**Accepted in *Limnologica*, 04/11/16**

**Short communication**

# Impoundments facilitate a biological invasion: dispersal and establishment of non-native armoured catfish *Loricariichtchys platymetopon* in a Neotropical river

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**Keywords:** hydroelectric dam, armoured catfish, environmental, Anthropocene

**Running title:** *Loricariichthys platymetopon* in the lower Paranapanema River

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**Abstract**

Where dam construction eliminates natural barriers to fish movement between previously disconnected catchments then this presents an opportunity for the movement of species between previously discrete assemblages. Here, the movement of a non-native armoured catfish, *Loricariichthys platymetopon*, is detailed from its natural range in the lower Paraná River basin, Brazil, into its invasive range in the upper basin following construction of the Itaipu Dam. Its upstream dispersal into a major tributary, the Paranapanema River, is outlined, with focus on its establishment within hydroelectric dams. This case study thus provides further evidence of how river regulation can increase opportunities for biological invasions.

**Short communication**

Construction of dams is a major anthropogenic influence on rivers that disrupt hydrological regimes, increase habitat fragmentation, block fish migration routes, impact fish spawning grounds and facilitate the development of biological invasions (Clavero and Hermoso, 2011; Agostinho et al., 2016). Alterations in fish assemblages usually result, with a general shift from lotic to lentic species, with the composition of functional guilds moving to more generalist species (Noble et al., 2007; Clavero and Hermoso, 2011). These hydrological and ecological alterations are often allied to an increase in biological invasions due to the creation of 'invasion windows'. These invasions result from the disruption to the native assemblages that facilitate the integration of new species into the permanently altered system (Júlio Júnior et al., 2009). The likelihood of finding non-native species in impounded reservoirs is estimated as between 2.4 and 300 times that of natural lakes, with multiple invaders often present in such habitats (Johnson et al., 2008). Where dam construction also eliminates natural barriers to fish movement between previously disconnected catchments then this presents a further opportunity for species' movement between previously discrete assemblages (Júlio Júnior et al., 2009; Vitule et al., 2012).

Fish invasions raise considerable ecological concerns due to their potential detrimental impacts arising from, for example, their predation of native fishes, increased inter-specific competition and disruptions to ecosystem functioning (Gozlan et al., 2010). Thus, as dam construction and fish passage can facilitate invasions through providing connection between previously unconnected fish assemblages then understanding the subsequent invasion consequences of impoundment is important (Vitule et al., 2012). For example, Júlio Júnior et al. (2009) reported construction of Itaipu Dam on the Paraná River, Brazil, in the 1970s and early 1980s had the effect of removing the natural geographic barrier to fish movement of the Sete Quedas Falls. This connected the fish assemblages of the Upper and Lower Paraná River basins for the first time. The result was 33 fishes native to only the lower basin were able to disperse upstream and colonise the upper basin.

Here, following Júlio Júnior et al. (2009) and Vitule et al. (2012), the dispersal and subsequent invasion of one of these species is outlined in more detail, the armoured catfish *Loricariichthys platymetopon*. This omnivorous species grows to lengths of around 30 cm, with maturity at lengths of approximately 15 cm (Ferraris, 2003). Endemic to the Lower Paraná River basin, it was non-native to the upper basin, including the Paranapanema River and its hydroelectric reservoirs. Using a combination of literature review and field studies, the objectives were to identify potential vectors of dispersal of non-native *L. platymetopon* into the Paranapanema River and quantify its subsequent establishment and relative abundance in a new habitat, the Capivara Reservoir, whose construction was completed in 1979.

The construction of Itaipu Dam on the Paraná River, Paraná State, southern Brazil, is documented in Júlio Júnior et al. (2009) and Vitule et al. (2012). The focus of this study, the Paranapanema River, located between São Paulo and Paraná States, in southeast and southern Brazil, currently has 11 hydroelectric power plants along its length, with its original course transformed by a succession of reservoirs (Fig. 1, Garcia et al., 2012). To identify the upstream movement of *L. platymetopon* from the lower Paraná River and up into the Paranapanema River, literature was reviewed on alterations to the river's fish assemblage (all available literature that was reviewed are provided in Results). Then, fish samples were analysed that had been collected between 1990 and 2010 from the Capivara Reservoir, also located on the border of the states of São Paulo and Paraná (latitude 22$^{o}$40'-22$^{o}$60'S, longitude 51$^{o}$19'-51$^{o}$31' W; Fig. 1). These samples provided data on the relative abundance and biological parameters of *L. platymetopon*. Sampling was generally completed in 1990/91, 1992/93, 1994/95, 2001/02, 2003/04 and 2009/10, with some less intensive sampling also completed in 1999. For some aspects of data reporting purposes, the sampling site of Sertanópolis Point (23°01'16'' S, 50°57'13''W) was used, as this was the one site that was fished across all of the study period on the reservoir.

Figure 1.

Figure 1. *Loricariichthys platymetopon* invasion history in the Paranapanema River basin, Brazil: High Paraná River basin invasion (Paranapanema River basin) after flooding the geographical barrier of Salto de Sete Quedas (Sete Quedas Falls) (A); dispersion upstream on the Paranapanema River by the Canoas I and Canoas II Complex fish ladders (B).

Sampling was through deployment of multi-mesh gill nets (mesh size 2 to 12 cm, total net area 2000 $m^2$) that were fished continuously for 24 hours. After lifting the nets, all captured fish were euthanized using an anaesthetic overdose before being fixed in 10% formalin and taken to the laboratory where they were identified to species, counted, measured (standard length, *SL*, nearest mm) and weighed (*W*, nearest g). Relative abundance was calculated as catch per unit effort expressed as the number of fish sampled per $m^2$ of net per hour for each sampling year. Samples of juvenile fishes were also collected by sweeping the water with a pond net (250 mm wide, 1 mm mesh). The length-weight data enabled calculation of the condition factor ($K = (W/ SL$^3) × 100) of all captured specimens to be determined and compared between sampling years and months using ANCOVA in SPSS (general linear model), where covariates were sampling month for annual comparisons and year for monthly comparisons.

*Dispersal of Loricariichthys platymetopon into the Upper Paraná River*

Of the 33 fish species that were able to move from the lower to the upper Paraná River due to construction of the Itaipu Dam, (Júlio Júnior et al., 2009; Vitule et al., 2012), at least 4 species have been documented as establishing and dispersing into different floodplain environments, including *L. platymetopon* (Gaspar da Luz et al., 2004). Studies completed to the end of the 1990s suggested *L. platymetopon* was not yet present in the Capivara Reservoir (Bennemann et al., 2000) (Fig. 1). Britto & Carvalho (2006) did, however, detect a high presence of *L. platymetopon* between 1993 and 2000 in samples collected further downstream in Taquaruçu reservoir, where they comprised up to 14% of all fish captured. The upstream movement of *L. platymetopon* from Itaipu through the Paranapanema River was facilitated by their movement occurring before the construction of the Rosana Dam (constructed 1987) and the Taquaruçu Dam (constructed 1989). The Capivara Dam should, however, have prevented their further movement upstream as it was built in 1979 and so was present as an impassable barrier as *L. platymetopon* moved upstream (Fig. 1). However, the species was able to bypass this dam due to management activities, including the cleaning of power turbines in the dam by employees, during which any entrained fishes were manually moved into the reservoir (Marcutti et al., 2005; Orsi 2010).

*Loricariichthys platymetopon in the Capivara Reservoir and their biological parameters*

The initial detection of *L. platymetopon* in fish samples collected from the Capivara area of the Paranapanema River was in 1999. At Sertanópolis Point, no *L. platymetopon* were recorded in samples collected between 1990 and 1996, but they were captured in 2001 and have been present in each sample collected since then. Catch per unit effort (CPUE) was 3.1 fish h $m^{-2}$ in 2001/02 (12.7% of total CPUE), 3.3 in 2003/04 (11.7% of total CPUE) and 3.7 in 2009/10 (9.4% of total CPUE). This relatively high contribution to total CPUE is despite samples containing up to 79 fish species (Carvalho et al., 2005; Hoffmann et al., 2005; Orsi and Sodré, 2006; Orsi, 2010). Moreover, their capture was always associated with shallow, littoral habitats in the reservoir, and the species does not require the inundation of floodplain areas in wet periods for the provision of spawning and nursery areas. This is a contrast to many of the native fishes and suggests it could be a distinct life history advantage that facilitated invasion (Marcutti et al., 2005; Orsi, 2005).

The length distribution of these fishes in samples was between 140 and 340 mm (Fig. 2a, b). The absence of smaller individuals is likely to be due to the minimum gill net mesh sizes used. Sweeping with hand nets also captured juveniles of 20 to 30 mm between 2002 and 2009, suggesting their reproductive and recruitment success. Comparison of body condition over time suggested no significant shifts during their time in the reservoir, as indicated through comparison of *K* of individuals between fish captured in 2002 and 2010 (ANCOVA: $F_{1,700} = 0.24$, $P > 0.05$; effect of month of sample as co-variate: $F_{1,700} = 7.20$, $P = 0.01$). Given the significant effect of month in that model, then the effect of month on *K* was tested with sample year as the covariate. The overall model was significant (ANCOVA: $F_{1,700} = 2.98$, $P = 0.03$), with the estimated marginal means indicating that months of peak condition was between September and December (Fig. 2c), suggesting this is the period of gonad development with spawning likely to occur around January and February. However, this is speculative given the paucity of reproductive data available to the study.

Figure 2.

Figure 2. Length frequency of samples of *Loricariichthys platymetopon* collected in the Capivara Reservoir, Brazil, by gill netting in (a) 2002 and (b) 2009, and (c) their condition (*K*) by month, where values represent estimated marginal means from the general linear model where the effect of year was controlled. * difference between *K* in that month and *K* in February is significant according to pairwise comparisons adjusted for multiple comparisons (Bonferroni).

*Ecological fish ladders as route of an introduction of non-native species*

Mitigation measures to restore the longitudinal connectivity between specific riverine environments that have been separated by dams, such as fish ladders or fish passes, is used worldwide (Agostinho et al., 2007a). In Brazil, authorities have been concerned about the consequences of the blockage of migration routes on fisheries and they have taken measures to address the problem (Agostinho et al., 2004). The installation of new fish passages in Brazilian dams is popular and in some states their installation on dams is mandatory (Pelicice and Agostinho, 2008). The lower Paranapanema River has two structures installed: one in Canoas I and another in Canoas II (Fig. 1B). These fish ladders were operational from November 2000 and, according to Britto and Carvalho (2013), have not worked sufficiently to allow the passage of impacted species, including *Prochilodus nigricans*, *Oxydoras niger* and *Leporinus friderici* (Agostinho et. al., 2007b; Pelicice and Agostinho, 2008). In addition, fish passages can also provide a dispersal route for non-native species (Júlio Jr. et al., 2009; Vitule et al., 2012; Agostinho et al., 2014).

Although it is a non-migratory species, *L. platymetopon* may have used the fish passes to disperse and cross the Canoas I and II dams (Fig. 1B). Souto et al. (2011) reported the capture of adult individuals in Canoas II Reservoir and during some more recent work in the two reservoirs (Canoas I and II) between 2010 and

2012, there were 17 and 9 individuals captured in the passes respectively (Orsi and Almeida, 2011).

*Conclusion*

The regulation of rivers through activities such as damming causes substantial alterations to fluvial habitats (Dudgeon, 2000). Although their advantage is to provide electricity production through hydropower, this can be at the expense of losing many river functions important for fish (Agostinho et al., 2007a). This then reduces the ability of the ecological communities to resist disturbance (Richardson, 2000), making impoundments highly vulnerable to invasion via their transformation into 'invasion windows' for non-native fish. This case study highlights this; through being able to move into a previously inaccessible ecoregion and then disperse - with assistance from human activities - *L. platymetopon* has established and become highly invasive in the reservoirs of the upper Paraná River basin, notably Capivara Reservoir, resulting in increased biological homogeneity of the fish assemblage.

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