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Density, Recruitment, and Shell Growth of *Limnoperna fortunei* (Mytilidae), an Invasive Mussel in Tropical South America

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ABSTRACT

Limnoperna fortunei (Dunker, 1857) is an invasive freshwater bivalve native to rivers and streams of China and Southeast Asia. In 2001, it was discovered in Itaipú Reservoir, and its population has grown considerably since then. The aim of this study was to estimate density, recruitment, and individual growth of *L. fortunei* in a subtropical region from a field experiment using an artificial substrate. Samples were collected between December 2004 and December 2005 at Bela Vista Reservoir in Foz do Iguaçu, Brazil. Mussels were counted and measured to generate size-frequency and distribution data. Maximum and minimum densities (± standard deviation) were 204 ± 17 ind.100 cm^{-2} and 94 ± 22 ind.100 cm^{-2}, respectively. Shell length ranged between 1 and 36 mm, and shell length frequency indicated presence of young mussels with variable densities throughout the period surveyed. The von Bertalanffy model fitted successfully in all cases explaining more than 96% of the variation in shell length. Measured growth parameters ($k = 2.35$ $year^{-1}$, $L_{\infty} = 38$ mm) were different from those estimated for populations of *L. fortunei* in a temperate region.

INTRODUCTION

Limnoperna fortunei (Dunker, 1857) is an invasive freshwater bivalve native to rivers and streams of China and Southeast Asia. However, the number of works on the biology of this species is low. A review was published by Darrigran and Damborenea (2006). It was first reported in the South American continent on the coast of Río de la Plata (34°52'S, 57°48'W) in 1991 (Pastorino et al. 1993). Since 1991, the species spread from a temperate climate to a subtropical area. In 1998, it arrived to the Brazilian Pantanal (Oliveira et al. 2006); this habitat has freshwater wetlands and dry tropical forest.

Density and individual growth of *L. fortunei* were estimated in different areas. Boltovskoy and Cataldo (1999) analyzed changes in the size-frequency structure of mussels colonizing experimental frames deployed in the channel that diverts water from a nuclear power plant in a locality in the south Paraná River (33°58'S, 59°12'W). Maroñas et al. (2003) described individual growth of *L. fortunei* in a natural habitat in the Rio de la Plata estuary (34°52'S, 57°48'W). Both studies were made in a temperate region. Also, dos Santos et al. (2008) evaluated shell length variation over a one-year period in specimens of *L. fortunei* from a tropical region (Guaíba Lake, Brazil). Due to its demographic explosion, this bivalve has rapidly become a major nuisance for industrial and power plants that use river water, and it affects trophic interactions and availability of food for both pelagic and benthic species (Boltovskoy and Cataldo 1999, Darrigran and Mansur 2006). In 2001, *L. fortunei* was first detected in the Itaipú Reservoir where it damaged water cooling systems (Zanella and Marenda 2002).

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Thus, the aim of this study was to estimate density, recruitment, and individual growth of *L. fortunei* from data collected from artificial substrates deployed at Bela Vista Reservoir, Brazil.

MATERIALS AND METHODS

The Bela Vista Reservoir is located at the Itaipú's Reservoir borders in a subtropical region (25°24'32.17''S, 54°35'14.46''W). From December 2004 to December 2005, samples were scraped from PVC buoys at a depth of 0.20 m. Three 10 x 10 cm samples were used to estimate density at each location, according to Maroñas et al. (2003) and dos Santos et al. (2008).

Shell length was measured to the nearest 0.5 mm using vernier caliper, and length class distribution was constructed using 1 mm size classes. Recruitment was estimated considering all young mussels with a shell length ≤ 5 mm (Darrigran and Damborenea 2006, Darrigran et al. 2007). Cohorts were estimated following Bhattacharya (1967) using FISAT II (Version 1.1.2, FAO-ICLARM Fish Assessment Tools) (Gayanilo et al. 1996). Distributions were broken down into unimodal components where each progression mode represented a cohort, which was confirmed using NORMSEP (Pauly and Caddy 1985). Growth was estimated from changes in mean cohort shell length. The von Bertalanffy growth equation was fitted to shell length data obtained from the polymodal distribution. It was expressed as $L_t = L_\infty [1 - e^{-k(t - t0)}]$, where L_t is shell length of mussel at age t, L_∞ is the asymptotic maximum growth, k is the growth coeficient, and t_0 is time at age 0 (settlement date). L_∞ was estimated by the Taylor's method ($L_\infty = L_{t\,max}/0.95$) (Pauly 1984), using a maximum shell length that was found in October ($L_{t\,max}$ = 36 mm). Growth parameters k and t_0 were estimated by an iterative method (Moreteau 1987, Maroñas et al. 2003, Blanchard and Feder 2000).

RESULTS

A total of 4,987 individuals was measured. Mean mussel density changed seasonally, with the highest and the lowest densities recorded in December 2004 (204 ind.100 cm^{-2} ±17SD) and May 2005 (95 ind.100 cm^{-2} ±22 SD), respectively. Mean density decreased during May when temperature began to fall, but after July the number of individuals increased (Fig. 1). Young mussels (recruits) were observed throughout the period surveyed. Mean number of recruits was estimated for each sampling date, and the

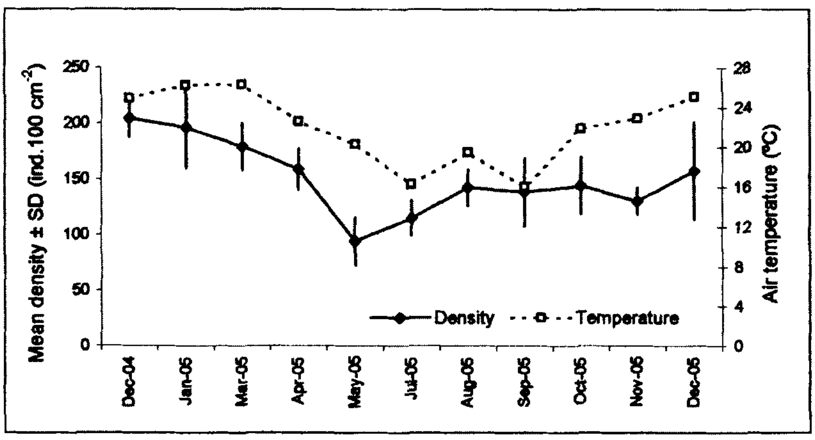

Figure 1. Seasonal changes in mean density (± SD) of *Limnoperna fortunei* collected from artificial substrates in the Paraná River (Bela Vista Reservoir, Brazil) and monthly mean air temperature.

highest mean density of young mussels was in December 2004 (n = 179 ind.100 cm^{-2}). From August to December 2005, density of young mussels decreased, reaching the lowest values (n < 30 ind.100 cm^{-2}) (Fig. 2).

Length-frequency distribution of mussels showed a variable distribution of mean shell length during the entire period. Seventeen cohorts were obtained from the polymodal distribution, and each cohort was numered, in order of assessment (e.g., C1, C2, ..., C_n). Individual growth was estimated using those cohorts that were well represented (Table 1). Maximum theoretical shell length (L_∞) estimated by Taylor's equation was 38 mm, and it was kept fixed while the others parameters were estimated by an iterative process. Figure 3 shows von Bertalanffy growth curves fitted to the most representatives cohorts, which were C4, C5, C6, C7, C10, C11, C12, and C13. All growth parameters estimated for each cohort are summarized in Table 2. The von Bertalanffy model explained, in all cases analyzed, more than 96% of the variation in shell length, and it was extrapolated to get a time reference when maximum theoretical shell length would be reached. Theoretical longevity was estimated at 3.1 years (± 0.2). Growth data showed that this population of *L. fortunei* reached 95% of its maximum theoretical shell length (L_t = 36 mm) in 1.3 years (± 0.2). Growth coefficient (k) estimated for each cohort tended to decrease due to growing period that occurred at low temperatures (Table 2 and Fig. 1). A mean k value of 2.35 was estimated with a 95 % confidence interval of 2.04 - 2.67.

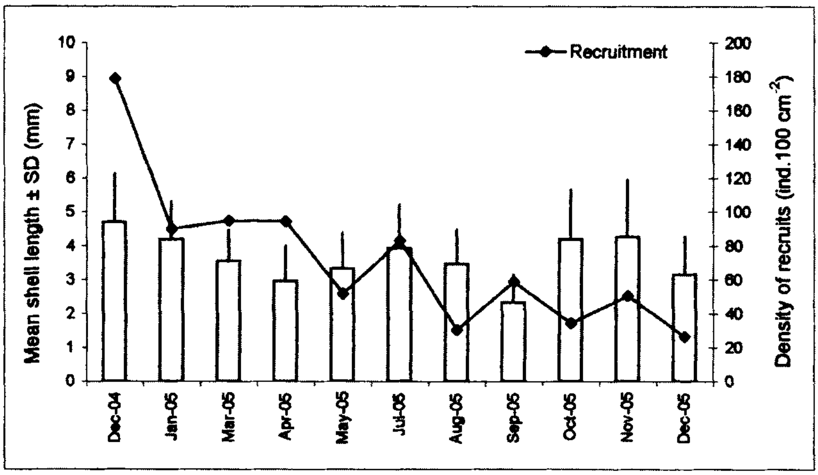

Figure 2. Mean shell length (± SD) of young mussels (recruits) and density of recruitment estimated for each sampling date in the Paraná River.

DISCUSSION

L. fortunei has been present in the Río de la Plata basin since 1991; it became established 15 years ago and expanded its range since (Darrigran and Mansur 2006). By 2003, *L. fortunei* had colonized almost all of the Plata basin, extending its range northward and reaching the Pantanal and the states of São Paulo and Minas de Gerais (Brazil) (Darrigran 2002, Boltovskoy et al. 2006). Since 2001, *L. fortunei* has inhabited the Itaipú Reservoir, and its population has continued to increase (Zanella and Marenda 2002). Maximum density estimated in this research was 204 ind.100 cm^{-2}. This was similar to that estimated by Mansur et al. (2003) in Guaíba, Brazil (27,275 ind.m^{-2}). Nevertheless, results obtained from field surveys in the Río de la Plata (Argentina), where this population is established, showed a maximum density of 122,000 and 150,000 ind.m^{-2} (Boltovskoy and Cataldo 1999, Darrigran et al. 2003).

Temperature, salinity, oxygen, and food supply can all directly affect mussel population characteristics and growth rate by increasing or decreasing somatic growth (Theisen 1973, Morton 1982, Tedengren and Kautsky 1986, Seed and Suchanek 1992, Chase and Bailey 1999, Blanchard and Feder 2000, Darrigran et al. 2007, Karatayev et al. 2007). The variability in length-frequency distribution that was observed could be related to some of the factors mentioned above. The highest air temperatures registered in this region (35°C) could result mortality during the summer. This phenomenon was observed by dos Santos et al. (2008) in Guaíba Lake (Brazil). Montalto and Marchese (2003), in laboratory experiments, showed lethal response in young and adult *L. fortunei* exposed to 35°C water for two hours. Also, *Dreissena polymorpha* and *Mytilus californianus* showed a similar response when they were exposed to high temperature (Karatayev et al. 2006, Coe and Fox 1942).

In our study, growth parameters estimated for each cohort were higher than those estimated by Boltovskoy and Cataldo (1999) (L_∞ = 35 mm, k = 1 year^{-1}) and Maroñas et al. (2003) (L_∞ = 36 mm, k = 0.35 year^{-1}) for *L. fortunei* in a temperate region of Plata basin. Our study area has a subtropical climate, while the Río de la Plata has a temperate one. Therefore, we suggest that differences in growth observed between these areas could be associated with the different climatological conditions. Maroñas et al. (2003) and Boltovskoy and Cataldo (1999) estimated a longevity of 3 and 3.5 years, respectively. Our results suggest a theoretical longevity of 3.1 years. Different authors suggest that when latitude increases, maximum size and growth rate decrease and longevity increases. Cooler temperatures and shorter growing seasons also affect these variables (Coe and Fox 1942, Gilbert 1973). According to our results, *L. fortunei* from tropical or subtropical areas has a greater growth rate, which can be explained by longer growth periods/stages.

Table 1. Mean shell length (mm) of *Limnoperna fortunei*. C_n = cohort number.

Sampling date	C1	C2	C3	C4	C5	C6	C7	C8	C9
12/21/04	29.8	20.8	13.7	4.7					
01/20/05	32.0	23.9	20.2	14.2	7.2	4.2			
03/04/05				21.9	11.2	7.0	3.6		
04/11/05		31.8		24.6	18.5	12.3		6.8	3.0
05/17/05					23.4	17.7	15.1	11.6	6.6
07/01/05						25.0	19.8		
08/17/05							24.2		
09/16/05						32.6			23.8
10/14/05									
11/17/05									
12/22/05							30.1		

Sampling date	C10	C11	C12	C13	C14	C15	C16	C17
12/21/04								
01/20/05								
03/04/05								
04/11/05								
05/17/05	3.3							
07/01/05	8.8	3.9						
08/17/05	16.0		8.1	3.5				
09/16/05		16.2	11.3	6.1	2.3			
10/14/05	24.8	20.2	15.9		8.2	4.2		
11/17/05		24.9	19.3	16.9		11.4	4.3	
12/22/05			25.6	20.7			10.2	3.2

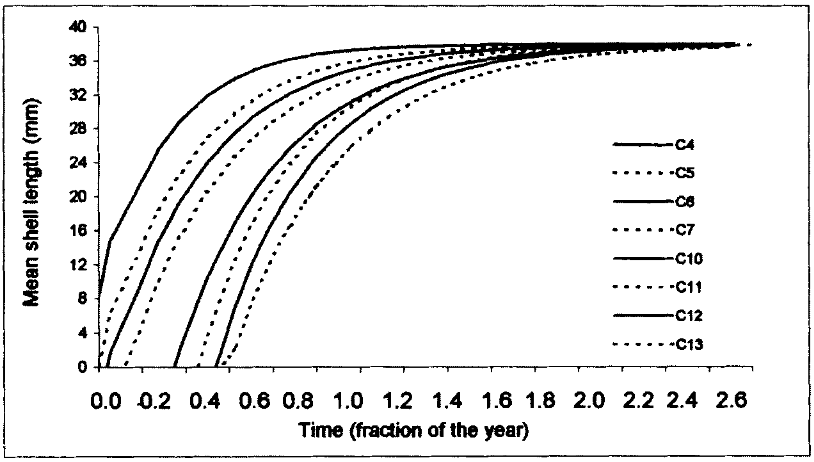

Figure 3. Von Bertalanffy growth curves fitted to mean shell lengths of cohorts 4, 5, 6, 7, 10, 11, 12, and 13. Time is calculated as fractions of the year starting from 1 January, 2005.

Table 2. Parameter values for von Bertalanffy growth model. C_n = cohort number, L_∞ = maximum shell length, k = growth coefficient, t_0 = time at age 0, and R^2 = regression coefficient.

Cohort	L_∞ (mm)	k (year^{-1})	t_0	Settlement date	R^2
C4	38	3.2	-0.071	12/06/04	0.99
C5	38	2.5	0.008	01/04/05	0.98
C6	38	2.3	0.061	01/23/05	0.96
C7	38	2.1	0.128	02/16/05	0.99
C10	38	2.1	0.345	05/06/05	0.97
C11	38	2.3	0.453	06/15/05	0.99
C12	38	2.2	0.532	07/14/05	0.96
C13	38	2.0	0.592	08/05/05	0.98

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