Original Article

Contrasting fish size distributions between Neotropical run-of-river and storage reservoirs

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Abstract: The spectrum size has been used to assess environmental disturbances and to understanding the energy flow in ecosystems. The objective of this work was to investigate if the operation regimes of reservoirs, including run-of-river and storage systems, interfere with the biomass spectra of fish fauna. We tested the hypothesis that the run of river reservoirs present higher proportions of large individuals than storage system. Samplings of fish fauna were carried out between January 2005 and December 2007 at six Neotropical reservoirs belonging to the sub-basin Iguaçu River and Coastal basin in São Jorge River, Brazil. The spectrum calculation was performed using the Pareto type I continuous distribution model. Reservoirs operated under run-of-river regime had significantly higher values than those operated under storage regimes. This study has elucidated some impacts of reservoir operating regime on biomass spectra and indicated differences in size spectra of fish assemblages among the sampled reservoirs. Therefore, it is important to incorporate management plans that take dam operating mode into account so that conservation of aquatic fauna, especially fish, is more effective.

Introduction

Body size is a fundamental trait of living organisms, being linked with many important physiological and ecological processes (Giacomini et al., 2016; Wheeland and Rose, 2016; Brown, et al., 2004; Elton, 1927). The relationship between body size and abundance denominated size spectrum, is a concept initially developed by Sheldon et al. (1972), in which the authors assessed the distribution from bacteria biomass to whales and hypothesized that aquatic biomass is uniformly distributed among logarithmic class sizes. This approach provide important information about trophic ecology (Petchey and Belgrano, 2010; Gaedke, 1993; Gaedke, 1992) and environmental disturbances (Gamble et al., 2006; Shin et al., 2005), besides that, it has contributed for a better understanding of aquatic communities function and the regulatory processes of energy flow in these environments (Zhou et al., 2010; Layman et al., 2005; Thiebaux and Dickie, 1992; Rodríguez and Mullin, 1986).

As approaches based on body size are independent of the taxon, individuals with the same body size are considered energetically equivalent, and used as a reference for simplification of food webs. Size-based indicators has been used for studies of fish assemblages to assess impacts caused by fishing activity on stock size, marine food web dynamics (Gamble et al., 2006; Shin et al., 2005; Rice and Gislason, 1996) and fish communities in reservoirs (Kantoussan et al., 2009). Thus, the use of spectrum size models are relevant to fisheries science in the context of the ecosystem approach to fisheries management. The theory behind of spectrum size includes several mathematical derivations and estimation methods that are described in a number of detailed publications and their appendices (Andersen et al., 2015; Sprules and Barth, 2015; Reuman et al., 2008, White et al., 2007; Andersen and Beyer, 2006; Brown and Gillooly, 2003).

Freshwater ecosystem are vulnerable to anthropogenic disturbance due to landscape
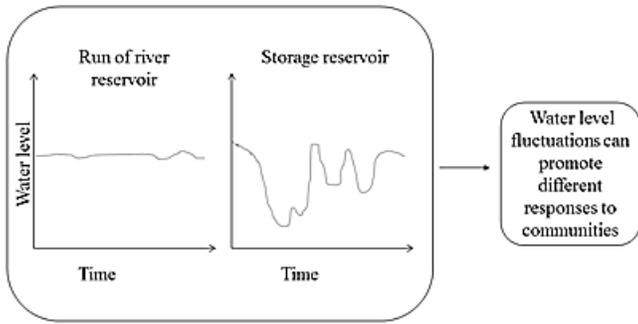

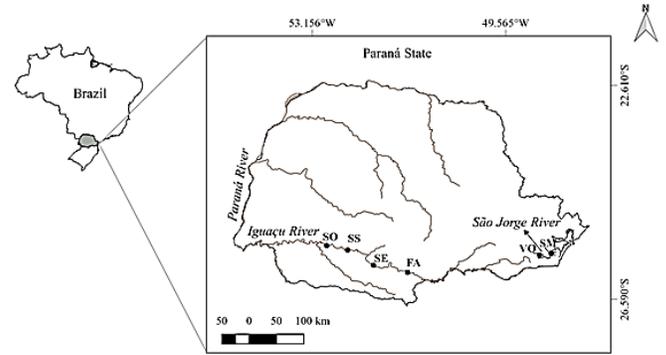Figure 1. Conceptual model about differences in water level fluctuations.

Figure 2. Location of the six Neotropical reservoirs sampled from January 2005 to December 2007. SO=Salto Osório, SS=Salto Santiago, SE=Segredo, FA=Foz do Areia, VO=Vossoroca and SM=Salto do Meio.

influences on habitat and fishes (Van der Lee and Koops, 2015). Reservoirs are historically recent environments and considered as complex ecosystems, with characteristics distinct from those of natural rivers and lakes (Fernando and Holcik, 1991). The main Neotropical water basins are altered by dams, which were built for various purposes such as power generation, irrigation and urban water supply (Stenberg, 2006; Agostinho et al., 1999). These systems are exposed to natural and artificial forces that determine dynamic characteristics; in addition to climatological and hydrological events, reservoir operational regime, manner of construction, and use also interfere with the system dynamics and spatial and temporal organization (Straskraba et al., 1993). Further, reservoir operation significantly impacts river hydrology, changing the magnitude, frequency, duration, and timing of the flow regime (Suen, 2011). In this context, the reservoir operation mode can be classified according to the control mechanism for everted and turbined water. Run-of-river systems whose characteristics are more similar to natural lakes and storage systems in which water stock is kept high mainly in high rainfall periods, enables the maintenance of activity in dry periods. Therefore, the storage system tend to cause more disturb than run-of-river system due to higher water level fluctuations (Poff and Hart, 2002). These characteristics promote fragmentation and transformation of the river, as well as changes in species diversity, trophic structure and community composition (Poff et al., 1997; Ward and Stanford, 1995). The conceptual model about differences in water level fluctuations in reservoir are provided in Figure 1.

In this context, the aim of this study was to assess the size spectrum distributions in fish in Neotropical reservoirs, specifically to answer the following question: is there difference in fish size spectrum in reservoirs with different operating regimes? For this, we tested the hypothesis that the run of river reservoirs present higher proportions of large individuals than storage system.

Materials and Methods

Study Area: This study was conducted in six reservoirs located in the state of Paraná, southern Brazil. Four reservoirs were analyzed in the Paraná river basin, belonging to the following sub-basin: Iguaçu River and two reservoirs belonging to the Coastal basin in São Jorge River (Fig. 2). The Iguaçu River present an area of approximately 72.000 km^2 and the high unevenness of the basin constituted a great attraction for the hydroelectric exploitation, resulting in a cascade of five reservoirs that alters their physical, chemical and biological attributes (Baumgartner et al., 2012). The fish fauna of Iguaçu River present a high degree of endemism due to geographic isolation caused by Iguazu Falls.

The Coastal basin is formed by rivers draining directly into the Atlantic Ocean and present a total area of 5.630,8 Km^2. They are rivers with great slope, rapids and greater speed of current, as a result of this, several reservoirs were designed for the production of

Table 1. Physical factors of the analyzed reservoirs. Locations were paired as follows: Pair 1: FA and SE; Pair 2: SS and SO; Pair 3: VO and SM (FA=Foz do Areia, SE=Segredo, SS=Salto Santiago, SO=Salto Osório, VO=Vossoroca, SM=Salto do Meio and *=Data not found).

Physical factors	FA	SE	SS	SO	VO	SM
Operation regime	Storage	Run-of-river	Storage	Run-of-river	Storage	Run-of-river
Sub-basin	Iguaçu	Iguaçu	Iguaçu	Iguaçu	Coastal	Coastal
Fill year	1980	1992	1980	1975	1931	1931
Area (km^2)	139	80.6	208	55	5.1	0.1
Sampling	Quarterly	Quarterly	Bimonthly	Bimonthly	Quarterly	Quarterly
Average depth (m)	40.0	36.6	35	25.5	4.0	*
Altitude	742	607	506	397	814	722
Residence time (days)	105	47	50.8	16	110	*

energy (Rodrigues et al., 2005). These reservoirs present wide heterogeneity of morphometric and limnological characteristics. For analysis criteria, the reservoirs were grouped in pairs with one run-of river and one storage system each, according to the sub-basin in which they belong, area and proximity to the operating system (Table 1).

Sampling: Samplings were carried out between January 2005 and December 2007 (Table 1). Data collection took place in non-adjacent bank regions at points located upstream the dam in six reservoirs using mesh gill nets between 2.4 cm and 16 cm. Nets were exposed for 24 hours and collections took place at 8, 16 and 22 hours. Fish were anesthetized with benzocaine hydrochloride (250 mg/L), as required by Resolution No. 714/CFMV as of July 20, 2002, which regulates procedures and methods of euthanasia in animals (CFMV, 2002). After anesthesia fish were fixed in 10% formalin and 70% alcohol (Shibatta and Cheida, 2003) and assigned ID based on location, shift, and sampling month. Specimens were subsequently taken to the laboratory for analysis.

Analysis were performed at the Laboratory of Ichthyology at the State University of West Paraná, Toledo campus. Specimens were classified according to Graça and Pavanelli (2007), Britski et al. (1999) and Eschmeyer (1990). Weights and length were obtained for all specimens. The list of species and their respectively abundances are provided in Table 2.

Data Analysis: The richness of species was assessed using the number of individual captured (See supplementary material). To represent the size spectrum, we used the biomass of all individuals captured in each reservoir. The spectrum calculation was performed using the Pareto type I continuous distribution model for each reservoir. According to this model, the probability of finding individuals that are older or of a specific size decays on a logarithmic scale as size increases. This has been used for the analysis of biomass frequency distributions (White et al., 2008; Vidondo et al., 1997). The derivation of the Pareto type I model is described by the following equation:

$$\log_2(\text{Prob}(s \geq S)) = c* (\log_2(K) - \log_2(S))$$

Where Prob($s \geq S$) is the fraction of individuals over a given size (s) taken at random (S). The constant c is the slope of the size spectrum, representing the frequency distribution of fish body size. Thus, when c=-1, the frequency distribution is uniform between individual fish of different sizes; if c<-1, the frequency of smaller individuals is higher than large individuals; if c>-1, the frequency of large individuals is greater that smaller individuals. The Pareto model was fitted by non-linear regression using the least squares method. The possible effects of reservoir operation regime on the biomass spectra of fish assemblages were assessed using paired t test, both using the software Statistica 7.1® (Stat Soft, 2005). Results were considered significant at P<0.05.

Results

The slopes of the biomass spectra of fishes observed in each reservoir indicated that reservoirs Foz do Areia (storage), Salto Santiago (storage), Salto Osório (run of river) and Vossoroca (storage) tended to have higher concentrations of small individuals (c<-1), while Segredo (run of river) show equal distribution between large and small (c~-1). Salto do Meio (run of

Table 2. Species collected from January 2005 to December 2007 at six neotropical reservoirs and their respective abundances (FA=Foz do Areia, SE=Segredo, SS=Salto Santiago, SO=Salto Osório, VO=Vossoroca and SM=Salto do Meio).

TAXON	Common Name	FA	SE	SS	SO	VO	SM
Atheriniformes							
Odontesthes bonariensis (Valenciennes, 1835)	"Peixe-rei"	-	174	282	30	-	-
Characiformes							
Apareiodon vittatus (Garavello, 1977)	"Canivete"	67	716	88	294	-	-
Astyanax altiparanae Garutti & Britski, 2000	"Tambiú"	33	28	331	38	61	61
Astyanax bifasciatus Garavello & Sampaio, 2010	"Lambari-do-rabo-vermelho"	13902	2100	5270	1812	-	-
Astyanax dissimilis Garavello & Sampaio, 2010	"Lambari"	647	24	12	7	-	-
Astyanax gymnodontus (Eigenmann, 1911)	"Lambarizão"	184	256	1047	265	-	-
Astyanax janeiroensis (Eigenmann, 1908)	"Lambari-do-rio"	-	-	-	-	-	4
Astyanax longirhinus Garavello & Sampaio, 2010	"Lambari"	4	2	-	-	-	-
Astyanax minor Garavello & Sampaio, 2010	"Lambari-do-rabo-amarelo"	1651	1363	4100	292	-	-
Astyanax serratus Garavello & Sampaio, 2010	"Lambari"	7	-	-	-	-	-
Bryconamericus ikaa Casciota, Almirón & Azpelicueta, 2004	"Lambarizinho"	206	529	18	10	-	-
Bryconamericus pyahu Azpelicueta, Casciotta & Almirón, 2003	"Lambarizinho"	2	-	-	-	-	-
Characidium sp.	"Charutinho"	4	-	-	-	-	-
Cyphocarax santacatarinae (Fernández-Yépez, 1948)	"Saguaru"	4	-	-	-	-	-
Deuterodon iguape Eigenmann, 1907	"Lambari"	-	-	-	-	2265	1475
Deuterodon sp. A	"Lambari"	-	-	-	-	1262	384
Deuterodon sp. D	"Lambari"	-	-	-	-	12413	460
Hoplias malabaricus (Bloch, 1794)	"Traíra"	180	24	-	-	213	165
Hoplias aff. malabaricus (Bloch, 1794)	"Traíra"	-	-	38	18	-	-
Leporinus elongatus (Valenciennes, 1850)	"Piapara"	3	-	-	-	-	-
Leporinus friderici (Bloch, 1794)	"Piau"	2	-	-	-	-	-
Leporinus macrocephalus (Garavello & Britski, 1988)	"Piauçu"	-	-	-	-	-	-
Leporinus obtusidens (Valenciennes, 1837)	"Piau"	4	-	-	-	-	-
Leporinus octofasciatus (Steindachner, 1915)	"Piau-listrado"	2	-	-	-	-	-
Leporinus sp.	"Piau"	-	-	-	1	-	-
Oligosarcus longirostris Menezes & Géry, 1983	"Saicanga"	1372	262	256	306	-	-
Prochilodus lineatus (Valenciennes, 1837)	"Corimba"	116	-	-	-	-	-
Salminus brasiliensis (Cuvier, 1816)	"Dourado"	1	-	-	-	-	-
Serrapinnus sp.	"Piabinha"	-	-	-	-	-	1
Cypriniformes							
Cyprinus carpio (Linnaeus, 1758)	"Carpa-comum"	5	2	2	-	1	-
Hypophthalmichthys nobilis (Richardson, 1845)	"Carpa-cabeça-grande"	1	-	-	-	-	-
Gymnotiformes							
Gymnotus inaequilabiatus (Valenciennes, 1839)	"Morenita"	6	2	1	-	-	-
Gymnotus sylvius (Albert & Fernandes-Matioli, 1999)	"Morenita"	2	-	-	-	-	-
Perciformes							
Australoheros kaaygua (Casciotta, Almirón & Gómez, 2006)	-	3	-	-	-	-	-
Australoheros sp.	"Acará"	-	-	-	-	-	2
Crenicichla iguassuensis (Haseman, 1911)	"Joaninha"	69	122	27	30		
Crenicichla sp.	"Joaninha"	17	15	6	14		
Geophagus brasiliensis (Quoy & Gaimard, 1824)	"Cará"	227	168	50	15	842	260
Micropterus salmoides (Lacepède, 1802)	"Boca-grande"	-	-	-	-	77	8
Oreochromis niloticus (Linnaeus, 1758)	"Tilápia-do-nilo"	1	3	1	-	-	-
Tilapia rendalli (Boulenger, 1897)	"Tilápia"	17	24	4	3	136	1
Siluriformes							
Ancistrus sp.	"Cascudo-roseta"	4	3	-	-	-	-
Corydoras ehrhardti (Steindachner, 1910)	"Limpa-fundo"	-	-	-	-	53	26
Corydoras paleatus (Jenyns, 1842)	"Limpa-fundo"	889	1072	540	133	1	-
Glanidium ribeiroi (Haseman, 1911)	"Bocudo"	26	93	4	18	-	-
Hypostomus ancistroides (Ihering, 1911)	"Cascudo-pintado"	-	-	-	-	2	2
Hypostomus aspilogaster (Cope, 1894)	"Cascudo"	-	-	-	-	1	-
Hypostomus boulengeri (Eingenmann & Kennedy, 1903)	"Cascudo"	-	-	-	-	-	1
Hypostomus commersoni (Valenciennes, 1836)	"Cascudo"	80	223	13	2	88	30
Hypostomus derbyi (Haseman, 1911)	"Cascudo"	36	73	4	9	-	-
Hypostomus myersi (Gosline, 1947)	"Cascudo"	7	6	1	2	-	-
Hypostomus sp. 1	"Cascudo"	-	-	-	-	-	3
Hypostomus sp. 2	"Cascudo"	-	-	-	-	-	1
Isbrueckerichthys sp.	"Cascudinho"	-	-	-	-	-	1
Pimelodus britskii Garavello & Shibatta, 2007	"Mandi-pintado"	1024	1397	-	-	-	-
Pimelodus ortmanni Haseman, 1911	"Mandi-pintado"	44	181	459	685	-	-
Pseudoplatystoma corruscans (Spix & Agassiz, 1829)	"Pintado"	-	-	-	-	-	1
Rhamdia branneri Haseman, 1911	"Bagre, jundiá"	3	5	1	7	-	-
Rhamdia quelen (Quoy & Gaimard, 1824)	"Bagre-amarelo"	-	-	-	-	30	42

Table 2. Continued.

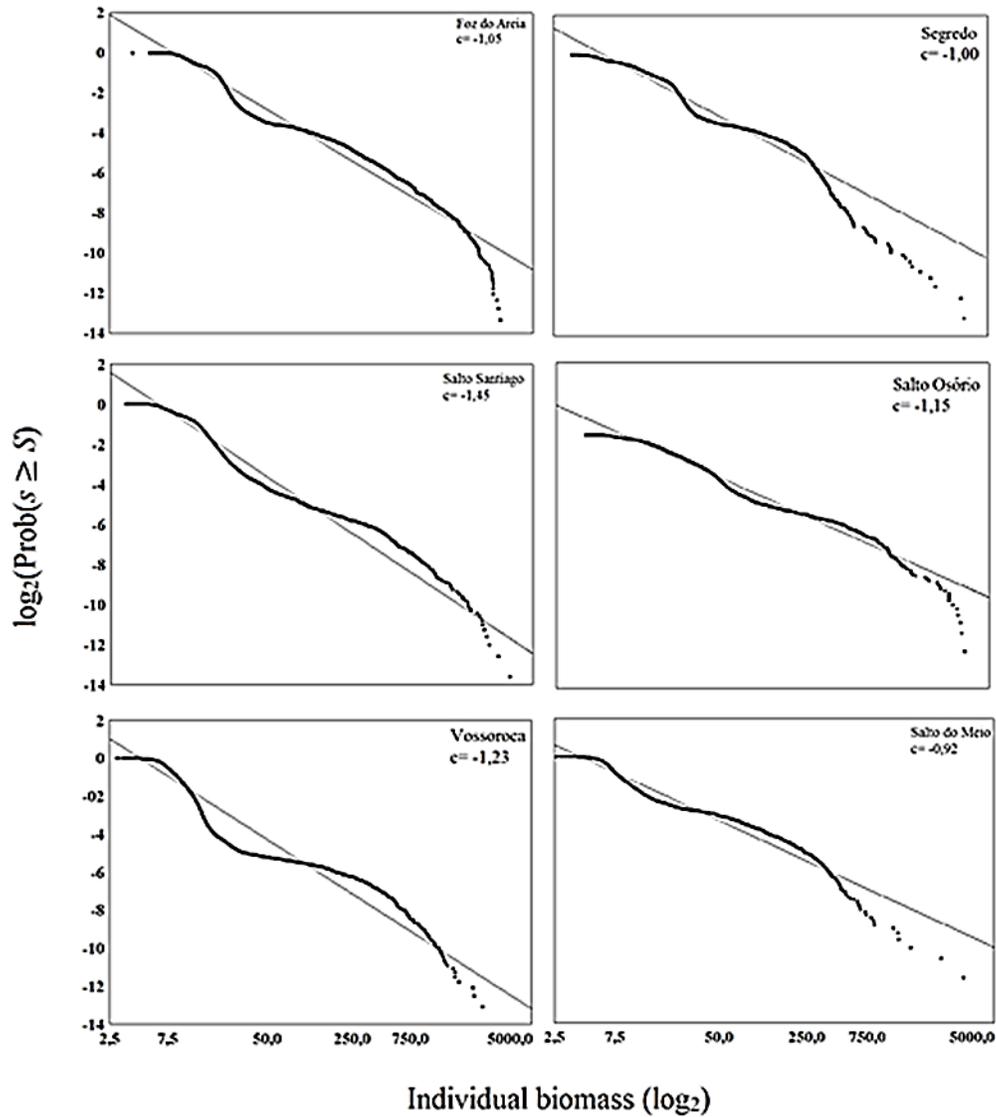| TAXON	Common Name	FA	SE	SS	SO	VO	SM
Rhamdia voulezi Haseman, 1911	"Bagre, jundiá"	34	18	4	2	-	-
Rineloricaria sp.	"Cascudo-espada"	-	-	-	-	237	259
Steindachneridion melanodermatum (Garavello, 2005)	"Surubim"	-	1	-	-	-	-
Tatia jaracatia Pavanelli & Bifi, 2009	"Bagre-sapo"	-	-	-	1	-	-
Total Richness		**40**	**29**	**26**	**25**	**16**	**21**

Figure 3. Size spectra of fish assemblages in the studied reservoirs, adjusted using the Pareto type I model.

river), showed a higher proportion of large individuals ($c > -1$) (Fig. 3). The reservoirs operated under run-of-river regime had significantly higher values than did those operated under storage regimes (paired t test: $t = 3.777$, $P = 0.032$).

Discussion

The results indicated differences in size spectra of fish assemblages among the sampled reservoirs. Here, abiotic events that could to determine some relationships between body size distributions and the environment were not evaluate. However, the physical characteristics differences were considered in each reservoir and how these aspects can change the communities and to provide some information about ecological processes which regulate these environments.

Fluctuations in reservoir water level due to

accumulation operating regime cause flooding of bank areas considered critical for fish feeding (Hahn et al., 1998) and may act as a disturbance factor, altering the structure and stability of fish assemblages (Tundisi et al., 2003). The increase in nutrients from the decomposition of flooded vegetation provides an increase in primary productivity, and a consequent increase in smaller sized individuals. According to Agostinho et al. (2001), flooding may favor juveniles and may thus influence the size distribution patterns. The success of higher proportions of small individuals in accumulation regime reservoirs possibly is likely due to fluctuations in water level that provide better conditions for some species. For example, the genus *Astyanax* have adhesive eggs (Sato et al., 2006) and fractional spawning (Agostinho, 1999), facilitating the use of margin areas as sites for spawning and juvenile shelter when the reservoir contains abundant water (i.e., high water level). When the opposite occurs, that is, lower water level, the edges and vegetation are exposed and there is a tendency toward increased turbidity, which reduces the visibility for piscivorous fish and consequently, decreases predation rate (Robertis et al., 2003).

Important ecological interactions and physiological processes in aquatic ecosystems are dependent on body size (e.g., mortality, transfer efficiencies, metabolism and growth) (Kerr and Dick, 2001). Consequently, researchers have been incorporating biomass spectrum theory into models designed to estimate size-dependent ecological processes. For example, Benejam et al. (2015) examined the effect of land use on the size structure of fish communities in subtropical streams. Van der Lee and Koops (2015) investigated correlations between body size of fish with habitat loss. Jennings et al. (2002) quantified trophic transfer efficiencies using a combination of biomass spectrum data and production-body size and trophic level-body size relationships. Furthermore, the current understanding of regulatory processes and trophic dynamics of aquatic ecosystems has been focused on ecological studies (Jansson et al., 2007; Shin and Cury, 2004) and approaches using body size have been used to primarily to provide information

concerning conservation of aquatic environments (Petchey and Belgrano, 2010), trophic structure, and biotic interactions in fish assemblages (Emmrich et al., 2011; Jennings et al., 2001). In this sense, body size is crucial for predicting responses to energy flow, species diversity and population densities (Layman et al., 2005).

From an ecological point of view, trophic dynamics are highly sensitive to environmental disturbances resulting from fluctuations in water level (Tundisi et al., 2003), and these changes are key components for the reorganization of fish assemblages for which feeding grounds and reproduction are affected (Agostinho et al., 2007). Although reservoirs are dominant components of hydrological landscapes, studies of the effects of operating regime on biomass spectra are scarce, making it difficult to make inferences regarding size distribution and energy flow in communities. Besides that, others factors can be associate to the differences in sizes distributions. The size of individual in ecological community is affected by many kinds of processes, for example, environmental changes, species invasion and management (Petchey and Belgrano, 2010). According to metabolic theory of ecology, a greater part of variation among organisms, including their ecological roles and life history, is limited by their body sizes, chemical composition and operating temperatures (Brown et al., 2004).

This study has elucidated some impacts of reservoir operating regime on the size distributions and this suggests that energy transfer occurs more efficiently through fish fauna in reservoirs with lower fluctuations in water level, such as run-of-river regimes. However, more researches is needed to unreavel relationships between body size distributions and the ecological processes regulating the energy flow in reservoirs. In addition, researches which consider abiotic factors and others relevant aspects are need considering the acceleration of transformations at the landscape caused by impoundments. Finally, it is important to incorporate management plans that take dam operating mode into account so that conservation of aquatic fauna, especially fish, is more

effective.

Acknowledgments

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