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ORIGINAL ARTICLE

Growth of the burrowing crayfish *Parastacus nicoleti* (Philippi, 1882) (Crustacea, Decapoda, Parastacidae)

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ABSTRACT

We examined the individual growth of the burrowing crayfish *Parastacus nicoleti* (Philippi, 1882) based on a sample of 1,425 specimens. Individuals were collected monthly from November 1981 to December 1982, in the marshy wetlands of the "Pangal" homestead in Reumen, southern Chile. The Cephalothorax Length (CL) and Body Weight (BW) were recorded for all specimens. The asymptotic length parameters (L_∞) and the growth coefficient (k) were established using the Gulland and Holt method (1959). The t_0 parameter was obtained through the inverse von Bertalanffy equation and the length-weight relationship was determined according to the equation proposed by Ricker (1975). The asymptotic size and weight were 45.754 mm and 18.50 g, respectively. The growth constant was 0.703/year. Estimated longevity was 4.32 years. We concluded that *P. nicoleti* is a relatively small species with poor growth indicators for size and weight and, consequently, is not an attractive species for commercial aquaculture purposes.

KEY WORDS

Longevity, freshwater crayfish, growth parameters, asymptotic size and weight, southern Chile.

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Introduction

The burrowing crayfish *Parastacus nicoleti* (Philippi, 1882) inhabits underground waters from semimarshland areas of Chile (Rudolph, 2010; 2013). Its distribution ranges from the locality of Gorbea (39°05'S 72°38'W) (Araucanía Region) to the Chaqueihua River (41°26'S 73°06'W) (Los Lagos Region) in southern Chile (Rudolph, 2010; 2013). It burrows galleries of variable morphology in these terrains, which can reach depths of up to 2.0 m during the summer (Kilian, 1959). This species plays an important ecological role, as a keystone trophic regulator and ecological engineers in the marshy wetlands of the Cordillera de la Costa of the Los Rios and Los Lagos Regions (Rudolph and Almerão, 2015). Nevertheless, biological knowledge about this species is still scarce and fragmented. The few studies carried out have concentrated mainly on describing the burrowing behavior (Kilian, 1959), embryonic and early postembryonic development (Rudolph and Zapata, 1986), sexual system (Rudolph, 1995), burrow structure and associated physicochemical parameters (Rudolph, 1997). In spite of this lack of knowledge, some authors have classified this species according to the conservation categories established by the IUCN (2012) considering, for this purpose, the degradation of its natural environment due to anthropic action, as the main threat to its conservation. Thus, Bahamonde *et al.* (1998) and Rudolph and Crandall (2005; 2007) classified it as Vulnerable (VU); Buckup (2010) and Almerão *et al.* (2015) as Data deficient (DD); and the Ministerio del Medio Ambiente de Chile (MMA, 2013) (Ministry of the Environment), as Least Concern (LC). These different categorizations reveal the need for additional studies, especially with regard to the population ecology and reproductive biology in order to achieve a more precise evaluation. In this way, it will be facilitated the progress in terms of implementing efficient of conservation measures.

Knowledge about the individual growth of a species is of transcendental importance to estimate population size more accurately (Arreguín *et al.*, 1991). Furthermore, it is indispensable when determining the commercial culture viability of a given species (Lobão *et al.*, 1987), and fundamental to the design of opportune and efficient management, protection and conservation strategies (Rodríguez and Bahamonde, 1986; Wright-López *et al.*, 2009). Taking this into account, the aim of study is to characterize the individual growth of *P. nicoleti,* based on measurements of length and weight, using the biological growth model of von Bertalanffy (1938).

Materials and Methods

Sampling

The *P. nicoleti* specimens were collected with a manual suction pump applied directly over the entrances to their burrows in the marshy wetlands of the "Pangal" homestead (39°59'S 72°52'W), located in the locality of Reumén, province of Valdivia, Los Ríos region, southern Chile. Monthly samples were taken from November 1981 to December 1982, at 14 different points, one for each sampling. The animals captured were deposited in plastic bags and fixed in 70% ethanol for subsequent identification and analysis in the laboratory, using the morphological characters described by Ribeiro and Araujo (2017). The cephalothorax length (CL) of each specimen was measured in millimeters, from the distal end of the rostrum to the posterior margin of the carapace, and wet body weight (W) was recorded in grams, after leaving specimens to drain for three minutes on filter paper. In both types of recording, the sex of the individuals was indistinguishable, since *P. nicoleti* is a partial protandric hermaphrodite species with six gonopore patterns (Rudolph, 1995), making it difficult to distinguish the sex of its representatives externally.

Length-weight relationship

The length-weight relationship was determined applying the equation proposed by Ricker (1975): $W = aL^b$ where W is weight in grams, L is length of the cephalothorax in millimeters and b is the allometric growth constant. The parameters a and b were estimated by the weighted least squares (WLS) method using the SPSS v. 19 program, prior to linearization of the model through logarithmic transformation.

Growth parameters

Estimation of growth was based on analysis of the frequency distribution of cephalothorax length, identifying age groups using the Bhattacharya's method (Bhattacharya, 1976) of the FiSATT II program (Gayanilo *et al.*, 2005). First, the growth coefficient k

and the asymptotic length (L_∞) were estimated using the Gulland and Holt (1959) method, that served as a basis for estimating theoretical age t_0, according to the von Bertalanffy (1938) equation as follows:

$-\ln\left(1-\frac{L_t}{L_\infty}\right) = -k\,t_0 + k\,t$. The Taylor equation (1958) was used for calculation of longevity:

$t_{\max} = t_0 + \frac{3}{k}$, where t_{max} is the maximum age or time required to reach 95% of the asymptotic length (L_∞). The asymptotic weight is estimated according to the expression proposed by Csirke (1980): $W_\infty = aL_\infty^b$ where W_∞ is the asymptotic weight or average maximum weight.

Once the L_∞, W_∞, k and t_0 are estimated, the growth curves in length and in weight were determined, adjusted to the von Bertalanffy model (1938), according to the models $L_t = L_\infty\left(1-e^{-k(t-t_0)}\right)$ and $W_t = W_\infty\left(1-e^{-k(t-t_0)}\right)^b$, respectively.

Results

A total of 1,425 individuals were collected; the CL of 1,178 specimens ranged from 2.4 to 46.0 mm (247 specimens were discarded because of fractures in their carapace) and the body weight of all 1,425 individuals ranged from 0.01 to 20.07g (Tabs. 1, 2). In Tab. 1, we observe that the relative dispersions in size of the specimens caught fall within a range of 0.278 to 0.421, where the lowest and highest relative dispersion is produced in those specimens caught in November 1981 and January 1982, respectively. On the other hand, in Tab. 2, the weights recorded during the study period exhibit high relative variability, presenting values that differ significantly from the averages. The asymptotic length estimated by the growth curve (45.75 mm) was very similar to the CL of the largest specimen measured (46.0 mm).

Length-weight relationship

The size-weight relationship can be observed in Fig. 1, showing greater concentration in the lower values. The intercept of the linearized model is statistically significant for this curve ($|t| = 71.17$; $p < 0.01$), as is the slope of the model ($|t| = 76.51$; $p < 0.01$); thus, the length-weight relationship is established as W=0.00021 $L^{2.97}$. The value of the slope (b = 2.97) indicates an approximately isometric growth (Hartnoll, 1982), denoting that, as the individuals grow, their body proportions are maintained.

Growth parameters

The asymptotic length and growth coefficient estimated according to the Gulland and Holt (1959) method were L_∞ = 45.754 mm and k = 0.703 /year, respectively. Subsequently the theoretical age obtained employing the von Bertalanffy method was t_0 = 0.055 years. The longevity or maximum age (t_{max}) calculated was 4.32 years. The asymptotic weight (W_∞) was obtained using the estimated parameters of the size-weight relationship and the estimated asymptotic length (L_∞), obtaining the value of W_∞ = 18.50 *grs*.

The estimated models of size and weight were, respectively, $L_t = 45.754\left(1-e^{-0.703(t-0.055)}\right)$ and $W_t = 18.50\left(1-e^{-0.703(t-0.055)}\right)^{2.97}$.

Discussion

The estimated length-weight proportion indicated that growth of *P. nicoleti* is isometric (b≈3.0). The same pattern was found for *Parastacus pugnax* (Poeppig, 1835) (b≈3.0) (Ibarra and Arana, 2012) and for males of *Samastacus spinifrons* (Philippi, 1882) (b=3.0) (Bocic *et al.*, 1988). However, females of *S. spinifrons* showed negative allometry in growth (Bocic *et al.*, 1998).

The increase in length (K) estimated for *P. nicoleti* was higher than in other astacid and parastacid crayfishes from cold waters, except for *Austropotamobius torrentium* (Schrank, 1803) (see Tab. 3). In fact, this parameter is only comparable to the increase in length calculated for a species inhabiting warmer waters which has significant commercial importance, as the North American cambarid *Procambarus clarkii* (Girard, 1852) (Anastacio and Marques, 1995; Streissl and Hödl, 2002; Chiesa *et al.*, 2006; Scalici and Gherardi, 2007). However, the value of the asymptotic cephalothorax length for *P. nicoleti* is below the value estimated for all the species of crayfish whose individual growth parameters are presented in Tab. 3, with the exception of *Parastacus defossus* Faxon, 1898 (Noro and Buckup, 2009) and *P. brasiliensis*

Table 1. Cephalotorax length (CL) monthly average (mm) of the *Parastacus nicoleti* specimens.

Month	Year	n	Min	-	Max	Mean	SD	CV
November	1981	52	13.7	-	40.0	21.917	6.0868	0.278
December	1981	70	2.4	-	41.4	19.970	5.5975	0.280
January	1982	55	8.2	-	40.0	19.873	8.3750	0.421
February	1982	32	10.0	-	41.7	18.750	6.6005	0.352
March	1982	56	12.4	-	42.0	22.871	6.8950	0.301
April	1982	77	13.3	-	43.8	23.047	6.4920	0.282
May	1982	112	10.0	-	46.0	22.760	6.9150	0.304
June	1982	101	12.2	-	45.7	24.526	8.0336	0.328
July	1982	127	10.5	-	42.8	20.457	7.4319	0.363
August	1982	102	10.8	-	43.0	21.951	8.4211	0.384
September	1982	101	12.9	-	43.3	24.988	9.3646	0.375
October	1982	87	12.4	-	40.8	25.982	7.8921	0.304
November	1982	146	8.7	-	40.0	20.573	7.0924	0.345
December	1982	61	10.4	-	40.2	20.782	8.1874	0.394
Global		1,179	2.4	-	46.0	22.226	7.7610	0.349

SD= stardard deviation
CV= coefficient of variation

Table 2. Average monthly weight (g) of the *Parastacus nicoleti* specimens.

Month	Year	n	Min	-	Max	Mean	SD	CV
November	1981	65	0.05	-	14.75	2.395	2.8008	>1
December	1981	116	0.03	-	14.30	1.465	2.0118	>1
January	1982	74	0.05	-	14.80	1.648	2.6334	>1
February	1982	33	0.19	-	15.48	2.000	2.8276	>1
March	1982	78	0.04	-	16.73	2.218	3.1371	>1
April	1982	89	0.04	-	17.03	2.672	3.3536	>1
May	1982	120	0.05	-	17.38	2.911	2.9965	>1
June	1982	108	0.02	-	20.07	3.485	3.7599	>1
July	1982	136	0.05	-	15.62	2.373	2.8642	>1
August	1982	138	0.01	-	16.33	2.587	3.4905	>1
September	1982	143	0.01	-	18.84	3.265	4.6800	>1
October	1982	83	0.39	-	15.15	5.019	4.0044	0.798
November	1982	174	0.05	-	12.86	2.055	2.7584	>1
December	1982	68	0.14	-	11.57	2.270	2.9365	>1
Global		1,425	0.01	-	20.07	2.614	3.3633	>1

SD= stardard deviation
CV= coefficient of variation

(von Martens, 1869) (Fries, 1984). These data suggest that *P. nicoleti* would be a relatively small species, with a rapid increase in length, at least prior to reaching between 20 and 30 mm CL (Fig. 2). Within this size range, the reproductive processes of *P. nicoleti* females would begin and, consequently, energy is diverted towards these processes and somatic growth slows down. According to Rudolph (1995), the puberty moult in *P. nicoleti* would occur between 20 and 25 mm CL, sizes that would be reached – according to the growth model of this species – after a period of between 318.6 and 430.6 days. Furthermore, the smallest size recorded for an ovigerous female was 29.2 mm CL (Rudolph, 1995).

Although the size and commercial weight of crayfish species that are successfully cultured worldwide vary considerably, in general, for a species to be considered attractive for human consumption, it must present a minimum size of 9 cm total length and weigh around 25 g (Huner and Lindqvist, 1995). The ideal weight should be around 40 g (Pérez *et al.*, 1997). According to our results, *P. nicoleti* would not be considered an attractive species for commercial aquaculture purposes because it would take four years to reach a size of approximately 43 mm CL (which corresponds to 90 mm total length) and, even then, its total body weight would only be 15.3 g (Figs. 2, 3). These sizes and weights are reached by two, cold water species commonly cultured in Europe, *Astacus astacus* (Linnaeus, 1758) and *Pacifastacus leniusculus* (Dana, 1852), in only two years (Ackefors, 2000). Furthermore, two Chilean species with a certain degree of commercial potential, *S. spinifrons* and

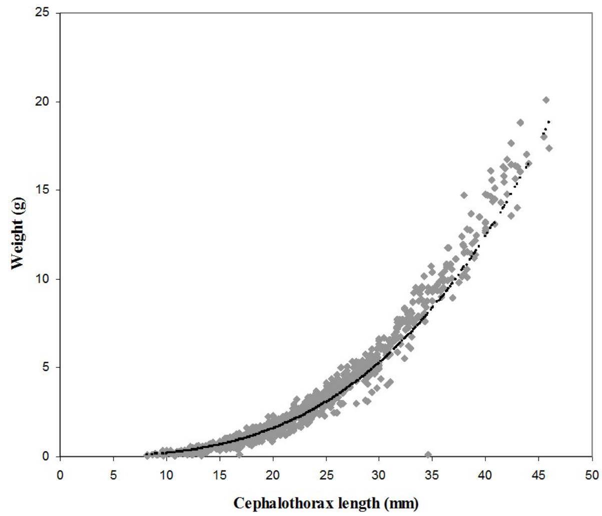

Figure 1. Size-weight relationship of the burrowing crayfish *Parastacus nicoleti*.

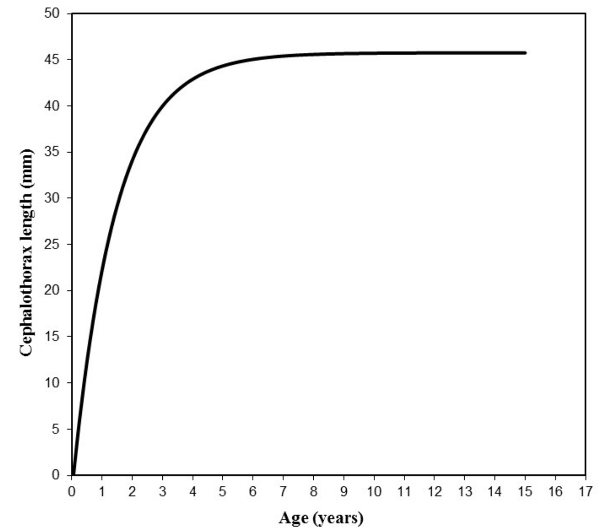

Figure 2. Length growth curve of the burrowing crayfish *Parastacus nicoleti* adjusted to the von Bertalanffy (1938) model.

Table 3. Individual growth parameters of some crayfish species.

Family	Specie	L∞ (mm)	K mm/year	Sex	Method	References
Astacidae	Aa	68.14	0.25	Both	GHM	Cukerzis (1979)
	Aa	70.24	0.23	Both	GHM	Cukerzis (1989)
	Ap	45.60	0.26	Female	GHM	Pratten (1980)
		54.20	0.21	Male	GHM	
	Ap	87.40	0.33	Female	GHM	Neveu (1996)
		105.40	0.30	Male	GHM	
	Ap	96.80	0.51	Female	GHM	Rallo and García-Arbenas
		201.40	0.47	Male	GHM	(2000)
	At	88.60	0.84	Female	GHM	Streissl and Hödl (2002)
		102.40	0.81	Male	GHM	
Cambaridae	Pc	56.00	0.68	Both	GM-MS	Anastacio and Marques (1995)
	Pc	62.00	0.23	Both	GM-MS	Fidalgo *et al.* (2001)
	Pc	64.30	0.70	Female	GM-MS	Chiesa *et al.* (2006)
		63.30	0.66	Male	GM-MS	
	Pc	65.50	0.69	Female	GM-MS	Scalici and Gherardi (2007)
		62.60	0.62	Male	GM-MS	
	Pc	74.60	0.32	Female	ELE	Scalici *et al.* (2010)
		68.30	0.33	Male	ELE	
Parastacidae	Cq	66.70	0.27	Both	GM-MS	Beatty *et al.* (2005)
	Pb	42.89	0.002	Both	GM, LR	Fries (1984)
	Pb	57.37	0.23	Both	GM-MS	Fontoura and Buckup (1989)
	Pd	30.98	0.0026	Both	GM, LR	Noro and Buckup (2009)
	Pp	59.50	0.334	Both	ELE-MR	del Valle (2002)
	Pp	55.90	0.35	Both	GHM-MR	Ibarra and Arana (2011)
	Pp	55.30	0.23	Both	MPA-MS	Ibarra and Arana (2012)
	Pn	45.75	0.703	Both	GHM-MS	In this study

Aa, *Astacus astacus* (Linnaeus, 1758); Ap, *Austropotamobius pallipes* (Lereboullet, 1858); At, *Austropotamobius torremtium* (Schrank, 1803); Pc, *Procambarus clarkii* (Girard, 1852); Cq, *Cherax quinquecarinatus* Gray, 1845; Pb, *Parastacus brasiliensis* (von Martens, 1869); Pd, *Parastacus defossus* Faxon, 1898; Pp, *Parastacus pugnax* (Poeppig, 1835); Pn, *Parastacus nicoleti* (Philippi, 1882); GM: Growth Model, MR: Mark-Recapture , LR: Laboratory rearing , MS: Monthly Samples, GHM: Gulland and Holt´s (1959) method, ELE: ELEFAN , MPA: Modal progression analysis.

P. pugnax are capable to reach 30 g weight in 3 years (Rudolph *et al*., 2010; Ibarra and Arana, 2011).

On comparing the growth parameters of the two Chilean species of *Parastacus* Huxley, 1879, it was verified that *P. nicoleti* reaches the asymptotic size in less time than *P. pugnax*. Furthermore, both species would reach 40 mm CL at approximately three years of age. However, from this size onwards, the increase in length of *P. pugnax* greatly exceeds that of *P. nicoleti* (Fig. 4). Furthermore, *P. pugnax* would reach a weight of approximately 20 g (age = 2.5 years) and of 40 g (age = 4 years). According to our results, *P. nicoleti* is not capable to reach these weights during its life cycle (Fig. 5).

Our results suggest that *P. nicoleti* lives 4.32 years, similar to many other decapods (75.1%) whose life span fluctuates between 1 and 10 years (Vogt, 2012). Nevertheless, *P. nicoleti* longevity is relatively short when compared to many species of Parastacidae that inhabit cold waters within the galleries and reach an average maximum age of 25.6 years (McLay and van den Brink, 2016). Thus, the short life span of *P. nicoleti* appears somewhat enigmatic, since this species is also a primary burrower that inhabits cold waters with an average temperature of 12.1°C (maximum of 17.5°C; minimum of 8.5°C) (Rudolph, 1997). On the other hand, this concurs with the longevity estimated for other species of *Parastacus*, such as *P. defossus* and *P. brasilensis* (Tab. 4). Like *P. nicoleti*, these species are not subject to extraction for commercial purposes and occupy similar habitats with comparable life styles, although at lower geographic latitudes (Fries, 1984; Noro and Buckup, 2009).

The freshwater crayfish (Astacoidea and Parastacoidea) are characterized by their direct development, with incubation of large eggs, rich in vitellus, hatching at juvenile stage 1, parental care up to juvenile stage 2 and release in juvenile stage 3 (Vogt, 2013). Rudolph (1986) describes the external morphology of these three stages of early post embryonic development in *P. nicoleti*, and records their CL. Thus, the first juvenile measures on average 2.6 mm, the second 3.2 mm and the third 3.8 mm. If the growth model of this species is employed, estimated ages of the juveniles 1, 2 and 3 would be approximately 51, 58 and 65 days, respectively. These ages differ from the data provided by Rudolph (1986) who verified

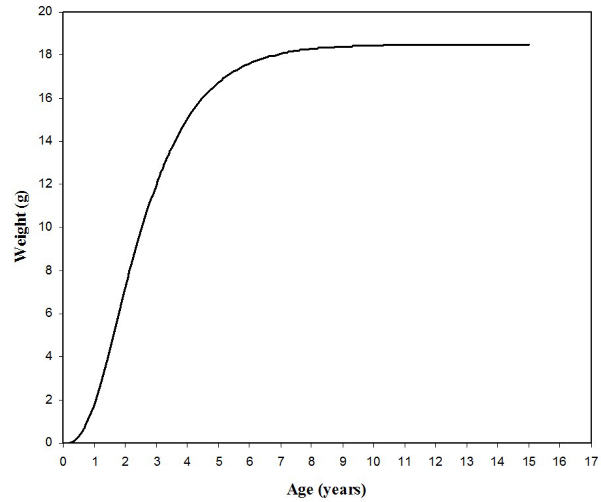

Figure 3. Weight growth curve of the burrowing crayfish *Parastacus nicoleti* adjusted to the von Bertalanffy (1938) model.

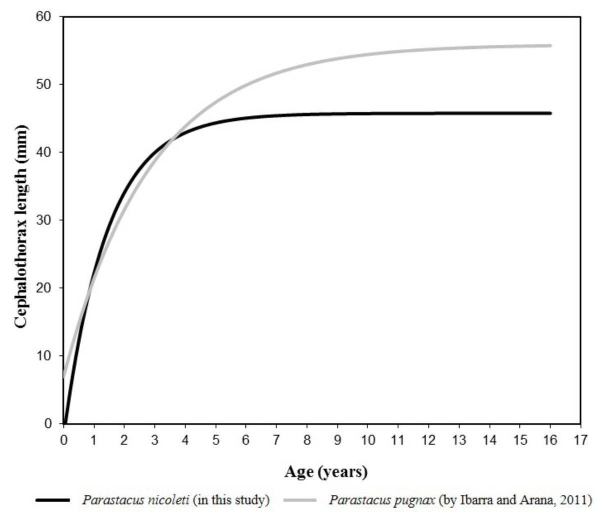

Figure 4. Comparison between length growth curves of *Parastacus nicoleti* and *Parastacus pugnax* adjusted to the von Bertalanffy (1938) model.

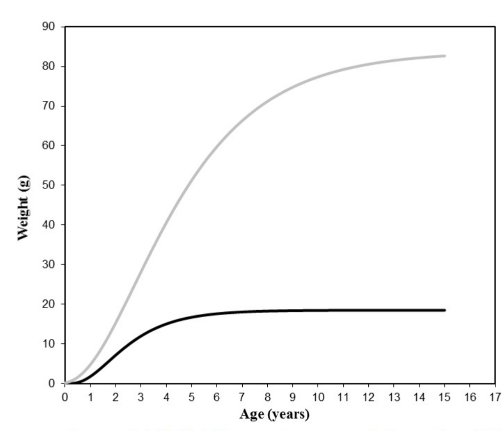

Figure 5. Comparison between weight growth curves of *Parastacus nicoleti* and *Parastacus pugnax* adjusted to the von Bertalanffy (1938) model.

Table 4. Longevity of some crayfish species.

Family	Species	Longevity (years)	References
	Al	7.4	Deval *et al.* (2007)
Astacidae	Aa	> 10	Skurdal and Taugbol (2002)
	Pl	16.7	Belchier *et al.* (1998)
Cambaridae	Pc	1-1.5	Reynolds *et al.* (1992)
	Cs	1.5	Walls (2009)
Cambaroididae	Cj	11.0	Kawai *et al.* (1992)
	Cqa	3.0	Sheeby (1992)
	Pd	3.3	Noro and Buckup (2009)
	Pn	4.3	In this study
Parastacidae	Pb	4.3	Fries (1984)
	Pp	8.9	Ibarra and Arana (2011)
		13.6	Ibarra and Arana (2012)
	Ag	60.0	Lukhaup and Pekny (2008)

Al, *Astacus leptodactylus* Eschscholtz, 1823; Pl, *Pacifastacus leniusculus* (Dana, 1852); Cs, *Cambarellus shufeldtii* (Faxon, 1884); Cj, *Cambaroides japonicus* (de Haan, 1841); Cqa, *Cherax quadricarinatus* (von Martens, 1868); Ag, *Astacopsis gouldi* Clark, 1936. Other abbreviations see Tab. 3.

that, at water temperatures of between 6.0 y 18.0° C (x=13.9° C), hatching occurs 65 days after laying, juvenile 2 emerges after 110 days and juvenile 3 at 134 days. These differences can probably be attributed to the effect of temperature. There is a lot of evidence supporting the belief that growth of crustaceans is related to water temperature (Kawai *et al.*, 1997; Hartnoll, 2001; Reynolds, 2002; Mc Lay and van den Brink, 2016) and that there is a negative correlation between temperature and time taken to reach a given stage in the life cycle (Pinheiro and Taddei, 2005).

Finally, taking into account that *P. nicoleti*: 1. is a burrowing species with a poorly developed pleon and, consequently has a low meat yield; 2. presents low growth rates, we conclude that it would not be an attractive species for commercial aquaculture purposes.

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