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A preliminary fish assemblage index for a transitional river–reservoir system in southeastern Brazil

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ABSTRACT

Large river–reservoir systems are some of the most difficult aquatic ecosystems to assess because: (1) they typically lack minimally disturbed reference sites; (2) the reservoirs are not natural systems to begin with; and (3) reservoirs with high exchange rates are transitional systems between rivers and lakes. These features are further complicated in Brazil where fish species taxonomy is incomplete (let alone fully described ecologically), where waters naturally have high organic and thermal loadings, and where dams and reservoirs provide most of the nation's electricity and water supplies. As a first step towards generating a biological tool for assessing the effects of reservoirs on rivers, we developed a preliminary River–Reservoir Fish Assemblage Index (RRFAI) in a transitional river–reservoir system in southeastern Brazil. To do so, we gill-netted fish monthly between October 2006 and September 2007 (excluding May and July 2007) immediately upriver of the reservoir, in the upper reservoir, in the lower reservoir, and immediately downriver of the reservoir. In developing our RRFAI we sought fish assemblage metrics to represent ecological characteristics including richness, habitat, trophic, tolerance, and resilience guilds. Despite clear differences in fish assemblage composition between river and reservoir sites, we found 9 metrics common to both systems that were nonredundant and had low sampling variability (number of native species, number of characiform species, number of siluriform species, % omnivorous individuals, % invertivorous individuals, % non-native carnivorous individuals, % intolerant individuals, % tolerant individuals, number of tolerant species). Fish assemblage condition was significantly and consistently lower in the lower reservoir. There was no significant difference between the dry and wet season in RRFAI scores, suggesting that a single season sample should usually suffice. Further research is needed along distinct disturbance gradients in multiple river–reservoir systems in Brazil to confirm the sensitivity of our preliminary RRFAI for assessing the physical and chemical habitat disturbances common to such systems.

1. Introduction

Reservoirs are intermediate between lotic and lentic ecosystems (Gelwick and Matthews, 1990; Wetzel, 1990; Straskraba et al., 1993; Irz et al., 2006); however, biological cross-ecosystem studies are rare (Pace, 1991). This lack of cross-system research hinders development and application of either a lentic or a lotic multimetric index to assess river–reservoir biological condition. In reservoirs, modification of the hydrologic cycle may cause increased annual flow stability by reducing peak flows and increasing low flows, or they may cause daily fluctuations in water level associated with peak consumer demands. These altered flows reorganize local biotic communities (Bergkamp et al., 2000). According to the Serial Discontinuity Concept (Stanford and Ward, 2001), dams create discontinuity in the original river condition that can be divided into discrete regions within which the community structure and dynamics differentially respond to disturbance. This discontinuity can result in a cascade of ecological effects (Vinson, 2001).

Multimetric fish-based indices of biological integrity (IBIs) have been developed for streams and rivers throughout the world (Hughes and Oberdorff, 1999; Roset et al., 2007). However few such indices have been developed for lakes (Appelberg et al., 2000; Drake and Pereira, 2002) and even fewer for reservoirs (Jennings et al., 1995). The use of multimetric indices to monitor reservoir biological condition is an infrequently applied approach, reflecting the difficulty of applying such indices to artificial systems relative to rivers. Jennings et al. (1995) were the first to propose an adapta-

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tion to the IBI for assessing reservoirs. They suggested a new name for the index (RFAI = Reservoir Fish Assemblage Index), excluding the term biotic integrity. They justified this modification because of the absence of natural or reference conditions in reservoirs and their artificial nature.

An RFAI may be an efficient tool to monitor reservoirs; however, it needs to be adapted for transitional river and reservoir zones. A river–reservoir RRFAI will enable environmental managers to monitor river–reservoir systems and to assess the impact of reservoirs on what previously were entirely lotic systems. Such monitoring programs in transitional river–reservoir systems are necessary in Brazil, where almost all electricity and urban water supplies come from dammed rivers. Increased demand for such services has triggered dam and reservoir construction in southeastern Brazil despite the substantial impacts that damming rivers has on natural river systems by impairing fish migrations (Marengo and Alves, 2005), altering flows, and reducing physical habitat structural heterogeneity. Nonetheless reservoirs may remove nutrients and suspended sediments via sedimentation, improving water quality downriver of dams (Klapper, 1998). Therefore, our objectives in this study were to (1) develop a preliminary RRFAI from fish assemblage data collected monthly during the wet and dry seasons, and (2) use that RRFAI to evaluate the effect of Funil Reservoir on Paraíba do Sul River fish assemblages.

2. Material and methods

2.1. Study area

Built in 1969 for hydroelectricity, Funil Reservoir (22°30′–22°38′S, 44°32′–44°42′W, 440 m above sea level) is located in the middle reach of the Paraíba do Sul River within the Atlantic Forest biome of southeastern Brazil. Funil is the largest artificial impoundment on the river, with an area of 40 km^2, maximum depth of 70 m, and water retention time of 10–50 days. The climate is subtropical with monthly mean temperatures of 18–24 °C. Rainfall is greatest in the summer months (December–January; 200–250 mm per month) and lowest in the winter months (June–August; <50 mm per month; Marengo and Alves, 2005). Approximately 1.8 million people live in municipalities with nonexistent or poor sewage treatment in the Paraíba do Sul watershed upriver of Funil Reservoir, meaning that the river receives large pollutant loads; mainly domestic and industrial effluents (Pinto et al., 2006b). The high nutrient loads flow to the eutrophic reservoir, stimulating algal blooms and high productivity (Soares et al., 2008). There is little soil cover around the reservoir because of agriculture, and fluctuating water levels contribute to shoreline erosion and suspended sediments (Branco et al., 2002).

2.2. Sampling methodology

We sampled over a distance of 35 km in four zones, each representing different habitat conditions of the system, to assess differences along the longitudinal axis of the river-reservoir-river (Fig. 1; Table 1). Zone 1, the Paraíba do Sul River upriver of the reservoir, is characterised by seasonal changes in flow and water level associated with seasonal changes in rainfall. During the wet season, the river covers part of the riparian zone, which increases shelter and food for fish (Pinto et al., 2006a). Zone 2, the upper reservoir, is close to an artificial barrier formed by rocks that increase physical habitat complexity and depth and decrease current velocity. Zone 3, the lower reservoir, has the greatest transparency, greatest depth, a sandy and muddy substrate, and a wide and unvegetated littoral zone because of water level changes. Zone 4, the Paraíba do Sul River downriver of the reservoir, has a very complex habitat,

Table 1
Subsurface water quality and physical characteristics for the four sampled zones of the Paraíba do Sul River–Funil Reservoir system. DO = dissolved oxygen saturation (%), C = conductivity (μS cm^{-1}) and pH expressed as mean ± Standard Error.

Zones/coordinates	Current speed	Predominant substrate	Mean depth (m)	Variables	Season	
					Dry	Wet
1 – 22°31′50.7″S 44°42′64.0″W	Lotic	Clay	4	DO	71.9 ± 4.6	82.8 ± 1.7
				C	87.3 ± 1.4	98.4 ± 4.0
				pH	7.0 ± 0.1	7.1 ± 0.1
2 – 22°31′63.0″S 44°40′83.0″W	Semi-lentic	Pebbles, rocks	11	DO	92.9 ± 10.1	99.0 ± 5.0
				C	82.9 ± 1.5	91.5 ± 2.4
				pH	7.9 ± 0.1	7.8 ± 0.2
3 – 22°31′64.6″S 44°34′00.8″W	Lentic	Sand, clay	20	DO	91.1 ± 9.4	95.7 ± 5.4
				C	87.5 ± 1.4	62.35 ± 8.2
				pH	8.2 ± 0.2	7.7 ± 0.2
4 – 22°31′33.4″S 44°34′65.1″W	Lotic	Sand, clay, pebbles	3	DO	41.3 ± 2.9	65.3 ± 5.6
				C	80.4 ± 1.5	74.7 ± 6.4
				pH	6.7 ± 0.1	6.7 ± 0.1

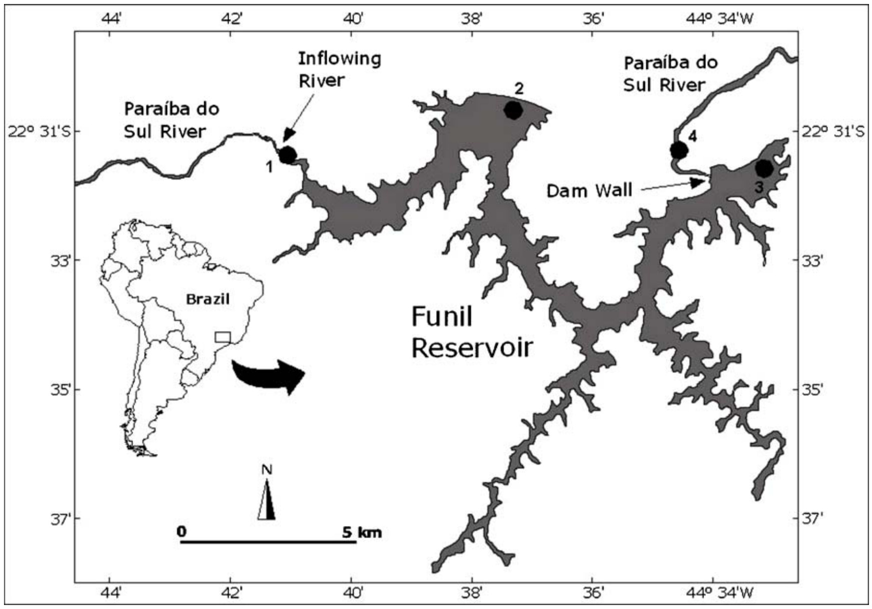

Fig. 1. The transitional Paraíba do Sul River–Funil Reservoir system and zones sampled (1–4). The surface water is shaded and the reservoir flows left to right.

regulated flow dictated by the hydroelectric plant, coarse substrate, and small islands and trees.

We sampled fish monthly at four sites chosen randomly within each zone October 2006–September 2007 (excluding May and July). At each of the four sites, we set three gill nets (30-m long by 2.5-m high) of different mesh sizes (2.5, 4.5 and 6.5-cm between opposite knots) to sample an area of 900 m^2 per zone. The nets were deployed near shore during the afternoon and retrieved the following morning, fishing for approximately 15 h. All collected fish were identified, counted, weighed (g) and measured for total length (mm). Vouchers were fixed in 10% formalin for 48 h, subsequently preserved in 70% ethanol, then deposited in the reference collection of the Laboratory of Fish Ecology, Universidade Federal Rural do Rio de Janeiro. We also measured dissolved oxygen saturation (%), pH and conductivity ($\mu S\ cm^{-1}$) during the morning at a constant depth of 20 cm below the surface and approximately 3 m from the shore with a multiprobe (Horiba W-21, Horiba Trading Co., Shanghai).

2.3. Candidate metrics

Development of multimetric indices is based on comparing a study area with areas having few environmental disturbances (Oliveira et al., 2008). Pristine reference environments with similar geomorphologic conditions to any study area are difficult to find because few such places now exist. Hence, least disturbed environments are used to estimate reference conditions (McDonough and Hickman, 1999; Stoddard et al., 2006; Zhu and Chang, 2008; Kanno et al., 2010). Such procedures were used successfully by Pinto and Araújo (2007) in the middle reaches of the Paraíba do Sul main channel to assess diffuse pollution, and by Petesse et al. (2007a) on the Barra Bonita Reservoir in southeastern Brazil.

We tested 28 candidate metrics (Table 2) classified by: richness, habitat, trophic, tolerance, and resilience guilds. We based species classifications on the literature and professional knowledge. Two types of origins were attributed to fish species richness (native and non-native; Araújo et al., 2003) for the middle reaches of the Paraíba do Sul River basin. Non-native species may alter fish assemblage structure through competition or predation, indicate disturbed environments that allow them to thrive (Lyons et al., 1995; Moyle and Light, 1996; Ganasan and Hughes, 1998), or simply indicate biological pollution (Lomnicky et al., 2007; Whittier et al., 2007). The number of native species was adapted from the total number of species proposed by Karr (1981) and used by Ganasan and Hughes (1998) to eliminate the influence of non-native species that tend to occur in degraded environments. The number of individuals that represented 90% of the total sample was proposed by Araújo et al. (2003) for use as a dominance proxy, assuming that subtropical fish assemblages dominated by few species have low richness, evenness, resilience and stability.

Two habitat guilds were assigned (benthic and water column; Araújo, 1998) to assess the habitat attribute in the RRFAI. Characiforms (except the Erythrinidae) use the water column, whereas siluriforms are benthic. Petesse et al. (2007a) also used this attribute for the Barra Bonita Reservoir. Characiforms are water column species that use vision to search for food; are capable of large and small movements; are mainly associated with margins shelters, riparian zones, macrophytes, and marginal vegetation; and are sensitive to increased turbidity, river impoundment and reduced riparian vegetation. Siluriforms are benthic habitat specialists, mainly associated with rocky shelters, and are sensitive to sedimentation and substrate homogenization. The numbers of characiform and siluriform species was proposed by Araújo (1998) as an indicator of habitat degradation in Brazilian rivers. Pinto and Araújo (2007) reported that the number of characiform species decreased with increased turbidity and/or reduced vegetation, whereas the number of siluriform species decreased with sedimentation, substrate homogenization and/or low dissolved oxygen concentrations.

Trophic attributes were classified as follows: omnivores (absence of specialized diet), carnivores (feed on vertebrates or their scales or fins), FPOM feeders (eat periphyton or fine particulate organic matter from the sediment), invertivores (consume mostly microcrustaceans, gastropods and insects) and herbivores (graze on macrophytes and filamentous algae; Araújo et al., 2009). Trophic metrics were originally proposed by Karr (1981) and these attributes are used to assess changes in ecological function and processes (Hughes and Gammon, 1987; Ganasan and Hughes, 1998; Davies and Jackson, 2006). The proportion of omnivorous individuals is presumed to increase with environmental degradation (Karr, 1981) as a result of the likely simplification and reduction of the food base. On the other hand, % of invertivorous individuals and % of FPOM individuals indicate structured systems with a diverse food

Table 2
Candidate metrics for the RRFAI, their expected response (ER) to environmental degradation (− = negative, + = positive) and the selective process for their rejection (red = redundant and var = variability). F = final metrics for river (riv) and reservoir (res) sites.

Candidates metrics	Code	System	ER	Selection		References
				riv	res	
Species composition and richness						
Number of species to account for 90% of the sample	NE9	riv/res	−	red	F	Araújo et al. (2003), Pinto et al. (2006a), Petesse et al. (2007a)
Total number of species	NTE	res	−		red	Bozzetti and Schulz (2004), Petesse et al. (2007a), Pyron et al. (2008)
Total number of native species	NEN	riv/res	−	F	F	Araújo et al. (2003), Pinto et al. (2006a), Ferreira and Casatti (2006), Magalhães et al. (2008)
Number of siluriform species	NES	riv/res	−	F	var	Araújo (1998), Araújo et al. (2003), Pinto et al. (2006a,b), Pinto and Araújo (2007)
Number of characiform species	NECh	riv/res	−	F	F	Araújo (1998), Araújo et al. (2003), Pinto et al. (2006a), Pinto and Araújo (2007)
Number of non-native species	NEE	riv/res	+	var	var	Petesse et al. (2007a), Magalhães et al. (2008)
Number of migratory species	NEM	riv/res	−	var	var	Araújo (1998);
Shannon diversity index for native species	DSEN	riv	−	red		Magalhães et al. (2008)
Evenness for native species	EEN	riv	−	red		Magalhães et al. (2008)
Abundance						
Total number of individuals	NTI	riv	−	red		Petesse et al. (2007a), McDonough and Hickman (1999)
% of characiform individuals	PIC	riv/res	−	red	red	Ferreira and Casatti (2006)
% of siluriform individuals	PIS	riv/res	−	F	F	Ferreira and Casatti (2006)
Trophic structure						
Number of carnivorous species	NECa	riv	−	red		Bozzetti and Schulz (2004)
Number or native carnivorous species	NECN	riv	−	F		Bozzetti and Schulz (2004)
Number of omnivorous species	NEO	riv/res	+	red	Red	Magalhães et al. (2008)
Number of invertivorous species	NEIN	riv/res	−	var	var	McDonough and Hickman (1999)
Number of FPOM feeding species	NEDE	riv/res	−	red	var	
% of omnivorous individuals	PIO	riv/res	+	F	F	Araújo et al. (2003), Pinto et al. (2006a), Petesse et al. (2007a), Pyron et al. (2008)
% of invertivorous individuals	PIIN	riv/res	−	F	F	Araújo (1998)
% of FPOM feeding individuals	PIDE	riv/res	−	F	red	
% of non-native carnivorous individuals	PICE	riv/res	+	F	F	
% of native carnivorous individuals	PICN	res	−		F	Pinto and Araújo (2007), Petesse et al. (2007a)
% of individuals with specialized habits	PIHE	res	−		red	Petesse et al. (2007a)
Tolerance						
Number of intolerant species	NEI	riv/res	−	F	var	Bozzetti and Schulz (2004), Petesse et al. (2007a), Magalhães et al. (2008)
Number of tolerant species	NET	riv/res	+	F	F	
% of intolerant individuals	PII	riv/res	−	F	F	Araújo (1998), Magalhães et al. (2008), Zhu and Chang (2008)
% of tolerant individuals	PIT	riv/res	+	F	F	Magalhães et al. (2008)
Reproduction						
Number of highly resilient species	NEAR	res	+		red	Petesse et al. (2007a)

base available to specialist species (Araújo, 1998; Flecker, 1996). Such conditions commonly disappear in reservoirs because of their great depth and hypolymnial anoxia (Cassemiro et al., 2005). To assess the capacity of the food web to sustain top predators, number of carnivorous species (Bozzetti and Schulz, 2004) and % of carnivorous individuals (Araújo, 1998) were replaced by number and % of native carnivorous species to eliminate the effect of introduced and numerous carnivorous species in Funil Reservoir (e.g., *Cichla kelberi* and *Plagioscion squamosissimus*). Percent of non-native carnivorous individuals was used to assess the dominance of these opportunist predators, which are adapted to lentic conditions.

According to Lyons et al. (2000), species that used to be abundant but became occasional because of environmental degradation are considered intolerant. Intolerant species tend to disappear at the beginning of the degradation process associated with urban and agricultural development (which increases turbidity and temperature and decreases dissolved oxygen concentrations). Under such conditions, the number of tolerant species tends to increase in number and biomass (Ganasan and Hughes, 1998). Intermediate species are neither intolerant nor tolerant (e.g., Hughes and Gammon, 1987; Magalhães et al., 2008). The number of intolerant species (Karr et al., 1986) represents species that are extirpated or reduced in population size because of increased system degradation. Such species may have long recovery periods following environmental rehabilitation. We also used number of tolerant species, % of tolerant individuals, and % of intolerant individuals to capture such influences.

Species resilience was evaluated according to Musick (1999) using four levels of potential productivity: very low (population doubles in >14 years), low (population doubles in 4.5–14 years), medium (population doubles in 1.4–4.4 years) and high (population doubles in <13 months). These categories are based on population parameters such as r_m (intrinsic rate of population growth year^{-1}), K (von Bertalanffy growth coefficient year^{-1}), t_{max} (maximum age, years), t_m (age at first maturity, years) and fecundity (number of eggs). The source for these data was FishBase (Froese and Pauly, 2008). Petesse et al. (2007b) used resilience to assess the reproductive compensation of reservoir species. According to Petesse et al. (2007b), reservoir water fluctuations may expose the bottom in littoral zones and tributary mouths, which may limit spawning areas and reduce juvenile recruitment via decreased food and shelter.

2.4. Metric selection and scoring

We were hindered in developing our RRFAI by the absence of sufficiently comprehensive physical and chemical habitat data and minimally disturbed reference sites. Consequently, following Karr (1981), Hughes and Noss (1992), Hughes et al. (1998) and Bozzetti and Schulz (2004), we based our RRFAI metrics and scoring on ecological theory. For example, we assumed that higher numbers or percents of native species, characiform species, siluriform species, invertivorous individuals, and intolerant individuals were desirable characteristics of river–reservoir systems. On the other hand, we assumed that lower percents and numbers of omnivorous individuals, non-native carnivorous individuals, tolerant individuals, and tolerant species were desirable. Lacking true minimally disturbed reference sites and depending on the desirable characteristic of the metric, we based our metric scoring on the highest or lowest scores obtained from our samples (Ganasan and Hughes, 1998; Bozzetti and Schulz, 2004).

We eliminated candidate metrics that had low range and were redundant. Metrics with a scoring range <3 were rejected and metric pairs with a Spearman correlation coefficient > |0.7| were considered redundant (Baptista et al., 2007; Whittier et al., 2007). For each pair of redundant metrics, we followed Hering et al. (2006), excluding the metric with the highest correlation with other metrics.

Each metric was scored continuously (0–10) based on the highest raw values in this study. Continuous scoring was proposed by Minns et al. (1994) and Ganasan and Hughes (1998), contrary to the discrete class scoring (1, 3, or 5) proposed by Karr (1981), as it was believed that continuous scoring decreases the step changes in scoring when raw metric values differ by only one unit. We used the 5th and 95th percentiles of raw values to exclude the effects of extreme values that may impair metric interpretation. Metrics that were believed to decrease with environmental degradation received the highest scores (10; corresponding to the 95th percentile of observed raw values) and lowest scores (0; based on the 5th percentile of observed raw values). For metrics believed to increase with environmental degradation, a 10 corresponded to the 5th percentile of raw values, and a 0 corresponded to the 95th percentile of raw values.

Calculation of the total RRFAI score followed Klemm et al. (2003), with the score for each zone calculated as the sum of individual metric scores multiplied by 10 and divided by the total number of metrics. Thus, the final score ranged between 0 and 100, irrespective of the number of metrics used, facilitating comparisons between indices having differing numbers of metrics. The final RRFAI scores were assigned different classes of quality: acceptable (>80), moderately impaired (60–80) and impaired (<60; Ganasan and Hughes, 1998). According to Ganasan and Hughes (1998), many classes/categories can confound interpretation and, consequently, decisions by environmental managers.

The RRFAI was calculated for each zone and each month. Monthly evaluation is not typical for multimetric index studies, but it was performed to detect monthly changes in each zone and to choose the best period to apply the index. Seasonal (dry and wet season) RRFAI scores were obtained by averaging the monthly scores. The wet season was characterised by monthly October 2006 to February 2007 rainfall ranging from 100 to 400 mm, whereas the dry season was characterised by monthly March to September 2007 rainfall of 0–57 mm.

2.5. Data analysis

We used non-metric multidimensional scaling (NMDS) ordination to highlight the longitudinal pattern of ichthyofaunal structure and to confirm the existence of river and reservoir assemblages. NMDS is a non-parametric technique that aids visualizing the relationships of fish assemblages among zones by producing a 2-dimensional plot of relationships among the samples. Samples were classified as river or reservoir. River samples typically display greater species richness and both water column and benthic species; reservoir samples typically include abundant non-native and native species with lentic ecomorphotypes. We performed NMDS with PRIMER 5 software (Primer-E 2000) on a Bray–Curtis similarity matrix. NMDS is a 3-dimensional ordination of samples reduced to a 2-dimensional plot. The quality of the plot is indicated by its stress value: values <0.2 give a potentially useful 2-dimensional picture, stress <0.1 corresponds to a good ordination and stress <0.05 is an excellent representation (Clarke, 1993). Temporal (seasonal) and spatial (zonal) variability of the RRFAI was evaluated via a two-way ANOVA. If F was significant ($p < 0.05$), the *a posteriori* Tukey's HSD multiple comparison test was used to assess differences in RRFAI values among zones and between seasons.

3. Results

3.1. Fish assemblages

Thirty-five fish species were collected, including five non-natives (14.3% of individuals). The greatest number of species was recorded in zone 2 ($N = 28$), followed by zone 3 ($N = 25$); river zones had 24 species each (Table 3). The greatest number of individuals was recorded in zone 1 ($N = 1261$), zone 2 ($N = 1210$) and zone 3 ($N = 1209$). Individual abundance was greatest in January for zone 1, November for zone 2, September for zone 3 and October for zone 4.

Two fish assemblage structures were found: a river assemblage represented by samples from zones 1 and 4, located on the right side of the diagram; and a reservoir assemblage represented by samples from zones 2 and 3, located on the left side of the diagram (Fig. 2). Therefore index scores were calculated separately for river zones and reservoir zones, as well as in a combined river–reservoir RRFAI following Stoddard et al. (2008).

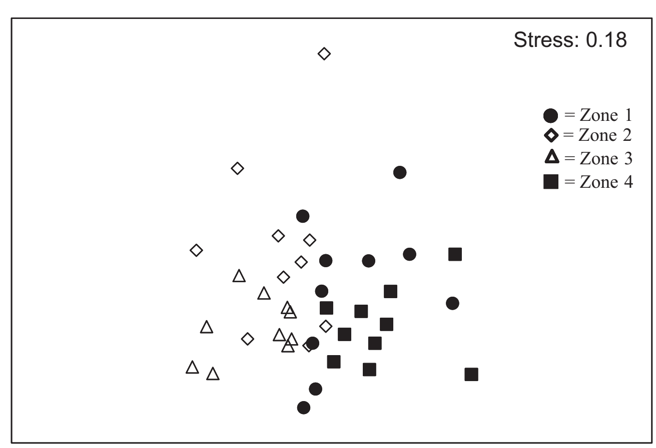

Fig. 2. Non-metric multidimensional scaling ordination based on Bray-Curtis similarity, with monthly samples coded by zones (1, 2, 3 and 4) in the Paraíba do Sul River–Funil Reservoir system. Zones 1 and 4 are immediately upriver and downriver of the reservoir, respectively; zones 2 and 3 are the upper and lower reservoir, respectively.

Table 3
Total number of individuals (*N*) per zone and their size range (TL in mm) in the Paraíba do Sul River–Funil Reservoir system.

Species	*N*	%	Zones				
			Individuals				
			1	2	3	4	TL
Astyanax bimaculatus	1618	35.6	366	418	718	117	89–149
Pimelodus maculatus	969	21.3	422	135	70	343	98–350
Astyanax parahybae	283	6.2	114	4	10	155	90–140
Hoplosternum littorale	229	5.0	70	115	37	7	127–210
Metynnis maculatus	223	4.9	11	190	16	7	118–149
Cichla kelberi	211	4.6	3	7	201	0	110–271
Plagioscion squamosissimus	208	4.6	77	70	54	7	105–360
Hypostomus auroguttatus	181	4.0	26	66	7	81	190–354
Oligosarcus hepsetus	105	2.3	24	16	22	43	149–303
Geophagus brasiliensis	78	1.7	0	45	28	5	139–228
Leporinus copelandii	65	1.4	33	20	2	10	164–435
Hypostomus affinis	61	1.3	21	17	7	16	248–354
Hoplias malabaricus	55	1.2	18	19	8	10	150–417
Leporinus conirostris	48	1.1	13	26	3	6	248–354
Gymnotus carapo	41	0.9	10	26	1	4	237–341
Callichthys callichthys	25	0.5	16	8	2	0	125–172
Astyanax giton	23	0.5	0	0	0	23	95–115
Cyphocarax gilbert	23	0.5	18	5	0	0	180–230
Rineloricaria sp.	16	0.4	0	2	1	14	135–160
Pachyurus adspersus	14	0.3	2	2	10	0	215–252
Eigenmannia virescens	12	0.3	7	1	0	4	209–300
Hoplerythrinus unitaeniatus	9	0.2	3	5	1	0	171–220
Oreochromis niloticus	9	0.2	0	3	5	1	230–316
Rhinelepis aspera	8	0.2	0	5	0	3	249–275
Leporinus mormyrops	6	0.1	1	3	0	2	160–185
Probolodus heterostomus	5	0.1	0	1	1	3	107–126
Piaractus mesopotamicus	4	0.1	3	0	1	0	100–122
Crenicichla lacustris	4	0.1	0	1	0	3	290–913
Characidium lauroi	3	0.1	1	2	0	0	204–209
Brycon insignis	2	<0.1	1	1	0	0	180–190
Rhamdia sp.	2	<0.1	0	0	0	2	140–160
Pimelodus fur	2	<0.1	0	0	2	0	123–149
Glanidium albescens	2	<0.1	1	0	0	1	145–150
Astyanax sp.	1	<0.1	0	0	1	0	120
Synbranchus marmoratus	1	<0.1	0	0	1	0	415
Total number	4548	100	1261	1211	1209	866	
Species	35		24	28	25	24	

3.2. RRFAI development

Three metrics proposed for the river zones and six proposed for the reservoir zones were rejected because of range < 3 and eight river zone metrics and six reservoir zone metrics were rejected for redundancy (Table 2). The number of native species was included in the RRFAI in spite of being correlated with the number of characiform species and the number of omnivorous species, because species richness is important in tropical areas for representing overall habitat complexity.

The river and reservoir indices were based on 13 and 11 metrics, respectively, whereas the combined RRFAI was based on the nine metrics shared by the river and reservoir indices (Table 4). For both systems, the origin class included number of native species; the habitat class was represented by number of characiform species and % siluriform individuals; the trophic class included % omnivorous individuals, % invertivorous individuals and % non-native carnivorous individuals; and the tolerance guild was represented by percent intolerant individuals, percent tolerant individuals, and number of tolerant species. For river zones, the habitat class also included number of siluriform species, the trophic class included number of carnivorous native species and % FPOM feeding individuals, and the tolerance class included number of intolerant species. The reservoir zones had two exclusive metrics: number of individuals to account for 90% of the sample in the richness category and % native carnivorous individuals in the trophic class.

No zones were classified as having acceptable biological quality based solely on expectations from ecological theory and the categories suggested by Ganasan and Hughes (1998). Final RRFAI scores ranged from 12.43 (zone 3) to 68.10 (zone 4), with most scores <50, suggesting that the entire Paraíba do Sul River–Funil Reservoir system that we studied was impaired. The river zones were classified as impaired during most of the study period, except in October (zone 1) and January (zone 4), when these zones were classified as moderately impaired. The reservoir zones were classified as impaired each month. Zone 2 had higher RRFAI scores than zone 3 in all months examined except January. No significant difference was detected for RRFAI between seasons (Table 5).

4. Discussion

To our knowledge, the RRFAI is the first river–reservoir multimetric index that has been developed, but it is only a preliminary starting point for conducting bioassessments of Brazilian river–reservoir systems. Clearly further research along varied physical and chemical habitat disturbance gradients in many river–reservoir systems in Brazil is needed to determine whether our preliminary RRFAI is widely applicable for assessing river pollution as well as the effects of reservoirs on lotic fish assemblages.

Sampling season is an important aspect of assessing biological condition of water bodies (Hughes and Peck, 2008). In most biological assessment programs, only one season is sampled (Plafkin et al.,

Table 4
Selected RRFAI metrics for Paraíba do Sul River–Funil Reservoir system including Best (B) and Worst (W) observed values and the respective 5th and 95th percentiles punctuation for the river and reservoir.

	Selected metrics	River				Reservoir				RRFAI			
		B	W	5	95	B	W	5	95	B	W	5	95
1	Number of native species	14	3	3.5	13	13	6	6	12	14	3	5	13
2	Number of siluriform species	5	0	0.5	5								
3	Number of characiform species	9	2	2.5	8.5	7	2	2.5	7	9	2	2.5	8
4	Proportion of siluriform individuals	77.5	0	6.0	77.5	67.9	2.5	2.7	59.5	77.5	0	2.8	74.8
5	Number of sp. to account for 90% of the sample					8	2	2	8				
6	Number of carnivorous natives species	4	0	0.5	3.5								
7	% of omnivorous individuals	40	92.8	41.4	92.6	38.7	98.7	41.7	92.06	38.7	94.5	41.4	92.6
8	% of native carnivorous individuals					12.2	0	0.14	10.7				
9	% of invertivorous individuals	5.5	0	0	4.6	6.2	0	0	5.8	6.2	0	0	5.5
10	% of FPOM feeding individuals	31.3	0	0	30.0								
11	% of non-native carnivorous individuals	0	100	0	93.3	5.2	100	10.6	100	0	100	2.5	9
12	Number of intolerant species	5	0	0	4								
13	% of intolerant individuals	14.7	0	0	14.7	19	0	0	17.6	19.7	0	0	15.2
14	% of tolerant individuals	62.2	95.6	66.9	94.8	44.2	96.2	47.2	95.3	44.2	98.2	562	959
15	Number of tolerant species	5	12	5	11	4	9	4.5	9	2	9	2.5	9

Table 5
F-Values calculated by two-way ANOVA and Tukey's test for comparisons of RRFAI between zones (1, 2, 3 and 4) and seasons (wet and dry) in the Paraíba do Sul River–Funil Reservoir system.

	F	*p*	Tukey's test
Zones	4.927	0.006*	1, 4 > 3
Seasons	0.851	0.363	ns
Zones × seasons	0.050	0.985	ns

* $p < 0.05$.

1989; Barbour et al., 1999; Hughes and Peck, 2008). The sampling approach used in our study was also used for the middle-lower reaches of the Paraíba do Sul River by Pinto and Araújo (2007) to develop an IBI. They suggested that the dry season was the preferred sampling season because of increased sampling efficiency, reduced lateral habitat connectivity, less pollution dilution, and decreased habitat availability (abiotic factors may dominate the wet season in rivers; Ode et al., 2005). We collected monthly samples throughout the year to detect temporal and seasonal variation in fish assemblages and RRFAI scores in the different zones. When samples were assessed by dry and wet season, we found no significant differences in RRFAI scores.

The spatial pattern in RRFAI that we found (Fig. 3) was consistent with the expectation that the lower reservoir significantly alters fish assemblage condition along the river-reservoir-river axis. A trend of decreasing RRFAI scores from zone 1 to zone 3 with an increase in zone 4 was found. The zones were generally classified as impaired, confirming the overall degradation that has been reported in other assessments using physicochemical measurements (Branco et al., 2002; Soares et al., 2008). Although additional physical and chemical indicators are necessary to determine the major causes of the impaired fish assemblage in zone 3, our results appear reasonable and indicate the potential for using a single RRFAI in both lotic and lentic systems.

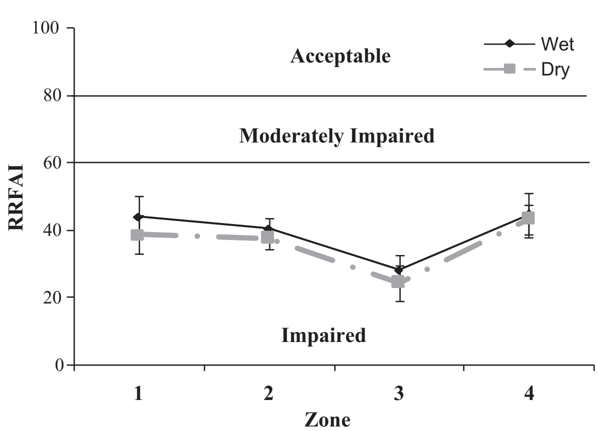

Fig. 3. Means and standard errors (vertical lines) of monthly RRFAI scores for the four zones (1, 2, 3 and 4) during the dry and wet seasons in the Paraíba do Sul River–Funil Reservoir system. Zones 1 and 4 are immediately upriver and downriver of the reservoir, respectively; zones 2 and 3 are the upper and lower reservoir, respectively.

5. Conclusions

A preliminary River–Reservoir Fish Assemblage Index (RRFAI) based on ecological theory was developed in a transitional river–reservoir system in southeastern Brazil as a first step towards generating a biological tool for assessing the effects of reservoirs on rivers. The spatial pattern was consistent with the expectation that the lower reservoir significantly alters fish assemblage condition along the river-reservoir-river axis. We suggest that a single season (dry season) sample should usually suffice to apply the index. We believe this approach will be helpful for water resource management, but further research is needed along distinct disturbance gradients to confirm the sensitivity of our preliminary RRFAI for assessing the physical and chemical habitat disturbances common to such systems.

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