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Tendency towards homogenization in fish assemblages in the cascade reservoir system of the Tietê river basin, Brazil

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A B S T R A C T

Measurements of biotic homogenization are important for ascertaining the nature and extent of human impacts on biodiversity, especially in relation to habitat alteration, species introductions and water quality degradation. All of these impacts are typical of impounded systems. Our objectives in this study were to investigate the increasing biotic homogenization and the impacts of introduced species in the Tietê cascade reservoir system (State of São Paulo, Brazil). Biotic homogenization is the replacement of local biota by non-indigeonous species, leading to a gradual increase in biotic similarity over time. In this study, the decades analyzed (1980–89, 1990–99 and 2000–2009), revealed the progressive loss of the native species in the system. We used Jaccard's coefficient to measure the changes in biotic homogeneity across decades. In the first comparison (2000s vs. 1980s), the predominant process observed was differentiation, meaning that the biotic assemblages, in the sequence of five reservoirs studied, became more dissimilar. These changes were related to the extirpation of common species from reservoirs. In the second comparison period (2000s vs. 1990s), we observed a tendency towards biotic homogenization, meaning that the number of species in common among reservoirs was increasing. This shift was related to the loss of unique native species and the progressive environmental maturation of each reservoir. The process of homogenization may continue as the reservoirs age and as introduced fish species are dispersed and native species are displaced. For example, we observed the replacement of *Geophagus brasiliensis* (native) by *Geophagus surinamensis* (non-native) in the downstream reservoirs, likely due to the introduction of non-native predators *(Cichlidae* spp.).

1. Introduction

The morphological, physiochemical and biological characteristics of cascade reservoirs, combined with anthropogenic hydraulic management and water uses, make these systems extremely complex (Tundisi and Straškraba, 1999). Furthermore, the downstream reservoirs are affected by the characteristics of the reservoirs farther upstream. Consequently, at basin scale, spatial and temporal changes in the fish species assemblages are not easily predictable. The principal impacts of impoundment are related to the progressive erosion of biodiversity, the introduction of alien species and the replacement of native species. Reservoirs are an ideal pathway for the dispersal of non-indigenous species (Havel et al., 2005), allowing them to spread throughout the river basin from the single point of introduction at the impoundment. Human activities facilitate the establishment of non-native species by disturbing the natural landscape and increasing the "propagule pressure" (Leprieur et al., 2008), intending with this term the total number of non-native individuals introduced. Lockwood et al. (2009) affirms that propagule pressure is related to the concept of "minimum viable population size" in conservation biology. The loss of longitudinal connectivity in impounded rivers the most affects native species, while the diffusion of alien species is facilitated by their own biological traits and by humans. The introduced species are, in general, opportunistic and tolerant of a wide range of environmental conditions. They are characterized by great environmental adaptability including reproductive strategies (e.g., pelagic eggs, parental care and partial deposition). These traits promote their establishment and spread into the novel environment, making them extremely invasive. Non-native species are thus frequently responsible for the loss of native species, pathogen introduction and habitat structure modifications that disrupt the function of the invaded ecosystem and cause economic losses to humans (Clavero and García-Berthou, 2005; Ricciardi, 2007). For these reasons, the dynamics and causes of changes in fish species assemblages are currently the subjects of pressing scientific inquiry. Such studies are a prerequisite for

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the establishment and implementation of policies pertaining to conservation or management of aquatic ecosystems.

In its medium-low course, the Tietê river basin has a sequence of six cascade reservoirs built to generate hydroelectric power. The cascade system impact was high and responsible for biodiversity loss, the introduction of non-native species, hydraulic alterations and structural habitat changes. As expected, the changes in the fish assemblages that resulted from the impoundment consistently included the disappearance of the large migratory species (*Pseudoplatystoma corruscans*, *Salminus brasiliensis*, *Zungaro zungaro*) and those intolerant or not pre-adapted to lentic conditions (several species of *Astyanax* sp., *Hypostomus* sp. and *Leporinus* sp.) (Agostinho et al., 1999, 2007; Fernando and Holcik, 1991). In the 1980s, intending to compensate for this impact, CESP (Companhia Energetica de São Paulo), then an electricity company in São Paulo State, deliberately introduced several non-native species of commercial interest (*Pterygoplichthys anisitsi*, *Tilapia rendalli*, *Oreochromis n. niloticus*, *Plagioscion squamossissimus*, *Cyprinus carpio* and *Cichla* spp.). Others, such as *Triportheus nematurus* and decapod crustaceans (*Macrobrachium* sp.), were introduced to facilitate the establishment of their non-native predators (Magalhães et al., 2005; Torloni et al., 1993a). Some introductions were accidental, as with *Astronotus ocellatus*, *Metynnis maculatus*, *Hyphessobrycon eques*, *Hoplosternum littorale* and probably of *Geophagus surinamensis* and *Satanoperca jurupari*, or resulted from the actions of sport fishers, as in the case of *Micropterus salmoides*.

The profound alteration suffered by the river ecosystem in the last 50 years focused our interest to investigate (i) the transformation of the fish assemblages throughout the cascade system over time and (ii) the effects of the introduced species on the native assemblages. Our first objective was to characterize the system in terms of biotic homogenization, the increasing similarity between assemblages over time. Biotic homogenization results from the extirpation of unique species from otherwise similar assemblages or from the introduction of non-native species to otherwise different assemblages (Rahel, 2002). Homogeneity is considered a more useful metric than diversity for evaluating environmental quality because diversity is unaffected or tends to increase as a consequence of the introduction of more environmentally tolerant species. To investigate the effect of introduced species, we examined the cases of the native species *Geophagus brasiliensis* and *Pimelodus maculatus*, both of which have current distributions and abundances that are markedly different than those in the historical records.

1.1. Study site

Listed in longitudinal order from upstream to downstream, the reservoirs in the cascade system of the Tietê river basin are Barra Bonita, Bariri, Ibitinga, Promissão, Nova Avanhandava and Três Irmãos (Fig. 1). The upper five reservoirs are managed by the AES-Tietê electricity company and were the subjects of our study. The system is used primarily for the production of electricity and shipping of agricultural products and secondarily for public and industrial water provisioning, disposal of domestic and industrial sewage, irrigation and fishing. The principal morphological and hydrological features of the reservoirs, along with years of construction and power-generating capacity, are summarized in Table 1. Based on area and volume classification the reservoirs, with the exception of Bariri, are of medium size (Straškraba, 1999). The sinuosity index (SI) is high, meaning that all the reservoirs have a shape far from a circle. They are dendritic, due to the presence of many tributaries and Promissão reservoir is the deepest ($\bar{z} = 15.30$m) and largest of the study sequence. The average retention time varies from 16 (Bariri) to 135 (Promisão) days.

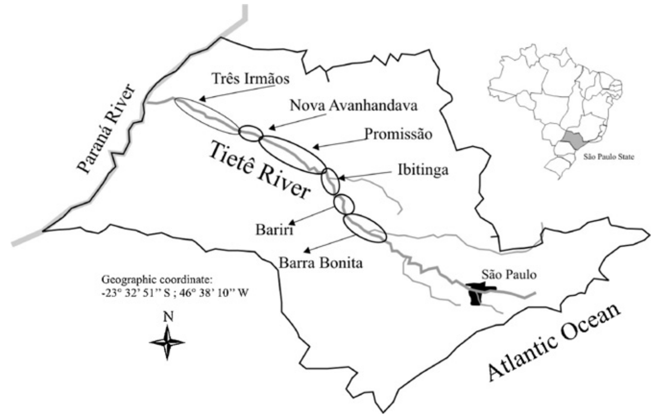

Fig. 1. Study area in the Tietê cascade reservoir system, State of São Paulo, Brazil.

The Yearly Maximum Range Index (YMXR), representative of the difference between maximum and minimum water levels during the year (Cohen and Radomski, 1993), allows their aggregation in two groups: those with high YMXR (Barra Bonita and Promissão) and those with low YMXR (Bariri, Ibitinga and Nova Avanhandava). The former group, apart from the hydroelectric production, act as storage reservoirs for great volumes of water to be used to assure normal hydroelectricity production in the entire cascade system over a year. On the contrary, the second group is used for hydroelectric production only. The hydraulic management compromises the recruitment and productivity of the fish assemblages in the two groups of reservoirs. The operation of Barra Bonita and Promissão power stations, affects the synchrony between reproductive cycles of native species and flooding phase (Bailly et al., 2008; Vazzoler and Menezes, 1992) while, the operation of the Bariri, Ibitinga and Nova Avanhandava power plants affect the availability of food, shelter and adequate substrate as nursery habitat (Bunn and Arthington, 2002).

The water quality in the cascade system improves in the downstream direction (Barrella and Petrere, 2003) because the most significant sources of pollution (the metropolitan and industrial area of São Paulo capital city) are far upstream, close to the Barra Bonita reservoir. In particular, the auto-depuration and sedimentation of suspended particles, improve the levels of dissolved oxygen and water transparency in the downstream reservoirs (Barbosa et al., 1999), allowing the gradual change of the macrophytes community from floating and emergent (Barra Bonita and Bariri) to submerged (Ibitinga, Promissão and Nova Avanhandava reservoir) (Carvalho et al., 2005).

Land use near the reservoirs is principally devoted to agriculture, especially sugar cane and pasture.

2. Materials and methods

Considering the radical habitat transformation due to the impoundment and the absence of ichthyologic surveys before the dams' construction, the analyses were conducted in three temporal phases: the 1980s, 1990s and 2000s. The 1980s and 1990s are considered to be representative of the "original" (historical) pool of species present in the area in the initial and intermediate phases, respectively, corresponding to the beginning of the impoundment. Non-native species were excluded from these pools, while the native species in the 2000s were included in accordance with Rahel (2000) and Marchetti et al. (2001, 2006). The 2000s species list included both native and introduced species sampled in the present study. Previously published data were used for to compile the species lists for the historical phases (1980s and 1990s): Torloni