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Size-selective predation of the catfish *Pimelodus pintado* (Siluriformes: Pimelodidae) on the golden mussel *Limnoperna fortunei* (Bivalvia: Mytilidae)

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ABSTRACT. This paper describes the size-selective predation on *Limnoperna fortunei* (Dunker, 1857) by *Pimelodus pintado* (Azpelicueta, Lundberg & Loureiro, 2008) from the time it arrived at the Mirim Lagoon basin (2005). Sampling was carried out using bottom trawl in depths of 3-6 m, from January to November 2005, and from October to November 2008. *Pimelodus pintado* began to prey upon *L. fortunei* soon after its arrival (austral spring of 2005). On the spring of 2008, *L. fortunei* was found to be the most important food item of *P. pintado*. The variation in length of the mussels (0.7-3.2 cm, with a mode of 1.3 cm) indicates that the species is now fully established in the system. Our data indicates that large individuals of *P. pintado* incorporate more mussels in their diets than small individuals. However, regardless of their size, *P. pintado* individuals predate only on small (<1.4 cm) representatives of *L. fortunei*. This prey size corresponds to a phase when the mussel is more mobile and readily available for fish. Larger, more aggregated prey groups that are attached to hard substrates are avoided by fish predators.

KEY WORDS. Diet; freshwater invasion; opportunistic predator; Mirim Lagoon.

The Asian freshwater golden mussel, *Limnoperna fortunei* (Dunker, 1857), was first recorded in the Americas in 1991, from the coast of the Rio de la Plata, by Pastorino *et al.* (1993). *Limnoperna fortunei* has the capability of colonizing a wide range of habitats and has few natural predators, widely colonizing freshwater and estuarine environments in the Neotropical region. Since its introduction, the species has expanded its range to Argentina, Brazil, Paraguay and Uruguay (Darrigran *et al.* 1998, Darrigran & Ezcurra de Drago 2000, Darrigran 2002, Oliveira *et al.* 2006).

In 1998, the Asian freshwater golden mussel was recorded at the northern reaches of the Patos Lagoon drainage basin (Mansur *et al.* 1999, 2003) and, in the next years, it was found in the southern portion of the basin in densities of up to 140,000 ind/m^2. After that, population densities stabilized at averages 60,000 ind/m^2 (Mansur *et al.* 2003). The golden mussel invaded the Mirim Lagoon in 2005 through the São Gonçalo Channel, which connects the Mirim and Patos Lagoons (Langone 2005, Burns *et al.* 2006b, Colling *et al.* 2012, Lopes & Vieira 2012).

There is little question now that catastrophic biological events like these can profoundly affect entire ecosystems to the point that the invader species monopolizes a large proportion of the resources available (Sylvester *et al.* 2005, Darrigran & Damborenea 2011). The cascading effects of such trophic web disruptions can be extremely important (Power 1992, Ruetz *et al.* 2002, Thorp & Casper 2003). The high densities of golden mussel and the fact that individuals become fixed to the substrate by their byssal threads create a new microenvironment. This microenvironment, in turn provides a new habitat for some epifaunal species and, at the same time, can lead to the displacement of other benthic organisms (Santos *et al.* 2012). Since its invasion of South America, *L. fortunei* has threatened the survival and modified the natural occurrence and abundance of several native macroinvertebrate species (Darrigran *et al.* 1998, Darrigran 2002, Santos *et al.* 2012), including the Anomura crab *Aegla platensis* Schmitt, 1942 in the São Gonçalo Channel (Lopes *et al.* 2009).

The predation strength of fish upon the golden mussel ranges from negligible to efficient, when the total control of the mussel's population growth is achieved (Stewart *et al.* 1998, Bartsch *et al.* 2005). In some cases, mussel predators showed increased productivity and growth as a result of the new food supply (Poddubnyi 1966, Boltovskoy *et al.* 2006, Karatayev *et al.* 2007). Ancillary data on Argentine freshwater fish yields support to the above conclusions, suggesting that *L. fortunei* may have had a positive effect on fish biomass in Neotropical systems (Boltovskoy *et al.* 2006).

Catfish of the genus *Pimelodus* have omnivorous feeding habits (Garcia *et al.* 2006,2007whichare characterized by a generalist feeding behavior and the opportunistical exploitation of eventual peaks in prey abundance (Bonetto *et al.* 1963, Montalto *et al.* 1999, Braga 2000, Garcìa & Protogino 2005). The use of *L. fortunei* as a food source by *Pimelodus* spp. (Paraná River and Patos Lagoon basin) had been previously reported

(Montalto *et al.* 1999, Cataldo *et al.* 2002, Darrigran & Damborenea 2011). For this reason, we hypothesized that the catfish *Pimelodus pintado* (Azpelicueta, Lundberg & Loureiro, 2008) at the Mirim Lagoon would incorporate the Asian freshwater golden mussel in its diet.

The objective of this study was to describe the chronological incorporation of *L. fortunei* into the diet of *P. pintado*, from the time the prey arrived in the São Gonçalo Channel, at the Mirim Lagoon basin. Additionally, we show that *P. pintado* selects mussel prey within a certain size range, from the wide range of sizes available in the environment.

MATERIAL AND METHODS

The Mirim Lagoon basin is located between 31 and 34°S and 52 and 54°W in the eastern part of the South American central plains (Fig. 1). The basin area covers 62,250 km^2, with 29,250 km^2 in southern Brazil and the remaining 33,000 km^2 in eastern Uruguay. The main geographical feature of this basin is the Mirim lagoon itself, with an average area of 3.749 km^2 (Bracco *et al.* 2005). During periods of intense rainfall, water from the Mirim Lagoon and its adjacent wetland system drain through the natural São Gonçalo Channel (75 km long, 200 to 500 m wide, 6 m maximum depth) into the Patos Lagoon, which ultimately connects with the Atlantic Ocean through the Rio Grande channel. The São Gonçalo Channel Dam divides the São Gonçalo Channel into a freshwater environment to the south and an estuarine environment to the North (Burns *et al.* 2006a, Moura *et al.* 2012).

Bottom fauna samples were obtained from the limnetic region of the São Gonçalo Channel between 31°48'S, 52°23'W and 32°7'S, 52°35'W (Fig. 1). Bottom trawl was carried 3 to 6 m deep, from January to November 2005, and from October to November 2008. Every season, four samplings at three different sampling areas (Dam, Tigre and Piratini), totalizing twelve samplings per season, were carried out using a fishermen's wooden boat (10.9 m long with a 60-Hp engine). Five-minute tows (approximately 400 m) were performed using a 10.5 m (head rope) shrimp trawl (1.3 cm bar mesh wings and body with a 0.5 cm bar mesh cod end liner) and a pair of weighted outer doors (Lopes *et al.* 2009, Lopes & Vieira 2012).

Representatives of *P. pintado* collected in each tow were stored in separate plastic bags and fixed in 10% formaldehyde. Voucher specimens were deposited at "Coleção Ictiológica da FURG" number 6,056 (25) 6061 (6). At the laboratory, the total length (TL) of each individual was measured to the nearest millimeter. Stomachs were extracted by cutting out the esophagus and pylorus and fixed in 70% alcohol. Prey items were identified to the lowest taxonomic level, counted and grouped into categories. We determined Frequency of Occurrence (FO%), Percent Area (PA%) and Index of Relative Importance (IRI) of the *P. pintado* diet for samples collected during the austral summer (January and February), autumn (April), winter (July and August) and the austral spring (September, October and November) of 2005 and the austral spring (October and November) of 2008. IRI was determined as FO% x (PN%+PA%), where PN% are number percent (Hyslop 1980) of each food item. We compared de relative importance of the golden museel in the stomachs of catfish sampled in the spring of 2005 with those sampled in the spring of 2008 (three years after *L. fortunei* occurrence was recorded in the system).

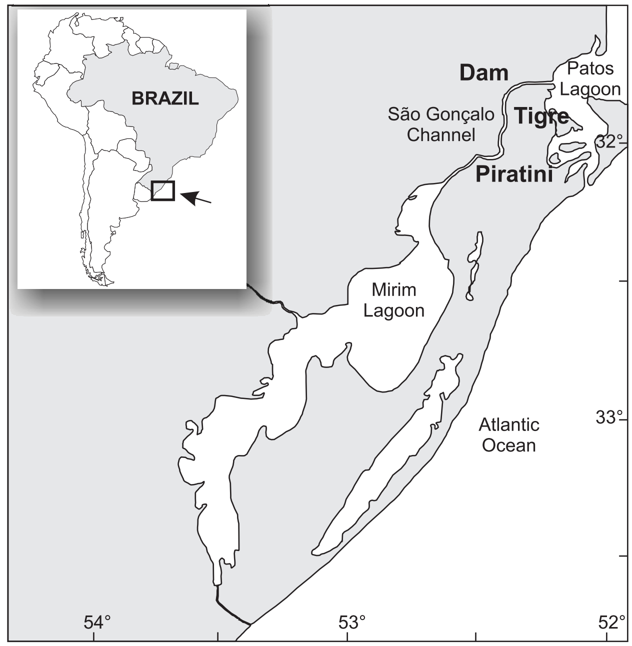


Figure.1 Mirim Lagoon (drainage basin, 62.250 km^2) and the São Gonçalo channel that connects it with the Patos Lagoon. The limnetic region is localized southern the dam. The sampling areas are show (Dam, Tigre and Piratini).

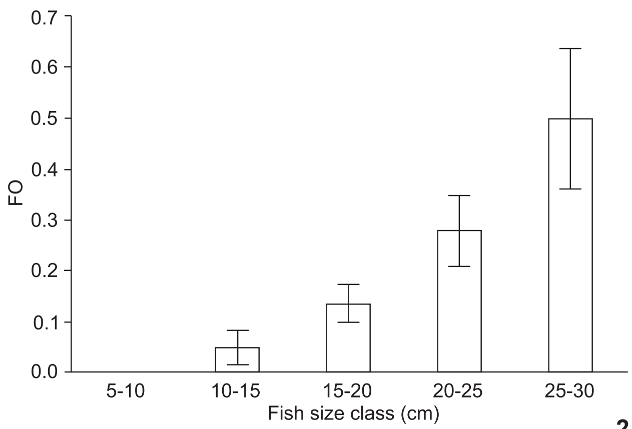
Using an electronic caliper with accuracy of 0.01 mm, the maximum shell length of *L. fortunei* prey was measured using the individuals present in the stomachs of *P. pintado*, as well as using the specimens collected in the environment (bottom trawl, during 2008). The maximum length was considered as the distance from the anterior end, situated just above and ahead of the umbones, until the rear end of the shell (Mansur *et al.* 1987).

After logarithmic transformation (log_{10}+1) the differences between the sizes of golden mussels found in the digestive tract of different sizes classes of *P. pintado* were tested using one-way analysis of variance (size class 10-15 cm TL, N = 6; size class 15-20 cm TL, N = 52; size class 20-25 cm TL, N = 51; size class 25-30 cm TL, N = 38) (Zar 1999). The differences between the sizes of golden mussels found in the digestive tract of all *P. pintado* and those collected in the environment were tested using the nonparametric Kolmogorov-Smirnov test (Sokal & Rohlf 1995).

RESULTS

Asian golden mussels were not observed in the stomachs of catfish collected during the austral summer, autumn or winter of 2005. The first record of the mussel was during the austral spring (September, October and November) of 2005, when it was found in 21.8% of the 180 stomachs of *P. pintado* (10-30 cm TL). In this period, *L. fortunei* represented 1.8% of the Relative Importance Index (IRI) in the diet to *P. pintado* (Table I).

During the austral spring of 2005, *L. fortunei* individuals were only observed in the stomachs of fish larger than 14 cm, and large fish incorporated more mussels in their diets (Fig. 2). The length golden mussel shells (0.3-1.4 mm) found in the digestive tracts of *P. pintado* did not differ significantly among the different predator length class analyzed (Fig. 3, ANOVA, $F_{3,143} = 0.9744$, $p = 0.407$).



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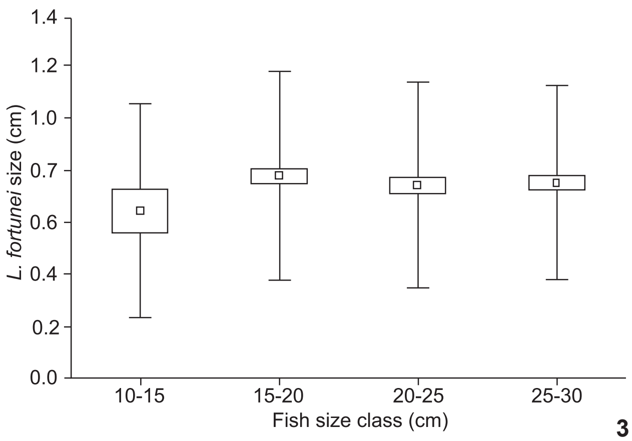

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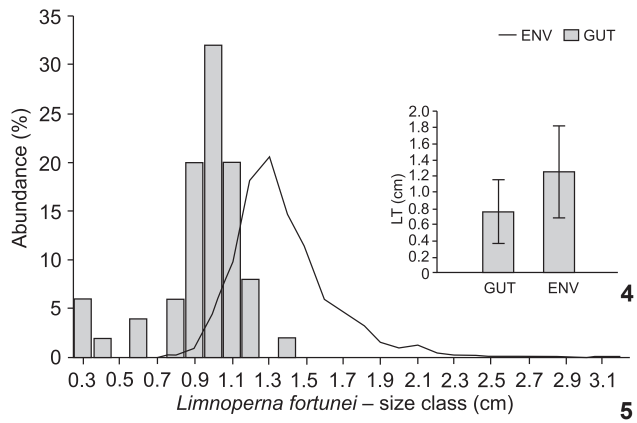
Figures 2-3. (2) Frequency of occurrence of *Limnoperna fortunei* in the digestive tracts of *P. pintado* at different fish size class analyzed in the spring of 2005. The line represent the standard deviation and the bars represent mean. (3) Box plot of *Limnoperna fortunei* shell size distribution by *Pimelodus pintado* size class in the spring of 2005.

In the austral spring of 2008 (Table I), *L. fortunei* was found in 60.8% of the 30 stomachs of *P. pintado* analyzed and was the most important food item in the diet of the cat fish (IRI = 31.4%). Specimens of *L. fortunei* (N = 7789) collected by the shrimp trawl in 2008 were measured and compared with the 51specimens found in the stomachs of *P. pintado* (20.7-30.5 cm TL) sampled in the same area. The length range of fortune of the mussel in the environment (n = 7789) was 0.7 to 3.2 cm, with a mode of 1.3 cm TL, and the shell length of mussels found in the in the guts (n = 147) of *P. pintado* ranged from 0.3 to 1.4 cm (Fig. 4) and the nonparametric Kolmogorov-Smirnov test revealed a significant difference (Fig. 5, D = 0.82491, $p < 0.001$) between them.



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Figures 4-5. (4) Shell size distribution of *Limnoperna fortunei* collected in the environment (ENV), and in the guts (GUT) of *Pimelodus pintado* at the spring of 2008. (5) Mean size and 95% confidence interval of *Limnoperna fortunei*.

DISCUSSION

Boltovskoy & Cataldo (1999) showed that during the first year of the introduction of *L. fortunei*, mussels reached up to 2.0 cm in length, and by the end of their second year, some reached 3.0 cm. The maximum length of mussels in this study was 3.2 cm. Additionally, Burns *et al*. (2006b) recorded the species in the São Gonçalo Channel for the first time in 2005. Both facts suggest that the species was already fully established in São Gonçalo Channel in 2008 (Lopes & Vieira 2012).

The mean shell length of *L. fortunei* found in the digestive tracts of *P. pintado* were similar for the different predator length classes analyzed and reached a maximum size of 1.4 cm (Fig. 3). Montalto *et al*. (1999) and Lopes & Vieira (2012) showed that Asian golden mussels are predated in different development stages by several fish species in the Neotropical region, but small mussels (< 1.5 cm) were more frequent and abundant in fish guts. Cantanhêde *et al*. (2008) analyzed the diet of a

Table I. Seasonal variation of the Frequency of Occurrence (FO%), Percentage by Number (PN%), Percentage by Area (PA%), and Relative Importance Index (IRI%) of items found in the diet of *Pimelodus pintado* during 2005 and 2008.

Items	2006							2008			
	Summer	Autumn	Winter	Spring				Spring			
	FO%	FO%	FO%	FO%	PN%	PA%	IR%	FO%	PN%	PA%	IR%
Small crustaceans	13.51	47.89	65.48	74.15	63.77	40.07	67.76	17.39	7.04	3.64	1.97
Crabs	20.27	2.82	1.19	3.40	0.21	2.34	0.08	21.74	2.18	19.75	5.06
Insects	35.14	60.56	64.29	57.14	15.33	19.27	17.40	65.22	16.26	8.11	16.85
L. fortunei	–	–	–	**21.77**	5.16	4.49	1.85	**60.87**	18.83	34.77	31.37
Corbicula spp.	–	4.23	11.90	2.72	0.25	0.12	0.01	13.04	1.94	1.02	0.41
Heliobia spp.	27.03	12.68	7.14	16.33	3.16	0.87	0.58	47.83	51.70	9.20	30.88
Fish	70.27	49.30	16.67	21.29	4.28	7.42	2.17	4.35	0.24	2.68	0.13
Plant	2.70	35.21	15.48	39.46	3.23	22.98	9.10	52.17	3.88	17.52	11.84
Other	9.48	4.23	2.38	19.73	1.93	2.07	0.69	26.09	1.94	2.98	1.36
Mineral	–	9.86	4.76	13.61	2.70	0.37	0.37	8.70	0.97	0.32	0.12

predator fish larger than *P. pintado* (*Pterodoras granulosus*; 17-55 cm TL) and found similar results, whereas the size range of *L. fortunei* individuals ranged from 0.8 to 1.7 cm in mean, although the mussel is well known to reach more than 3 cm (Boltovskoy & Cataldo 1999, Maroñas *et al.* 2003, Mansur *et al.* 2008).

Young and adult *L. fortunei* individuals have a considerable ability to move to new locations with some taxis, suggesting that this represents an ability to avoid predation by hiding (Lopes & vieira 2012). The distance that mussels are able to move decreases with increasing shell length, and they tend to aggregate after reaching 1.5 cm TL (Uryu *et al.* 1996). The observations of the present study suggest that more mobile individuals of *L. fortunei* (smaller than <1.4 cm) are able to crawl over the bottom and are probably more readily available in the São Gonçalo Channel to fish such as *P. pintado* than larger and more aggregated mussels that get attached to the hard substrate. Fish with a generalist feeding behavior are good samplers of prey diversity and can easily detect new sources of food, and are flexible enough to exploit eventual peaks in prey abundance (Glova & Sagar 1989, Mendoza-Carranza & Vieira 2007). Then, independently from the size of individuals, the catfish under study consumes only golden mussels that are smaller than 1.4 cm TL, which implies that the predator prefers smaller prey because they are more readily available.

It is important to note that *L. fortunei* was first reported in the limnetic zone of the São Gonçalo Channel in January 2005 (Burns *et al.* 2006b). Since the diet of *P. pintado* is influenced by the availability of food in the environment, the data presented here suggest that the trend observed in this study, i.e., the absence of *L. fortunei* in the stomachs of *P. pintado* from the austral summer to the winter and the presence of it in the spring 2005, is a good indicator that *L. fortunei* started to be abundant in the limnetic zone of the São Gonçalo Channel during the austral spring of 2005. At the present time, *L. fortunei* is fully established in the São Gonçalo Channel (Colling *et al.* 2012, Lopes & Vieira 2012).

Little empirical information is available to explain the success of invaders (Mansur *et al.* 2012). The arrival and spread of *L. fortunei* at the Mirim Lagoon will probably bring rapid changes in the benthic community as well as the displacement of other mollusk species, as described by Darrigan (2002) and Darrigran & Damborenea (2005) for other South American fresh water habitats. Currently, unpublished data suggest that *L. fortunei* is much more abundant in the dense vegetated limnetic part of the São Gonçalo Channel (61 km long and 17 m wide) than in the wide open Mirim Lagoon itself (3,749 km^2 area) which has few hard subtracts for mussel fixation (Lopes *et al.* 2009).

With the invasion of *L. fortunei* in the Neotropical region, dietary changes have been noted in omnivorous fishes, which have switched from a low quality, predominantly plant-based diet, to an energetically rich diet dominated by invasive mollusks (Montalto *et al.* 1999, Ferriz *et al.* 2000, Boltovskoy *et al.* 2006, Lopes & Vieira 2012). With the invasion of *L. fortunei*, part of the organic matter in the turbid São Gonçalo Channel will be filtered and modified into a form available to organisms that cannot feed on small particles, like fishes.

Lopes & Vieira (2012) shows that 12 of 19 predators in the Mirin/São Gonçalo Channel feed on *L. fortunei*. Regardless of the size and foraging behavior of the predator, individuals smaller than 14 mm on average are preyed upon. The incidence of individuals of *L. fortunei* smaller than 14 mm in the diet of detritivorous fishes like *Rineloricaria microlepdogaster* and *R. strigilata*, which do are not adapted to predate on mollusks, confirms the hypothesis that individuals of golden mussel up to 14 mm TL are more vagile than larger individuals (Uryu *et al.* 1996), and frequently move on the bottom of the São

Gonçalo Channel, being more available to fish predation than individuals larger than 14 mm TL, which tend to be clustered or hindered in crevices of the substrate (Lopes & Vieira 2012).

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