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# FLOW REGULATION BY DAMS AFFECTING ICHTHYOPLANKTON: THE CASE OF THE PORTO PRIMAVERA DAM, PARANÁ RIVER, BRAZIL

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## ABSTRACT

The effects of a dam closure (Porto Primavera Dam) on reproduction of the main species that use the floodplain located below a nursery area were determined. Specifically, we examined, before and after the closure of the dam, the spatial distribution of larvae and the differences in density according to life strategy (migratory and non-migratory species). Fifteen points distributed along the channels of the Paraná, Ivinheima and Paranapanema rivers were sampled, between 1997 and 2001, (October 1997 to December 1998—pre; and between January 1999 to March 2001—post closure), during the spawning period of most fish species found in the region (October to March). Samplings were always conducted at night, using a conical-cylindrical plankton net (0.5 mm mesh) with a flowmeter attached. There were significant differences in larvae densities between pre and post dam closure for several species. Also, there were significant differences between the pre and post-closure periods for densities of migratory and non-migratory species, and between sampling sites. These findings indicate decline in densities and number of taxa caught after the closure of the dam. Larvae of migratory species, formerly common in the entire study area, were registered only in points influenced by the non dammed rivers (such as the Ivinheima River), indicating that the closure of Porto Primavera caused negative impacts on fish reproduction downstream of the dam. 

KEY WORDS: eggs and larvae; flow regulation; dams; Paraná River

## INTRODUCTION

Construction of dams is an old and important human intervention in natural systems. Reservoirs interfere in any river where they are built, altering water flow and terrestrial and aquatic systems in a drastic and permanent way (Tundisi, 1999). Construction of reservoirs modifies intensity, duration and periods of floods, reduces loads of nutrients in seasonally flooded areas and creates, in segments immediately below the dam, unstable thermal and hydrodynamic conditions. Dams also intercept migratory routes of various species, impacting the biogenic capacity of a system and availability of food and shelter for juvenile fish (Agostinho *et al.*, 1993).

Hydrological and limnological conditions in rivers regulated by dams may affect fish spawning. This is especially true for migratory species, which require specific thermal conditions and floods that work as a trigger mechanism for spawning, and subsequent survival of eggs, larvae and fries (Agostinho *et al.*, 1993). Thus, in the process of occupation of a new reservoir, extinction or reduction in the abundance of migratory species that present some restriction to lentic environments is expected (Nakatani, 1997).

Various studies in South America analysed impact of dams on fish communities (Godinho and Godinho, 1994; Petrere Jr., 1996; Ponton and Vauchel, 1998; Merona and Albert, 1999). Few dealt with impacts of dams on fish reproduction, as the case of the work conducted by Agostinho *et al.* (1993) that analysed the impacts of the Itaipu

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Dam (located in the Paraná River, in the border between Brazil and Paraguay). However, all works cited above focused on adult fish. Studies that evaluate effect of dams on fish larvae are practically non-existent for the Neotropical region, and this work is the first for the Upper Paraná River floodplain.

Porto Primavera Dam (officially named Engineer Sérgio Motta) is located 28 km upstream from the confluence of the Paranapanema and Paraná rivers. The first filling stage of the reservoir was concluded in December 1998 and the second in March 2001, flooding an area of 2250 km$^2$ (CESP—Companhia Energética de São Paulo, 2002). This dam is a physical barrier that intercepted migration routes of the main reophilic fish species, impeding their access to upper reaches where they used to spawn. Then, this study aimed to evaluate the effects of the closure of Porto Primavera Dam on fish larvae (ichthyoplankton), analysing possible differences between pre and post closure periods in (i) the spatial distribution of fish larvae abundance and, (ii) in density of larvae according to life strategy (migratory and non-migratory species).

## STUDY AREA

The Paraná River is the second largest hydrographic basin in South America, and is the tenth largest river in the world considering flow. It is 3870 km long, from the confluence of the Paranaíba and Grande rivers to the La Plata estuary. The upper and part of the middle stretches are located within Brazil, draining an area of 891 000 km$^2$, equivalent to 10.5% of its territory (Paiva, 1982). Of this area, only a short stretch of approximately 200 km, situated between Porto Primavera Dam and the city of Guaíra (Paraná State, Brazil), does not present any dam. Above this stretch, the Paraná River and its main tributaries are heavily dammed, with 130 dams higher than 10 m, most of them in cascade. Among these reservoirs, 26 have areas above 100 km$^2$, covering about 93% of the total 14 000 km$^2$ surface area and a total accumulated volume of 250 109 m$^3$ (Agostinho *et al.*, 1995).

Specifically, this study was carried out in the area between the mouths of Paranapanema and Ivinheima rivers (22° 38′ 56″ S / 53° 04′ 53″ W—22° 59′ 64″ S / 53° 39′ 02″ W). In this segment, the Paraná River presents a wide braided channel, low declivity (0.09 m/km), with an extensive floodplain on its west margin. Also, there is a large accumulation of sediments on its bed, giving origin to several bars and small islands (Agostinho *et al.*, 1994).

## MATERIALS AND METHODS

### *Samplings*

Samples were collected from October 1997 to March 2001, and included the pre (October 1997 to December 1998) and post (January 1999 to March 2001) closure periods of Porto Primavera Dam. Samplings were conducted at night near the surface of the water (approximately 20 cm deep) at 15 points, using conical-cylindrical plankton nets (0.5 mm mesh) equipped with a flowmeter. Nets were exposed against the current for 10 min.

Sample points were distributed in the channels of the Paraná (13 points), Ivinheima (1 station) and Paranapanema (1 station) rivers (about 500 m from their mouths). Two points in the Paraná River were located in the area of influence of the Baía and Ivinheima rivers (about 200 m below the mouth) (Figure 1). Samples were preserved in 4% formalin buffered with calcium carbonate. Larvae abundance was expressed in a standard way (number of larvae per 10 m$^3$ of filtered water), according to Tanaka (1973), modified by Nakatani *et al.* (2001). Identification of larvae was carried out in accordance with the development sequence technique proposed by Ahlstrom and Moser (1976) and Nakatani *et al.* (2001).

### *Data analysis*

In order to evaluate the effects of the Porto Primavera Dam closure in the spatial distribution of larvae, we evaluate changes in density along the points sampled. It was assumed that points located closer to the dam were the most impacted by the dam closure. Thus, the study area was divided into three subareas: a) Paranapanema Subarea, points 1 to 5, from the Paranapanema River to near the mouth of the Baía River; b) Baía Subarea, points 6 to 9 and 15, from the mouth of the Baía River to near the mouth of the Ipoitã Channel; c) Ivinheima

 

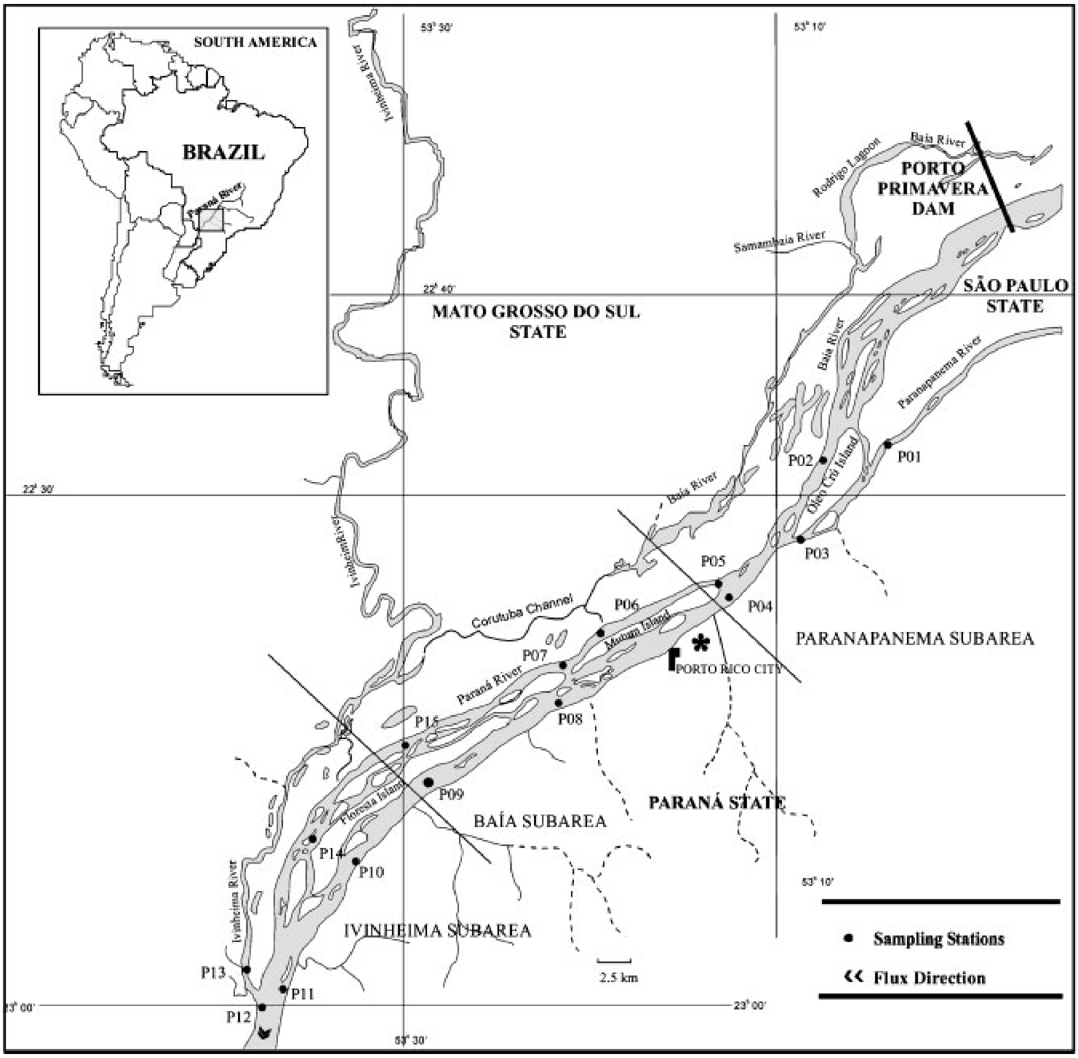


Figure 1. Map of the upper Paraná River showing the location of the sampling stations

Subarea, points 10 to 14, from below the mouth of the Ipoitã Channel to the mouth of the Ivinheima River (Figure 1).

Densities of the main species were used to evaluate possible alterations, considering life strategies (migratory and non-migratory species). Only taxa with high densities were analysed (above 0.95 individuals/10 $m^3$). They were the non migratory *Bryconamericus stramineus* EIGENMANN 1908, *Plagioscion squamosissimus* (HECKEL, 1840) and *Hypophthalmus edentatus*, SPIX 1829; and the migratory *Pseudoplatystoma corruscans* (AGASSIZ, 1829), *Pterodoras granulosus* (VALENCIENNES, 1833), *Pimelodus* spp. and *Salminus maxillosus*, VALENCIENNES, 1849 (Agostinho *et al.*, 2003). Differences between mean densities were evaluated using analysis of variance (two-way ANOVA), with periods (pre and post closure) and sampling points as factors. As seven ANOVAs were carried out, we applied, before, a multivariate analysis of variance (MANOVA; considering the two factors and the densities of nine species) to determine if differences in the densities are greater than mere chance (Johnson, 1998). This procedure is also known as protected ANOVA (Scheiner, 1993). The statistical analyses were carried out using Statistica® software. Data were log transformed in order to meet assumptions of MANOVA and ANOVA.

 

## RESULTS

### *Spatial and temporal variations in larvae composition and abundance*

Differences in composition and abundance of larvae between the pre- and post-closure periods of Porto Primavera Dam were evident. At practically every sample points, there were alterations in number of taxa and densities of larvae. In some cases, species formerly caught (pre closure) were no longer caught (post closure).

### *Paranapanema subarea*

At station 1, located immediately above the mouth of the Paranapanema River, only minor differences in composition and densities of captured larvae were observed in the pre- and post-closure periods. Of the 11 taxa caught, only two species recorded previously (*Gymnotus* cf. *carapo* and *Iheringichthys labrosus*) were not recorded after closure (Figure 2A).

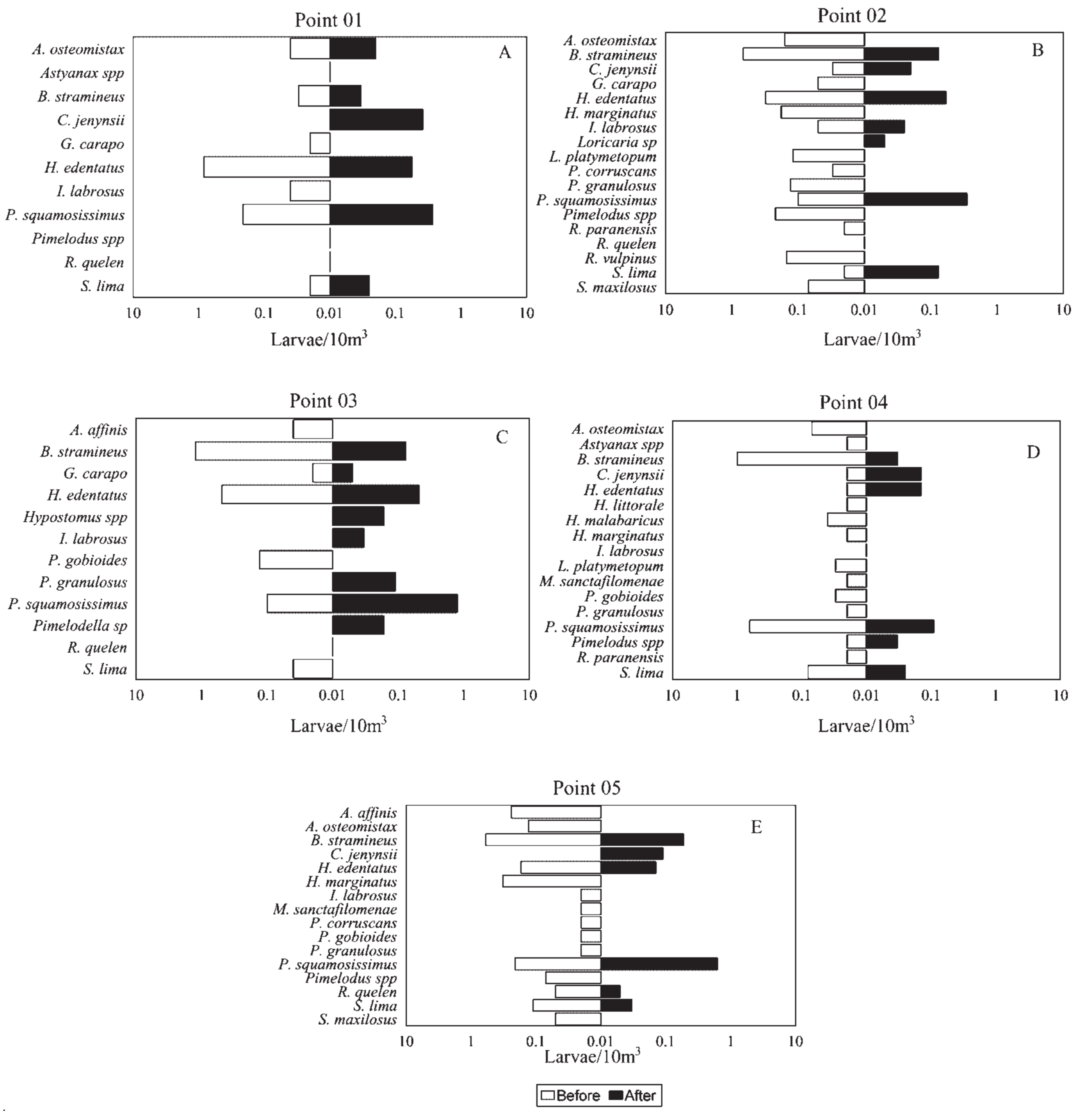


Figure 2. Densities of fish larvae in the Paranapanema subarea during pre and post-closure periods of Porto Primavera Dam, located in the Upper Paraná River

 

For points 2, 4 and 5, located in the main channel of the Paraná River, clear differences were observed in the composition of larvae before and after closure (Figures 2B, 2D and 2E). Among the species absent after the closure are commercially important migratory species, such as *Salminus maxillosus* and *Pseudoplatystoma corruscans*, in addition to less popular, but commercial important, species like *Pimelodus* spp. Among the species present in the pre- and post-closure, only the non-migratory *Plagioscion squamosissimus*, *Hypophthalmus edentatus* and *Bryconamericus stramineus* maintained similar densities.

Station 3, located in the main channel of the Paraná River, presented opposite results than those of the other station of this subarea. In the period before the closure, seven taxa were caught and after the closure, eight were caught. However, none species is considered migratory (Figure 2C).

### *Baía subarea*

In this subarea, fall in density was recorded at every station sampled. Absence of commercially important migratory species such as *S. maxillosus* and *Pimelodus* spp., and increase in densities of non-migratory species such as *H. edentatus* and *P. squamosissimus* was also observed in the post-closure period (Figure 3).

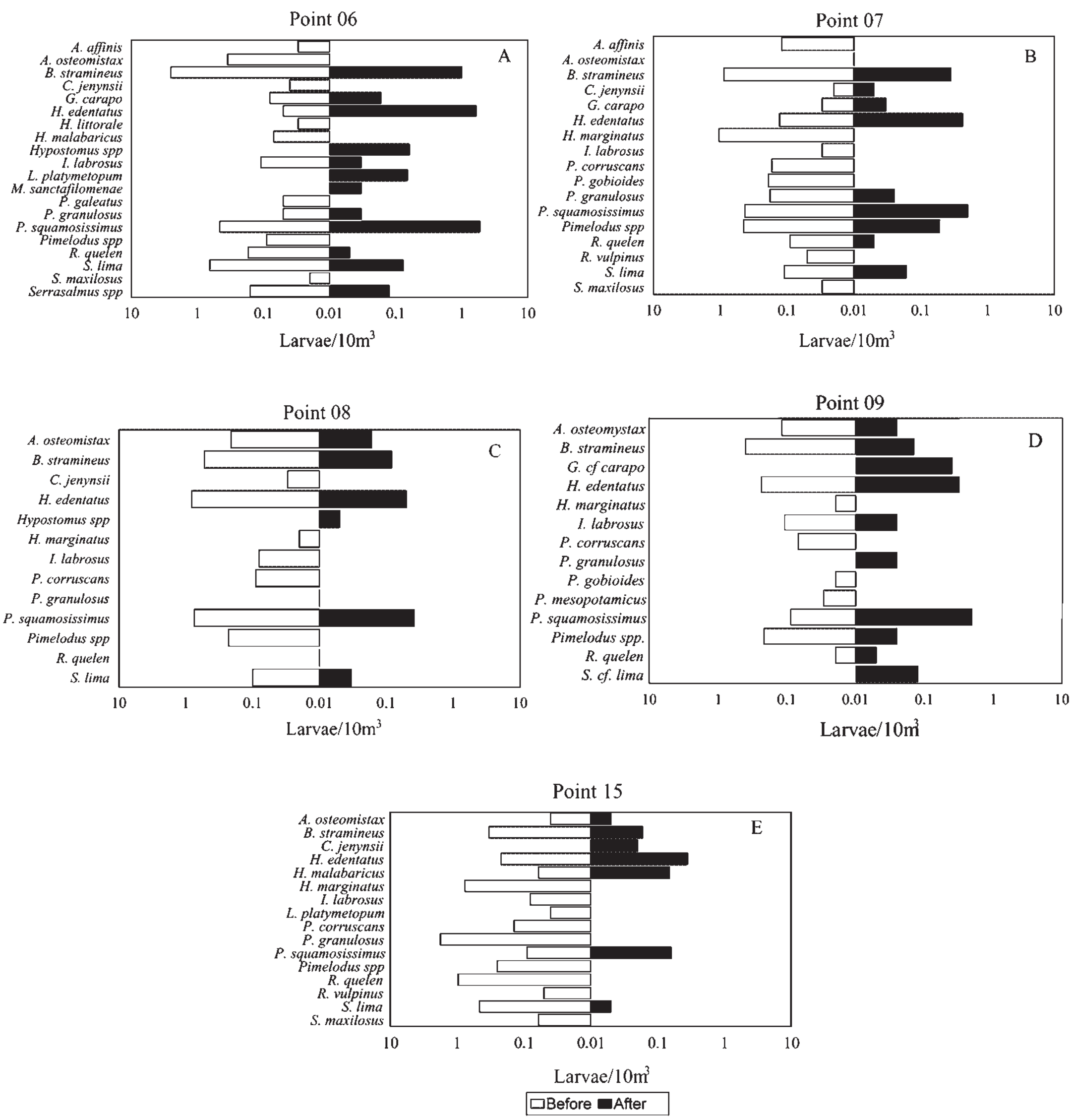


Figure 3. Densities of fish larvae in the Baía subarea in the pre and post-closure periods of Porto Primavera Dam, located in the Upper Paraná River

 

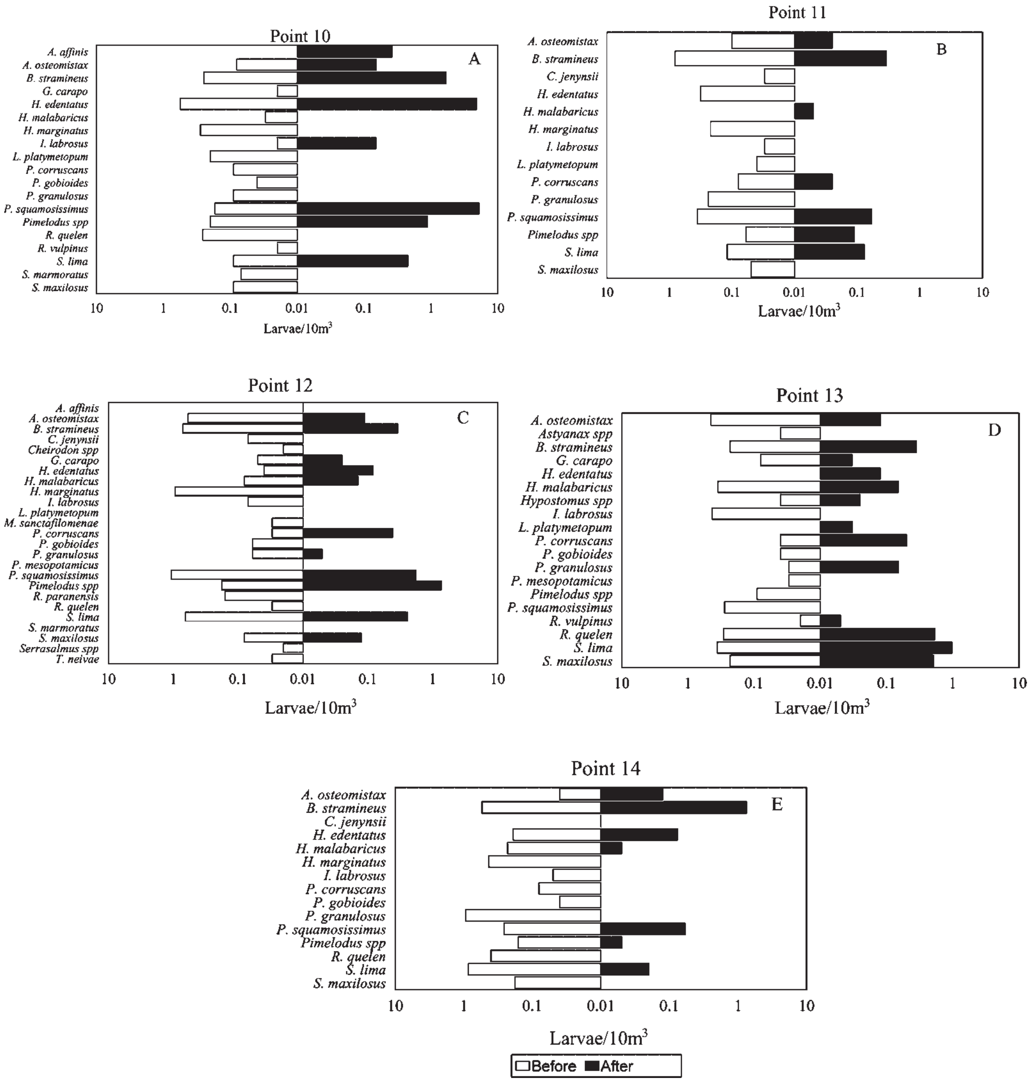

Figure 4. Densities of fish larvae in the Ivinheima subarea in the pre and post-closure periods of Porto Primavera Hydroelectric Dam, located in the Upper Paraná River

*Ivinheima subarea*

A conspicuous difference in number of taxa and density was observed for points 10, 11 and 14. Species considered migratory were rare after the closure, whereas non-migratory species (*B. stramineus*, *P. squamosissimus* and *Surubim lima*), common in the two periods, maintained their densities or presented greater densities after the closure (Figures 4A, B and E). However, points 12 and 13 did not present relevant differences in number of taxa and densities during the pre- and post-closure periods, but high densities of migratory species were registered in both periods (Figures 4C and 4D).

*Spatial and temporal variations in the abundance of the main species*

Results of the MANOVA applied to the densities of the seven main species revealed significant differences between the factors analysed (periods and sampling points; R of Rao $> 1.86$; $p > 0.0001$). These results indicate the appropriateness of determining differences in density for each species separated.

 

Table I. Results of the two-way ANOVAs applied to the density of non-migratory fish larvae

| Species | Points | | | Period | | | Interaction | | |
|---|---|---|---|---|---|---|---|---|---|
| | DF | *F* | *p* | DF | *F* | *p* | DF | *F* | *p* |
| *H. edentatus* | 14 | 0.73 | 0.75 | 1 | 0.66 | 0.42 | 14 | 0.86 | 0.60 |
| *B. stramineus* | **14** | **5.62** | **0.0001** | **1** | **34.66** | **0.0001** | **14** | **1.90** | **0.025** |
| *P. squamosissimus* | 14 | 1.47 | 0.12 | 1 | 0.32 | 0.57 | 14 | 0.84 | 0.62 |

DF = degrees of freedom; $F$ = ANOVA statistic; $p$ = probability of finding an $F$ above the one already found.
Values in **bold** were significant ($p < 0.05$).

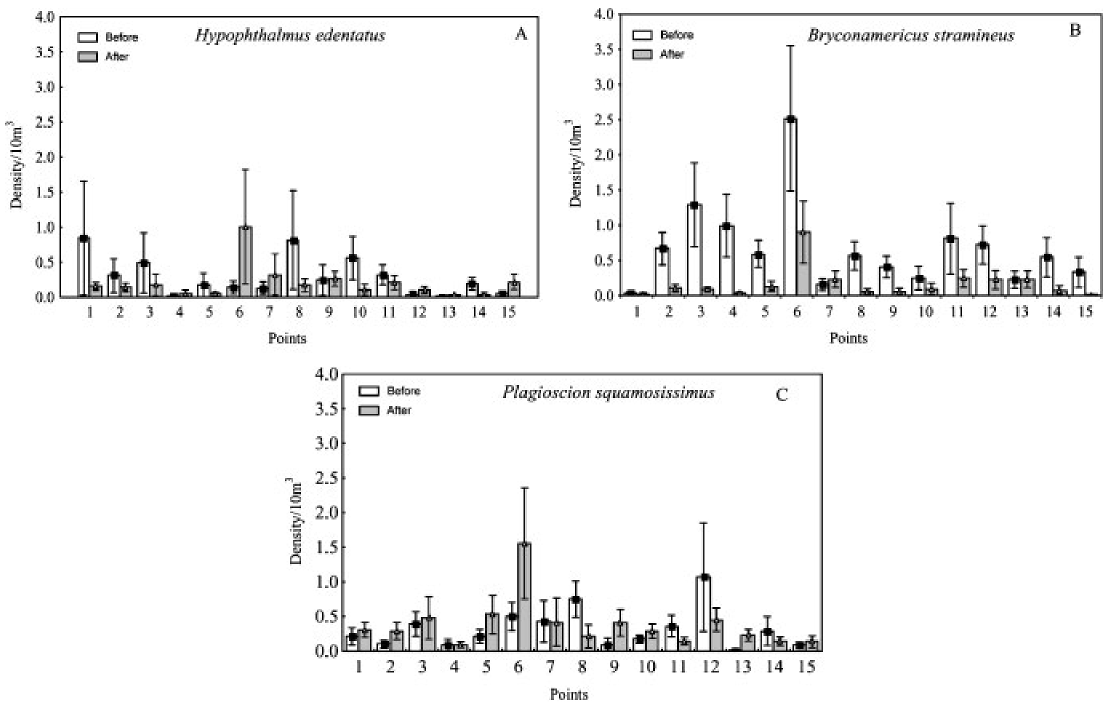


Figure 5. Average densities (bars) and standard error (lines) of non migratory fish larvae in the pre and post Porto Primavera Dam closure

## *Non-migratory species*

Non-migratory species were caught at every sampling station in both periods analysed. For *H. edentatus*, there were no significant differences in mean larvae densities between periods and points ($F < 0.86$; $p > 0.40$) (Table I), due to the high variability in the data (Figure 5A).

*Bryconamericus stramineus* and *P. squamosissimus* presented opposite results between the two periods. *B. stramineus* presented a clear reduction in densities in the post-closure period at practically every sampling station (Figure 5B); whereas densities of *P. squamosissimus* (except points 8 and 12), increased at every station in the same period (Figure 5C). For *B. stramineus*, the interaction between station and period was significant ($F = 1.90$; $p = 0.02$; Table I), indicating that densities at different points depended on the period considered. For *P. squamosissimus*, there were no significant differences between mean densities at the different points, in accordance with periods ($F < 1.47$; $p > 0.12$; Table I).

## *Migratory species*

In general, densities of all migratory species declined in the post-closure period at the points located in the main channel of the Paraná River. However, a conspicuous increase in density was registered in the Ivinheima River region.

Table II. Results of the two-way ANOVAs applied to the density of migratory fish larvae

| | Point | | | Period | | | Interaction | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | DF | *F* | *p* | DF | *F* | *p* | DF | *F* | *p* |
| *P. granulosus* | **14** | **2.03** | **0.01** | **1** | **6.05** | **0.01** | **14** | **2.18** | **0.01** |
| *Pimelodus spp.* | 14 | 1.40 | 0.15 | 1 | 0.04 | 0.84 | 14 | 1.38 | 0.16 |
| *P. corruscans* | 14 | 1.50 | 0.11 | 1 | 2.30 | 0.13 | 14 | 1.68 | 0.06 |
| *S. maxillosus* | **14** | **3.18** | **0.001** | 1 | 1.21 | 0.27 | 14 | 1.20 | 0.27 |

DF = degrees of freedom; $F$ = ANOVA statistic; $p$ = probability of finding an $F$ above that already found.
Values in **bold** were significant ($p < 0.05$).

For *P. granulosus*, the interaction between points and periods was significant ($F = 2.18$; $p = 0.01$; Table II), showing that variation in densities among points depended on the period considered. In the period before the closure, high densities of this species were recorded at 14 and 15. After the closure, larvae of this species practically disappeared, captured only at station 13, in the Ivinheima River, however, with low densities (Figure 6A).

*Pimelodus* spp. was caught practically at every sampling station in the pre-closure period. After the closure, there was a noticeable reduction in densities at the points located in the Paraná River Channel and a conspicuous increase at points 12 and 13 (Ivinheima River region) (Figure 6B). However, differences in density averages were not significant ($F < 1.50$; $p > 0.15$).

*Pseudoplatystoma corruscans* and *S. maxillosus* were caught at almost every sampling station, both in the Paraná channel and in main tributaries (except Paranapanema River) in the period before the closure. After the closure, larvae of these species were caught only in the Ivinheima River region (points near its mouth) (Figures 6C and 6D). For *P. corruscans*, significant differences in mean densities were not verified ($F < 2.40$; $p > 0.05$; Table II). But, for *S. maxillosus*, only the factor station was significant ($F = 3.18$; $p < 0.001$), a result maybe due to the high density recorded at station 13 (Ivinheima River).

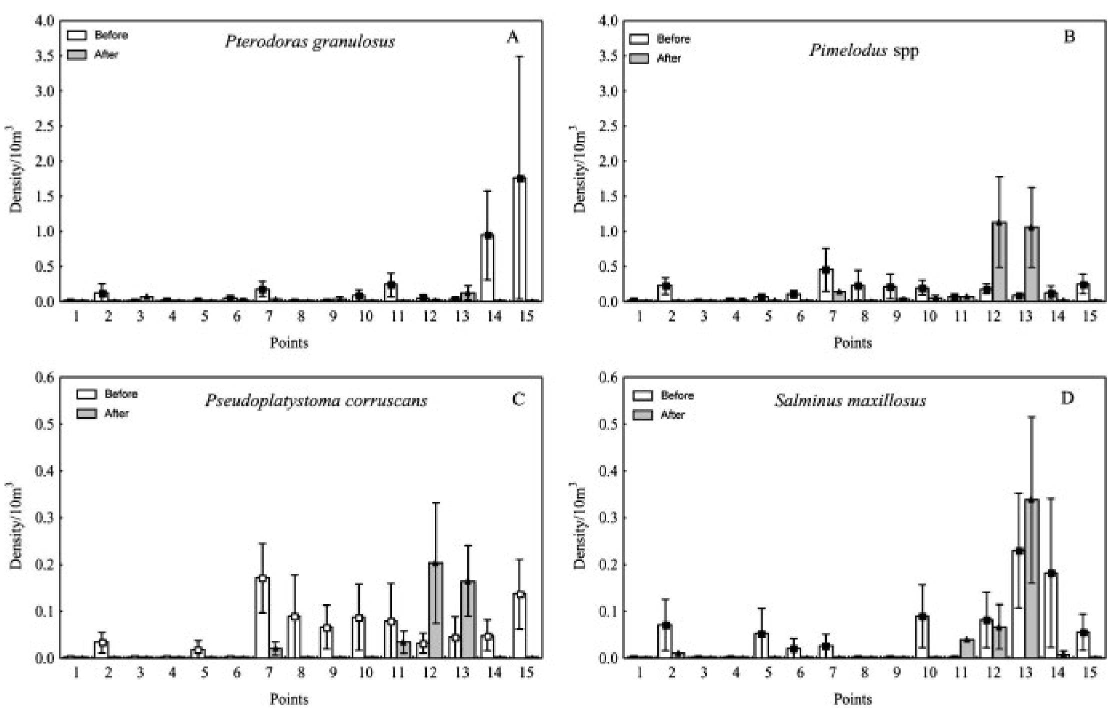


Figure 6. Mean densities (bars) and standard error (lines) of migratory fish larvae in the pre and post periods of Porto Primavera Dam closure

 

## DISCUSSION

In the three sampled subareas, there was a reduction in the number of taxa and densities of species caught between the two periods, especially in the Paranapanema Subarea. This fact maybe a result of the increase in water transparency (Secchi depth), due to retention (by the dam) of suspended solids (Agostinho *et al.*, 2004a), making eggs and larvae more susceptible to predation. Apparently, this is one of the main factors that explain the reduction of migratory fish species below dams (Petrere Jr., 1996). In fact, Agostinho *et al.* (2002) mention that in high transparency water, larvae of migratory and large-sized species are naturally preyed on, even by small fish species belonging to diverse feeding habits (e.g. foragers, insectivores and planktophagues).

For the Baía and Ivinheima subareas, reductions in number of taxa and densities were lower. The presence of these tributaries may have influenced the results since they are not dammed, and, therefore, transport large quantities of suspended material, reducing, in part, the increased water transparency of the Paraná River. Also, they are spawning sites of various migratory and non-migratory fish species. Only in points influenced by the Baia and Ivinheima rivers, densities and number of taxa caught did not vary between the pre- and post-closure periods, revealing the importance of these areas as spawning grounds, especially for migratory species. The other points in the main channel of the Paraná River presented profound alterations in densities, with reduction in or absence of species in the second period, which demonstrates the great impact caused by the closure of Porto Primavera Dam.

The closure of Porto Primavera Dam prompted alterations in densities of practically every species analysed in this study, both non-migratory and migratory. Among the non-migratory species, *B. stramineus* and *H. edentatus* presented lower densities in the post-closure period at almost every sampled station. This demonstrates that even species that do not depend on increased water levels or on long migrations to spawn were exposed to considerable degree of impact. Probably due to reduction in adequate spawning sites or flow control imposed by the dam, in addition to the probable increase in predation resulted from clear waters.

In general, *P. squamosissimus* maintained similar or greater densities in the second period (in relation to the first), revealing that the environmental conditions formed after the closure of the dam did not interfere or, at the minimum, favoured this species. Among the main characteristics of *P. squamosissimus*, call attention its high reproductive potential, spawning occurs in several batches, and eggs are small (0.5 mm) and pelagic. Its larvae are also pelagic (Agostinho and Julio Jr., 1999; Nakatani *et al.*, 2001).

Although the construction of a dam impacts all fish species in a river, migratory ones are undoubtedly the most affected. Main forms of impact suffered by these species are the interruption of migration routes and flood control due to dam operation. In this study, all migratory species presented clear differences in densities between pre- and post-closure periods of the dam.

The reduction in or absence of migratory species after the closure of Porto Primavera and their increase only at the points in the Ivinheima River and its area of influence reveal that the Paraná River, in the area covered in this study, does not present favourable spawning conditions for migratory species. The main reason for this appears to be the physical barrier imposed by the dam, which impedes the continuity of upstream migrations and, if favourable sites are not found, spawning does not occur. Similar situation was found by Sato *et al.* (1987) in the São Francisco River, that due to the presence of Três Marias Dam, various migratory species did not reach their spawning grounds and, consequently, they were not later found in the floodplain upstream from the dam.

Agostinho *et al.* (1993), in an evaluation of the reproductive activity of the fish community in the first kilometres downstream from the Itaipu Dam, verified through histological analysis of ovaries, presence of oocytes in different phases of atresia and absence of post-ovulatory follicles (indicative of spawning) in *Brycon orbignyanus*, *Mylossoma orbignyanus*, *Pterodoras granulosus* and *Prochilodus lineatus* (all considered medium or large-sized migratory and commercially important species), which indicates that spawning of these species did not occur in that area.

Petrere Jr. (1994) emphasizes that in addition to the interruption of adult migration, presence of dams impedes the dispersion of juveniles to nursery areas located downstream. Samples taken before the closure of Porto Primavera Dam, at points located a few kilometres below the dam (approximately 5 km) revealed the catch of migratory fish larvae in advanced stages of development (pre-flexion, flexion and post-flexion of the notochord). Therefore, it is possible that these larvae drifted from areas located above the dam, indicating that in addition to blocking the migratory route, Porto Primavera Dam impedes the dispersion of eggs and larvae to the area downstream (Sanches, unpublished data).

 

Another factor to be considered is the flow control imposed by the dam closure during the formation of the reservoir. The retention of water affects the connectivity of the river-floodplain system, altering the entire dynamics of the floodplain, including its biota (Agostinho *et al.*, 2004a). During the studied period, a conspicuous fall in water level was observed after the closure of the dam.

Migratory species reproductive cycles are intimately linked to variation in water level. They usually spawn in open waters of a river, releasing pelagic eggs and hatched larvae drift to inundated areas and marginal lagoons (Agostinho *et al.*, 2004b). Development begins (Nakatani *et al.*, 1997) in these nurseries that offer abundant food and shelter to juveniles. If flooding does not occur, eggs and larvae stay in the main channel and are susceptible to predation by fish and other aquatic organisms.

Apparently, this situation happened when Porto Primavera Dam was closed. Its closure occurred at the end of 1998 and beginning of 1999, exactly during the spawning season of most fish species in the region. Then, the closure disrupted the stimulus for spawning and the mechanism that disperse eggs and larvae. If the closure had been carried out after the spawning season, the impact on reproduction of migratory species would be lower.

High densities of migratory species larvae in the Ivinheima River demonstrate the importance of its integrity for the reproduction of these species. This river does not present any dam yet, with characteristics that are exclusively dependent on the hydrological regime, and, in addition, it crosses the last floodplain of the Upper Paraná River.

Thus, the Ivinheima River apparently constitutes the only route available for migratory species in this last lotic stretch of the Paraná River within Brazilian territory, which demonstrates the extreme importance of preserving this river, as mentioned by Agostinho *et al.* (2001), who suggest the creation of protected areas or conservation units in this region, specifically from the mouth of the Paranapanema River to the beginning of the Itaipu Reservoir, a stretch that includes the floodplain and the lower parts of the Ivinheima River. Action is already taken by Federal, State and Local governments, with the creation of the National Park of Ilha Grande, State Park of Ivinheima and Protected Area of Ilhas e Varzeas do rio Paraná.

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