REVISTA
BIOCIÊNCIAS

Ed.26 | 2 | 2020

# Somatic growth, longevity, and morphological sexual maturity of the marine ornamental crab *Mithraculus forceps* in natural conditions.

## *Crescimento somático, longevidade e maturidade sexual morfológica do caranguejo marinho ornamental* Mithraculus forceps *em condições naturais.*

Barros-Alves, S.P.[1], Alves, D.F.R.[2], Freire, F.A.M.[3], Cobo, V.J.[4]

[1]Universidade do Estado de Minas Gerais – Unidade Ituiutaba, [2]Universidade Federal de Uberlândia, [3]Universidade Federal do Rio Grande do Norte, [4]Departamento de Ciências Biológicas, Universidade de Taubaté

***RESUMO***

O objetivo deste estudo foi determinar taxas de crescimento, longevidade e o tamanho da maturidade sexual morfológica do caranguejo *Mithraculus forceps* em condições naturais na costa sudeste brasileira. Os caranguejos foram coletados mensalmente de fevereiro de 2004 a janeiro de 2006 no sublitoral rochoso da Ilha da Vitória, litoral norte paulista. Os caranguejos foram sexados e mensurados quanto à maior largura da carapaça (CW). As curvas de crescimento para ambos os sexos foram obtidas por meio do modelo de von Bertalanffy. Um total de 1529 caranguejos foram capturados, incluindo 712 machos e 817 fêmeas. As curvas de crescimento de machos e fêmeas foram descritas pelas equações $CWt = 17.75\ [1–e^{-0.0056(t-1.418)}]$ e $CWt = 13.64\ [1–e^{-0.0064(t+0.017)}]$, respectivamente. A comparação entre as curvas de crescimento de machos e fêmeas mostrou que uma única curva não descreve o padrão de crescimento para esta espécie. A longevidade foi estimada em 2,23 e 1,95 anos para machos e fêmeas, respectivamente. O tamanho estimado no qual 50% da população está morfologicamente madura foi 5,4 e 7,3 mm CW para machos e fêmeas, respectivamente. As curvas de crescimento obtidas para *M. forceps* condizem com a de outros Brachyura, em que machos tendem a crescer mais do que as fêmeas. As fêmeas direcionam mais energia para reprodução, enquanto os machos investem mais energia no crescimento somático e alcançam tamanhos maiores do que as fêmeas. O tamanho maior dos machos pode conferir uma vantagem ao defender territórios e na competição por parceiras, facilitando a proteção das fêmeas durante a cópula.

Palavra-chave: Organismos de aquários; Mithracidae; caranguejo-aranha.

***ABSTRACT***

The goal of this investigation was to determine the growth rates, longevity and size at morphological sexual maturity for the crab *Mithraculus forceps* in its natural environment on the southeastern Brazilian coast. Crabs

REVISTA
BIOCIÊNCIAS
Ed.26 | 2 | 2020

were collected monthly from February 2004 through January 2006 in the rocky sublittoral of Vitória Island on the coast of São Paulo state. The crabs were sexed and measured for the greatest carapace width (CW). The growth curves for both sexes were obtained according to the von Bertalanffy model. A total of 1529 crabs were caught, including 712 males and 817 females. The growth curves of males and females were described by the equations $CWt = 17.75 [1–e^{-0.0056(t-1.418)}]$ and $CWt = 13.64 [1–e^{-0.0064(t+0.017)}]$, respectively. Comparison between male and female growth curves showed that a single curve cannot describe the growth pattern for this species. Longevity was estimated at 2.23 and 1.95 years for males and females, respectively. The size at which 50% of the population is estimated to be mature was 5.4 and 7.3mm CW for males and females, respectively. The growth curves obtained for *M. forceps* are consistent with those of other Brachyura, in which males tend to grow more than females. Females must direct more energy to reproductive tasks, while males invest more energy into somatic growth and reach larger sizes than females. The larger size of males may confer an advantage when defending territories and competing for mates and facilitate securing the female during copulation.
***Keyword***: Ornamental trade; Mithracidae; spider crab.

***INTRODUCTION***

The ornamental marine spider crab *Mithraculus forceps* A. Milne-Edwards, 1875, belongs to the superfamily Majoidea Samouelle, 1819 and family Mithracidae MacLeay, 1838 (NG et al., 2008; WINDSOR & FELDER, 2014). This crab has a wide geographical distribution in the Western Atlantic, from North Carolina to southern Florida, the Gulf of Mexico, Antilles, Venezuela and Brazil, where it is found at Fernando de Noronha and Rocas Atoll, and along the coast from the states of Maranhão to São Paulo (MELO, 1996). They are common inhabitants of hard bottoms, in rock crevices, coral heads, and even on sandy bottoms (WILLIAMS, 1984; MELO, 1996).

The demand for ornamental marine organisms has grown exponentially in recent decades (WOOD, 2001; BALAJI et al., 2009; RHYNE et al., 2014; PRAKASH et al., 2017), and crabs are very popular (CALADO et al., 2003; GURJÃO & LOTUFO, 2018). Many species of brachyuran crabs, hermit crabs and porcellanid crabs are increasingly marketed (e.g., species of *Calcinus, Paguristes, Porcellana, Platypodiella* and *Stenorhynchus*) (CALADO et al., 2003; RHYNE et al., 2017). The spider crab *M. forceps*, also called the emerald crab or red-ringed clinging crab, is very popular among aquarium hobbyists for its ability to control or even remove algae, mainly *Valonia ventricosa* J. Agardh, 1887 (Chlorophyta) (OLSEN & WEST, 1988; RHYNE et al., 2005; FIGUEIREDO et al., 2008; GURJÃO & LOTUFO, 2018).

Investigations of the biology of *M. forceps* are important, considering the increasing exploitation in its natural environment, and will provide useful information for eventual laboratory rearing to help satisfy the demand for ornamental specimens (RHYNE et al., 2005). In recent years, some investigators have called attention to the role of *M. forceps* in this ornamental market and have analyzed its productivity and profitability (FIGUEIREDO et al., 2008), larval development (PENHA-LOPES et al., 2005), and growth and survival of larvae and juveniles (RHYNE et al., 2005; PENHA-LOPES et al., 2006; 2007). However, there is no information on the growth of juveniles and adults of *M. forceps* in the field so far.

Studies of age and size as estimators of growth and longevity provide basic parameters to evaluate the effects of exploitation on natural populations of commercial interest, and the ecological performance of these species based on their growth rates (GULLAND, 1959; DIELE & KOCH, 2010). The von Bertalanffy model is one of the most used tools for analyzing growth, providing an estimate of the maximum theoretical size that an individual can attain. This model also gives a relationship between body size and growth rate (VALENTI et al., 1987). Growth curves are commonly applied for species harvested for the food market, such as shrimps and lobsters (KARP et al., 1986; LEUNG, 1986; LEUNG & SHANG, 1989; PIMENTA et al., 2005), but have rarely been used for ornamental species (e.g., FIGUEIREDO & NARCISO, 2006; HALACHMI, 2006).

The goal of this investigation was to determine the growth rates, longevity and size at morphological sexual maturity for the marine ornamental crab *Mithraculus forceps* in natural conditions from a population on the southeastern Brazilian coast.

## *MATERIAL AND METHODS*

Individuals of *Mithraculus forceps* were collected monthly from February 2004 to January 2006 at Vitória Island (23°44’04’’S – 45°01’35’’W) on the southeastern Brazilian coast, state of São Paulo. The crabs were hand-caught active search by SCUBA divers during daytime dive sessions, with a catch effort of four hours per month. The specimens were identified according to Melo (1996). For each specimen of *M. forceps* the greatest carapace width (CW) was measured with a vernier caliper (0.1 mm). Sex and developmental stage (juvenile or adult) were identified from the external morphology of the abdomen and appendages, classified as: adult female, with large abdomen, covering almost the entire ventral thorax surface and hairy pleopods; adult male, with narrow abdomen, with two pairs of small gonopods; juvenile male and female, with triangular shape, 2 and 4 pairs of non-hairy pleopods for males and females, respectively (see HAEFNER, 1990).

The carapace width measurements were allocated to size-class intervals of 1.0 mm and plotted by month to define the mean width per age. The normality of the population size distribution was analyzed by the Shapiro-Wilk test ($\alpha$ = 0.05). Modal groups were determined separately for males and females using monthly size-frequency distributions with the software PeakFit (PeakFit v.4.06 SPSS Inc. for Windows, Copyright 1991-1999, AISN Software Inc.) (FONSECA & D'INCAO, 2003). Different number of peaks representing different cohorts were fitted to the observed size-frequency distributions using an automated least square fitting procedure (Automatic Peak Fitting Detection and Fitting, Method I – Residual), as performed by Pimenta et al. (2005) and Baeza et al. (2013).

Next, the growth parameters of both sexes were fitted to our dataset using the von Bertalanffy (1938) growth curve, represented by the equation: $CW_t = CW_\infty[1–e^{-K(t-to)}]$, where "$CW_t$" carapace width at time t; "$CW_\infty$" asymptotic size; "k" growth constant; "e" base of natural logarithms; "t" age of individuals; and "$t_o$" initial age.

Also, we used trial-and-error iterations to estimate the values for k and $t_o$. Growth curves for both males and females were estimated using cohort (modal) progression through time. To estimate growth parameters, all the cohorts were fitted to the von Bertalanffy growth model using an automated least squares fitting procedure (SOLVER, software EXCEL). The growth curves were compared between males and females using the F-test (Cerrato, 1990; Chen et al., 1992) and longevity ($t_{max}$) was calculated using the inverse von Bertalanffy growth function: $t_{max} = t_o-(1/k)\ln[1-(CW_{max}/CW_\infty]$, where "k" growth constant; "$t_o$" age (in years) estimated by the von Bertalanffy model; "$CW_{max}$" maximum size; and "$CW_\infty$" asymptotic size.

The relative frequency of adult individuals (%) was plotted on a size-class graph in order to estimate the size at morphological sexual maturity. The data were fitted to a sigmoid curve, according to the results of the logistic regression, where: $CW_{50}$ = carapace width at 50% of adult individuals; r = slope of the curve. The equation was adjusted by the least-squares method (SOKAL & ROHLF, 2012).

## *RESULTS*

A total of 1529 specimens of *Mithraculus forceps*, including 712 males and 817 females were collected. The females collected had sizes ranging from 2.7 to 16.7 mm CW, and the males from 2.6 to 21.8 mm CW. The size-frequency distribution for the crabs pooled over the entire sampling period showed a polymodal and non-normal pattern for males ($W$ = 0.987; $p$ < 0.001) and a unimodal, non-normal pattern for females ($W$ = 0.993; $p$ < 0.001) (Fig. 1). Both sexes were recorded in the smallest size class (2.5˫3.5 mm CW); however, only males were recorded in the largest size class 17.5˫22.5 mm CW, while the largest size class containing females was 16.5˫17.5 mm CW (Fig. 1).

Nine cohorts were detected for males and females, according to the modal dispersion analysis (Figs. 2 and 3), respectively. Table 1 shows the estimated parameters used to obtain the growth curve for each sex. The growth curves for carapace width for males and females were described by the equations $CW_t = 17.75 [1–e^{-0.0056(t-1.418)}]$ and $CW_t = 13.64 [1–e^{-0.0064(t+0.017)}]$ (Fig. 4a, b), respectively. According to these equations, males reach a larger asymptotic size than females, however with a smaller growth coefficient (Table 2). Comparisons among growth curves indicated that a single curve cannot describe the growth for both males and females ($F_{calculated}$ = 41,99; $F_{table}$ = 2.71; $p < 0.01$). The estimated longevity was 2.23 years for males and 1.95 years for females (Table 2).

Table 1. Growth parameters (CW∞; k; tmax) for the cohorts of males and females of *Mithraculus forceps* from Vitória Island (CW∞: asymptotic size (mm); k: growth constant; tmax: longevity).

Tabela 1. Parâmetros de crescimento (LC∞; k; tmax) para as coortes de machos e fêmeas de *Mithraculus forceps* da Ilha da Vitória (LC∞: tamanho assintótico (mm); k: constante de crescimento; tmax: longevidade).

| Sexes | Cohorts | $CW_\infty$ (mm) | k | $t_{max}$ (years) |
|---|---|---|---|---|
| MALE | 1 | 19.34 | 0.006 | 1.94 |
| | 2 | 18.19 | 0.006 | 2.03 |
| | 3 | 17.32 | 0.007 | 1.65 |
| | 4 | 18.09 | 0.005 | 2.63 |
| | 5 | 17.08 | 0.005 | 2.65 |
| | 6 | 17.53 | 0.005 | 2.43 |
| | 7 | 17.55 | 0.005 | 2.66 |
| | 8 | 17.12 | 0.005 | 2.42 |
| | 9 | 17.39 | 0.005 | 2.74 |
| FEMALE | 1 | 15.21 | 0.005 | 2.13 |
| | 2 | 14.60 | 0.007 | 1.70 |
| | 3 | 14.55 | 0.006 | 1.82 |
| | 4 | 13.54 | 0.007 | 1.67 |
| | 5 | 11.64 | 0.007 | 1.68 |
| | 6 | 12.33 | 0.006 | 2.01 |
| | 7 | 12.35 | 0.007 | 1.60 |
| | 8 | 12.24 | 0.006 | 1.85 |
| | 9 | 11.11 | 0.006 | 1.85 |

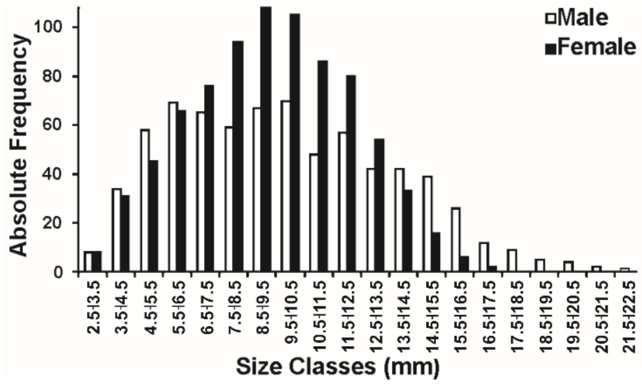


Figure 1. Size-frequency distribution for males and females of *Mithraculus forceps*, during the study period at Vitória Island.

Figura 1. Distribuição de frequência de tamanho para machos e fêmeas de *Mithraculus forceps*, durante o período de estudo na Ilha da Vitória.

The estimated age for the smallest captured male (5.1 mm CW) was 48 days, almost two months; while the age of the smallest female (6.4 mm CW) was estimated at 87 days, about three months. The size of 50% of mature individuals was estimated at 5.4 and 7.3 mm for males and females respectively (Fig. 5a, b), reached after 51 days for males and 105 days for females.

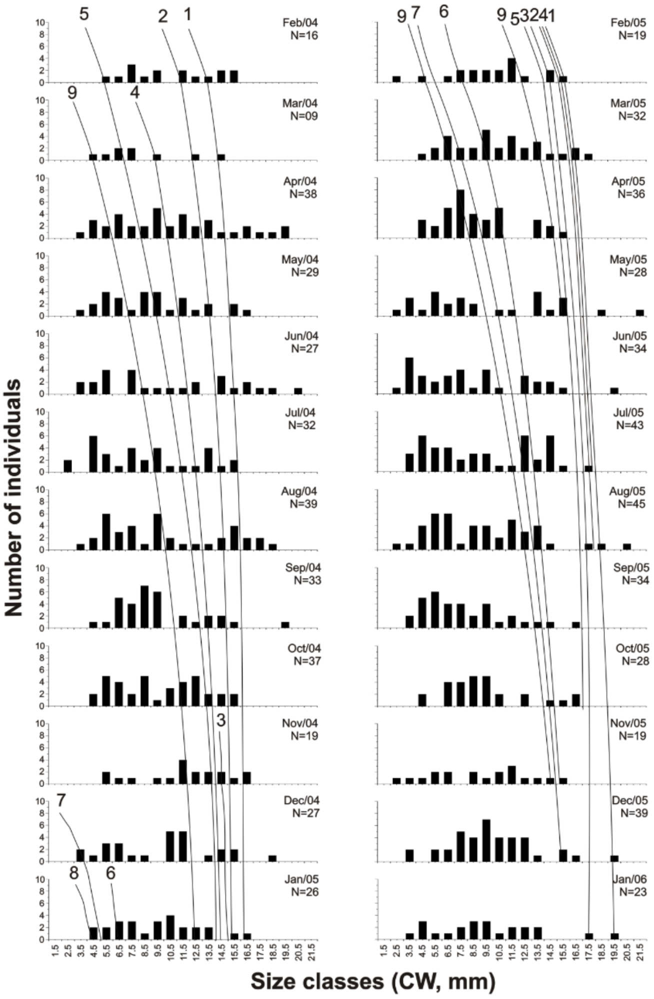


Figure 2. Size-frequency distribution and modal progression analysis of cohorts in males of *Mithraculus forceps*, during the study period at Vitória Island.

Figura 2. Distribuição de frequência de tamanho e análise de progressão modal de coortes em machos de *Mithraculus forceps*, durante o período de estudo na Ilha da Vitória.

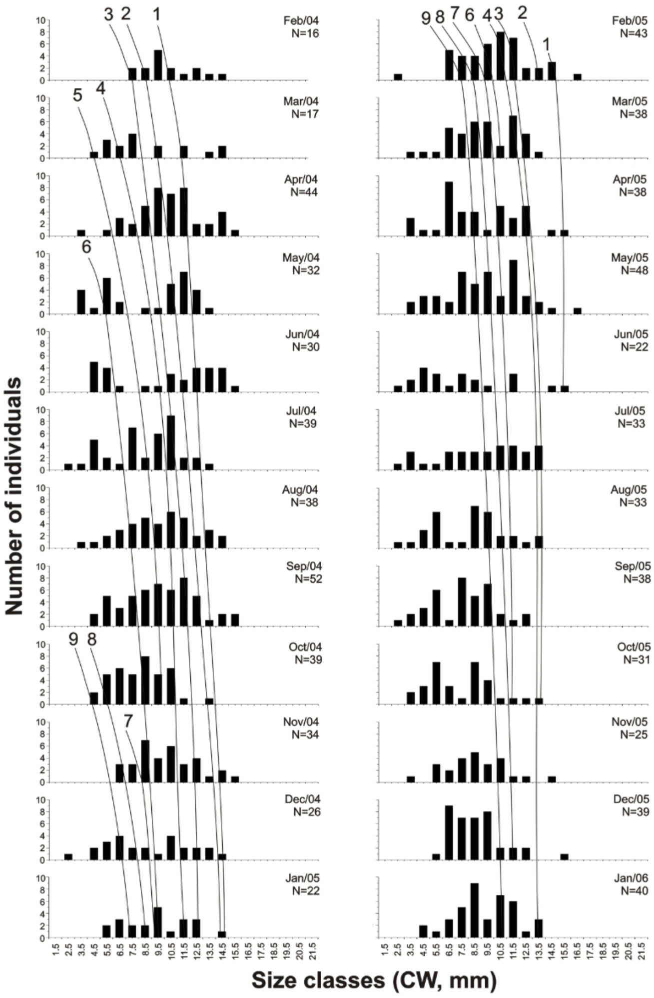


Figure 3. Size-frequency distribution and modal progression analysis of cohorts in females of *Mithraculus forceps*, during the study period at Vitória Island.

Figura 3. Distribuição de frequência de tamanho e análise de progressão modal de coortes em fêmeas de *Mithraculus forceps*, durante o período de estudo na Ilha da Vitória.

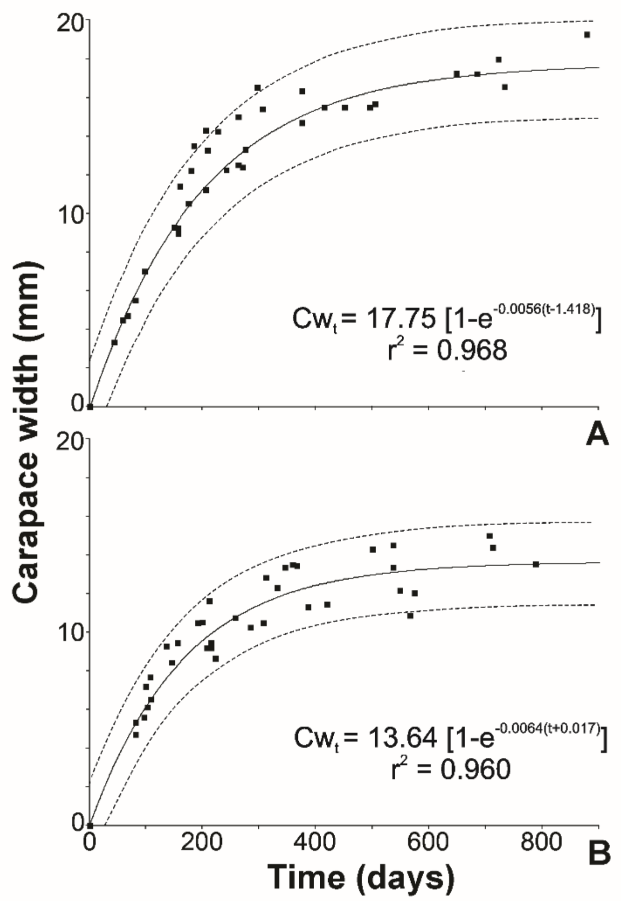


Figure 4. Mean growth curves estimated for males (A) and females (B) of *Mithraculus forceps* from Vitória Island, based on the von Bertalanffy model. [Center line= mean; dotted lines= prediction intervals (95%)].

Figura 4. Média das curvas de crescimento estimados para machos (A) e fêmeas (B) de *Mithraculus forceps* da Ilha da Vitória, baseado no modelo de von Bertalanffy. [Linha central = média; linhas pontilhadas = intervalos de predição (95%)].

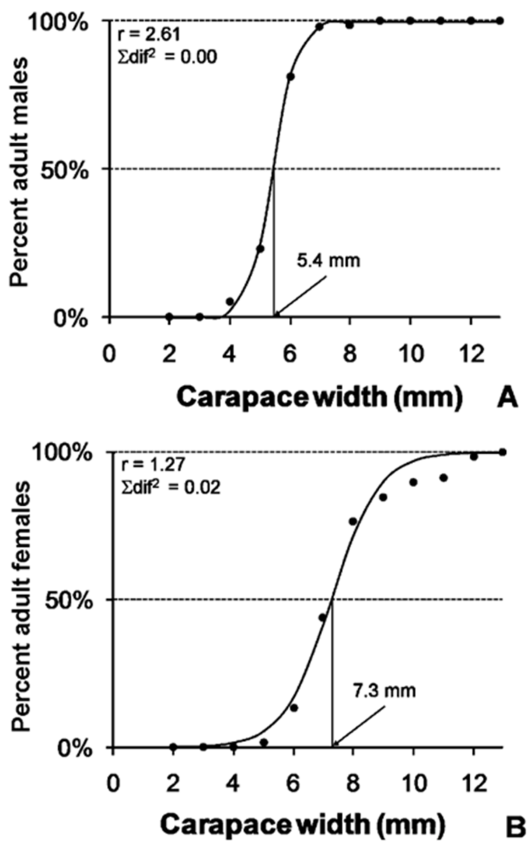


Figure 5. Adjustment of the logarithmic function, indicating the carapace width at which 50% of crabs are mature ($CW_{50}$) for males (A) and females (B).

Figura 5. Ajuste da função logarítmica indicando a largura da carapaça na qual 50% dos caranguejos estão maduros ($LC_{50}$) para machos (A) e fêmeas (B).

Table 2. Estimates of carapace-width growth curves, according to the von Bertalanffy method, for males and females of *Mithraculus forceps* from Vitória Island ($CW_\infty$: asymptotic size (mm); k: growth constant; $t_o$: age at birth; $t_{max}$: longevity).

Tabela 2. Curvas da largura da carapaça estimadas, de acordo com o método de von Bertalanffy, para machos e fêmeas de *Mithraculus forceps* da Ilha da Vitória ($LC_\infty$: tamanho assintótico (mm); k: constante de crescimento; $t_o$: idade; $t_{max}$: longevidade).

| | $CW_\infty$ (mm) | k (/year) | $t_o$ (/year) | Equation | $t_{max}$ (days; years) |
|---|---|---|---|---|---|
| Male | 17.75 | 0.0056 | 1.418 | $CW_t = 17.75\ [1–e^{-0.0056(t-1.418)}]$ | 817.03; 2.23 |
| Female | 13.64 | 0.0064 | - 0.017 | $CW_t = 13.64\ [1–e^{-0.0064(t+0.017)}]$ | 714.97; 1.95 |

***DISCUSSION***

The largest asymptotic sizes recorded for males of *M. forceps* agree with those expected for most brachyuran crab species. The calculated asymptotic size, for both sexes, was smaller than that of the largest crab caught. From the fits to the mathematical models, the size-growth curves do not preclude that males reach a larger size than females in this population. This estimate agrees with the suggestion of Hartnoll (1983), that the individuals of a population must grow asymptotically, with growth rates depending on the somatic growth from successive molts during ontogeny, which may differ between the sexes. However, we consider that this growth must be significant until the change of puberty, assuming that *M. forceps* has determined growth, as well as other Majoidea crabs. The growth pattern in spider crabs is of the 'determinate' (HARTNOLL, 1982, 1985), whereby the crab molts through a series of instars until a terminal molt occurs, after which there is no more molts. This terminal molt is also the 'puberty molt', marked by morphological changes (HARTNOLL, 1963), and indicating in almost all cases the onset of sexual maturity. However, the von Bertalanffy growth model can also be applied for the determinately growing decapods (VOGT, 2019), as well as studied by Gonçalves et al. (2020) for the majoid crab *Libinia ferreirae* Brito Capello, 1871.

The pattern in which males reach larger sizes than females was recorded for several other brachyuran crabs, including *Callinectes danae* Smith, 1869 (BRANCO & MASUNARI, 1992; KEUNECKE et al., 2008), *Portunus sanguinolentus* (Herbst, 1783) (LEE & HSU, 2003), *Uca (Minuca) rapax* (Smith, 1870) (CASTIGLIONI et al., 2004), *Ucides cordatus* (Linnaeus, 1763) (PINHEIRO et al., 2005; DIELE & KOCH, 2010), *Hepatus pudibundus* (Herbst, 1785) (KEUNECKE et al., 2007), and also *L. ferreirae* (GONÇALVES et al., 2020). In contrast, some species such as *Neohelice granulata* (Dana, 1851) (LUPPI et al., 2004) and *Callinectes ornatus* Ordway, 1863

(KEUNECKE et al., 2008) show the inverse pattern, with females reaching a final size that is larger than males. The different growth observed for both sexes are influenced by their reproductive traits. Females cease their growth when reach the terminal molt, investing their energy in production, breeding and care of fertilized eggs. Hence, males have more energy to direct toward somatic growth, mainly during puberty, providing them with an advantage regarding protection of the female and/ or against agonistic behaviors (HARTNOLL, 1982; 1985; LÓPEZ-GRECO & RODRÍGUEZ, 1999; HARTNOLL et al., 2006).

The faster female growth rates (k) can be viewed as compensation for their smaller asymptotic size compared to males. Other brachyuran species show the same pattern of females exhibiting faster growth rates (k) than males, as reported by D'Incao et al. (1993) for *N. granulata*, by Josileen & Menon (2005) for *Portunus pelagicus* (Linnaeus, 1758), by Pimenta et al. (2005) for *Armases rubripes* (Rathbun, 1897), by Ferreira & D'Incao (2008) for *Callinectes sapidus* Rathbun, 1896, by Diele & Koch (2010) for *U. cordatus*, and by Gonçalves et al. (2020) for *L. ferreirae*. However, some brachyuran species also show the inverse pattern, with males growing faster, as reported for *C. danae* (BRANCO & MASUNARI, 1992), *U. cordatus* (PINHEIRO et al., 2005) and *H. pudibundus* (KEUNECHE et al., 2007). Nonetheless, growth rates vary through the life of an individual and may differ between the sexes with respect to type of growth and reproductive strategy of the species (HARTNOLL, 1982).

The longevity estimated for *M. forceps* in this study for both sexes is close to the limits recorded for many other decapod crustaceans. Greater longevity for males, as recorded for *M. forceps*, was also recorded for *Aegla laevis* (Latreille, 1818) by Bahamonde & Lopez (1961), *C. sapidus* by Ferreira & D'Incao (2008), and *L. ferreirae* by Gonçalves et al. (2020). According to Swiech-Ayoub & Masunari (2001), this is likely related to higher female mortality rates, caused by stress in the post-reproductive period, or even the attached egg masses, which may increase the predation pressure on females carrying eggs. Greater longevity for females was recorded for *Aegla paulensis* Schmitt, 1942 (COHEN et al., 2011) and some species of brachyuran crabs including *U. cordatus* (PINHEIRO et al., 2005), *H. pudibundus* (KEUNECKE et al., 2007), and *C. danae* and *C. sapidus* (KEUNECKE et al., 2008), which illustrates the diversity of growth strategies available to crustaceans. Many factors might affect the age estimation in crustaceans, such as genetic advantages or even limb losses, because the energy expended to regenerate a limb will cause delays in growth (HARTNOLL, 1982; 1985). Nevertheless, estimating age based on size remains a valuable tool to analyze the growth pattern of a species, primarily through the use of a large data set such as that presented here, even considering individual variations.

The longevity rates, von Bertalanffy growth curve features, and the recorded sizes at morphological maturity can be applied in monitoring programs for natural populations of *M. forceps*, and also for developing policies concerning its exploitation, because this crab is considered as an ornamental species (RHYNE et al., 2005; FIGUEIREDO et al., 2008). The establishment of minimum legal sizes for exploitation was mentioned by Gasparini et al. (2005) as one of the principal steps in the development of policies regulating the exploitation of natural resources, for food and ornamental species, on the Brazilian coast. Basing upon the results of this study suggest minimum capture size of 5.4 mm CW for males and 7.3 mm CW for females, for natural populations on the southeastern Brazilian coast. At these sizes, 50% of the population is assumed to be morphologically mature and prohibiting the capture of specimens below these sizes will help to prevent overfishing of this species. However, considering the complexity of inspecting the size of the captured crabs, a viable strategy is to monitor the size of the individuals sold in the marine ornamental trade. Furthermore, also advise to prohibit the capture and/or sale of ovigerous females.

Another aspect to consider is the good potential for aquaculture shown by this species, with its short larval development time and high survival rates. As it is relatively easy to culture *M. forceps* in large numbers and at low costs in the laboratory (RHYNE et al., 2005; PENHA-LOPES et al., 2006; 2007; FIGUEIREDO et al., 2008), trading laboratory-cultured specimens as an alternative to harvesting from natural habitats should be supported, which would also lessen the negative human impact on the reefs where this species is found.

***ACKNOWLEDGEMENTS***

The authors are indebted Dra. Janet Reid for her constructive comments on early drafts of the manuscript and great help with the English language. We thank the “Omni Mare” Dive Center for logistic facilities provided during the collections. All sampling in this study has been conducted with applicable state and federal laws. V.J. Cobo is also grateful to the Universidade de Taubaté for financial support (Process # 251/2001-PRPPG). D.F.R. Alves is grateful to CNPq (Process # 134950/2007-0 Conselho Nacional de Desenvolvimento de Pesquisa Tecnológica) for the grants for his Master of Science course.

***REFERENCES***

BAEZA, J. A.; FURLAN, M.; ALMEIDA, A. C.; BARROS-ALVES, S. P.; ALVES, D. F. R.; Fransozo, V. Population dynamics and reproductive traits of the ornamental crab *Porcellana sayana*: implications for fishery management and aquaculture. **Sexuality and Early Development in Aquatic Organisms**, 1: 1-12, 2013. doi: 10.3354/seda000002

BAHAMONDE, N.; LOPEZ, M. T. Estudios biologicos en la population de *Aegla laevis laevis* (Latreille) de el Monte (Crustacea, Decapoda, Anomura). **Investigaciones Zoológicas Chilenas**, 7: 19-58, 1961.

BALAJI, K.; THIRUMARAN, G.; ARUMUGAM, R.; KUMARAGURUVASAGAM, K. P.; ANANTHARAMAN, P. A review on marine ornamental invertebrates. **World Applied Sciences Journal**, 7: 1054-1059, 2009.

BEVERTON, R. J. H.; HOLT, S. J. On the dynamics of exploited fish populations. **Fishery Investigations**, 2: 1-533, 1957.

BRANCO, J. O.; MASUNARI, S. Crescimento de *Callinectes danae* Smith (Decapoda, Portunidae) da Lagoa da Conceição, Florianópolis, Santa Catarina, Brasil. **Revista Brasileira de Zoologia**, 9: 53-66, 1992.

CALADO, R.; LIN, J.; RHYNE, A. L.; ARAÚJO, R.; NARCISO, L. Marine ornamental decapods: popular, pricey, and poorly studied. **Journal of Crustacean Biology**, 23: 963-973, 2003.

CASTIGLIONI, D. S.; SILVA-CASTIGLIONI, D.; NEGREIROS-FRANSOZO, M. L. Somatic growth of the fiddler crab *Uca rapax* (Smith, 1870) (Brachyura, Ocypodidade) from two subtropical mangroves. **Universidad y Ciencia,** 20: 15-22, 2004.

CERRATO, R. M. Interpretable statistical tests for growth comparisons using parameters in the von Bertalanffy equation. **Canadian Journal of Fisheries and Aquatic Sciences**, 47: 1416-1426, 1990

CHEN, D.; JACKSON, A.; HARVEY, H. H. A comparison of von Bertalanffy and polynomial functions in modelling fish growth data. **Canadian Journal of Fisheries and Aquatic Sciences**, 49: 1228-1235, 1992.

COHEN, F. P. A.; TAKANO, B. F.; SHIMIZU, R. M.; BUENO, S. L. S. Life cycle and population structure of *Aegla paulensis* (Decapoda: Anomura: Aeglidae). **Journal of Crustacean Biology**, 31(3): 389-395, 2011.

D'INCAO, F.; RUFINO, M. L.; SILVA, K. G.; BRAGA, A. C.; MARQUES, L. H. C. Crescimento de *Chasmagnathus granulata* Dana, 1851, em um marisma do estuário da Lagoa dos Patos, RS (Decapoda, Grapsidae). **Revista Brasileira de Biologia**, 53: 637-643, 1993.

DIELE, K.; KOCH, V. Growth and mortality of the exploited mangrove crab *Ucides cordatus* (Ucididae) in N-Brazil. **Journal of Experimental Marine Biology and Ecology**, 395: 171-180, 2010.

FERREIRA, L. S.; D'INCAO, F. Crescimento de *Callinectes sapidus* (Crustacea, Decapoda, Portunidae) no estuário da laguna dos Patos, RS, Brasil. **Iheringia, Série Zoologia**, 98: 70-77, 2008.

FIGUEIREDO, J.; NARCISO L. Productivity improvement of *Lysmata seticaudata* larval rearing protocol through modelling. **Aquaculture**, 261: 1249-1258, 2006.

FIGUEIREDO, J.; PENHA-LOPES, G.; LIN, J.; NARCISO, L. Productivity and profitability of *Mithraculus forceps* aquaculture. **Aquaculture**, 283: 43-49, 2008.

FONSECA, D. B.; D'INCAO, F. Growth and reproductive parameters of *Kalliapseudes schubartii* in the estuarine region of the Lagoa dos Patos (Southern Brazil). **Journal of the Marine Biological Association of the United Kingdom**, 83: 931-935, 2003.

GASPARINI, J. L.; FLOETER, S. R.; FERREIRA, C. E. L.; SAZIMA, I. Marine ornamental trade in Brazil. **Biodiversity and Conservation**, 14: 2883-2899, 2005.

GONÇALVES, G. R. L.; MIAZAKI, L. F.; BOLLA JR., E. A.; GRABOWSKI, R. C.; COSTA, R. C.; CASTILHO, A. L. Growth and longevity of the spider crab *Libinia ferreirae* (Majoidea, Epialtidae). **Nauplius**, 28: e2020003, 2020.

GULLAND, J. A. On the estimation of population parameters from marked members. **Biometrica**, 42: 269-270, 1959.

GURJÃO, L. M.; LOTUFO, T. M. C. Native species exploited by marine aquarium trade in Brazil. **Biota Neotropica**, 18(3): e20170387, 2018. http://dx.doi.org/10.1590/1676-0611-BN-2017-0387

HAEFNER, Jr. P. A. Morphometry and size at maturity of *Callinectes ornatus* (Brachyura, Portunidae) in Bermuda. **Bulletin of Marine Science** 46: 274-286, 1990.

HALACHMI, I. Systems engineering for ornamental fish production in a recirculating aquaculture system. **Aquaculture**, 259: 300-314, 2006.

HARTNOLL, R. G. The biology of Manx spider crabs. Proceedings of the Zoological Society of London, 141: 423–496, 1963.

HARTNOLL, R. G. Growth. In: BLISS, D. R. (Ed.). **The biology of Crustacea, embriology, morphology and genetics**. New York: Academic Press, 1982. p. 111-196.

HARTNOLL, R. G. Strategies of crustaceans growth. Paper from conference on the Biology and Evolution of Crustacea. **The Australian Museum Memoir**, 18: 121-131, 1983.

HARTNOLL, R. G. Growth, sexual maturity and reproductive output. In: WENNER, A. M. (Ed.). **Crustacean issue 3. Factors in Adult Growth**. Rotterdam: A. A. Bakelma, 1985. p. 101-128.

HARTNOLL, R. G.; BAINE, M. S. P.; GRANDAS, Y.; JAMES, J.; ATKIN, H. Population biology of the black land crab, *Gecarcinus ruricola*, in the San Andres Archipelago, Western Caribbean. **Journal of Crustacean Biology**, 26: 316-325, 2006.

JOSILEEN, J.; MENON, N. G. Growth of the blue swimmer crab, *Portunus pelagicus* (Linnaeus, 1758) (Decapoda: Brachyura) in captivity. **Crustaceana**, 78: 1-18, 2005.

KARP, L., SADEJ, A.; GRIFFIN, W. L. Cycles in agricultural production: the case of aquaculture. **American Journal of Agricultural Economics**, 68: 553-561, 1986.

KEUNECKE, K. A.; D'INCAO, F.; FONSECA, D. B. Growth and mortality of *Hepatus pudibundus* (Crustacea: Calappidae) in south-western Brazil. **Journal of the Marine Biological Association of the United Kingdom**, 87: 885-891, 2007.

KEUNECKE, K. A.; D'INCAO, F.; MOREIRA, F. N.; SILVA JR, D. R.; VERANI, J. R. Idade e crescimento de *Callinectes danae* e *C. ornatus* (Crustacea, Decapoda) na Baía de Guanabara, Rio de Janeiro, Brasil. **Iheringia, Série Zoologia**, 98: 231-235, 2008.

LEE, H. H.; HSU, C. C. Population biology of swimming crab *Portunus sanguinolentus* in the Waters off northern Taiwan. **Journal of Crustacean Biology**, 23: 691-699, 2003.

LEUNG, P. Applications of system modeling to aquaculture. **Aquacultural Engineering**, 5: 171-182, 1986.

LEUNG, P.; SHANG, Y. Modeling prawn production management systems: a dynamic Markov decision approach. **Agricultural Systems**, 29: 5-20, 1989.

LÓPEZ-GRECO, L. S.; RODRÍGUEZ, E. M. Size at the onset of sexual maturity in *Chasmagnathus granulata* Dana, 1851 (Grapsidae, Sesarminae): a critical overall view about the usual criteria for its determination. In: SCHRAM, R.; VAUPLEN, K. F. (Eds.). **Crustaceans and the Biodiversity Crisis**. Leiden Brill, 1999. p. 676-689.

LUPPI, T. A.; SPIVAK, E. D.; BAS, C. C.; ANGER, K. Molt and growth of an estuarine crab, *Chasmagnathus granulatus* (Brachyura: Varunidae), in Mar Chiquita coastal lagoon, Argentina. **Journal of Applied Ichthyology**, 20: 333-344, 2004.

MELO, G. A. S. **Manual de Identificação dos Brachyura (Caranguejos e Siris) do Litoral Brasileiro**. São Paulo, Plêiade/FAPESP. 1996.

NG, P. K. L.; GUINOT, D.; DAVIE, P. J. F. Systema brachyurorum: Part I. An annotated checklist of extant brachyuran crabs of the world. **Raffles Bulletin of Zoology**, 17: 1-208, 2008.

OLSEN, J. L.; WEST, J. A. Ventricaria (Siphonocladales–Cladophorales complex, Chlorophyta), a new genus for *Valonia ventricosa*. **Phycologia**, 27: 103-108, 1988.

PENHA-LOPES, G.; RHYNE, A. L.; LIN, J.; NARCISO, L. The larval rearing of the marine ornamental crab, *Mithraculus forceps* (A. Milne Edwards) (Decapoda: Brachyura: Majidae). **Aquaculture Research**, 36: 1313-1321, 2005.

PENHA-LOPES, G.; RHYNE, A. L.; LIN, J.; NARCISO, L. Effects of temperature, stocking density and diet on the growth and survival of juvenile *Mithraculus forceps* (A. Milne Edwards) (Decapoda: Brachyura: Majidae). **Aquaculture Research**, 37: 398-408, 2006.

PENHA-LOPES, G.; FIGUEIREDO, J.; NARCISO, L. Modelling survival and growth of *Mithraculus forceps* larvae and juveniles (A. Milne Edwards, 1875) (Decapoda: Brachyura: Majidae) in aquaculture. **Aquaculture**, 264: 285-296, 2007.

PIMENTA, A. M.; BARUTOT, R. A.; D'INCAO, F.; FONSECA, D. B. Growth of *Armases rubripes* (Rathbun, 1897) in the estuary of the Lagoa dos Patos, Southern Brazil. **Nauplius**, 13: 183-189, 2005.

PINHEIRO, M. A. A.; FISCARELLI, A. G.; HATTORI, G. Y. Growth of the mangrove crab *Ucides cordatus* (Brachyura, Ocypodidae). **Journal of Crustacean Biology**, 25: 293-301, 2005.

PRAKASH, S.; BAEZA, J. A. A new species of *Lysmata* Risso, 1816 (Crustacea, Decapoda, Lysmatidae) from the Gulf of Mexico. **Zootaxa**, 4363(4): 576-582, 2017.

RHYNE, A. L.; PENHA-LOPES, G.; LIN, J. Growth, development, and survival of *Mithraculus sculptus* (Lamarck) and *Mithraculus forceps* (A. Milne Edwards) (Decapoda: Brachyura: Majidae): economically important marine ornamental crabs. **Aquaculture**, 245: 183-191, 2005.

RHYNE, A. L.; TLUSTY, M. F.; KAUFMAN, L. Is sustainable exploitation of coral reefs possible? A view from the standpoint of the marine aquarium trade. Current Opinion in Environmental Sustainability 2014, 7:101–107, 2014. http://dx.doi.org/10.1016/j.cosust.2013.12.001

RHYNE, A. L.; TLUSTY, M. F.; SZCZEBAK, J. T.; HOLMBERG, R. J. Expanding our understanding of the trade in marine aquarium animals. **PeerJ**, 5: e2949, 2017.

RICKER, W. E. Computation and interpretation of biological statistics of fish populations. **Bulletin of the Fisheries Research Board of Canada**, 191: 1-382, 1975.

SOKAL, R. R.; ROHLF, F. J. **Biometry: the principles and practice of statistics in biological research.** New York, W. H. Freeman and Co. 2012.

SWIECH-AYOUB, B. P.; MASUNARI, S. Biologia reprodutiva de *Aegla castro* Schmitt (Crustacea, Anomura, Aeglidae) no Buraco do Padre, Ponta Grossa, Paraná, Brasil. **Revista Brasileira de Zoologia**, 18: 1019-1030, 2001.

VALENTI, W. C.; DE MELO, J. T. C.; LOBÃO, V. L. Crescimento de *Macrobrachium acanthurus* (Wiegmann, 1836) do Rio Ribeira de Iguape (Crustacea, Decapoda, Palaemonidae). **Revista Brasileira de Biologia**, 47: 349-355, 1987.

VOGT, G. A compilation of longevity data in decapod crustaceans. **Nauplius**, 27: e2019011, 2019.

VON BERTALANFFY L. A quantitative theory of organic growth. **Human Biology**, 10: 181-213, 1938.

WILLIAMS, A. B. **Shrimps, lobsters, and crabs of the Atlantic coast of the Eastern United States, Maine to Florida.** Washington, D.C., Smithsonian. 1984.

WINDSOR A. M.; FELDER D. L. Molecular phylogenetics and taxonomic reanalysis of the Family Mithracidade MacLeay (Decapoda: Brachyura: Majoidea). **Invertebrate Systematics**, 28: 145-173, 2014.

WOOD, E. M. **Collection of coral reef fish for aquaria: Global trade, conservation issues and management strategies.** London, Marine Conservation Society. 2001.