

Fish assemblage along the longitudinal gradient in Taabo Reservoir showed that á–diversity did not change significantly between the riverine, transitional and lacustrine zones. However, total species richness was higher in the lacustrine zone and lower in the riverine. This pattern may be due to fish migration and the fact that Taabo Reservoir can be considered as a local spatial scale. Thus, the lake–river connection is a homogeneity factor of local fish assemblages, strongly associated to migratory regional richness (Huston, 1997; Meschiatti et al., 2000).

Beta diversity was relatively high between the transitional and lacustrine environments and also between the riverine and the lacustrine; while this index was low between the transitional and the riverine. These results showed more similarity between the transitional and the riverine zones. This homogeneity in composition among the two habitats may result from higher connectivity between zones, since they are contiguous and the fish may swim more easily between them. The high β–diversity between the transitional and the lacustrine despite the connectivity denotes a predominance of several typical fish in the lentic system. The same reason could explain high β–diversity between the riverine and lacustrine sites.

Different reasons could explain fish diversity along the longitudinal gradient of Taabo Reservoir. The riverine zone is directly influenced by Bandama River upstream, which could dictate the limnological characteristics along this gradient, such as part of the organic and suspended material carried to Taabo Reservoir may be originate in this environment and could constitute temporary habitats for initial life stages of some migratory species. The riverine zone is the main habitat for several species that are adapted to the formerly pristine stream habitat. Those species may also spend some of their life cycle in both the transitional and lacustrine zones. Ultimately, the riverine zone accounts for number of species of the transitional and lacustrine zones (Agostinho et al., 1999).

The transitional zone of the longitudinal gradient is characterized by a high abundance of submerged and floating macrophytes in the littoral and pelagic areas. Aquatic plants are important habitats for fish because they increase spatial heterogeneity and feeding resource availability (Thomaz and

Bini, 1999). Also, in this intermediate or ecotone environment, both lotic and lentic species may co–exist, using the habitat temporally; hence the species richness tends to increase. As it is known, ecotones play an important role in fish diversity (Kolasa and Zalewski, 1995) and community structure (Willis and Magnuson, 2000) in aquatic ecosystems.

In the studied reservoir, the relative high richness of the lacustrine zone may be related to his wide surface comparatively to the riverine and transitional zones. It is recognized that fish diversity is correlated to habitat diversity. Therefore a wide area with high spatial heterogeneity could provide an important species richness (Agostinho et al., 1997b). This pattern about species richness in the lacustrine zone was not similar to those recorded in other reservoirs such as Itaipu across Paraná River (Benedito — Cecíllo et al., 1997), Foz de Areia in the Iguaçu River (Agostinho et al., 1997a), Jurumirim in Paranapanema River (Carvalho et al., 1998). These authors recorded the smallest species richness in the lacustrine zone.

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Sažetak

RAZNOLIKOST RIBA U UMJETNOM JEZERU ZAPADNE AFRIKE, HIDROELEKTRANA TAABO, OBALA BJELOKOSTI

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Uzorci riba jezera hidroelektrane Taabo u Obali Bjelokosti proučavani su u odnosu na uzdužni gradijent (rijeka — nasip) koji se odnosi na riječnu, prijelaznu i jezersku zonu. Podaci su sakupljani na pet lokaliteta. Struktura zajednica riba analizirana je s pomoću alfa i beta–indeksa raznolikosti. Ukupno u cijelom ekosustavu bile su 53 vrste riba. Ukupno bogatstvo vrsta zabilježeno na svakoj ekološkoj zoni jest 42, 43, odnosno 45 vrsta, i to u riječnoj, jezerskoj

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i prijelaznoj zoni. Alfa–raznolikost nije se značajno razlikovala duž uzdužnoga gradijenta već je dosegla najvišu vrijednost (33 vrsta) u prijelaznoj zoni, a najnižu (18 vrsta) u riječnoj i jezerskoj zoni. Beta–raznolikost je pokazala da je veća sličnost riba kod prijelazne i riječne zone (βw = 0,43), a niža između riječne i jezerske zone (βw = 0,79).

Ključne riječi: raznolikost riba, uzdužni gradijent, umjetno jezero, rezervoar Taabo, zapadna Afrika

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