

LONG-TERM CHANGES ON THE STRUCTURE OF FISH ASSEMBLAGES IN THE LOBO-BROA RESERVOIR, UPPER PARANÁ RIVER ECOREGION, BRAZIL

SANCHEZ, A. L.^{1*}; MATSUBARA, K. G.² & ESPÍNDOLA, E. L. G.¹

1. Universidade de São Paulo-USP, Escola de Engenharia de São Carlos, Núcleo de Ecotoxicologia e Ecologia Aplicada, Programa de Pós-Graduação em Ciências da Engenharia Ambiental, São Carlos, SP, Brasil.

2. Universidade de São Paulo-USP, Escola de Engenharia de São Carlos, Departamento de Hidráulica e Saneamento, Programa de Pós-Graduação em Engenharia Hidráulica e Saneamento, São Carlos, SP, Brasil.

*Corresponding author: andrejimbio@yahoo.com.br

ABSTRACT

Sanchez, A. L.; Matsubara, K. G. & Espíndola, E. L. G. (2018). Long-term changes on fish assemblages. *Braz. J. Aquat. Sci. Technol.* 22(1). eISSN 1983-9057. DOI: 9516/bjast.v22n1. The freshwater fishes are threatened by anthropic disturbances. Modification of natural patterns of fish biodiversity are often coincident with the environmental degradation, introductions of non-native species and the biotic homogenization. Our study investigated the trends of a retrospective analysis and the changes on the structure of fish assemblages in a tropical reservoir. To attempt it, information between the 1970's to 2010's decades of Lobo-Broa reservoir were compiled, integrating long-term environmental data. The results obtained suggest the composition of species had an increase in similarity, being referred as a biotic homogenization process. Thus, the species with higher constancy of occurrence became constant, reflecting an increased constancy of opportunistic species with a declining number of native species. In conclusion, our study reported the anthropic impacts on local fish assemblages' changes and homogenization that can increase species extinction risk. This long-term environmental monitoring is an important alert about the ecological risks and uncertainties posed by anthropic disturbances, supporting the development of fishery policy and management on the regional and global conservation.

Key Words: Ichthyofauna monitoring; Environmental degradation; Biological invasion; Biotic homogenization; Tropical reservoir.

INTRODUCTION

The concern about biodiversity loss underscores the need to quantify and understand the temporal changes (Dornelas et al., 2012). Long-term datasets can be used for multiple applications in monitoring and conservation of biological diversity, identifying the potential drivers and targets of changes (Magurran et al., 2010). These integrated retrospective data have clarified where are the most vulnerable species and where and how human change the ecosystems (Pimm et al., 2014).

For freshwater ecosystems the effects of anthropogenic activities are associated with the degradation of physical habitat condition and the discharge of contaminants (Allan & Flecker, 1993). The major drivers for fish ecology are identified as habitat loss, hydrologic modification, water pollution, and introduction of non-native species (Mota et al., 2014). Indeed, the introductions of non-native fish species are often coincident with the anthropogenic modification of natural habitats and understanding its pathways and impacts are important for helping prevent new introductions and invasions (Garcia et al., 2017).

In this sense, most native species are declining

because of this environmental disturbance and are being replaced by a much smaller number of expanding non-native species that thrive in human-altered environments (McKinney & Lockwood, 1999). This process reduces regional differences among biota, being referred as biotic homogenization (Rahel, 2000). The introduction of non-native species and their subsequent invasions of adjacent areas are considered as major agents of biotic homogenization (Daga et al., 2016). Therefore, the homogenization extends across all levels of biological organization and may have a synergistic integration with many aspects of the current global environmental crisis (e.g. Rahel, 2007; Olden et al., 2010; Vitule et al., 2011; Daga et al., 2015).

Thus, it is apparent that the aquatic ecosystems of Lobo-Broa reservoir, as well as the Upper Paraná freshwater ecoregion, has been heavily modified due to a range of multiples mechanisms involved to anthropic perturbation. Limnology reports pointed about the damage on its aquatic biodiversity from biotic and abiotic sources (e.g. Pereira et al., 2008; Tundisi & Matsumura-Tundisi, 2014; Rodrigues-Filho et al., 2015; Tundisi et al., 2015). Rodrigues-Filho et al. (2015) reported the multiple land uses influence the water bodies and their quality. In this context, the reservoir

is characterized by the accelerated eutrophication. The alteration of the diffuse nutrients input, sediment, pesticides and pathogens are associated with some intensive agricultural practices (Scanlon et al., 2007), deforestation (Ferreira et al., 2015), and urbanization (Clements et al., 2010). These effects have accelerated the rate and extent of eutrophication process through loadings of nutrients into aquatic ecosystems (Chislock et al., 2013).

The introduction of non-native species and the extirpation of native populations have resulted in significant changes in freshwater fish faunas at regional and global scales (Olden et al., 2010). Here, the aim of this study is to demonstrate the historical trends and the changes on the structure of fish assemblages in a tropical reservoir. We contrasted changes across the periods between 1975 and 2011, integrating the long-term environmental data. The fish available studies were compared with the similarities and dissimilarity and determined which of the species contribute most to the changes. We predicted that fish assemblages organization over the years was drive by the anthropic alteration and the process of biotic homogenization on reservoir.

MATERIALS AND METHODS

Study area

This research was conducted in a lentic ecosystem, which is part of the Lobo watershed, the Lobo-Broa reservoir. It was built in a tributary of the Jacaré Guaçu River (central portion of the state of São Paulo, Southeastern Brazil). It is located on the right bank of the Tietê River of the Upper Paraná River ecoregion, on the Water Resources Management Unit of the Tietê/Jacaré. This region (22°15'S and 47°49'W; 940m maximum altitude) includes the municipalities of Itirapina and Brotas, and is inserted in the Environmental Protection area of the Corumbataí, Botucatu and Tejuπά (Chalar & Tundisi, 1999). The hydrographic network is mainly formed by the damming of the Itaqueri and Lobo rivers, besides the tributaries streams Limoeiro, Água Branca, Geraldo and Perdizes (Figure 1). The reservoir is shallow (mean depth 3m), short retention time (less than 20 days) and with a drainage area of 230km² (Tundisi & Matsumura-Tundisi, 2014).

The reservoir can be divided into three regions: 1 - lacustrine (deeper and closer to the dam), 2 - median (with greater influence of one of the tributaries, which is used for recreation) and 3 - upstream (downstream of Itaqueri and Lobo rivers, with greater amounts of aquatic macrophytes). The soil in the area is sandy with fertile patches due to the presence of basalt (Tundisi & Matsumura-Tundisi, 2014). According to Köppen

(1948), the region climate is considered Cwa mesothermal subtropical, being controlled by the equatorial and tropical air masses, with two distinct seasons, dry (May to October) and a wet or rainy (November to April) (Tundisi & Matsumura-Tundisi, 2014). In addition to energy production, the reservoir has been used for recreation and sport fishing, besides that urbanization process have been established in the last decade.

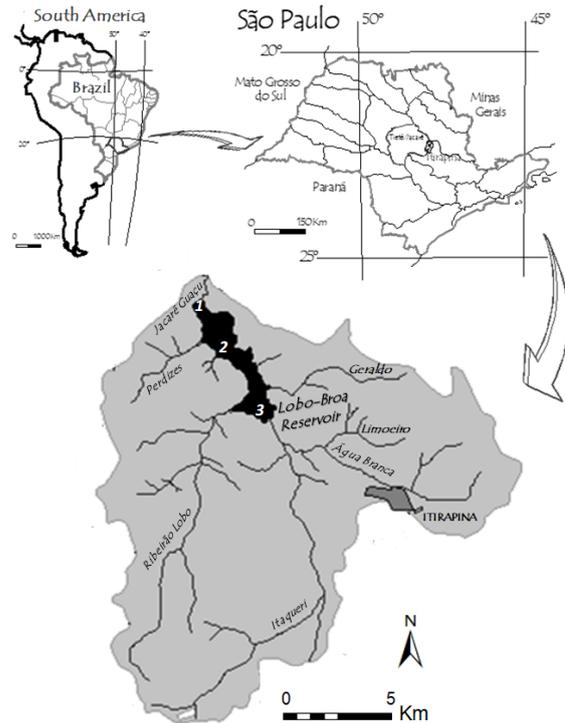


Figure 1 - Study area map and the Tietê/Jacaré Water Resources Management, with emphasis on the Lobo Watershed. The following elements are identified: the lotic zones of streams and tributaries and the limnetic zone of the Lobo-Broa reservoir with the sampling localities, 1 - lacustrine region (22°17'02"S; 47°90'45"W), 2 - middle region (22°19'12"S; 47°89'59"W) and 3 - upstream region (22°21'32"S; 47°87'90"W).

The Lobo-Broa reservoir demonstrated an accelerated chemical degradation process evidenced by the historical data of dissolved phosphorus concentration, a-Chlorophyll levels and reservoir trophic state index since the 1970's to the early decades of the 2010's (Figure 2). Water samples were collected and kept on ice for laboratory analysis of dissolved phosphorus concentration ($\mu\text{g.L}^{-1}$), total phosphorus ($\mu\text{g.L}^{-1}$) and a-Chlorophyll ($\mu\text{g.L}^{-1}$) (Freitas, 2012). The levels of dissolved phosphorus concentration had increase from 1972 ($9\mu\text{g.L}^{-1}$) to 2010 ($30\mu\text{g.L}^{-1}$) and an increase of a-Chlorophyll levels from 1972 ($5\mu\text{g.L}^{-1}$) to 2010 ($33\mu\text{g.L}^{-1}$). For the trophic state index, calculated using the total phosphorus, the reservoir changed the condition of oligotrophic-mesotrophic to hipereutrophic. This degradation was mainly related to increased nu-

trient input the aquatic system.

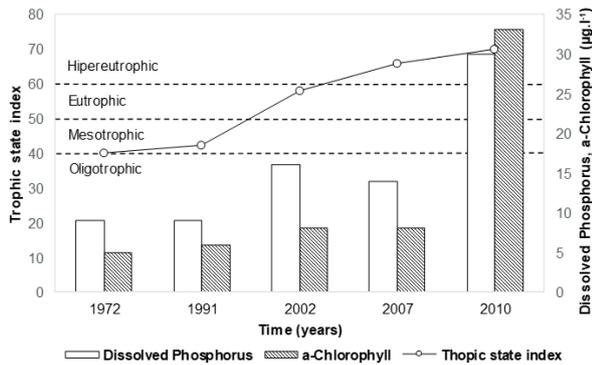


Figure 2 - Lobo-Broa reservoir dissolved phosphorus concentration, a-Chlorophyll and the reservoir trophic state index timeline between the 1970's to 2010 decades, mean results for dry and rainy periods, characterizing the serious accelerated eutrophication in the locality over the years (modified from Freitas, 2012).

Fish data and sampling

To characterize the structure of fish assemblages in the Lobo-Broa reservoir over the years, were used the historical data available in thesis, scientific papers and books. The analysis was compiled by the data of Albino (1987), Marinelli (2002), Pereira (2005), Fragoso et al. (2005) and compared with the present study. These works compose the main data of fish assemblages' studies conducted in the locality with through gill nets. Therefore, the sampling spans from 1975 to 2011.

Fishes were collected using gill nets of different mesh sizes (3.0, 4.0, 6.0, 8.0, 10, 12 and 14 cm between opposite knots) in the lacustrine, middle and upstream region of the Lobo-Broa reservoir (Figure 1). Gill nets were maintained for 24 hours at the sampling points. They were placed early in the morning and were replaced in the morning after (Albino, 1987).

The Albino's sampling was conducted in 1987 from a compilation of species listed by the technical staff of the Department of Biological Sciences, Federal University of São Carlos between 1975-1984. Nevertheless, his work does not provide detail of sampling information such as the time of the year, frequency and total samples taken. The sampling of Marinelli (2002) conducted in March and August 2000. Pereira (2005) sampled in November 2002, June and September 2003, and January, March, July and September 2004. Fragoso et al. (2005) conducted a sampling from January to November 2003. The present study the samples were conducted in April, July and October 2010 and January 2011 during the dry, rainy and intermediate seasons.

This analysis process and data extraction provided a list of long-term fish data into Lobo-Broa reser-

voir. The species fish list was updated and compared with "Check list of the freshwater fishes of South and Central America" (Reis et al., 2003) and Fishbase. The voucher species were deposited in the fish collection of Ecotoxicology and Applied Ecology Center, University of São Paulo, Brazil and Department of Biological Sciences, Federal University of São Carlos, Brazil.

Data analysis

Species constancy indices were calculated and classified according to Dajoz (1978), following the formula: $Ic = n / N$. Where n: number of samples in which a species was collected; N: total number of samples, with species being considered constant $50 \leq Ic < 100$, accessory $Ic \leq 25 < 50$ or accidental $0 < Ic < 25$.

Additionally, the quantitative fish data in the present study were expressed in catch per unit effort (CPUE), using the formula: $CPUE = \text{individuals number} / \text{gill net area (m}^2\text{)} * \text{hours in the water}$. The total sampling fishing effort was $115.2 \text{ m}^2 \times 24 \text{ hours}$.

The change in similarity between historical ichthyofauna studies was based on Jaccard's coefficient of similarity (Krebs, 1989). The clustering was calculated by the unweighted pair-group average of the presence-absence species data. To test whether treatments differed statistically in their dissimilarities, the decades groups studies, defined in the cluster analysis, were conducted a permutational multivariate analysis of variance (PERMANOVA) (Warton et al., 2012).

The PERMANOVA is a technique that is widely used for simultaneously testing the response of multivariate abundances to one factor. The PERMANOVA used a presence x absence matrix, being the significant p-value can arise because treatments differ in their dissimilarity, or in their within-treatment dissimilarity, or both. The permutational analysis of multivariate dispersions (PERMDISP) employed to discern whether the dispersions in the composition dissimilarities among the years differed in their within-treatment. PERMDISP use F statistics to compares among-group differences in the distance from observations to their group centroid and the significances are tested via permutations of least-squares residuals (Heino, 2013). Then, similarity percentage analysis (SIMPER) was employed to determine which of the species contribute most to the similarities and dissimilarity. All these calculations was calculated by PERMANOVA+ for Primer v6 software package (Clarke & Gorley, 2006).

RESULTS

The ichthyofauna of Lobo-Broa reservoir, sampling from 1975 to 2011, resulted in 19.519 individuals, distributed in 28 species, 13 families and 4 orders

(Table 1). With respect to the presence of species in the various sampling, five species were present in only one sample (*O. pintoi*, *Leporinus sp.*, *P. lineatus*, *C. iheringi* and *C. paranaense*), one species in two samples (*S. heterodon*), three species in three samples (*C. modestus*, *C. carpio* and *P. meeki*), six species in four samples (*A. fasciatus*, *H. malabaricus*, *H. unitaeniatus*, *H. littorale*, *C. kelberi* and *O. niloticus*) and 6 species were common to all studies (*A. altiparanae*, *L. friderici*, *R. quelen*, *H. ancistroides*, *C. rendalli* and *G. brasiliensis*).

The fish studies were cluster according to Jaccard's coefficient of similarity into three distinct groups (1970/1980's, 2000's and 2010's decades) (Figure 3). The species with highest constancy values among the studies were *A. altiparanae*, *A. fasciatus*, *H. ancistroides*, *C. rendalli*, *O. niloticus*, *G. brasiliensis* and *C. kelberi*. For the constancy indices, there was an increasing trend for the constant species listed during sampling and a decreasing trend for the accessory and accidental species.

The PERMANOVA showed that the abundance did not differed significantly between the decades groups ($F=5.02$, $p\text{-value}=0.089$). The average distance to the group centroid based on assemblage dissimilarities also not differed between the groups decades

(PERMADISP, $F=5.64$, $p\text{-value}=0.286$). The pairwise comparisons tests between the decades groups also not differed (PERMADISP, $t_{1970/1980s-2000s} = 2.655$, $p\text{-value}=0.502$; $t_{2000s-2010s} = 2.655$, $p\text{-value}=0.484$).

The SIMPER analysis revealed that the most contribute to the similarities within the decades groups (Table 2). For 2000's grouping with 74.23% similarity were *G. brasiliensis* (12.75%), *C. modestus* (12.75%), *A. altiparanae* (12.03%), *H. malabaricus* (10.88%), native species, followed for *O. niloticus* (10.96%) and *C. rendalli* (8.06%), non-native species. The results show the dissimilarity between the decades groups. For the 1970/1980's and 2000's groups with 63.60% dissimilarity were *C. modestus* (11.48%) and *H. unitaeniatus* (8.12%), native species, *O. niloticus* (10.57%) and *C. kelberi* (8.07%), non-native species. In relation to the 1970/1980's and 2010's groups with 56.40% dissimilarity were *O. pintoi* (15.04%), *H. unitaeniatus* (11.28%) and *A. altiparanae* (7.52%), native species, *O. niloticus* (7.52%) and *C. kelberi* (7.52%), non-native species. And for the 2000's and 2010's groups with 36.87% dissimilarity were *O. pintoi* (14.3%), *C. modestus* (14.3%), *H. malabaricus* (12.98%) and *R. quelen* (6.32%), native species, *O. niloticus* (6.07%), non-native species.

Table 1 - Ichthyofauna list with orders, families, origin and the index values of constancy of species classified as constant (CT), accessory (AS) or accidental (AD) in the Lobo-Broa reservoir between the 1970's to 2010's decades. The results show the fish data of Albino (1987), Marinelli (2002), Pereira (2005), Fragoso et al. (2005) and the present study. The quantitative fish data in the present study were expressed in CPUE.

Species	Origin	Albino, 1987	Marinelli, 2002	Pereira, 2005	Fragoso et al., 2005	Present study	CPUE
Characiforms							
Characidae							
<i>Astyanax altiparanae</i> Garutti and Britski, 2000	Native	0.50 (CT)	0.92 (CT)	1.0 (CT)	1.0 (CT)	1.0 (CT)	6.4E ⁻⁰²
<i>Astyanax fasciatus</i> (Cuvier, 1819)	Native	0.61 (CT)	1.0 (CT)	1.0 (CT)	-	0.75 (CT)	8.7E ⁻⁰³
<i>Oligosarcus pintoi</i> Amaral Campos, 1945	Native	-	-	-	-	1.0 (CT)	3.6E ⁻⁰³
Erythrinidae							
<i>Hoplias malabaricus</i> (Bloch, 1794)	Native	0.33 (AS)	0.83 (CT)	0.91 (CT)	1.0 (CT)	-	-
<i>Hoplerethrinus unitaeniatus</i> (Spix and Agassiz, 1829)	Native	-	0.37 (AS)	1.0 (CT)	0.86 (CT)	0.75 (CT)	2.5E ⁻⁰³
Anostomidae							
<i>Leporinus friderici</i> (Bloch, 1794)	Native	0.30 (AS)	0.04 (AD)	0.64 (CT)	0.14 (AD)	0.5 (CT)	1.1E ⁻⁰³
<i>Leporinus sp.</i>	Native	-	-	0.09 (AD)	-	-	-
<i>Leporinus octofasciatus</i> Steindachner, 1915	Native	0.28 (AS)	-	-	-	-	-
Curimatidae							
<i>Cyphocharax modestus</i> (Fernandez-Yépez, 1948)	Native	-	1.0 (CT)	1.0 (CT)	1.0 (CT)	-	-
Prochilodontidae							
<i>Prochilodus lineatus</i> (Valenciennes, 1837)	Native	-	-	-	0.28 (AS)	-	-
Cypriniforms							
Cyprinidae							
<i>Cyprinus carpio</i> Linnaeus, 1758	Non-native	-	0.12 (AD)	0.09 (AD)	0.14 (AD)	-	-
Siluriforms							
Heptapteridae							
<i>Rhamdia quelen</i> (Quoy and Gaimard, 1824)	Native	0.25 (AS)	0.08 (AD)	0.91 (CT)	1.0 (CT)	0.5 (CT)	1.8E ⁻⁰³
<i>Pimelodella meeki</i> Eigenmann 1910	Native	-	-	0.36 (AS)	0.86 (CT)	0.25 (AS)	3.6E ⁻⁰⁴
<i>Cetopsorhamdia iheringi</i> Schubart and Gomes, 1959	Native	0.11 (AD)	-	-	-	-	-
Callichthyidae							
<i>Hoplosternum littorale</i> (Hancock, 1828)	Native	-	0.08 (AD)	0.64 (CT)	0.28 (AS)	0.5 (CT)	1.8E ⁻⁰³
Loricariidae							
<i>Hypostomus ancistroides</i> (Ihering, 1911)	Native	0.25 (AS)	0.29 (AS)	0.91 (CT)	1.0 (CT)	0.75 (CT)	1.8E ⁻⁰³
Perciforms							
Cichlidae							
<i>Coptodon rendalli</i> (Boulenger, 1897)	Non-native	0.33 (AS)	0.8 (CT)	0.54 (CT)	1.0 (CT)	0.75 (CT)	8.7E ⁻⁰³
<i>Oreochromis niloticus</i> (Linnaeus, 1758)	Non-native	-	0.8 (CT)	1.0 (CT)	1.0 (CT)	0.5 (CT)	3.4E ⁻⁰³
<i>Cichlasoma paranaense</i> Kullander, 1983	Native	-	0.67 (CT)	-	-	-	-
<i>Geophagus brasiliensis</i> (Quoy and Gaimard, 1824)	Native	0.33 (AS)	1.0 (CT)	1.0 (CT)	1.0 (CT)	0.75 (CT)	4.3E ⁻⁰²
<i>Cichla kelberi</i> Kullander and Ferreira, 2006	Non-native	-	0.25 (AS)	1.0 (CT)	1.0 (CT)	0.5 (CT)	3.2E ⁻⁰³

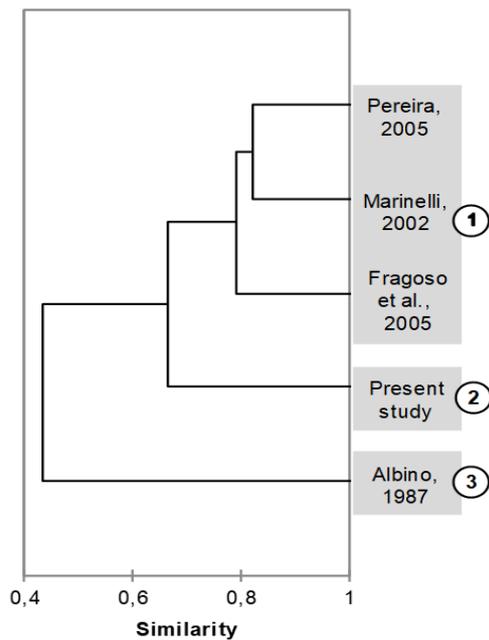


Figure 3 - The clustering similarity of the fish studies of Lobo-Broa reservoir between the 1970's to 2010's decades. The analysis used Jaccard coefficient with the unweighted pair-group average of the presence-absence data. The numbered circles represent the following decades groups: 1 = 2000's; 2 = 2010's; 3 = 1970/1980's.

DISCUSSION

The results of the present study demonstrated that the structure of fish assemblages in the Lobo-Broa reservoir, sampled between 1975 and 2011 by Albino (1987), Marinelli (2002), Fragoso et al. (2005), Pereira (2005) and the present study, has a low diversity of species. This has to do with the region characteristics, as well as imposed geographical barriers (a waterfall downstream of the reservoir's dam and the damming of the Itaqueri and Lobo rivers). Thus, making their ecosystems more susceptible to changes caused by anthropic alterations.

The samples were cluster into three distinct groups according to the decades: one sampling group of 1970/1980's decades, another sampling group in the early decade of the 2000's and this present study in the 2010's decade. Over time, the ichthyofauna composition had an increase in similarity in the local biota, as a possible consequence of the species changes due to the local anthropogenic degradation over the years. Pelicice & Agostinho (2009) has reported a tendency for biotic homogenization after the introduction of non-native predator in Brazilian reservoirs.

Table 2 - Results of SIMPER with the species that accounted the most to the similarities within the grouping of the 2000's decade (Marinelli, 2002; Pereira, 2005; Fragoso et al., 2005) and the dissimilarity of the 1970/1980's (Albino, 1987), 2000's and 2010's (Present study) decades of the Lobo-Broa reservoir studies. Percentage of each species as well as cumulative percentage are presented.

2000's			1970/1980's and 2000's		1970/1980's and 2010's		2000's and 2010's		
Species	%	Cum. %	Species	%	Cum. %	%	Cum. %	%	Cum. %
<i>Astyanax altiparanae</i>	12.03	37.53	<i>Astyanax altiparanae</i>	5.38	63.59	7.52	63.91	-	-
<i>Astyanax fasciatus</i>	4.42	90.51	<i>Astyanax fasciatus</i>	5.25	68.85	-	-	5.83	59.79
<i>Cichla kelberi</i>	6.04	86.09	<i>Cichla kelberi</i>	8.07	38.25	7.52	56.39	5.8	65.59
<i>Coptodon rendalli</i>	8.06	67.43	<i>Cichlasoma paranaense</i>	-	-	-	-	3.62	90.34
<i>Cyphocharax modestus</i>	12.75	25.49	<i>Coptodon rendalli</i>	5.22	74.06	6.32	70.23	-	-
<i>Geophagus brasiliensis</i>	12.75	12.75	<i>Cyphocharax modestus</i>	11.48	11.48	-	-	-	-
<i>Hoplerythrinus unitaeniatus</i>	6.58	74.01	<i>Geophagus brasiliensis</i>	7.69	45.94	6.32	76.54	-	-
<i>Hoplias malabaricus</i>	10.88	59.37	<i>Hoplerythrinus unitaeniatus</i>	8.12	30.17	11.28	26.32	3.64	86.73
<i>Hypostomus ancistroides</i>	6.05	80.06	<i>Hoplias malabaricus</i>	6.61	52.55	4.96	81.5	12.98	41.58
<i>Oreochromis niloticus</i>	10.96	48.48	<i>Hoplosternum littorale</i>	3.53	86.94	7.52	33.83	3.87	83.08
			<i>Hypostomus ancistroides</i>	5.08	79.14	7.52	41.35	4.31	79.21
			<i>Leporinus friderici</i>	-	-	-	-	4.72	70.31
			<i>Leporinus octofasciatus</i>	3.21	90.15	4.21	85.71	-	-
			<i>Oligosarcus pintoii</i>	-	-	15.04	15.04	14.3	14.3
			<i>Oreochromis niloticus</i>	10.57	22.05	7.52	48.87	6.07	53.97
			<i>Pimelodella meeki</i>	4.26	83.4	3.76	93.23	4.58	74.9
			<i>Rhamdia quelen</i>	5.67	58.22	3.76	89.47	6.32	47.9
Average similarity	74.23 %		Average dissimilarity	63.60 %		56.40 %		36.87 %	

The process of degradation of the Lobo-Broa reservoir's aquatic biota can be evidenced by ongoing changes. These changes related to the watershed use and occupation and the increased input of nutrients cause by human activities (Rodrigues-Filho et al., 2015). In addition, the replacement of the original riparian vegetation may cause on fishes a decrease of aquatic habitats, food resources and local biodiversity (Ferreira et al., 2015). Over the years the Lobo-Broa reservoir has been heavily modified due to an accelerated process of degradation also can increase the risk of local species extinction. This process can be visualized from the increasing concentration levels of dissolved phosphorus, a-Chlorophyll and the reservoir trophic state index. Tundisi et al. (2015) warns about the impact of the eutrophication and cyanobacteria blooms in the Lobo-Broa reservoir as consequence of climatological interactions and hydrological changes with perturbation on ecosystem services and fish mortality. Nutrient input is carried downstream from the tributaries to inner areas of the reservoir mainly from untreated domestic sewage. At smaller spatial scales the fishes' distributions and dispersal are determined by a combination of biotic and abiotic factors (Olden et al., 2010). However, non-native species introduced into reservoirs cause serious problem for the conservation of biodiversity, resulting in spatial and temporal biotic homogenization and/or differentiation (Daga et al., 2015).

Biotic homogenization refers to a regional decrease in beta-diversity over time, resulting from the widespread exotic species and loss of native endemics (McKinney & Lockwood, 1999). In this sense, the results of PERMANOVA and PERMADISP indicated that fish assemblages' composition did not change drastically into the reservoir along the years, but differ in the species constancy on the different studies groups. The SIMPER results evidence that species with higher constancy of occurrence became constant as time passed (*C. kelberi*, *C. rendalli*, *O. niloticus*, *O. pinto*, *A. altiparanae*, *G. brasiliensis* and *H. ancistroides*), reflecting an increased constancy of introduced non-native species or opportunistic natives. Concomitantly, were registered a declining number of native species (*L. octofasciatus* and *C. iheringi*). Charles Darwin (1809-1882) reported that non-native species might share adaptive traits with the closely related native species that would increase their chances of establishing a foothold in a new ecosystem (Skóra et al., 2015). Thus, the decline of local species can be attributed to invasions of non-native species, creating competitive advantages for invading species such as new microhabitats and ecological niches (Byers, 2002). In this sense, as an example a long-term study in three basins in the State of Paraná, Southern

Brazil, showed a beta diversity decreased over space and time for the studied reservoirs, indicating that fish assemblages are becoming even more homogenized overtime (Daga et al., 2015).

In this context, for artificial reservoirs the major expected consequences are the increase in establishment of introduced non-native fish species, through translocations, stocking and hydrographic modifications and, consequently, the extirpation of endemic and endangered species or populations (Daga et al., 2016). Literature review revealed that the first introduction of non-native fish in the Lobo-Broa reservoir occurred in the 1960's, with the African tilapia, *C. rendalli* (recently recombined from *Tilapia rendalli* by Dunz & Schliewen, 2013), followed by *O. niloticus* and the Asian carp, *C. carpio*, for which there is no precise information on the date of introduction (Rocha et al., 2011). Additionally, there are records on the first introductions of these species into the cascade of reservoirs in the Middle and Lower Tietê River, São Paulo, Brazil: 1952 for cichlids and 1939 for the cyprinid (Smith et al., 2005). The most recent introduction in the Lobo-Broa reservoir dates to the 1990s. A specie from the Amazon basin, *C. kelberi* (formerly referred to as *Cichla cf. ocellaris* (Rocha et al., 2011). Fragozo et al. (2005) showed that *C. kelberi* became constant after its introduction in the locality.

As the study area has no aquaculture history, the main vector responsible for the introduction of those non-native species was the sport fishing (stocking or bait releases). Elsewhere in Brazil, those species has been introduced into different ecoregions, incrementing sport fishing and aquaculture, but causing serious implications for native fish populations (Pelicice & Agostinho, 2009). Therefore, the identification of non-natives species vectors and pathways in fish inventories is important to determine how future introductions could be prevented via surveillance and regulation (Zieritz et al., 2017).

In Brazil, there is a long legacy of introduction of non-native fish (Frehse et al. 2016), including numerous translocations between South American ecoregions that are diverse in their species richness (Reis et al., 2016). In addition, the normative approach (i.e., laws and inspections) has failed to control or prevent introductions because inspections and monitoring are minimal or non-existent and besides that the society is generally unaware of this issue (Azevedo-Santos et al., 2015). Thus, it is crucial for prevent new introductions and invasions, especially those in the Neotropics, and understand the interactions involving non-native species and the human-altered ecosystems (Frehse et al., 2016).

The results obtained in this study compiles and characterize the changes on the structure of fish as-

semblages in the Lobo-Broa reservoir over more than four decades of scientific researches. The changes evidenced a homogenization process that most native species are declining and are being replaced by a much smaller number of introduced species or opportunistic natives. In general, the homogenization of Earth's biological communities is accelerating and is an underappreciated aspect of global environmental change (Rahel, 2000).

Our retrospective analysis reported the temporal trends about the water quality and the changes that accompany fish assemblages into the reservoir, which have resulted in local fish changes and homogenization. This data analysis provides a more precision and quality on current knowledge of the introduced species that can be applied to developing policy and management on the regional and global conservation (Garcia et al., 2017). Furthermore, our study are an important register and alert to environmental managers about the ecological risks and uncertainties posed by anthropic disturbances, supporting the implementation of effective conservation strategies. Therefore, highlighting the importance of long-term environmental monitoring for future fishery management, precautionary approach about invasions and impact from non-native species.

ACKNOWLEDGEMENTS

The authors would like to thank the National Council for Scientific and Technological Development (CNPq) (process number 131889/2010-9 and 305023/2009-8) and State of São Paulo Research Foundations (FAPESP) (process number 2009/17060-0) for the grants and fellowships for this project. We are grateful to Fernanda de Oliveira Martins and the team from UNESP - São José do Rio Preto Ictiology Laboratory for the help with taxonomic identifications.

REFERENCES

Albino, A.L.D. 1987. Estudo sobre a fauna de peixes da bacia do rio Jacaré-Guaçu, SP com uma avaliação preliminar dos efeitos de dois barramentos. Tese de Mestrado. Programa de Pós-Graduação em Ecologia e Recursos Naturais. UFSCAR. 187 p.

Allan, J.D. & Flecker, A.S. 1993. Biodiversity conservation in running waters. *BioScience*. 43: 32-43.

Azevedo-Santos, V.M.; Pelicice, F.M.; Lima-Junior, D.P.; Magalhães, A.L.B.; Orsi, M.L.; Vitule, J.R.S. & Agostinho, A.A. 2015. How to avoid fish introductions in Brazil: education and information as alternatives. *Natureza & Conservação*. 13(2): 123-132.

Byers, J.E. 2002. Impact of non-indigenous species on natives enhanced by anthropogenic alteration of selection regimes. *OIKOS*. 3 p.

Chalar, G. & Tundisi, J.G. 1999. Main processes in the water column determined by wind and rainfall at Lobo (Broa) Reservoir. Implications for phosphorus cycling. In: Tundisi, J.G. & Straskraba, M. 1999. Theoretical reservoir ecology and its applications. São Carlos, Backhuys Publishers. 1: 53-65 pp.

Chislock, M.F.; Doster, E.; Zitomer, R.A. & Wilson, A.E. 2013. Eutrophication: causes, consequences, and controls in aquatic ecosystems. *Nature Education Knowledge*. 4(4): 10.

Clarke, K.R. & Gorley, R.N. 2006. PRIMER v6: User manual/tutorial. Plymouth Marine Laboratory, Plymouth. 192 p.

Clements, W.H.; Vieira, N.K.M. & Sonderegger, D.L. 2010. Use of ecological thresholds to assess recovery in lotic ecosystems. *Journal of The North American Benthological Society*. 29(3): 1017-1023.

Daga, V.S.; Skóra, F.; Padial, A.A.; Abilhoa, V.; Gubiani, E.A. & Vitule, J.R.S. 2015. Homogenization dynamics of the fish assemblages in Neotropical reservoirs: comparing the roles of introduced species and their vectors. *Hydrobiologia*. 746(1): 327-347.

Daga, V.S.; Debona, T.; Abilhoa, V.; Gubiani, E.A. & Vitule, J.R.S. 2016. Non-native fish invasions of a Neotropical ecoregion with high endemism: A review of the Iguazu River. *Aquatic Invasions*. 11(2): 209-223.

Dajoz, R. 1978. *Ecologia Geral*. 4 ed. Vozes. 472 p.

Dornelas, M.; Magurran, A.E.; Buckland, S.T.; Chao, A.; Chazdon, R.L.; Colwell, R.K.; Curtis, T.; Gaston, K.J.; Gotelli, N.J.; Kosnik, M.A. & McGill, B. 2013, January. Quantifying temporal change in biodiversity: challenges and opportunities. *Proceedings of the Royal Society B*. 280(1750): 20121931.

Ferreira, C.; Casatti, L.; Zeni, J.O. & Ceneviva-Bastos, M. 2015. Edge-mediated effects of forest fragments on the trophic structure of stream fish. *Hydrobiologia*. 762(1): 15-28.

Fragoso, E.N.; Souza, E.; Velludo, M.R.; Soares, A.S. & Rocha, O. 2005. Introdução de espécies e estado atual da ictiofauna da represa do Lobo, Brotas - Itirapina, SP. In: Rocha, O.; Espíndola, E.L.G.; Fenerich-Verani, N.; Verani, J.R. & Rietzler, A.C. 2005. Espécies invasoras em águas doces - estudos de caso e propostas de manejo. Editora Universidade Federal de São Carlos, 416 p.

Frehse, F.A.; Braga, R.R.; Nocera, G.A. & Vitule, J.R.S. 2016. Non-native species and invasion biology in a megadiverse country: scientometric analysis

- and ecological interactions in Brazil. *Biological Invasions*. 18(12): 3713-3725.
- Freitas, L.D. 2012. Heterogeneidade espacial e temporal do zooplâncton em sistemas lóticos e lênticos da bacia hidrográfica do Lobo (Itirapina-Brotas/SP). Tese de Mestrado. Programa de Pós-Graduação em Ciências da Engenharia Ambiental. USP. 164 p.
- Garcia, D.A.Z.; Britton, J.R.; Vidotto-Magnoni, A.P. & Orsi, M.L., 2017. Introductions of non-native fishes into a heavily modified river: rates, patterns and management issues in the Paranapanema River (Upper Paraná ecoregion, Brazil). *Biological Invasions*. 1-13.
- Heino, J. 2013. Environmental heterogeneity, dispersal mode, and co-occurrence in stream macroinvertebrates. *Ecology and Evolution*. 3: 344-355.
- Krebs, C.J. 1989. *Ecological Methodology*. Harper & Row, New York. 654 p.
- Magurran, A.E.; Baillie, S.R.; Buckland, S.T.; Dick, J.M.; Elston, D.A.; Scott, E. M.; Smith, R.I.; Somerfield, P.J. & Watt, A.D. 2010. Long-term datasets in biodiversity research and monitoring: assessing change in ecological communities through time. *Trends in Ecology & Evolution*. 25(10): 574-582.
- Marinelli, C.E. 2002. Estrutura da comunidade, habitats e padrões de distribuição da ictiofauna em ecótonos do reservatório do Broa, SP. Tese de Mestrado. Programa de Pós-Graduação em Ciências da Engenharia Ambiental. USP. 225 p.
- McKinney, M.L. & Lockwood, J.L. 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. *Trends in Ecology & Evolution*. 14(11): 450-453.
- Mota, M.; Sousa, R.; Araujo, J.; Braga, C. & Antunes, C. 2014. Ecology and conservation of freshwater fish: time to act for a more effective management. *Ecology of Freshwater Fish*. 23: 111-113.
- Olden, J.D.; Kennard, M.J.; Leprieur, F.; Tedesco, P.A.; Winemiller, K.O. & García-Berthou, E. 2010. Conservation biogeography of freshwater fishes: recent progress and future challenges. *Diversity and Distributions*. 16(3): 496-513.
- Pelicice, F.M. & Agostinho, A.A. 2009. Fish fauna destruction after the introduction of a non-native predator (*Cichla kelberi*) in a Neotropical reservoir. *Biological Invasions*. 11(8): 1789-1801.
- Pereira, J.M.A. 2005. A atividade pesqueira na represa do Lobo-Broa (Itirapina, Brotas-SP): caracterização e composição da captura. Tese de Mestrado. Programa de Pós-Graduação em Ciências da Engenharia Ambiental. USP. 154 p.
- Pereira, J.M.A.; Petreire-Jr, M. & Ribeiro-Filho, RA. 2008. Angling sport fishing in Lobo-Broa reservoir (Itirapina, SP, Brazil). *Brazilian Journal of Biology*. 68: 721-731.
- Pimm, S.L.; Jenkins, C.N.; Abell, R.; Brooks, T.M.; Gittleman, J.L.; Joppa, L.N.; Raven, P.H.; Roberts, C.M. & Sexton, J.O. 2014. The biodiversity of species and their rates of extinction, distribution, and protection. *Science*. 344(6187): 1246752.
- Rahel, F.J. 2000. Homogenization of fish faunas across the United States. *Science*. 288(5467): 854-856.
- Rahel, F.J. 2007. Biogeographic barriers, connectivity and homogenization of freshwater faunas: it's a small world after all. *Freshwater Biology*. 52(4): 696-710.
- Reis, R.E.; Albert, J.S.; Di Dario, F.; Mincarone, M.M.; Petry, P. & Rocha, L.A. 2016. Fish biodiversity and conservation in South America. *Journal of Fish Biology*. 89(1): 12-47.
- Reis, R.E.; Kullander, S.O. & Ferraris-Jr., C.J. 2003. Check list of the freshwater fishes of South and Central America. EDIPUCRS, Porto Alegre. 742 p.
- Rocha, O.; Espíndola, E.L.G.; Rietzler, A.C.; Fenerich-Verani, N. & Verani, J.R. 2011. Animal invaders in São Paulo State reservoir. *Oecologia Australis*. 15: 631-642.
- Rodrigues-Filho, J.L.; Degani, R.M.; Soares, F.S.; Periotto, N.A.; Blanco, F.P.; Abe, D.S.; Matsumura-Tundisi, T.; Tundisi, J.E. & Tundisi, J.G. 2015. Alterations in land uses based on amendments to the Brazilian Forest Law and their influences on water quality of a watershed. *Brazilian Journal of Biology*. 75(1): 125-134.
- Scanlon, B.R.; Jolly, I.; Sophocleous, M. & Zhang, L. 2007. Global impacts of conversions from natural to agricultural ecosystems on water resources: quantity versus quality. *Water Resources Research*. 43: 403-437.
- Skóra, F.; Abilhoa, V.; Padial, A.A. & Vitule, J.R.S. 2015. Darwin's hypotheses to explain colonization trends: evidence from a quasi-natural experiment and a new conceptual model. *Diversity and Distributions*. 21(5): 583-594.
- Smith, W.S.; Espíndola, E.L.G. & Rocha, O. 2005. As espécies de peixes introduzidas no rio Tietê. In: Rocha, O., Espíndola E.L.G.; Fenerich-Verani, N.; Verani, J.R. & Rietzler, A.C. 2005. Espécies invasoras em águas doces - Estudos de caso e propostas de manejo. Editora Universidade Federal de São Carlos. 414 p.
- Tundisi, J. G. & Matsumura-Tundisi, T. 2014. The ecology of UHE Carlos Botelho (Lobo-Broa Reservoir) and its watershed, São Paulo, Brazil. *Freshwater Reviews*. 6(2): 75-91.
- Tundisi, J.G.; Matsumura-Tundisi, T.; Tundisi, J.E.M.; Blanco, F.P.; Abe, D.S.; Contri Campanelli, L.; Sidagis Galli, G.; Silva, V.T. & Lima, C.P.P. 2015.

A bloom of cyanobacteria (*Cylindrospermopsis raciborskii*) in UHE Carlos Botelho (Lobo/Broa) reservoir: a consequence of global change? *Brazilian Journal of Biology*. 75(2): 507-508.

Vitule, J.R.S.; Skóra, F. & Abilhoa, V., 2012. Homogenization of freshwater fish faunas after the elimination of a natural barrier by a dam in Neotropics. *Diversity and Distributions*. 18(2): 111-120.

Warton, D.I.; Wright, S.T. & Wang, Y. 2012. Distance-based multivariate analyses confound location and dispersion effects. *Methods in Ecology and Evolution*. 3(1): 89-101.

Zieritz, A.; Gallardo, B.; Baker, S.J.; Britton, J.R.; van Valkenburg, J.L.; Verreycken, H. & Aldridge, D.C., 2017. Changes in pathways and vectors of biological invasions in Northwest Europe. *Biological Invasions*. 19(1): 269-282.

Submetido: Outubro/16
Revisado: Agosto/17
Aceito: Dezembro/17
Publicado: 15 de Setembro/18