*Chapter*

# SPAWNING AND NURSERY HABITATS OF NEOTROPICAL FISH SPECIES IN THE TRIBUTARIES OF A REGULATED RIVER

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## ABSTRACT

This chapter provides information on ontogenetic patterns of neotropical fish species distribution in tributaries (Verde, Pardo, Anhanduí, and Aguapeí rivers) of the Porto Primavera Reservoir, in the heavily dammed Paraná River, Brazil, identifying key spawning and nursery habitats. Samplings were conducted monthly in the main channel of rivers and in marginal lagoons from October through March during three consecutive spawning seasons in 2007-2010. Most species spawn in December especially in Verde River. Main river channels are spawning habitats and marginal lagoons are nursery areas for most fish, mainly for migratory species. The tributaries have high diversity of larvae species: a total of 56 taxa representing 21 families, dominated by Characidae. Sedentary species without parental care are more abundant (45.7%), and many long-distance migratory fish species are present (17.4%). Migrators included *Prochilodus lineatus, Rhaphiodon vulpinus, Hemisorubim platyrhynchos, Pimelodus maculatus, Pseudoplatystoma corruscans, Sorubim lima,* two threatened migratory species: *Salminus brasiliensis* and *Zungaro jahu*, and one endangered migratory species: *Brycon orbignyanus*. Most of these migratory species are vital to commercial and recreational fishing, and their stocks have decreased drastically in the last decades, attributed to habitat alteration, especially impoundments. The fish ladder at Porto Primavera Dam

appears to be playing an important role in re-establishing longitudinal connectivity among critical habitats, allowing ascent to migratory fish species, and thus access to upstream reaches and tributaries. Establishment of Permanent Conservation Units in tributaries can help preserve habitats identified as essential spawning and nursery areas, and can be key to the maintenance and conservation of the fish species in the Paraná River basin.

## INTRODUCTION

The Paraná River is the second longest river in South America, running through Brazil, Paraguay and Argentina over a course of some 3,089 kilometers (Agostinho and Júlio-Júnior, 1999), formed at the confluence of the Paranaiba and Grande rivers in southern Brazil. It is customarily divided into Upper, Middle, and Lower sections (Bonetto, 1989), each with distinctive geographic and biologic characteristics. The upper stretches are characterized by high human occupation and intense anthropogenic activities, and few areas are still in pristine conditions (Agostinho et al., 2007).

The diversity of fish is high in the Upper Paraná River basin, characterized by variety of reproductive strategies. Most species are sedentary or short-distance migratory, small and medium size with external fertilization, multiple spawning, short breeding periods and marked reproductive seasonality (Suzuki et al., 2004). Most large species migrate long distances to reproduce, and these species are considered the most important for commercial and recreational fisheries.

In the last decades the human interference in the Paraná River system has been considerable, and the most notable is the construction of dams (Agostinho and Gomes, 2002; Graça and Pavanelli, 2007), particularly on its upper reaches. Impoundments across the Upper Paraná River basin have had negative effects on natural fish populations for both sedentary and migratory species contributing to the diminished abundance and disappearance of fish species.

The fish community structure of a river depends on the integrity of the longitudinal connectivity of the system. The connectivity between river and floodplain or backwaters is essential in the life history of many fish (Lucas and Baras, 2001) that depend on seasonal use of flooded areas for spawning and feeding. Migratory fish in the Paraná River basin usually spawn in upper stretches of the large tributaries, and the lagoons are rearing areas in downstream sections of the tributaries of this river and along their borders and island (Agostinho et al., 2003; Nakatani et al., 2004). Thus, the blockage of the migratory routes with fragmentation of the environments and change from lotic into lentic conditions may induce local extinctions above barriers and reduce the fish populations downstream of those barriers (Makrakis et al., 2007a). The modification of the hydrologic cycle, attenuation of flooding and decrease of the reproduction areas and development of fish eggs and larvae are fundamental for that matter, though the intensity of the impacts depend on the location of the dam in relation to required habitats for different fish species.

Preservation or manipulation of critical spawning and nursery habitats can stabilize or increase the variable abundances and survival rates normally experienced by fish populations during early life, and thereby conserve or enhance fish populations (Fuiman and Werner, 2002). To better understand the population dynamic and the consequences of the

environmental variability that affect the initial life stages of fish and recruitment in the Paraná River Basin, we investigated if 1) fish species, primarily migratory fish, spawn in habitats of major tributaries to a large impoundment; and 2) tributaries have adequate spawning and nursery habitats to enable larval survival and development. To this end, spawning and nursery areas of fish species were studied over three spawning seasons (2007-2010) in the tributaries of the Porto Primavera Reservoir, in the heavily regulated Upper Paraná River, Brazil, identifying critical habitats for recruitment in this stretch of the basin where the information is still scarce. This chapter provides information that is relevant to the enhancement of early life stages of fish species expected to play an important role in the fisheries and and in the conservation of fish stocks in the Paraná River basin.

## TRIBUTARIES OF PORTO PRIMAVERA RESERVOIR

A unique impounded reach in the Upper Paraná River is the Upper Paraná River Floodplain (Figure 1). It stretches from downstream of Porto Primavera Dam to the upper reaches of the Itaipu Reservoir, spans as wide as 20 km, especially on the western margin (Agostinho et al., 2003), and has large tributaries on the eastern margin. Flooded areas include active and semi-active channels, lagoons, elongated lowlands associated with paleochannels, and lowlands associated with the flood basin (Souza-Filho and Stevaux, 2004).

The Engenheiro Sergio Motta Hydroeletric Powerplant (known as Porto Primavera), belonging to Companhia Energética de São Paulo-CESP, is located in the main channel of Upper Paraná River, above the floodplain, along the border between São Paulo and Mato Grosso do Sul, Brazil (Figure 1). The dam is 11.4-km long and 22 m high, and has 16 surface spillways, with a discharge capacity of up to 53,600$m^2.s^{-1}$ (Shibatta and Dias, 2006). A fish ladder (weir and orifice type) was built next to the dam, stretching 520 m to transcend the 19 m difference in elevations, allowing fish to reach the reservoir (Makrakis et al., 2007b). The Porto Primavera Reservoir drains a basin as large as 572,480 $km^2$, and it has an area of 2.250 $km^2$.

Large tributaries are present on the east and west banks of the reservoir with various aquatic habitats: Aguapeí, Verde, Pardo and Anhanduí rivers. The tributaries have different characteristics, such as width, depth, substrate type, and preservation of riparian zones. The Pardo and Anhanduí rivers are similar, characterized by high mean discharge and water level, while the Aguapeí River stands out among the rest mainly by high specific conductance and turbidity. Verde River is characterized by high pH and dissolved oxygen.

The 305-km long Aguapeí River (Figure 1), located in São Paulo state, is on the eastern bank of the Paraná River (Paiva, 1982). It is characterized by a meandering pattern, with a width of 30 m. Its banks are composed of shrub and trees, as well as for aquatic macrophytes and several lagoons. A stretch of approximately 11.5 km was sampled, establishing five sites (RAG 1 and RAG 5), four in lotic and one in an oxbow lake (RG5) that provides continuous connection with the river. This lagoon has an area of approximately 2.0 hectares, with riparian vegetation preserved (Companhia Energetica de São Paulo - CESP, 2006).

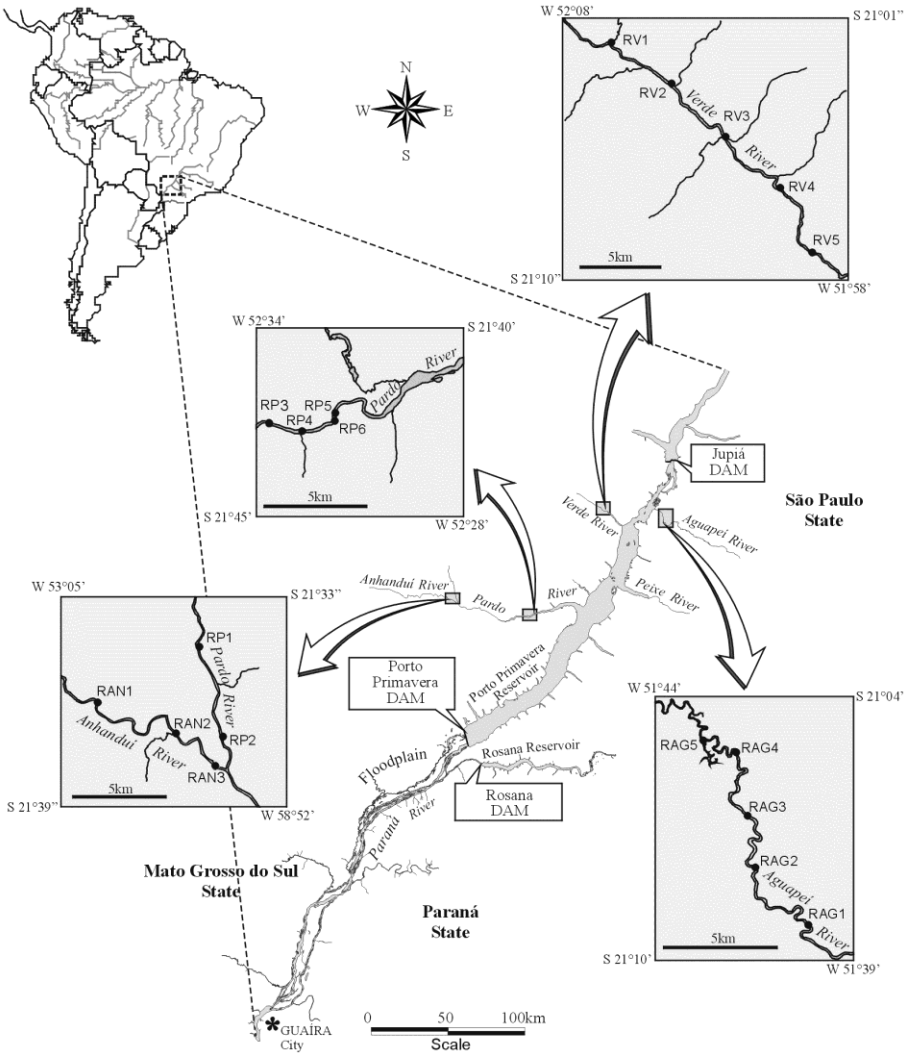


Figure 1. Sampling sites in the tributaries of Porto Primavera Reservoir, Upper Paraná River, Brazil.

The Verde River (Figure 1) is located on the western bank of the Parana River, covering an area of 3.3 km$^2$, part of the State of Mato Grosso do Sul (Paiva, 1982). The banks of this river are composed nearly pristine riparian vegetation. This river has many lagoons and wetlands areas. The study sites comprised five points (RV1 to RV5), all distributed in the main channel, totaling approximately 20km long.

The Pardo River (Figure 1) is located on the western bank of the Parana River, with an area of 35,050 km$^2$, in Mato Grosso do Sul State. The collections were conducted in two sections of the river totaling six different sampling sites. The first (upper section) presents only lotic sites (RP1 to RP2) located near the confluence area with the Anhanduí River covering a total of 9 km in length sampled. This section is totally free from the influence of the reservoir, has several areas of rapid waters and approximate width of 80 m. The riparian zone is well preserved, consisting of scrub and trees. Sites RP6 to RP3, in the lower section of the Pardo River, are located closer to the Porto Primavera Reservoir. The banks are composed

of woody vegetation and shrubs and include several floating banks of aquatic macrophytes. The width between the margins is approximately 150 meters. The segment sampled comprised around 10 km, with three points from a lotic stretch, and one in a marginal lagoon (RP5) that provides permanent connection to the river. The main tributary of the Pardo is the Anhanduí River (Figure 1), which is 290-km long (Paiva, 1982). This site features a well-preserved riparian zone with shrubs and trees. The collections covered only lotic sites on this river with three sampling sites (RAN1, RAN2 and RAN3) distributed over 6 km of the river.

## SPAWNING AND NURSERY HABITATS

Assessment of the temporal and spatial distribution of fish eggs and larvae in the tributaries of the Porto Primavera Reservoir, covering the Aguapeí, Verde, Pardo and Anhanduí rivers (Figure 1), were conducted monthly from October to March (reproductive period for major fish species from Paraná River Basin-Vazzoler, 1996) through 2007 to 2010, comprising three spawning seasons (1=2007/2008, 2=2008/2009, and 3=2009/2010). Ichthyoplankton samplings were conducted using a conical-cylindrical plankton net (0.5mm mesh) equipped with a flow meter for surface collections. Hauls were horizontal (20 cm deep) after nightfall (between 7 and 11 p.m.) during 10 minutes. Sampling included the main channel and marginal lagoons along the tributaries. Ichthyoplankton samplings were anesthetized with clove oil, fixed in buffered 4% formalin, and identified to the species level based on descriptions in Nakatani et al. (2001) and Graça and Pavanelli (2007). Species were also classified according to the reproductive strategies (Suzuki et al., 2004; Agostinho et al., 2003): MIG = long-distance migratory; SSC = sedentary without parental care; SCC = sedentary with parental care; SFIE = sedentary with internal fertilization and external development; and NC = species with unavailable information in literature.

Higher densities of fish eggs and larvae occurred between November and December, especially in 2009/2010 (spawning season 3; Figure 2). The fish reproduction period of major species from Upper Paraná River floodplain matches from October to March, and it is intensified by higher water temperature, longer days, and a rise in water level (Vazzoler, 1996); these factors trigger spawning. Water discharge is also a leading factor to trigger for reproduction of fish occupying the tributaries of Porto Primavera Reservoir; heavy rains contribute to the highest eggs abundance (in 2009/2010).

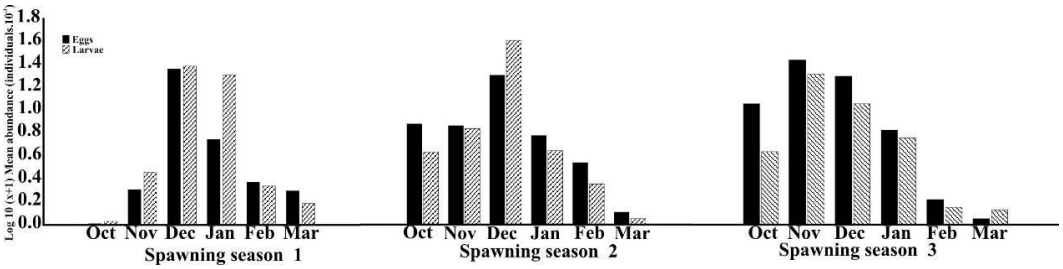


Figure 2. Mean abundance of fish eggs and larvae sampled in three spawning seasons (1=2007-2008); 2=2008-2009; 3=2009-2010), in the tributaries of Porto Primavera Reservoir, Upper Paraná River, Brazil.

The study tributaries were characterized by intense fish reproduction. High abundance of fish eggs and larvae occurs in all tributaries, especially in the Verde River (Figure 3). A longitudinal gradient has been reported in the distribution of eggs and larvae of fish species from the upper to the lower reaches of major tributaries of the Upper Paraná River; eggs have generally been more abundant at headwaters, decreasing toward the river mouth, and an opposite trend has been evidenced for larvae (Nakatani et al., 2004). Nevertheless, this pattern was not corroborated in the study tributaries as high abundances of fish eggs and larvae occurred throughout (Figure 4).

Spawning of most species occurs mainly in the main channel of tributaries, and lagoons are nursery habitats (Figure 3). Most fish that spawn in the main channel have pelagic eggs, efficient dispersion of eggs and larvae through flow, and larvae are placed in such a way as to facilitate their entry to nursery areas. However, species with demersal eggs prefer lagoons or shallow water to reproduce (Vazzoler, 1996), these eggs remain in the substrate adhered or not to marginal vegetation (Nakatani et al., 2001). Aquatic macrophytes in marginal lagoons provide favorable conditions for fish development due to abundant food and offer a wide availability of shelter. Cunico et al. (2002) state that the lagoons are true natural nurseries, supplying the needs of biological and ecological populations, such as breeding, feeding and growth.

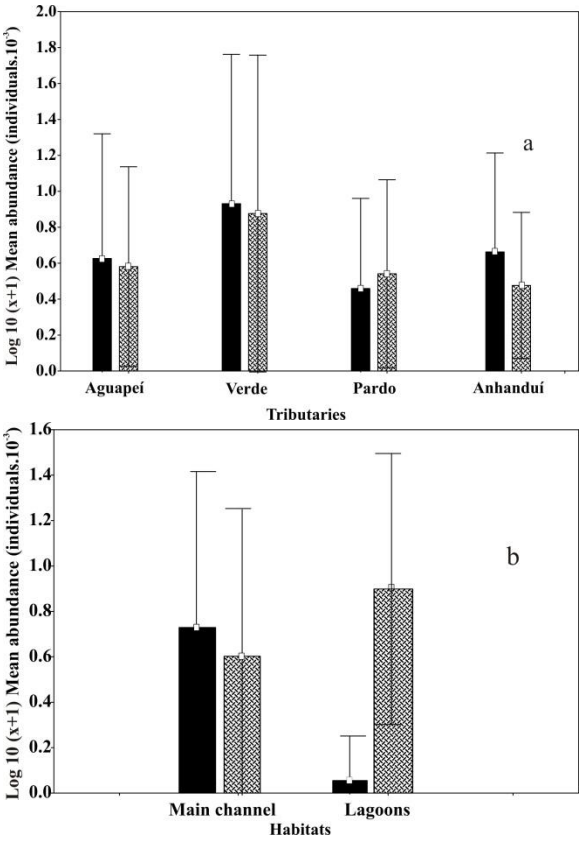


Figure 3. Mean abundance ± standard error of fish eggs (black bars) and larvae (gray bars) sampled in the tributaries (a) and the different habitats (b).

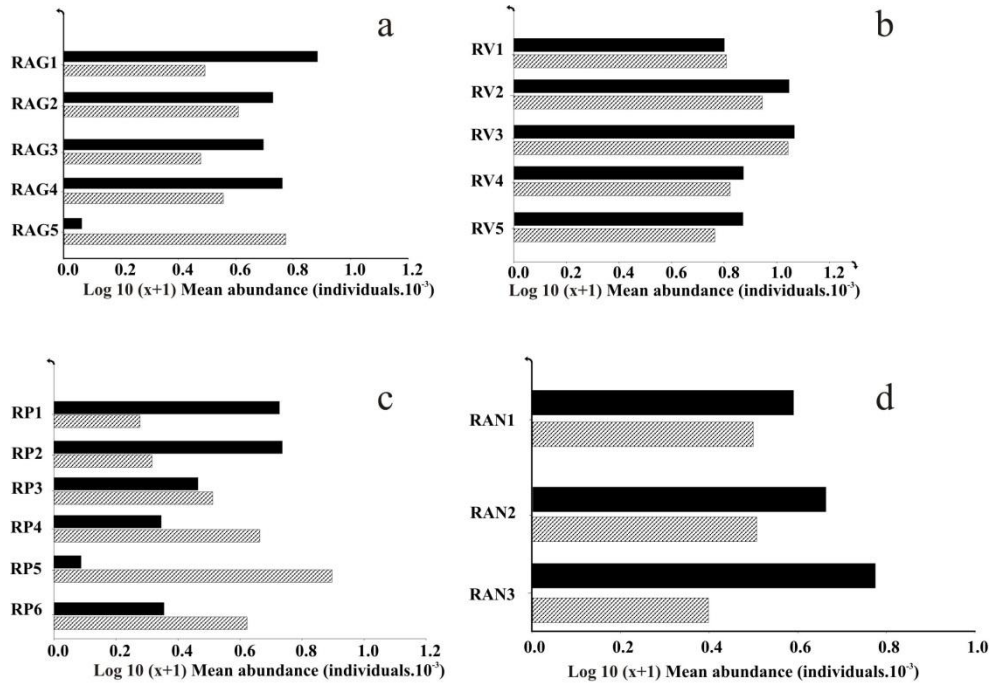


Figure 4. Mean abundance of fish eggs (black bars) and larvae (gray bras) in the different sampling sites of the tributaries: Aguapeí (a), Verde (b), Pardo (c), and Anhanduí (d).

## LARVAE SPECIES COMPOSITION

The Upper Paraná River has high fish species diversity; about 310 fish species are known (Langeani et al., 2007), and they exhibit various reproductive strategies (Suzuki et al., 2004). In all, 56 species of fish larvae were found in the tributaries of Porto Primavera Reservoir, mainly Characiforms (45%) and Siluriforms (43%) (Chart 1). The tributaries show differences in species composition indicating greater reproductive activity of these species for a given tributary, and may be related to the characteristics of the site. The Verde River presents the greatest number of taxa, consequence of wetlands in this tributary, which benefit during the floods, making it natural nurseries for many fish species. Changes in the water level can provide optimal conditions for the larval development as new environments and shelter are flooded (Lowe-McConnell, 1987; Junk et al., 1989).

Most larvae species found in the tributaries are non-migratory species (short migrators or sedentary species-76%) (Figure 5). Many of these species have no parental care (45.7%-SSC), others have parental care (19.6%-SCC), some have internal fertilization and external development (8.7%-SFIE), and others have internal fertilization and internal development (2.2%-SFII). Sedentary species usually spend all their life cycle in lentic environments of the Upper Paraná River, such as oxbow lakes, lagoons and wetlands, and they do not depend of the rainy season to breed, because the conditions for the survival of offspring are suitable for most of the year.

Of high importance is the occurrence of larvae of long-distance migratory species (17%-MIG) (Figure 6): curimba, *Prochilodus lineatus;* dourado, *Salminus brasiliensis*; piracanjuba, *Brycon orbignyanus;* dourado-cachorro, *Rhaphiodon vulpinus;* mandi, *Pimelodus maculatus*; bico-de-pato, *Sorubim lima*; pintado, *Pseudoplatystoma corruscans*; jaú, *Zungaro jahu*; and jurupoca/pintado, *Hemisorubim platyrhynchos/Pseudoplatystoma corruscans* (they are morphologically similar in the early stages of development). Among these species, *S. brasiliensis* and *Z. jahu* were already classified as threatened, *P. corruscans* as near threatened, and *B. orbignyanus* as endangered (high risk of extinction) (Abilhoa and Duboc, 2004). Long-distance migratory species generally spawn in the main channel, upstream from breeding habitats, and offspring drift downstream to reach nursery areas in lagoons, wetlands, and floodplain environments where they complete their development.

Larvae of migratory species occur in all tributaries of Porto Primavera Reservoir, but species composition varies, suggesting adults exhibit preference for tributaries (Figure 7). The highest abundance of migratory species are found in the Verde River, especially *B. orbignyanus*, *Z. jahu*, *S. brasiliensis*, and *H. plattyrhynchos/P. corruscans*. Comparing with other tributaries, this river seems to be the major holder of long-distance migratory species, because half of the species collected represent this behavior. Also, larvae of *P. lineatus* and *S. lima* occur mainly in the Aguapeí River. Higher abundances of *R. vulpinus* were found in the Pardo River and larvae of *P. maculatus* occurred especially in the Anhanduí River. Settlement patterns of habitat for some species reflect the suitability of an area for the survival of offspring in terms of food resources availability and refuge from predation (Arrington and Winemiller, 2006; Richardson et al., 2010).

**Chart 1. Mean densities (larvae/10m$^3$) of larvae species in the tributaries of Porto Primavera Reservoir, Upper Paraná River, Brazil. SSC=sedentary species without parental care; SCC= sedentary species with parental care; SFIE= sedentary species with internal fertilization and external development; SFII= sedentary species with fertilization and internal development; NC=no available information; MIG = migratory species.**

| Taxa | Tributaries | | | | Strategies |
|---|---|---|---|---|---|
| | Aguapeí | Verde | Pardo | Anhanduí | |
| **CHARACIFORM** | | | | | |
| Parodontidae | | | | | |
| *Apareiodon* spp. | ******** | | | | SSC |
| Prochilodontidae | | | | | |
| *Prochilodus lineatus* | | ******** | ******** | | MIG |
| Anostomidae | | | | | |
| *Leporinus friderici* | ******** | | | | SSC |
| *Leporinus* spp. | ******** | | | | SSC/MIG |
| Characidae | ******** | | ******** | | SSC |
| *Astyanax altiparanae* | | | | ******** | SSC |
| *Astyanax* spp. | ******** | ******** | | | SSC |
| *Bryconamericus* spp. | | ******** | | | SSC |
| *Hemigrammus marginatus* | | | | | SSC |
| *Hemigrammus* spp. | | | | | SSC |
| *Moenkhausia* aff. *sanctaefilomenae* | | ******** | ******** | | SSC |
| *Salminus brasiliensis* | | | | | MIG |
| *Brycon orbignyanus* | ******** | | ******** | ******** | MIG |
| *Serrasalmus* spp. | | | | | SCC |
| *Aphyocharax* spp. | ******** | | ******** | | SSC |
| *Roeboides descalvadensis* | | ******** | ******** | | SSC |
| *Serrapinus notomelas* | ******** | | | | SSC |
| *Serrapinus* spp. | | ******** | ******** | | SSC |
| Acestrorhynchidae | | | | | |
| *Acestrorhynchus* spp. | ******** | | ******** | ******** | SSC |
| Cynodontidae | | | ******** | | |
| *Rhaphiodon vulpinus* | ******** | ******** | | | MIG |
| Erythrinidae | | | | | |
| *Hoplias* spp. | | | | | SCC |
| Lesbisinidae | | | | | |
| *Pyrrhulina australis* | | | ******** | | SSC |
| **SILURIFORM** | | | | | |
| Cetopsidae | | | | | |
| *Cetopsis gobioides* | ******** | ******** | | | NC |
| Callichthydae | | | | | |
| *Hoplosternum littorale* | | ******** | ******** | | SCC |
| Loricariidae | | | | | |
| *Loricariichthys platymetopon* | ******** | ******** | ******** | | SCC |
| *Pterygoplichthys anisitsi* | | | ******** | | SCC |
| Heptapteridae | ******** | | ******** | ******** | |
| *Pimelodella* spp. | | | ******** | ******** | SSC |
| *Rhamdia quelen* | ******** | ******** | ******** | | SSC |

**Chart 1. (Continued)**

| Taxa | Tributaries | | | | Strategies |
|---|---|---|---|---|---|
| | Aguapeí | Verde | Pardo | Anhanduí | |
| Pimelodidae | | | | | |
| *H. platyrhynchos/P. corruscans* | | | | | MIG |
| *Hypophthalmus edentatus* | | | | ******** | SSC |
| *Iheringichthys labrosus* | | | ******** | | SSC |
| *Pimelodus maculatus* | | ******* | | | MIG |
| *Pimelodus* spp. | | | ******* | ******** | SSC/MIG |
| *Sorubim lima* | | | | | MIG |
| *Zungaro jahu* | | | | ******** | MIG |
| Doradidae | | | | | |
| *Trachydoras paraguayensis* | | | ******** | | SSC |
| Auchenipteridae | | | | ******** | |
| *Ageneiosus inermis* | | ******** | | | SFIE |
| *Auchenipterus osteomystax* | | | | | SFIE |
| *Parauchenipterus galeatus* | | | | ******** | SFIE |
| *Tatia neivai* | | | | | SFIE |
| **GYMNOTIFORM** | | | | | |
| Gymnotidae | | | | | |
| *Gymnotus* spp. | | | | | SCC |
| Sternopygidae | | | | | |
| *Eigenmannia* spp. | | ******** | | | SSC |
| Apteronotidae | | | | | |
| *Apteronotus* spp. | | | | ******** | SCC |
| **SYNBRANCHIFORM** | | | | | |
| Synbranchidae | | | | | |
| *Synbranchus marmoratus* | | ******** | ******** | | SCC |
| **CYPRINODONTIFORM** | | | | | |
| Poeciliidae | | | | | |
| *Pamphorichthys* sp. - "guaru" | ******** | | | | SFII |
| **PERCIFORM** | | | | | |
| Cichlidae | | | | | |
| *Geophagus* spp. - "cará" | | | ******** | | SCC |

| | | | | | | | | ******* |
|---|---|---|---|---|---|---|---|---|
| >1.0 | | 0.50-1.0 | | 0.11–0.49 | | 0.02 – 0.10 | | >0<0.01 |

Figure 5. Larvae of sedentary fish species of tributaries in Porto Primavera Reservoir, Upper Paraná River, Brazil. From top to bottom: *Hoplias* spp., *Apternotus* spp., *Gymnotus* spp., *Auchenipterus osteomystax*, *Loricariithys platymetopon*, and *Pterygoplichthys anisitsi*.

Figure 6. Larvae of migratory fish species in tributaries of Porto Primavera Reservoir, Upper Paraná River, Brazil. From top to bottom: *Brycon orbignyanus*, *Salminus brasiliensis*, *Rhaphiodon vulpinus*, *Prochilodus lineatus*, *Sorubim lima*, *Zungaro jahu*, and *Pimelodus maculatus*.

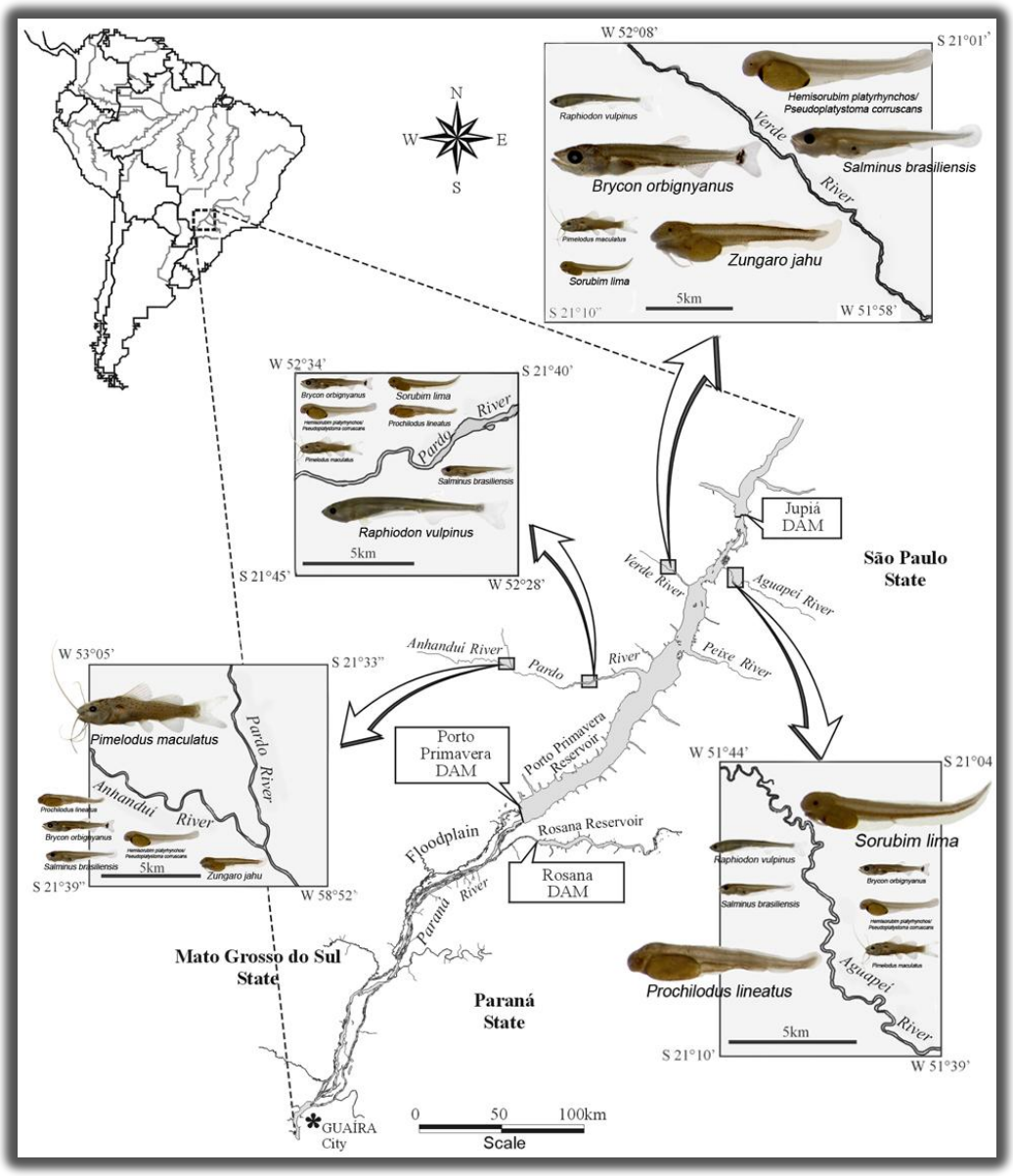


Figure 7. Distribution of the fish species larvae in the tributaries of Porto Primavera Reservoir, Upper Paraná River, Brazil. Larger larvae indicate higher abundances.

## FINAL CONSIDERATIONS

The tributaries of Porto Primavera Reservoir in the Upper Paraná River have suitable conditions for reproduction and development of many fish species with diverse reproductive strategies, including the long-distance migrators. The reproductive activity of the species in the study tributaries, and especially the long-distance migrators, is comparable to that in the

Upper Paraná River floodplain downstream Porto Primavera Dam, the last stretch of the Upper Paraná River free of impoundments, and the least impacted riverine environment in the region.

This importance is confirmed by the occurrence of larvae of long-distance migrators of 9 of 19 possible species occurring in the Upper Paraná River. We suggest the fish ladder at Porto Primavera Dam may be playing an important role in re-establishing longitudinal connectivity among critical habitats, allowing ascent of migratory fish species into the reservoir, and eventually access to upstream reaches and tributaries. This result contradicts Pelicice and Agostinho (2008), who suggested fish passages into reservoirs act as ecological traps.

Establishment of Permanent Conservation Units in tributaries of Porto Primavera Reservoir may help preserve habitats identified as essential spawning and nursery areas, and may be key to the maintenance and conservation of the fish species in the Paraná River basin. Considering that the Paraná River is highly impounded, special attention should be given to the few remaining low-impact habitats as they continue to be targets of hydropower development that will likely intensify impacts on migratory fish stocks. An essential responsibility is to encourage reservoir managers and resource agencies to conserve these tributaries and avoid actions that potentially can condemn some fish species to extinction.

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