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Downstream passage of fish eggs and larvae through the Porto Primavera fish ladder, Upper Paraná River, Brazil

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Introduction

Potamodromous fish species are characterized by seasonally migrate long distances between different habitats to complete their life cycle (Lucas & Baras, 2001; Carolsfeld *et al.*, 2003). These fish species commonly spawn in the main channel of rivers or in the upper parts of large tributaries, and nursery areas are lagoons and wetlands in the lower parts. They have a seasonal reproductive cycle synchronized with the floods (Winemiller, 1989), which provide areas with great availability of food and shelter for juveniles (Lowe-McConnell, 1987; Junk *et al.*, 1989; Vazzoler, 1996), and they depend on the lateral connectivity to keep their populations.

The connectivity between rivers and their floodplains, intensified by seasonal flooding, is modified by impoundments resulting from the construction of hydroelectric dams, or by permanent submersion of floodplain habitats, either by changes in the hydrological cycle of the river (Agostinho *et al.*, 2004). Fish passages were implanted at dams to attempt reestablishing the connectivity between different habitats and minimize the impact of the anthropogenic barrier on these populations.

Fish passages, especially fish ladders, were built in some dams in the highly regulated Parana River basin, as the fish ladder at the Engenheiro Sergio Motta Hydroelectric Power Plant, and located in the upper Paraná River, Brazil. However, there are many questions regarding to the effectiveness of those passages as a tool for the conservation on neotropical long-distance migratory species. Thus, this study aims to evaluate evidences of downstream passage of fish eggs and larvae in the fish ladder of the Engenheiro Sergio Motta Hydroelectric Power Plant (known as Porto Primavera), and specifically we would like to point out: 1) What is the condition of integrity of the larvae exhibiting at the beginning and end of this passage? 2) Is there evidence of migratory species larvae in the fish ladder?

Material and Methods

Ichthyoplankton sampling was conducted in the fish ladder monthly from October to March through 2007 to 2010, comprising three spawning seasons (1=2007/2008, 2=2008/2009, and 3=2009/2010). Stationary Conical-cylindrical plankton net (mesh of 0.5mm) was used to collect ichthyoplankton equipped with a flow meter, and exposed for 10 minutes. Samples were realized in two sites (Figure 1): 1) near the water intake (upper pool), and near at the mouth of the ladder (lower pool) in the twilight (both at dawn and nightfall).

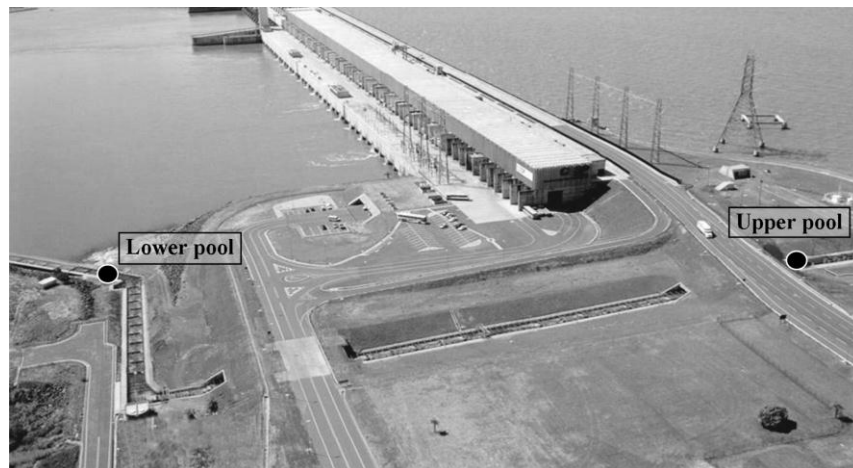


Figure 1. Localization of the sampling sites of the ichthyoplankton, upper and lower pools, in the fish ladder at the Engenheiro Sergio Motta Hydroelectric Power Plant (Porto Primavera), Upper Paraná River, Brazil.

Ichthyoplankton was anesthetized with benzocaine, fixed in buffered 4% formalin, and identified to the species level based on descriptions in Nakatani *et al.* (2001) and Graça & Pavanelli (2007). Larvae taxa identified to species level, genus, and family were also classified according to the reproductive strategies (Suzuki *et al.*, 2004; Agostinho *et al.*, 2003). The density of fish larvae were standardized to a volume of 10m³ water filtered according to Tanaka (1973) modified by Nakatani *et al.*(2001).

Analysis of variance (one-way ANOVA) was applied to verify differences in the density of fish eggs and larvae, considering the sampling sites (upper and lower pools), periods (nightfall and dawn), months (October to March), and spawning seasons (2007-2008, 2008-2009, and 2009-2010) as independent factors. In order to evaluate the condition of integrity of the larvae passing through the fish ladder, they were classified as: 1) undamaged: larvae in perfect condition, 2) partially damaged: when they have a little deformity but are easily identified; 3) totally damaged: very deformed larvae (100% deformed body), making their identification difficult (Figure 2).

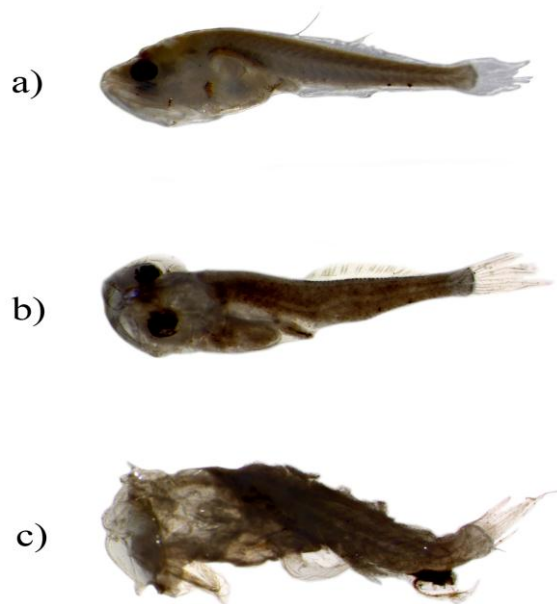


Figure 2. Illustration of *Plagioscion squamosissimus* larvae in different conditions of integrity: a) undamaged, b) partially damaged, c) and totally damaged.

The two-way ANOVA was applied to verify significant differences between the larvae density in different degrees of integrity (undamaged, partially damaged and completely damaged) as well as of these in relation to the sampling sites (upper and lower pools). The larvae densities of in different degrees of integrity were previously ranked to achieve the assumptions of normality and homoscedasticity. The Tukey test at a significance level of 5% was applied when significant differences were found by ANOVA using the software STATISTICA v.7.0.

Results and Discussion

During study period the occurrence of eggs in the fish ladder was low (16 eggs). The mean density of eggs did not differ among the months of sampling, as well as the spawning seasons. The fish larvae were more abundant prevailing from December to March. The mean densities differed significantly among months ($F=6.68$, $p < 0.00$) with higher mean densities verified in February. Significant differences also were found among spawning seasons ($F=2.00$, $p < 0.00$) especially for 2009/2010 when the mean density was much higher than other. However, the mean densities of fish eggs and larvae were similar between upper and lower pools of the fish ladder, and also among sampling period (nightfall and dawn). Therefore, they were not significantly different ($p > 0.05$).

Two-way ANOVA demonstrated significant differences in the density of larvae at different degrees of integrity ($F = 31.50$, $p < 0.005$). Most of the larvae sampled in the fish ladder were undamaged and partially damaged (Figure 3). However, the densities of larvae undamaged, partially damaged, and totally damaged were like with respect to sampling sites, so they did not differ significantly ($F = 0.26$, $p > 0.005$) (Figure 3).

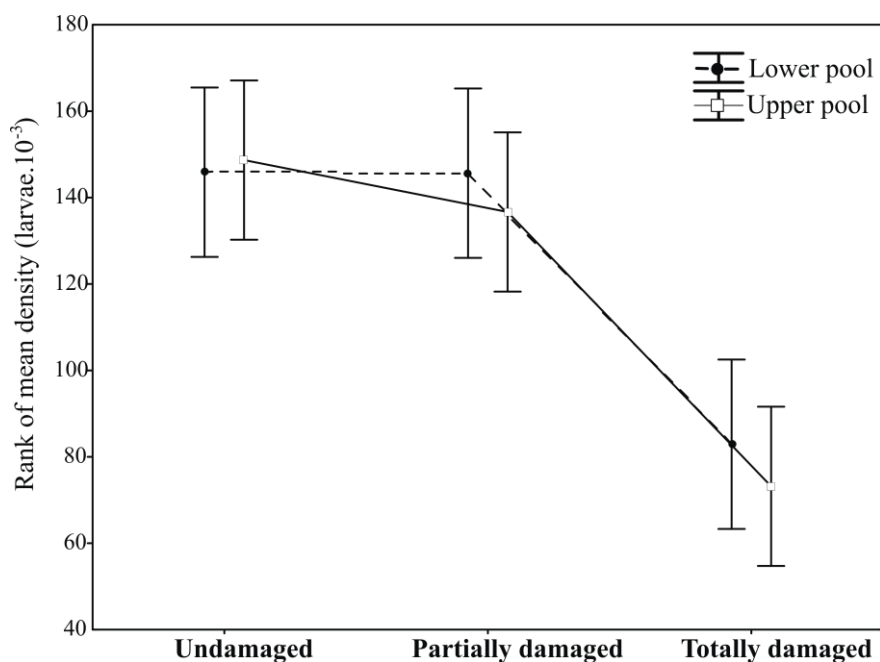


Figure 3. Ranked mean density of larvae (\pm standard error) in different conditions of integrity (undamaged, partially damaged, and totally damaged) at the sampling sites (upper and lower pools) in the fish ladder of the Porto Primavera.

Fifteen (15) taxa of larvae occurred in the fish ladder, especially Characiform (46.7%) and Siluriform (40.0%), including species with different reproductive strategies. Most larvae species found are non-migratory species (short migrators or sedentary species-73.3%).

We high light the evidence of two long-distance migratory species (MIG) (13.3%): *Rhaphiodon vulpinus* captured in the spawning season of 2008/2009 and *Sorubim lima* in the 2009/2010. Moreover two taxa, Anostomidae and *Pimelodus* spp., were classified as migratory/sedentary without parental care species (MIG/SSC) (13.3%) due to the possibility of belonging to one or other reproductive strategy. The species with the highest density of larvae were *Hypophthalmus edentatus* (maximum density of 2.13 larvae/10m³) and *Plagioscion squamosissimus* (1.22 larvae/10m³), both pelagic species habiting lentic environments.

Our study evidenced downstream passage of ichthyoplankton through a fish way, in this case the fish ladder of Porto Primavera. The low passive movement of eggs occurred in this study can be by predation and sedimentation processes, enhanced by reducing the flow velocity and increasing the transparency of water in dammed environments (Agostinho *et al.* 2002; Agostinho *et al.* 2007b).

The high densities of fish larvae observed between December and March in the fish ladder indicate a seasonal pattern that coincides with the period of greatest reproductive activity of the species. 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 of Paraná River; possibly prolonged period of heavy rains contributed to the highest ichthyoplankton abundance (in 2009/2010). The migratory fish species of Paraná River have a well-marked peak of reproduction from November to February, and the non-migratory species exhibit similar behavior, differing only by the fact that a few species spawning during April to September (Vazzoler, 1996).

The lack of significant differences in the density of ichthyoplankton observed between upper and lower portions of the fish ladder strengthens the evidence of drift of fish eggs and larvae through fish passage. Though we found larvae totaling damaged in both sites sampled

in the fish ladder, most of larvae were undamaged or partially damaged. Turbulence in the fish ladder, but especially the processing of sample (water filtering through the plankton net) could cause these deformities in the larvae. Some studies have shown mortality and injury of fish (juveniles and adults) by dam structures (Clay, 1995, Agostinho *et al.*, 2007a), however, studies at testing to these effects on the fish larvae are scarce.

The predominance of the non-migratory species found is mainly due to the high densities and *H. edentatus* and *P. squamosissimus*. These opportunistic species have high reproductive potential, and probably a high adaptability to changing environments, which explains the major events at these sites (Agostinho *et al.*, 1994). We emphasize the occurrence of larvae of two long-distance migratory fish species in the Porto Primavera fish ladder, *R. vulpinus* and *S. cf. lima*, with the possibility of incident of other because we also found larvae of Anostomidae and Pimelodus spp., classified in this study as migratory/sedentary species, which include migratory species. Studies realized by Agostinho *et al.* (2007b) in the ladder of Luiz Eduardo Magalhães Hydroelectric Power Plant (Lajeado), on the Tocantins River basin reported absence of larvae of long-distance migratory species in fish passage. Nevertheless, it shouldn't discard the possibility of the migratory species larvae occurring in this fish ladder since their identification was restricted to order level.

Conclusions

Future studies need to complement on monitoring and assessment continued of the downstream passage of fish eggs and larvae through the fish passage, including also upstream and downstream of the dam, as part of the protocol for monitoring and evaluating the efficiency of fish passages. Thus, the challenge of fish passage in the Neotropical region beyond the guidance and attraction to both upstream and downstream is to consider aspects of bioengineering to better positioning the water intake to promote greater efficiency of the passive movement of eggs and fish larvae.

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