Management of Biological Invasions (2014) Volume 5, Issue 2: 113–119
doi: http://dx.doi.org/10.3391/mbi.2014.5.2.04

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Research Article

Record of ascending passage of potamotrygonid stingrays through navigation locks: implications for the management of non-native species in the Upper Paraná River basin, Southeastern Brazil

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Received: 17 December 2013 / Accepted: 22 March 2014 / Published online: 28 April 2014

Handling editor: Katherine Dafforn

Abstract

In this paper we tested the hypothesis that potamotrygonid stingrays are expanding their distribution to novel areas via artificial passages constructed for river navigation in the Upper Paraná River basin, Southeastern Brazil. Individuals of *Potamotrygon falkneri* and *Potamotrygon motoro* were captured, fitted externally with t-bar anchor tags, and released downstream of the Jupiá Dam – a hydro power plant constructed in the 1970s that has no fish pass system, but had a navigation lock installed in 1998 for the movement of ships. A total of 182 stingrays were marked, and recaptures of individuals of both species occurred within a period of two to 12 months after the first capture, with recapture rates around 5% for *P. falkneri* (n=6) and 3% for *P. motoro* (n=2). Two individuals of *P. falkneri* were recaptured upstream of the Jupiá Dam, about eight kilometers from the first capture site. This fact attests to the ability of stingrays to overcome artificial barriers such as hydro power plants through navigation locks. The Upper Paraná River basin is densely populated, so the spread of potamotrygonids will increase the risk of injury from stingrays' barbs. Their use of navigation locks is relevant for management actions, including reducing the risk of human-stingray interactions.

Key words: alien species, biological invasions, mark and recapture method, spatial ecology, environmental impact, Potamotrygonidae

Introduction

Large stretches of major rivers in South America have been obstructed due the construction of hydroelectric dams. This has led to serious impacts on the environment, especially in hydrography and particularly on migratory fish species (Agostinho et al. 2005, 2008, 2012; Antonio et al. 2007; Godinho and Kynard 2009). Moreover, the destruction of natural barriers by hydro power plants has been responsible for important changes in the native ichthyofauna in South America due to the introduction of exotic taxa and colonization by non-native species (Orsi and Agostinho 1999; Agostinho and Júlio-Júnior 2002; Júlio-Júnior et al. 2009).

In the Paraná River, Southeastern Brazil, the Sete-Quedas Falls played an important role in the division of the ichthyofauna, delimiting the fourth zoogeographical province of the Paraná-Paraguay complex (sensu Ringuelet 1975). However, in 1982 this natural barrier was submerged after the filling of the reservoir formed by the Itaipu Dam, enabling the connection of fish faunas that were previously isolated (Bonetto 1986; Agostinho et al. 1992, 1997; Luiz et al. 2004). Therefore, several species of fishes restricted to the downstream of the Sete-Quedas Falls successfully colonized and spread over the upper course of the Paraná River (see Júlio-Júnior et al. 2009 and references therein for reviews). Among these, at least two species of potamotrygonid stingrays belonging to the genus

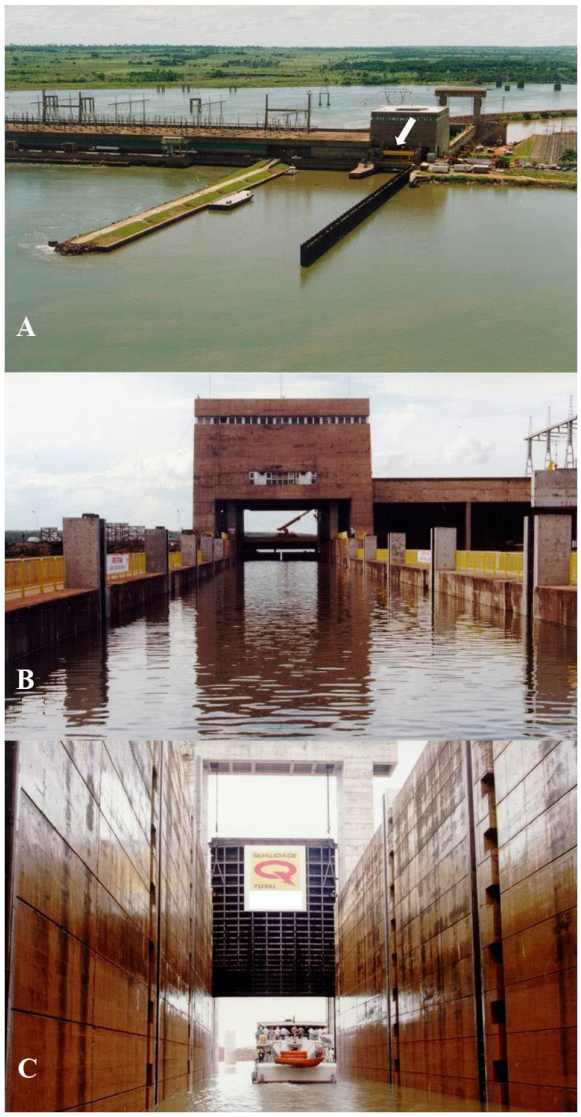

Figure 1. General view of the Jupiá Dam (A). It is possible to observe the location of the navigation lock in the dam (white arrow), and details of the floodgates up (B) and downstream (C). Credits: Companhia Energética de São Paulo – CESP.

Potamotrygon Garman, 1877 were recognized in the Upper Paraná River basin: *P. falkneri* Castex and Maciel (1963) and *P. motoro* (Müller and henle, 1841) (Agostinho et al. 1997; Garrone Neto et al. 2007; Júlio-Júnior et al. 2009). Today, both species are found more than 400 km upstream from the Sete-Quedas Falls, where their populations are apparently established and exhibit signs of expansion (Garrone Neto et al. 2007; Garrone Neto and Haddad Jr. 2010; Haddad Jr. et al. 2013). Impacts of this colonization on aquatic fauna have not been evaluated, but the predominantly benthic habit associated with the wide feeding spectrum of the stingrays suggests a possible overlap of niche with other species of similar habits (Garrone Neto 2009; Garrone Neto and Sazima 2009). In contrast, negative interactions between humans and stingrays have been identified as the main impact of this colonization, with injuries to bathers and fishermen reported and with the practice of 'negative fishing' (*i.e.* the capture and mutilation and/or death of stingrays for amateur and professional anglers) over several riverside communities of the Upper Paraná River basin (Haddad Jr. et al. 2004, 2013; Garrone Neto and Haddad Jr. 2010). Furthermore, reports on the use of navigation locks by the stingrays to expand their distributions in the Upper Paraná basin are known and demonstrate the high potential of dispersal of these animals (Garrone Neto et al. 2007). However, details about this fact remains unknown and very few mitigating measures or monitoring programs were adopted from government agencies and private institutions in the areas recently colonized by the stingrays.

Considering the potential for expansion of stingrays in the Upper Paraná River basin (a large waterway in a densely populated area of Southeastern Brazil), we report in this study the first record of the ascending passage of potamotrygonids through navigation locks. We discuss the implications of this phenomenon and propose some management actions and mitigation measures for two non-native species.

Methods

This study was carried out in the upper course of the Paraná River, Southeastern Brazil, between September 2012 and September 2013. The investigations were concentrated in the municipalities of Castilho and Três Lagoas (about 20°47'S, 51°37'W), on the border of the states of São Paulo and Mato Grosso do Sul. In this area, a hydro power plant named "Engenheiro Souza Dias – Jupiá Dam" has been in operation since 1979. This dam has no fish pass system, but installed a navigation lock in 1998 to allow the transit of ships along one of the largest waterway systems in South America, the Tietê-Paraná Hydroway (Figure 1).

To test the hypothesis that stingrays use artificial passages constructed for river navigation in some dams of the Upper Paraná River basin, individuals of *Potamotrygon falkneri* and *P. motoro* (Myliobatiformes, Potamotrygonidae) were captured

Figure 2. Satellite image of the study area, showing the locations where the potamotrygonids stingrays were released (point in white) and recaptured (points in red). The yellow arrow indicates the position of the navigation lock in the Jupiá Dam. Credits: GoogleEarth®.

captured and marked downstream from the Jupiá Dam in September and November 2012. Stingrays were captured using hand nets (called "puçá" by local fishermen) while snorkeling to prevent injuries to the animals, sexed, measured, weighed, fitted externally with t-bar anchor tags (Hallprint© model standard TBA), photographed and then released at the same capture site. Species identification was done in situ, based on the coloration of the animal's dorsum (following Rosa 1985 and Silva and Carvalho 2011). The sex recognition and sexual maturity of the individuals were based on the presence or absence of claspers (easily observed dorsally) and in previous data on the size of sexual maturity for *P. falkneri* and *P. motoro* in the same area (Garrone Neto 2010). Measures were taken to assess the stingrays' disc width (DW, i.e. the major distance between both pectoral fin margins). In order to enable future verification of the species identification, two additional specimens of each species were collected and stored at the Universidade Estadual Paulista Elasmobranch Collection as voucher-specimens (UNESP-CLP 0010.01, 0010.02).

Stingrays were predominantly recaptured with hand nets while SCUBA diving or snorkeling, and some were returned after being caught by professional and amateur anglers. The distances between capture and recapture locations were estimated using geographic coordinates obtained from GPS (in UTM; datum SAD 69) and extracted using GoogleEarth® for spatial analysis.

Results and discussion

A total of 182 stingrays were externally fitted with t-bar anchor tags. Of these, 112 individuals were identified as *P. falkneri* (males = 64; females = 48) and 70 as *P. motoro* (males = 49; females = 21). Recaptures of individuals of both species occurred in periods of two to 12 months after the first capture, with recapture rates around 5% for *P. falkneri* (n=6) and 3% for *P. motoro* (n=2). Most of the recaptures (n=6) were made predominantly in the area just downstream of the Jupiá Dam, in November 2012 (n=3), July 2013 (n=1) and September 2013 (n=1). The two remaining recaptures were made upstream of the Jupiá Dam by recreational anglers, who responded in August 2013 and October 2013 to the request for contact contained in the external tags (Figure 2). The recaptures upstream of the Jupiá Dam occurred at around 8 km from the first capture

Figure 3. A marked and recaptured young male *P. falkneri* (DW 20 cm) downstream the Jupiá Dam (A). It is possible to note the extremity of the t-bar anchor tag probably removed by a "piranha" (Serrasalmidae) (B). Credits: Jayson de Barros Huss (A) and Domingos Garrone Neto (B).

site. The identification of both specimens was only possible at the species (and not to the individual) level as *P. falkneri* (DW 35 cm), based on the few photos and descriptions sent by the recreational anglers. Verifying the sex and the reference number of individuals was not possible from both the incipient information provided by the anglers and the absence of the identification codes contained in the tags. The latter case occurred as a probably result of the tips of the tags containing the reference number being removed by predators such as piranhas (Serrasalmidae), that can be seen commonly biting the edges of the stingrays' pectoral fins in the study area and had already caused similar damage to the tags used in the study (Garrone Neto pers. com.) (Figure 3).

While great attention has been given to the use of fish ladders and other devices to mitigate the effects of dams on migratory fishes, few studies have addressed the effectiveness of navigation locks for fish passage (Nichols and Louder 1970; Margraf and Knight 2002; Smith et al. 2013). The role of navigation locks as fish passages is usually ignored or underestimated as a potential alternative to fishways (Larinier 2002; Larinier and Marmulla 2004). Some studies showed that navigation locks can be used for the transit of fishes through dams, highlighting its potential as an alternative to fish migration or even to ichthyofauna surveys; in this case, some authors attest that about two-thirds of the fish fauna associated with dams can be found inside of the locks (Moser et al. 2000; Margraf and Knight 2002). However, fish passage through locks is considered relatively unattractive due the low water flow and the incompatibility between fish migration and boat traffic. Furthermore, locks present opportunities for the dispersal of non-native species (Nichols and Louder 1970; Margraf and Knight 2002; Smith et al. 2013).

Although studies with mark-recapture provides no knowledge of the path traveled by the animals between the moment of its capture and recapture, the absence of a fish pass system in the Jupiá Dam and the recapture of two individuals of *P. falkneri* upstream of the dam confirms the passage of stingrays through the navigation lock. Garrone Neto et al. (2007) and Garrone Neto (2009) had already signaled this possibility, but they were not able to support this hypothesis. Our mark-recapture study corroborate this assumption, even despite only two individuals of *P. falkeri* were captured upstream the Jupiá Dam. Although no individuals of *P. motoro* had been recaptured upstream the Jupiá Dam, its occurrence in sympatry with *P. falkneri* suggests that *P. motoro* is potentially able to cross the dam through the navigation lock, since both species have similar behaviours and share the same habitats and resources in the study area (Garrone Neto and Uieda 2012).

In the upper course of the Paraná River, *P. falkneri* and *P. motoro* are known to use different environments throughout their development, with juveniles and sub-adults occupying predominantly shallow areas with depths less than four meters (Garrone Neto and Uieda 2012). In the area immediately downstream to the Jupiá Dam, a channel with about 2 km length, five meters depth and 150 meters width was constructed to allow a safe approximation of the ships, isolating the navigation area of the left margin of the Paraná River. This condition created a lentic environment in which the stingrays are abundant

and frequently sighted foraging next to the lock gates (Garrone Neto et al. 2007; Garrone Neto and Sazima 2009). Thus, the lentic environment existing inside this channel seems to contribute to the approximation and permanence of the stingrays close to or inside the navigation lock of the Jupiá Dam.

Moser et al. (2000) attested that the passage of dams by fishes through navigation locks is possible, especially by adults of benthic-pelagic species who prefer to inhabit areas with less turbulence, such channels and areas close to the lock gates. In our study, the two individuals of *P. falkneri* captured upstream of the Jupiá Dam were considered sub-adults, according to the existing data about the reproduction and habitat use of the species in the Upper Paraná River (Garrone Neto 2010; Garrone Neto and Uieda 2012). *P. falkneri* and *P. motoro* are considered predominantly benthonic and established in the study area. Reports of their frequent capture in areas located upstream the Jupiá Dam, close to other two nearby hydroelectric power plants ('Ilha Solteira' and 'Três Irmãos' dams), demonstrates that the use of anthropogenic pathways by stingrays to increase their distribution in the Upper Paraná River basin may be underestimated (Garrone Neto and Haddad Jr. 2010).

The record of elasmobranchs as alien species is not common in the literature. Ng et al. (2009) confirmed the presence of an established population of the South American ocellate river stingray, *P. motoro*, in the Upper Seletar Reservoir, Singapore. Although the authors confirmed the first introduction and establishment of potamotrygonid stingrays outside the Neotropics, this report was not the first record of this group as alien species, since Agostinho et al. (1997), Garrone Neto et al. (2007) and Júlio-Júnior et al. (2009) had already reported the occurrence and the establishment of potamotrygonids outside of their natural range in Southeastern Brazil. Unlike the situation in Singapore, where the Upper Seletar Reservoir is not inserted into a large waterway system as the Tietê-Paraná Hydroway, and impacts such as interactions between potamotrygonid stingrays and humans have not been detected in the newly colonized areas (Ng et al. 2009), *P. falkneri* and *P. motoro* have been present for at least ten years in the Upper Paraná River basin and are frequently involved in accidents with humans. Fatal incidents are not known in Brazil, but injuries provoked by stingrays usually have high morbidity rates and great potential to generate severe cases of infection and temporary or permanent incapacity (Haddad Jr. et al. 2004, 2012, 2013; Garrone Neto and Haddad Jr. 2010). Furthermore, due to the potential overlap of niche between the stingrays and other carnivorous species with predominantly benthic habits, management actions may be important to control their movements through the navigation locks and potential impacts on the aquatic fauna.

Physical and non-physical barriers have been widely used to control the expansion of non-native fish species in rivers and lakes around the world (Bulow et al. 1988; Verril and Berry 1995; Swink 1999; Taft 2000; Clarkson 2004; Noatch and Suski 2012). The management response to the introduction of some species of Asian carps in the United States is probably the best example of the combined use of technologies to interrupt and control the spread of exotic fish species. The U.S. Army Corps of Engineers, in cooperation with several other agencies, installed a series of electric barriers along the Chicago Sanitary and Ship Canal to prevent Asian carps and other invasive fish from moving between the waters of the Mississippi River and the Great Lakes, especially through the locks and waterways of the Chicago Area Waterway System (Rodriguez 2011; Stern et al. 2014). However, although the electric barriers are currently the most effective and least disruptive means of controlling Asian carps migration into the Great Lakes, some studies show that these animals are adapting to the electric barriers (Kelly et al. 2011; Ruebush et al. 2012). Thus, other technologies such sound-bubble-strobe light, acoustic and physical barriers are under development and/or being used in association with selective fishing, in way to reduce population levels and prevent upstream movements of Asian carps and other invasive fishes through the locks and waterways of the Chicago Area Waterway System (Kelly et al. 2011; Rodriguez 2011; Stern et al. 2014).

In the Upper Paraná River basin, as well as in the case involving the problem with Asian carps in the United States, there is no one-size-fits-all solution to the colonization of potamotrygonid stingrays. Due to the impracticality of closing the navigation locks of the Tietê-Paraná Hydroway, non-physical barriers which obstruct fish from an undesirable location without influencing the waterway, seem to be the most viable management approach to deterring the stingrays passage through the Jupiá Dam and nearby hydroelectric power plants. The use of selective fishing near the gates and inside of the locks can help to reduce the risk of stingrays passing for locations

upstream of the dams. Nevertheless, negative influences on non-target fishes and even risk to humans must be considered and evaluated before implementation as deterrent systems.

Considering the potential for expansion of potamotrygonid stingrays in the Upper Paraná River basin (a large waterway in a densely populated area of southeastern Brazil), the results of this study are relevant for directing management actions and mitigation measures of non-native species of medical importance. If we take into account the existence of numerous bathing locations and properties along rivers and reservoirs, the intense fishing activity in the Upper Paraná River basin and the high rate of morbidity from accidents caused by stingrays, it is expected that negative interactions between humans and stingrays will increase, leading to important changes in epidemiological profiles of envenomations in Southeastern Brazil. Thus, addition to the adoption of deterrent systems and investment in research, we emphasize the importance of educational activities with the population, the training of health professionals in risk areas and the prompt reporting of accidents by public health agencies, as well as the monitoring of the possible impacts of the colonization process on the aquatic fauna.

Acknowledgements

The field work would not have been possible without the exceptional collaboration of Jayson B. Huss, Gabriel R. S. Souza and Marcos T. Silveira. The recreational anglers Sérgio H. P. Moura and Donizete P. Castro kindly provided information about stingrays captured upstream of the Jupiá Dam. The Companhia Energética de São Paulo (CESP) kindly provided images of the Jupiá Dam. Camila M. H. Santos assisted with the deposit of the voucher-specimens. Three anonymous referees provided their time and valuable suggestions for the manuscript. The financial support of the São Paulo Research Foundation (FAPESP; grant #2011/18513-9) was essential and enabled the execution of the study. To all, sincere thanks are needed.

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