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Short Communication

Larger and heavier individuals of the invasive shrimp *Palaemon macrodactylus* in the Salado River, Argentina

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Abstract

Different populations of caridean shrimp species exhibit intraspecific variation in their life-history traits as a response to environmental heterogeneity. Although the invasive oriental shrimp *Palaemon macrodactylus* has been introduced worldwide relatively little is known of the basic biology of this species. Here we tested whether some basic biological characteristics of a recently reported population in a low-salinity environment in the Salado River, Argentina, differed from those reported elsewhere (including other invaded ecosystems). Individuals from the low-salinity Salado River were longer and heavier than those from fully marine areas of Argentina as well as from other habitats worldwide. The between-location differences reported in this study provide useful information to better understand the striking intraspecific variability of this invasive species.

Key words: invasive species; oriental shrimp; Decapoda; Caridea; Palaemonidae; Southwestern Atlantic coast

Introduction

A steadily increasing number of marine species have established breeding populations far outside their natural range as a consequence of human activities (d'Udekem d'Acoz et al. 2005). Invasive species constitute one of the current major environmental concerns and, therefore, are considered a significant component within the present state of global change. Furthermore, because of their generally irreversible and unmanageable characteristics, such species are considered to be one of the more serious threats to biodiversity of aquatic ecosystems (Sakai et al. 2001). The oriental shrimp *Palaemon macrodactylus* Rathbun, 1902 (Decapoda: Caridea: Palaemonidae) is a suprabenthic crustacean native to the coast of Japan and Korea, and the north coast of China (Newman 1963). After its first record from outside the species's original distribution in San Francisco Bay, California, USA in 1957 (Newman 1963), it has been introduced into a number of estuaries worldwide (Ashelby et al. 2013).

The available information on *P. macrodactylus* deals with its geographic distribution, ecologic interactions, larval development, egg structure, and morphological abnormalities (reviewed by Ashelby et al. 2013). Nevertheless, relatively few studies have analyzed the ecology and biology of *P. macrodactylus* in depth, and those investigations were confined to the species's area of origin (Omori and Chida 1988) in addition to certain European estuaries (González-Ortegón et al. 2010; Béguer et al. 2011a). This invasive shrimp was first reported in the southwestern Atlantic coast in a fully marine area in the Mar del Plata Harbor, Argentina (Spivak et al. 2006). Later, *P. macrodactylus* was reported both north and south of this initial detection point; specifically, where the shrimp has colonized brackish-water habitats along the Argentine coast (Martorelli et al. 2012). An understanding of the ecology and biology of *P. macrodactylus* is still at a preliminary stage in Argentina despite the species's invasiveness, and even though this shrimp began to play a key role in parasite ecology as a vector for the

Figure 1. Sampling site of *Palaemon macrodactylus* in the lower area of the Salado River (35°50' S, 57°25' W), Argentina.

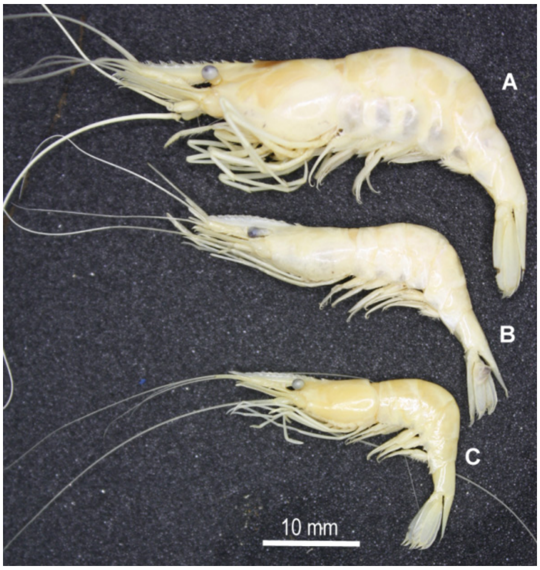

Figure 2. Individuals of the invasive shrimp *Palaemon macrodactylus* collected from the Salado River, Argentina. A) Ovigerous female (eggs removed); B) Nonovigerous female; C) Male. Photograph by N. Bonel.

spread of crustacean viral infections (Martorelli et al. 2010).

Different populations of conspecific organisms inhabiting dissimilar environmental conditions exhibit intraspecific variation within their life-history traits (Ituarte et al. 2007; Bonel et al. in press), most likely as a result of evolutionary forces and/or a more immediate plastic, epigenetic, response to environmental variations (Begon et al. 2006). As a part of an evaluation of the biology of *P. macrodactylus* along the Argentine coast, we analyzed the size and the weight of individuals of this invasive shrimp inhabiting a low-salinity environment: the Salado River. We asked whether the size and weight of individuals from that river were different from the corresponding data for the fully marine area where the shrimp had been first reported in Argentina as well as for other locations worldwide.

Methods

The Salado River, the southern tributary of Río de la Plata estuary, is a typical lowland river and the major drainage of the Buenos Aires province, Argentina. The lower area of the Salado is characterized by average ± SD (range in parentheses) annual: water temperature of 17.8±5.5 °C (10.0–31.8 °C), salinity of 2.83 ± 1.46 (0.9–5.0), and turbidity of 209 ± 247 NTU (10–1,000 NTU) (Neschuk et al. 2002; Solari et al. 2002). The presence of the invasive shrimp *P. macrodactylus* was recently reported in close proximity to the Salado River mouth in the Samborombón Bay (35°50'S, 57°25'W; Figure 1; Martorelli et al. 2012). Those authors performed a qualitative sampling and the shrimps (n = 113) were preserved in 96% ethanol and transported to the laboratory. We used these specimens in the present study.

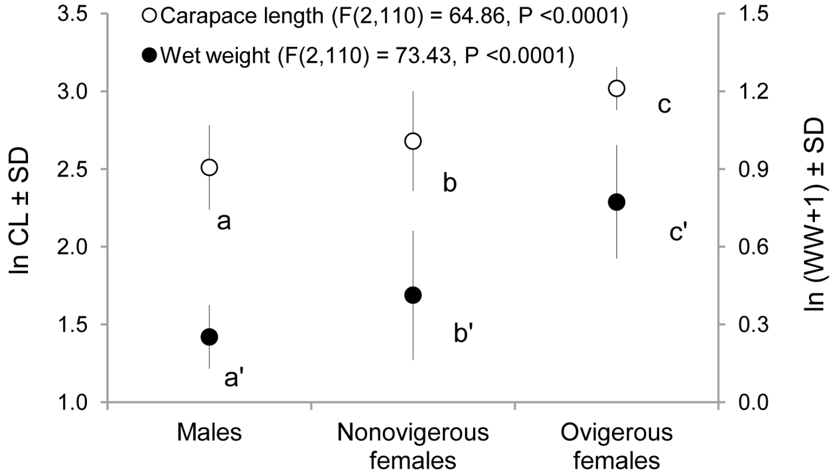

Figure 3. Results of one-way ANOVA and Tukey HSD test for differences in natural logarithm of carapace length (CL) and wet weight (WW) between males and nonovigerous and ovigerous females of *Palaemon macrodactylus*. Different letters (a, b, c, a', b', and c') indicate significant differences of carapace length and wet weight between groups. SD, standard deviation.

We first determined the sex of each shrimp by the presence or absence of an appendix masculina on the endopod of the second pleopod (Siegfried 1980). Females were divided into two reproductive stages, ovigerous and nonovigerous (Figure 2). Then, we measured the carapace length (CL) as the shortest distance between the posterior margin of the orbit and the middorsal posterior edge of the carapace with a digital caliper (precision, 0.01 mm) and wet weight (to 0.001 g) on a digital balance, with the ovigerous females being weighed after egg removal.

To test for differences in the mean carapace lengths and wet weights between the groups, we applied two independent one-way ANOVA and *post-hoc* tests (Tukey HSD). Body dimensions were transformed to the natural logarithms to homogenize the variances. We analyzed the relationship between wet weight (WW) and carapace length (CL) with the allometric equation: $WW = aCL^b$, where a is the intersect and b the allometric coefficient (or slope) of the equation (Béguer et al. 2011 a, b). The regressions were calculated separately for the three groups. The parameters of the allometric function were estimated by the iterative non-linear Gauss-Newton algorithm in the JMP statistical software (v9.0 SAS Institute). The correspondence of the curves fitted to different groups was then tested through the use of the sum of the squares from the F test. A nonsignificant F statistic indicated that a single curve was sufficient to describe the groups being compared (Blanchard and Feder 2000). By means of one-sample t-test, we tested whether the estimated allometric coefficients, for each group and pooled data, differed significantly from isometry (b = 3.0) and also against those reported in published studies. Lastly, we used the z-test to compare the carapace length and wet weight of *P. macrodactylus* from this study with the few published studies that reported the mean values and standard deviation.

Results and discussion

Mean carapace length differed significantly between the groups ($F_{(2,110)} = 64.86$, $P < 0.0001$; Figure 3): ovigerous females were significantly longer than nonovigerous females and males were significantly shorter than both female stages. Mean wet-weight also differed significantly ($F_{(2,110)} = 73.43$, $P < 0.0001$; Figure 3) between groups: ovigerous females were heavier than nonovigerous females and males were lighter than both groups of females. Sexual dimorphism in terms of the size of *Palaemon macrodactylus* is very likely related to differing growth rates *per se*, as the females grow faster and reach larger sizes than the males (Omori and Chida 1988; Vázquez et al. 2012). Since individual growth refers to an increase in size and/or mass of an organism with time (Brey 2001), we believe that the differences observed in the size and weight between sexes could well be a direct consequence of a higher growth rate in the *P. macrodactylus* females than in the males. The allometric relationships of wet weight as function of carapace length (Figure 4) between the three groups showed no significant differences

Table 1. Mean ± standard deviation (range in parentheses) of carapace lengths (CL, mm) and wet weights (WW, g) of *Palaemon macrodactylus* from the lower region of the Salado River (Argentina) and from published studies. Note: All data except those from Japan represent locations where this species is introduced. nd, no data.

		Males	Nonovigerous females	Ovigerous females	Total females	References
Salado River (Argentina)	CL	12.4 ± 3.1 (7.0-17.2)	15.2 ± 4.3 (6.9-22.0)	20.7 ± 2.8 (13.3-27.9)	19.6 ± 3.8 (6.9-27.9)	This study
	WW	0.296 ± 0.158 (0.030-0.620)	0.556 ± 0.383 (0.020-1.170)	1.220 ± 0.501 (0.350-2.530)	1.094 ± 0.546 (0.020-2.530)	
Mar del Plata Harbor (Argentina)	CL	nd (nd-7.5)	nd (4.5-nd)	nd (4.7-12.5)	nd (4.5-12.5)	Vázquez et al. (2012)
	WW	nd	nd	nd	nd	
Matsushima Bay (Japan)	CL	nd (nd-11.7)	nd	nd (8.5-nd)	nd (nd-16.7)	Omori and Chida (1988)
	WW	nd	nd	nd	nd	
Gironde Estuary (France)	CL	5.6 ± 1.0 (3.2-9.5)	nd	nd	7.0 ± 1.8 (3.4-13.1)	Béguer et al. (2011a)
	WW	0.179 ± 0.095 (0.029-0.629)	nd	nd	0.344 ± 0.271 (0.038-1.583)	
Guadalquivir Estuary (Spain)	CL	nd (nd-8.9)	nd	nd (nd-14.1)	nd (nd-14.1)	González-Ortegón (2008)
	WW	nd	nd	nd	nd	
Varna Lake (Bulgaria)	CL	nd	nd	nd	nd (nd-15.6)	St. Raykov et al. (2010)
	WW	nd	nd	nd	nd	
Black Sea (Romania)	CL	nd	nd	nd (5.9-15.8)	nd (5.9-15.8)	Micu and Niţă (2009)
	WW	nd	nd	nd	nd	

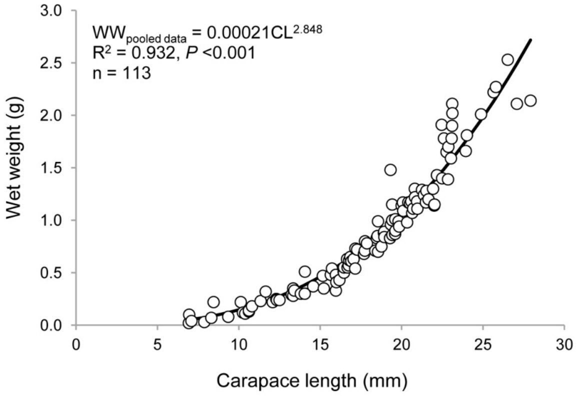

Figure 4. Allometric relationship of wet weight (WW) as function of carapace length (CL) for males and nonovigerous and ovigerous females of *Palaemon macrodactylus* collected from the lower area of the Salado River, Argentina.

($F_{(3,107)} = 1.924$, $P = 0.1301$). The coefficient for the combined data ($b = 2.848$) was significantly less than 3.0 (isometry) (one-sided $t = -1.7505$, df = 112, $P = 0.0413$).

The average carapace length of ovigerous females in this study was larger than the maximum carapace lengths reported for females in the same condition from the fully marine area where the invasive shrimp *P. macrodactylus* had been first reported in Argentina as well as from other habitats worldwide (Table 1). Previous to our work, the only other data available on the carapace length, the wet weight, and the allometry of *P. macrodactylus* were for the non-native population inhabiting the Gironde Estuary (Tables 1 and 2; Béguer et al. 2011a). Males and total females from the Salado River were significantly longer than

Table 2. Allometric parameters for wet weight (WW) as function of carapace length (CL) for individuals collected in the lower area of the Salado River, Argentina, and those reported from the Gironde Estuary, France. Data from the latter site were imported from Béguer et al. (2011a). The coefficients *a* and *b* are the parameters of the allometric function WW = $a\mathrm{CL}^b$.

	Salado River, Argentina				Gironde Estuary, France				One-sample *t*-test
	a	*b*	R^2	n	*a*	*b*	R^2	n	
Males	0.0007	2.3309	0.89	29	0.0011	2.8817	0.90	457	$t_{(26)}$ = -1.139, *P*=0.132
Nonovigerous females	0.0003	2.7130	0.93	16	0.0013	2.7502	0.94	440	$t_{(13)}$ = -0.917, *P*=0.188
Ovigerous females	0.0003	2.7230	0.97	68	0.0022	2.5567	0.91	110	$t_{(66)}$ = -0.892, *P*=0.188

those in the Gironde Estuary ($z_{(1.645)}$ = 2.088, *P* = 0.0184 and $z_{(1.645)}$ =2.997, P =0.0014; respectively); however, the mean wet-weight of males and females did not differ ($z_{(1.645)}$ = 0.635, *P* = 0.2628 and $z_{(1.645)}$ = 1.231, *P* = 0.1091; respectively). Béguer et al. (2011a) also reported negative length-weight allometry for the same three groups as reported here (Table 2). Contrary to what was expected, the coefficients estimated here and those from the Gironde Estuary showed no significant differences (Table 2). We think, however, that the lack of differences due to the small sample size available for the present study and would likely be found if a larger numbers and a greater size range were available for the Salado River.

Caridean shrimps often exhibit between-population variation within their life-history traits as an adaptive response to differing environmental conditions (Alon and Stancyk 1982; Ituarte et al. 2007). Intraspecific differences have been reported between populations of *P. macrodactylus* inhabiting marine and estuarine environments (Vázquez et al. 2012). We think that the dissimilarities in size between *P. macrodactylus* inhabiting the Salado River and those from other locations could be a consequence of a plastic response to environmental heterogeneity. Nevertheless, to understand completely the causality underlying the multitude of conditions and influences that could conceivably modulate the intraspecific variability of the life-history of *P. macrodactylus*, experimental manipulations, both *in situ* and *in vitro*, would be needed. The preliminary results in this study should be extrapolated with caution to other populations of *P. macrodactylus*. We believe, however, that the extremely large size and allometry reported in this study provide useful information to better understand the striking intraspecific variability of this globally invasive species.

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