Downstream migration of Neotropical potamodromous species through hydroelectric reservoir: myth or reality?

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Introduction

Most of neotropical migratory fish are potamodromous, locally known as 'piracema' fishes. They normally grow to a large size, are more abundant in undammed rivers, and are the most important commercial and recreational fishes in Brazil (Godinho & Kynard, 2009). Neotropical migratory fish travel long distances longitudinally during the reproductive season in search of habitats suitable for spawning. The movements are seen as mostly upstream and coincidental with the wet season, when the hydrometric level is increasing, although adults are generally thought to drift or migrate back to their downstream habitats (Agostinho *et al.*, 2003).

The downstream migration of Neotropical potamodromous fishes, particularly in relation to fish passage systems deployed at dams, has been the subject of controversial discussions. Studies have suggested that downstream passage, a commonly neglected issue, is much more problematic (Agostinho *et al.*, 2007; Lopes *et al.*, 2007; Agostinho *et al.*, 2008; Pelicice & Agostinho, 2008; Agostinho *et al.*, 2011; Pompeu *et al.*, 2011), and that once fish ascend to upstream reaches, individuals fail to return through the fishways to downstream ones. Serious concerns about downstream movement have been stated by Agostinho *et al.* (2011) and Pelicice & Agostinho (2008): 1) fishways would work as one-way routes, considering that many fish species pass these facilities on their upstream movements; and 2) fish ladder would play a

limited or non-existent role in the management, with the possibility of causing additional impacts.

While the upstream migration studies for many species of Paraná River are abundant in the literature (Godoy, 1957, 1967; Bonetto & Pignalberi, 1964; Bonetto *et al*., 1971, 1981; Bayley, 1973; Agostinho *et al*, 1993; Antonio *et al*., 2007; Okada *et al*., 1989; Makrakis *et al*., 2007a,b), there are a few records of the downstream migrations.

Mark-recapture studies conducted from 1997 to May 2006 by Unioeste, Itaipu, Entidad Binacional Yacyreta, and Companhia Energética de São Paulo, in the stretch of the Paraná River between the Engenheiro Sergio Motta (known as Porto Primavera) and Yacyreta Hydroelectric Power Plants, demonstrated that individuals of *Prochilodus lineatus* (curimba) and *Pterodoras granulosus* (armored catfish) marked and released in the Itaipu Reservoir were recaptured downstream of Itaipu dam (Makrakis *et al.*, 2007a). These recaptures occurred at the time there was not the Piracema Canal, a fishway built at Itaipu, which began operating in December 2002, suggesting that the turbines were the likely place of passage, because the downstream spillway is impractical due not only the impact of the fall, but because its low operating frequency. Evaluation of the movements of *Piaractus mesopotamicus* (pacu) also showed that 15 individuals moved from the Itaipu Reservoir to the Paraná River downstream of the dam before the opening of the Piracema Canal (Makrakis *et al.*, 2007b).

Considering that quantitative assessment of the downstream migrations is still scarce in fish passages in South America, and this is an important knowledge gap (Godinho & Kynard, 2009), this study aims to spread first evidences of downstream migration obtained with the methodology of telemetric monitoring for migratory fish using Passive Integrated Transponder (PIT-tag) installed on both Engenheiro Sergio Motta and Itaipu Hydroelectric Power Plants, Upper and Middle Paraná River.

Materials and Methods

The Engenheiro Sergio Motta Hydroelectric Power Plant (Fig. 1), known as Porto Primavera, belongs to the Companhia Energética de São Paulo (CESP). A fish ladder (weir and orifice type) was built on the left side of the dam, allowing fish to reach the reservoir. The ladder is 520 m long and 20 m elevation (for more details see Makrakis *et al.*, 2007c). About 400 km downstream it is located Itaipu Hydroelectric Power Plant (Fig. 1) on the border between Brazil and Paraguay. At the left bank of the dam, in the city of Foz do Iguaçu, Parana State, Brazil, is located the Piracema Canal, a fish pass system. This fish passage is 10.3 km long and 120 m elevation (see description in Fiorini *et al.*, 2006; Makrakis *et al.*, 2007d, 2011).

In the Itaipu Reservoir, factors such as low residence time of water (approximately 40 days), which causes internal displacement currents, seem to facilitate the orientation of some migratory species (Agostinho *et al.*, 1992). The Piracema Canal, the single of its kind in South America, is a multi-system, consisting of technical fishways, nature-like section, resting pools, comparable in most of its length to an artificial river with potential for dispersal of many species. Upstream migrations of several species in this system were certified in this fish transposition system (Hann *et al.*, 2007; Makrakis *et al.*, 2011; Fontes Jr, 2011). However, the presence of resident species, sedentary species, observed in studies conducted on Piracema Canal through experimental fishing (Makrakis *et al.*, 2007d, 2011), suggest colonization of the system and the possible spread in both directions (upstream and downstream).

Fig 1. Location of the Engenheiro Sergio Motta (Porto Primavera) and Itaipu Dam in the Paraná River. Arrows indicate downstream migration routes of *Prochilodus lineatus* and *Rhinelepis aspera*: dashed line (fish moved from fish ladder), and full line (fish moved from downstream fish ladder).

The telemetry system was installed in the fish ladder of the Engenheiro Sergio Motta Hydroelectric Power Plant and Piracema Canal (Itaipu) from November 2009, for monitoring and evaluation using Passive Integrated Transponder (PIT-tag). The technology use the system Tiris S 2000 described in Castro-Santos *et al.* (1996), Zydlewski *et al.* (2001) and Haro (2002). The installation of the same system at both hydroelectric was planned so that the tagged fish in Itaipu would eventually recorded in Porto Primavera and vice versa. In Porto Primavera, were installed eight antennas distributed equidistant along the fish ladder (Wagner, 2010). In Piracema Canal, initially antennas were installed just in Water intake (DIRE) (Fig. 2), located at the upper stretch of the system, and from June 2010 antennas also were installed in Initiation Channel (CAIN), located about 3 km downstream of the DIRE. In Porto Primavera system remained in operation for only five months, from November 13, 2009 to April 13, 2010.

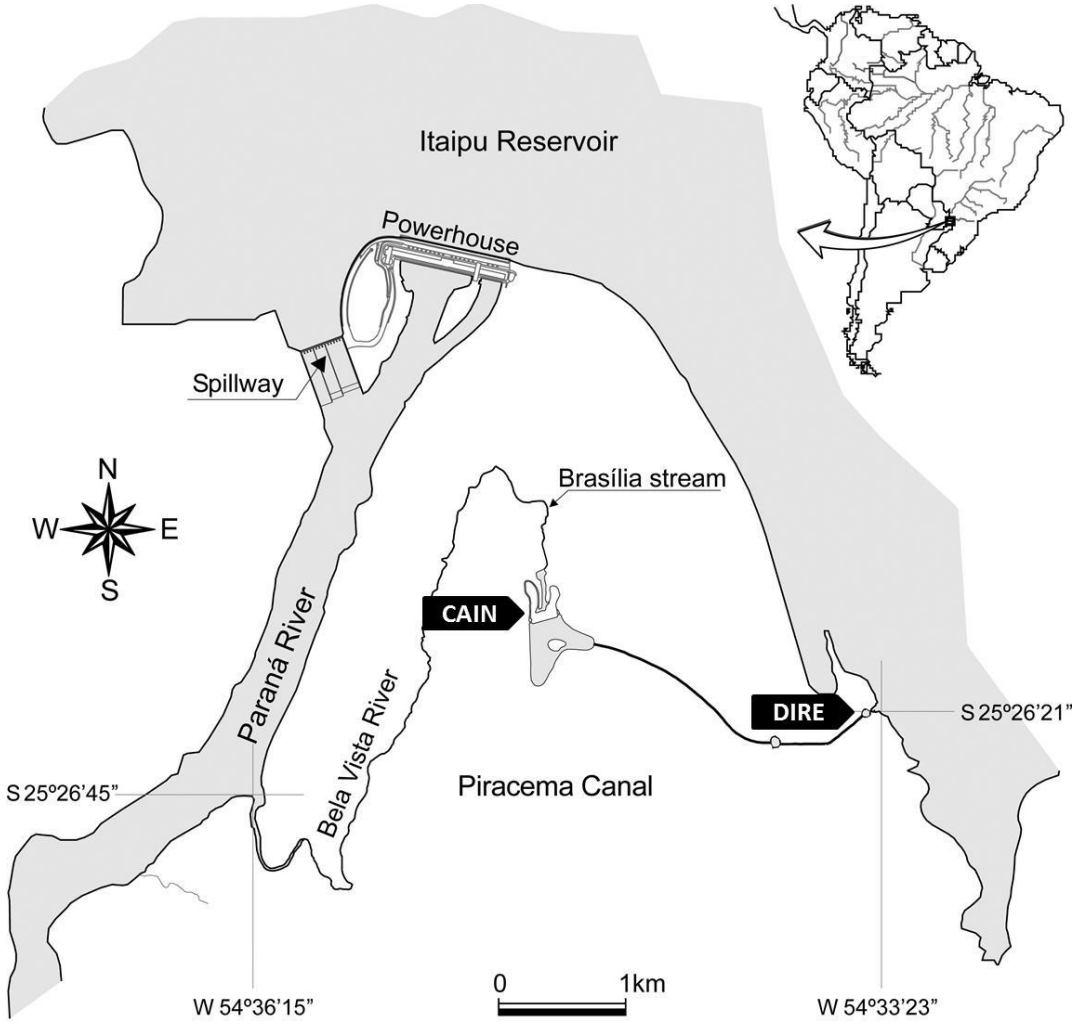

Fig. 2. The Piracema Canal at Itaipu dam, and the location of the antennas of the RFID system: Initiation Channel - CAIN (installed in June 2010) and Water intake - DIRE (installed in December 2009).

Results and Discussion

Fish of four long-distance migratory species (1074 fish) were tagged in Porto Primavera from November 2009 to February 2010 (*Brycon orbignyanus*, n=151; *Piaractus mesopotamicus*, n=304; *Prochilodus lineatus*, n=305, and *Rhinelepis aspera*, n=314) to evaluate the effectiveness of the fish ladder. These fish were released downstream of the fish ladder (approximately 1,100 m downstream) and in the fish ladder (to 85m from your mouth) (Wagner, 2010). Three of the fish were recorded some months later in the Piracema Canal at Itaipu dam (Table 1), moving downstream about 402km.

The first two fish (one *P. lineatus* and one *R. aspera*) (Fig. 1) were recorded by the readers in the Water intake - DIRE. These downstream movements corresponded to a time elapsed of 78 and 123 days for *P. lineatus* and *R. aspera*, respectively, after marking and release in Porto Primavera. However, they were not recorded in other points along the Piracema Canal, so it was not possible to determine whether these fish continued traveling through the system and neither the direction of movement. It´s important to emphasize that one *R. aspera* was released downstream of the fish ladder, moved upstream where it was recorded in the fish ladder, and then moved downstream.

It was registered in the Piracema Canal, migrating through the floodplain and the Itaipu Reservoir, with time elapsed of 75 days between record in the ladder and Piracema Canal (Table 1).

Table 1. Fish marked and released in Porto Primavera (downstream from dam and in the fish ladder) registered by RFID readers installed in the Piracema Canal (DIRE – Water intake and CAIN - Initiation Channel). TL=Total lenght; SL=Standard length. Date (dd/m/year) and time (hour) of release and recorded.

Species	TL (cm)	SL (cm)	Release site	Date and time of release	Date and time of recorded		
					Fish ladder	CAIN	DIRE
R. aspera	42.0	35.5	Downstream	01/12/2009 11:30	18/1/2010 16:54	-	03/4/2010 16:25
P. lineatus	49.6	40.3	Fish ladder	15/1/2010 11:00	-	-	03/4/2010 8:21
P. lineatus	57.1	46.0	Downstream	11/1/2010 19:20	Without recorded	14/12/2010 09:50	15/12/2010 14:02

The third fish (an individual of *P. lineatus* marked on January 11, 2010) (Fig. 1), was recorded almost a year later (on December 14, 2010) at CAIN (intermediate segment of the system) and the next day (on December 15, 2010), it also was recorded in DIRE, moving upstream through the Piracema Canal (Table 1). This suggests that, like other records previously obtained with external tags like LEA, the downstream movement may have occurred through the turbines or, less likely the spillway, or that fish may not have been registered before in the Piracema Canal due to brief outage periods of the RFID system.

The results found in this study suggest the pattern typically described in the literature for migratory species in the Paraná River basin; the possible downstream migration, after the reproductive period, as observed for the specimens of *P. lineatus* and *R. aspera*, registered in the Piracema Canal in April. However, it is possible that the second specimen of *P. lineatus* migrated downstream otherwise, or it was not registered due to brief periods of interruption RFID system. But records suggest the possible implementation of new reproductive migration the following spawning period (December 2010).

Although the trend of migration is significantly higher upstream, these results demonstrate convincingly that movements occur downstream, with strong evidence of the fish passaging through the structures of the dam, as reported by Pompeu & Martinez (2007) for the Santa Clara Hydroletric Power Plant, Mucuri River.

However, these assumptions will better elucidate requiring long-term studies, with the operation of RFID systems in the two fish passages in a continuous basis (uninterrupted), monitoring and evaluating all target species, the long-distance migratory, in order to clarify points obscure their spawning behavior and the real role of the fish passage systems for the neotropical fish species.

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