



## Population dynamics of *Macrobrachium amazonicum* (Heller, 1862) (Decapoda: Palaemonidae) in a Brazilian Amazon Estuary

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**Abstract.** Amazonian shrimp *Macrobrachium amazonicum* is a freshwater species of large abundance in the rivers of the Amazon basin and widely exploited by small-scale fishing and aquaculture. The objective of this study was to obtain the parameters of growth and mortality of specimens collected from May 2006 to August 2007 in the Guajará estuary with the aid of FISAT II program (FAO-ICLARM Fish Stock Assessment Tools). The asymptotic maximum length ( $L_\infty$ ) estimated was almost always greater for females and individual growth constant (K) greater for males in most cases.  $L_\infty$  varied from 36.5 to 46.9 mm and 0.2 to 0.44 K per year<sup>-1</sup>. The total mortality coefficient (Z) varied from 2.04 to 3.78 per year<sup>-1</sup> and (F) from 1.57 to 2.75 year<sup>-1</sup> due to fishing. Exploitation rates calculated warn about a situation of overexploitation of the species. The study of growth and mortality in crustaceans is of extreme importance, because it provides basic information to subsidize fisheries planning and management.

**Keywords:** Fishing resource; Amazon river shrimp; Fishing status; Coastal resources; Over exploitation.

**Resumo.** *Dinâmica Populacional de Macrobrachium amazonicum* (Heller, 1862) (Decapoda: Palaemonidae) em um Estuário Amazônico Brasileiro. O camarão-da-Amazônia, *Macrobrachium amazonicum*, é uma espécie dulcícola de larga abundância nos rios da bacia amazônica e amplamente explorada pela pesca artesanal e pela aquicultura. Este estudo teve como objetivo obter os parâmetros de crescimento e mortalidade dos exemplares coletados de maio/2006 a agosto/2007 no estuário Guajará com auxílio do programa FISAT II (FAO-ICLARM Fish Stock Assessment Tools). O comprimento máximo assintótico ( $L_\infty$ ) estimado foi quase sempre maior para as fêmeas e a constante de crescimento individual (K) maior para os machos na maioria dos casos. O  $L_\infty$  variou de 36.5 a 46.9 mm e K de 0.2 a 0.44 ano<sup>-1</sup>. O coeficiente de mortalidade total (Z) variou de 2.04 a 3.78 ano<sup>-1</sup> e por pesca (F) de 1.57 a 2.75 ano<sup>-1</sup>. As taxas de exploração calculadas alertam para um estado de sobreexploração da espécie. O estudo do crescimento e mortalidade em crustáceos é de extrema importância, por fornecer informações básicas para subsidiar o ordenamento e manejo pesqueiro.

**Palavras-chave:** Recurso pesqueiro; Camarão de água doce; Status pesqueiro, Recurso costeiro; Sobrepesca

## Introduction

*Macrobrachium amazonicum* is a freshwater shrimp of large distribution in Brazilian continental and estuarine waters (Holthuis 1952). In the Amazon, it is included among the most abundant species and represents an important resource in subsistence and commercial fishing of the Amazon estuary (Bentes et al. 2012). Even so, little is known about the volumes produced and/or marketed in the region (Bentes et al. 2011).

The only data of shrimp fishery production in the State of Pará are from fishing statistics obtained by IBAMA (Brazilian Institute of Environment and Renewable Natural Resources), in which the annual fisheries landings in key ports of the coastal zone are recorded, corresponding to various species together, as marine shrimps (*Farfantepenaeus subtilis*, *Xiphopenaeus kroyeri*, and *Litopenaeus schmitti*, among others) and freshwater shrimps (*M. amazonicum* and *M. surinanicum*) (IBAMA 2011).

In recent years they appeared different studies on the biology of *M. amazonicum*. Highlighting certain features in the cultivation environment, such as: the molting cycle (Hayd et al. 2008; Hayd 2007); fecundity and fertility (Lobão et al. 1986); larval development (Maciel 2007; Araújo and Valenti 2005; Vetorelli 2004; Araújo and Valenti 2003; Rojas et al. 1990; Magalhães 1985); relative growth (Coelho et al. 1982; Roverso et al. 1990; Moraes Riodades and Valenti 2002); density of cultivation (Kimpala 2007; Moraes Riodades et al. 2006; Moraes Riodades 2005; Kimpala 2004; Lobão et al. 1994); as well as the economic potential of these activities in Brazil (Brown et al. 2010; Kutty and Valenti 2010; Moraes Valenti and Valenti 2010; New 2005; Moraes-Riodades and Valenti, 2001; New et al. 2000; Odinetz Collart and Moreira 1996; Valenti 1993; Valenti 1985; Coelho et al. 1981) and in Venezuela (Romero 1982). In natural environment, known items of the species in different basins are: fecundity and fertility of the species (Silva et al. 2004); its oocyte development (Chaves and Magalhães 1993); reproductive strategies (Bentes et al. 2011; Porto 1998; Odinetz Collart 1991a; Odinetz Collart and Rabelo 1996); the population structure in the Tucuruí Hydroelectric Complex (Odinetz Collart 1991b); genetics (Vergamini et al. 2011) and morphology (Porto 2004); as well as the dynamics in the population of the Combu Island, Pará (Frédou et al. 2010).

The Amazon estuary is mainly a place of great productivity of *M. amazonicum*, since commercial catches of this species in this environment supply

the volume of Amazon shrimp consumed in the capital city of Belém, where the specimens are sold according to size (small, medium or large) at different prices. According to the perception of riverside population, who use *M. amazonicum* as resource in the Amazon estuary, the average size and abundance of individuals caught have been decreasing over time, probably due to the increased effort in the island region of the Guajará Bay, where this resource supports the families that live there.

As there are no studies that evaluate the populations of *M. amazonicum* in the Amazon estuary, except for the work by Frédou et al. (2010), which confirms a situation of overexploitation of the species on Combu Island, this study approaches the population dynamics of the species across the estuary region of the Guajará Bay, seeking to estimate growth and mortality parameters for the application of evaluation models regarding the situation of *M. amazonicum* exploitation. In this way, we intend to contribute to a greater knowledge about the species and subsidize fishing management initiatives.

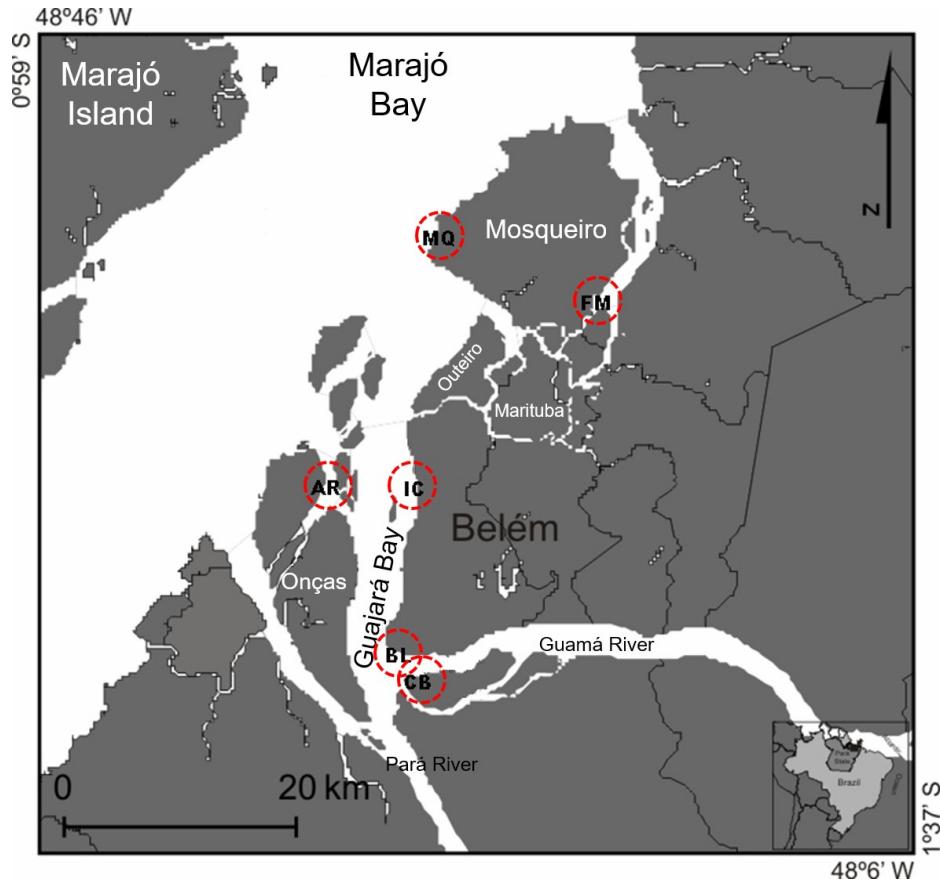
## Material and Methods

*Study area:* Guajará Bay (Figure 1) is a region of the Amazon estuary submitted to the mixture of continental waters and sediments that drain into the sea carried by the Amazon River (Barthem 1985). It has irregular bottom composed of sand and mud (fluid and compact), forming banks of sediments that are distributed according to the action of the river flows and tides (Gregório and Mendes 2009).

These characteristics give the estuary a very dynamic environment, including the presence of marine and freshwater species, whose catches and marketing represent important economical profits for the State of Pará (Bentes et al. 2011).

*Collection and processing of samples:* Specimens of *M. amazonicum* were obtained through monthly surveys from May 2006 to August 2007 in six sites of the Guajará Bay (Figure 1), namely: waterfront of Belém; Combu Island; Icoaraci district; Arapiranga Island; Mosqueiro Island; and Furo das Marinhas. Sampling was performed with traps –locally called *matapis*, which are made of natural fibers and recycled PET bottles– placed in pairs. Three types of *matapis* with different sizes were used: S (small), M (medium) and L (large). Detailed description of this fishing gear and its dimensions can be obtained in Bentes et al. (2011).

Traps were baited with babassu flour (*Orbignya speciosa*) and pieces of fish. The set of traps was



**Figure 1.** Localization of shrimp collection sites from May 2006 to August 2007 in the study estuary (State of Pará, Brazil). The codes refer to collection sites: MQ = Mosqueiro Island (Port of Pelé); FM = Furo das Marinhas (Mosqueiro Island); AR = Arapiranga Island; IC = Icoaraci District; BL = Waterfront of Belém; CB = Combu Island.

placed at low tide on the day before the new moon. At the first low tide the following day, the *matapas* were collected, totaling approximately 12 hours of stay in water.

Caught specimens were properly labeled and transported to the Laboratory of Fisheries Biology at the Federal University of Pará, where were measured the carapace length –CL = measure from the back of the orbit to the rear edge of the carapace (cm), without including the rostrum; using a digital pachymeter (Digimess model, accuracy 0.01mm) - and the total weight (g), with the assistance of precision balance (Mettler Toledo model, accuracy 0,001g).

Sex was determined by the observation of the endopodite morphology of the second pair of pleopods, as proposed by Ismael and New (2000).

*Analysis of the data:* From 9,117 individuals of Amazonian shrimp caught, 9,077 were identified regarding sex and they had the CL and the mass recorded. CL and body weight averages were tested through ANOVA between sex and months. Analyses were performed using FISAT II program (FAO/ICLARM Stock Assessment Tools, version

1.1.2, available at <http://www.fao.org.br/fi/statist/fisoft/fisat/>, (Gayanilo Jr. et al., 2000-2004). At the end of the analyses, the results corresponding to the values of CL were converted to total length (TL), according to the equation of linear regression,

$$TL = 11.158 + 3.8822 \text{ CL} \quad (\text{Equation 1}).$$

*Growth:* In order to estimate body growth for each sex, we used the monthly distributions of CL (mm), grouped into class intervals of 2 mm consider length of individuals range (Bentes et al., 2012). For the adjustment of the growth curve, we used von Bertalanffy's generalized model (1934) (Equation 2), establishing the function between TL and the age of the specimens from the following formula

$$L_t = L_\infty \left[ 1 - e^{-\frac{\{ -K(t-t_0) - CK \}}{2\pi} \sin(2\pi(t-t_s))} \right]$$

(Equation 2)

In which,  $L_t$  = Estimated total length at age  $t$  (mm);  $t$  = average age at length  $L_t$  (years);  $L_\infty$  = Asymptotic length (mm);  $K$  = Constant growth ( $\text{year}^{-1}$ ) – speed

at which the individual tends to reach  $L_\infty$ ; C = Oscillation amplitude of growth rate (ranging from 0 to 1);  $t_0$  = Age (year) at length  $L_t = 0$  obtained by Pauly's empirical equation (1979) (Equation 3):

$$\text{Log}_{10}(-t_0) = -0.392 - 0.275\text{Log}_{10}L_\infty - 1.038\text{Log}_{10}K \quad (\text{Equation 3})$$

$t_s$  = 'Summer point' - varying from 0 to 1 and corresponds to the time of year when the growth rate is higher.

The  $t_s$  is replaced by WP (winter point) in some routines, which designates the period of the year in which the growth rate is lower. This parameter can also vary from 0 to 1, in which '0' is equivalent to January 1<sup>st</sup> and '1' to December 31<sup>st</sup>.

From monthly distributions of CL frequency, we carried out the separation of age groups and determined the average length per cohort, via Bhattacharya's method (1967). For the adjustment of von Bertalanffy's model, from these data of average length by age class, we used Appeldoorn's methods (1987, 1989) and 'Length at age' routine of FISAT II program. Additionally, the same frequency distribution data were used for another adjustment of the growth curve by ELEFAN I method (Pauly and David, 1980, 1981), which identifies modes (peaks) and intermodal (valleys), after the calculation of averages in a process known as 'restructuring'. In all cases, the adjustments were performed considering the recruitment of two distinct cohorts per year, resulting from two different periods of spawning (Frédou et al. 2010).

Longevity or maximum age ( $t_{\max}$ ) was estimated from the observation of the growth curve graphs obtained through ELEFAN I.

Additionally, K and  $L_\infty$  estimates were used for calculation of the growth performance index ( $\phi'$ ), according to Moureau et al. (1986) (Equation 4) and subsequently compared with other estimates of other *Macrobrachium* species, obtained from growth parameters ( $L_\infty$  and K) in the literature.

$$\phi' = \log K + 2 * \log L_\infty \quad (\text{Equation 4})$$

**Mortality:** Natural mortality rate (M) of *M. amazonicum* was estimated by five methods using sexes separately:

1) Rikhter and Efimov (1976) (Equation 5) that related M with the age of the first maturity ( $t_{50}$ );

$$M = [(1.52(t_{50})^{0.72}) - 0.16] \quad (\text{Equation 5})$$

In which  $t_{50}$  corresponds to the age at which 50% of the population is mature, being estimated by von Bertalanffy's reverse equation, considering  $L_{50} = 11.5$  mm of CL, as obtained by Bentes et al. (2011).

2) Pauly's formula (1980) (Equation 6), which assumes that natural mortality is related to von Bertalanffy's growth parameters, K (year<sup>-1</sup>) and  $L_\infty$  (mm), as well as to the water average surface temperature, which for the area of study was established at 28 °C:

$$\ln(M) = -0.0066 - 0.27\ln(L_\infty) + 0.6543\ln(K) + 0.463\ln(T) \quad (\text{Equation 6})$$

3) Alverson and Carney (1975) (Equation 7), which estimates M from K and  $t_{\max}$ :

$$M = 3K / ((e^{0.38Kt_{\max}}) - 1) \quad (\text{Equation 7})$$

4) Hoenig (1983) (Equation 8), which relates natural mortality to the maximum age ( $t_{\max}$ ), indicating that the first is inversely proportional to the second;

$$M = e^{1.44 - 0.982 * \log(10(t_{\max}))} \quad (\text{Equation 8})$$

5) Roff (1984) (Equation 9) which relates mortality to the age of first sexual maturation ( $t_{50}$ );

$$M = 3K / (e^{Kt_{50}}) \quad (\text{Equation 9})$$

To obtain the total mortality rate (Z) we used the following methods:

1) Ricker's catch curve method (1975) (Equation 10), converted to lengths, through von Bertalanffy's reverse equation (1934);

2) Beverton and Holt's method (1956) (Equation 11) that calculates Z from the average lengths of catch and K and  $L_\infty$  parameters; and

3) Ault and Ehrhart's method (Equation 12) that is derived from Beverton and Holt's formula (1956) adding  $L_{\max}$  factors (higher length class caught).

$$\ln(C(L_1, L_2) \Delta t(L_1, L_2)) = C - Z*t((L_1 + L_2)/2)) \quad (\text{Equation 10})$$

In which: C = oscillation amplitude of population growth rate (ranging from 0 to 1);

$$Z = K \frac{(L_\infty - L_{\text{medium}})}{(L_{\text{medium}} - L')} \quad (\text{Equation 11})$$

$$\left( \frac{L_8 - L_{\max}}{L_8 - L'} \right)^{Z/K} = \left( \frac{Z(L' - L_{\text{med}}) + K(L_8 - L_{\text{med}})}{Z(L_{\max} - L_{\text{med}}) + K(L_8 - L_{\text{med}})} \right)$$

(Equation 12)

In which: L' = length from which 100% of individuals are vulnerable to fisheries;

$L_{\text{medium}}$  = average length of total catch;

From the rates of natural and total mortality, we calculated F (fishing mortality) and E (rate of exploitation) rates, according to equations 13 and 14.

$$F = Z - M \quad (\text{Equation 13})$$

$$E = \frac{F}{Z} \quad (\text{Equation 14})$$

All mortality parameters were calculated for males and females separately and later for both sexes together. In this case, the parameters of growth curve used were the averages obtained between the two sexes.

In order to estimate the pattern of recruitment in the fishing area, i.e., the intensity of recruitment pulses, were also used the frequencies of length and the parameters of von Bertalanffy's equation. Knowing the growth parameters, it was possible to calculate how long would have taken a determined size group to reach from  $L = 0$  mm up to the current size. The accumulation of frequencies (deducted the mortality) results in recruitment intensity over the course of a year.

*Yield per recruit:* The model of yield per recruit (Beverton and Holt 1956), used assuming 'knife edge' selectivity, was applied to both sexes together. This method assumes that the selection of individuals for fishing occurs at a certain point and that given a certain pattern of growth ( $K$  and  $L_\infty$ ) and natural mortality, yields of catches depend on the value of mortality by fishing ( $F$ ) and the size or age of the first catch ( $L_c$  or  $t_c$ ), respectively. For the use of this method, it was necessary to estimate  $L_c/L_\infty$  and  $M/K$  parameters reasons. Additionally, were used the average size of first catch ( $L_c$ ), obtained for both sexes together from commercial fishing data by Lucena Fredou et al. (2010). This total length value was converted to carapace length by Bentes' et al. formula (2011). Thus, we obtained the average total length (TL) of first catch,  $L_c = 4.45$  cm or 8.61 mm of carapace length (CL). In addition, were calculated  $t_c$  using von Bertalanffy's growth inverse equation ( $t_c = 0.5$ ) and also average growth parameters by sex.

From the average of the values found for fishing mortality (F) and total mortality (Z), were calculated the current exploitation rate, which was compared with the rates provided by FISAT routine:  $E_{0.1}$  = exploitation rate that corresponds to the point on the curve of yield per recruit, in which the slope is 10% of the maximum value;  $E_{sb50\%}$  = rate at which spawning biomass would be at 50% of virgin biomass;  $E_{max}$  = value of the exploitation rate obtained when the yield is maximum.

## Results

*Population structure:* The smallest individual catch had 1.55 mm carapace length (CL) and the largest one 44.72 mm. The overall average was 12.88 mm, which corresponds to 61.2 mm total length. The amplitudes of size and total weight, as well as averages and deviations for each sex and sexes together are listed in Table I.

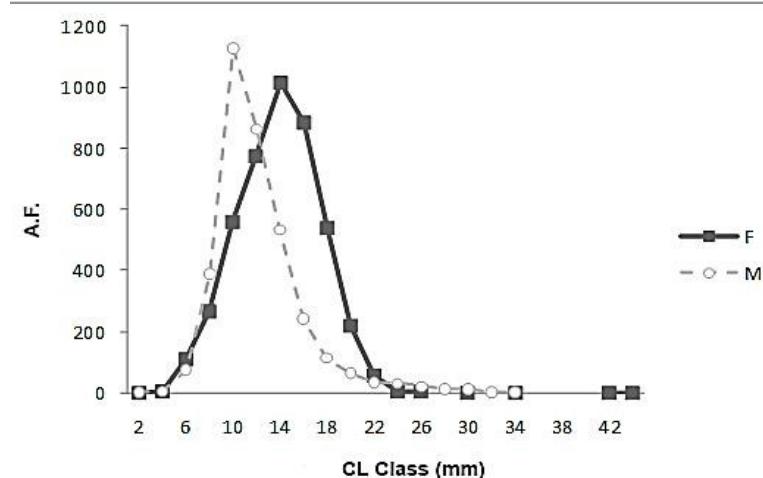
The average length (CL) and mass differed between sexes. Females were larger ( $F = 21.46$ ,  $p < 0.01$ ) and heavier ( $F = 339.7$ ,  $p < 0.01$ ) than males. Females were more abundant than males, but the latter predominated in the largest size classes (Chi-square: 910.99;  $p < 0.01$ ) (Figure 2).

*Body growth:* Regarding the frequency distribution of normal curves size by Bhattacharya's method, *M. amazonicum* showed two modes or one evident mode (Figures 3 and 4).

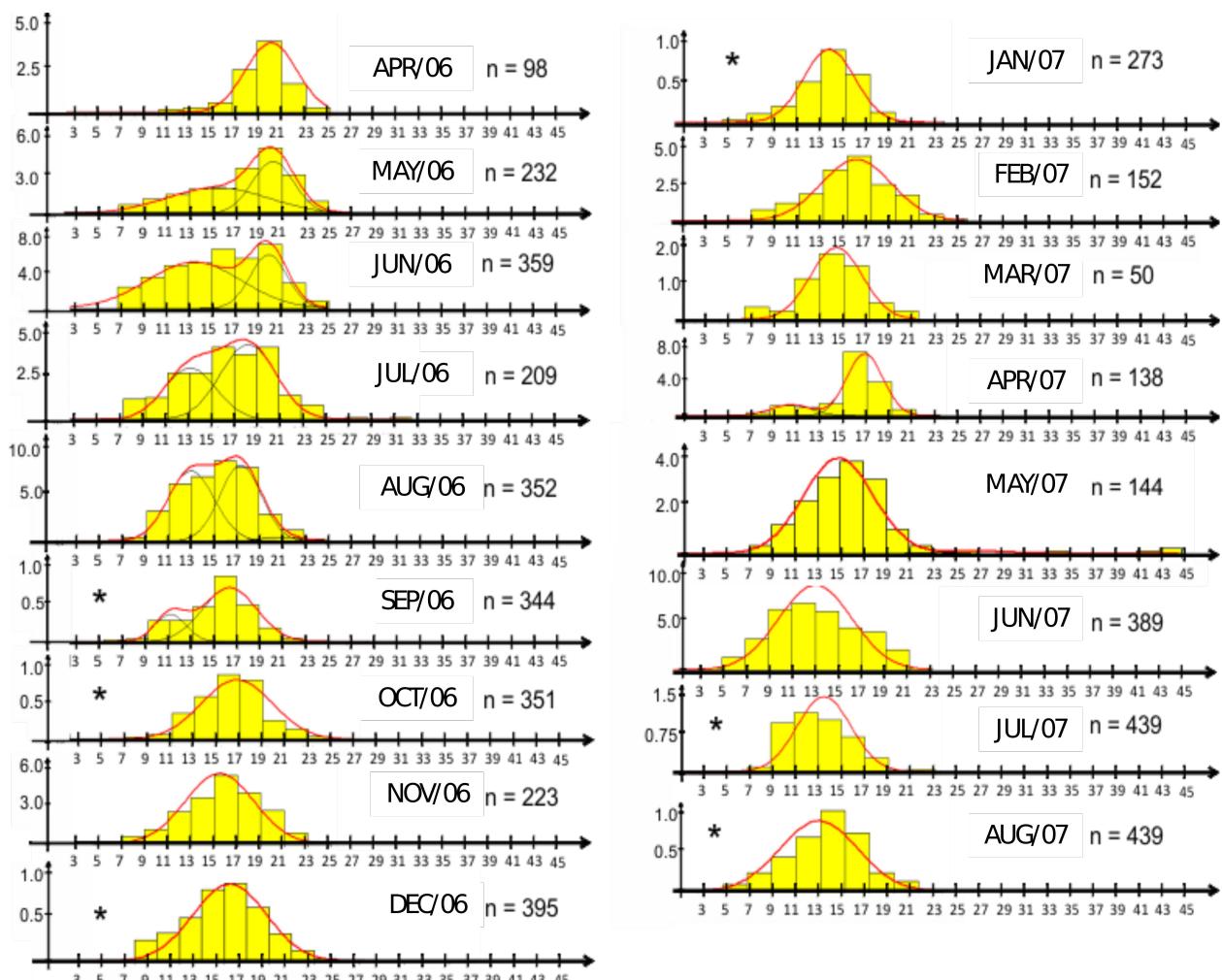
From the sequential observation of modal values, it was possible to confirm the recruitment of two annual cohorts for males (Figures 3 and 5A) and females (Figures 4 and 5B), which were probably born in April (cohort 1) and August/September (2 cohort), in the case of males, and May/June (cohort 1) and August/September (cohort 2) in the case of females. The young shrimps were recruited with carapace lengths that ranged from 11.44 to 13.64 mm.

**Table I.** Average carapace length variation and mass of Amazonian shrimps collected in the Guajará Bay (Pará). N = number of specimens collected in each category; CL = carapace length; SD = standard deviation; F = female; M = male; IND = indeterminate sex; and T = total of individuals.

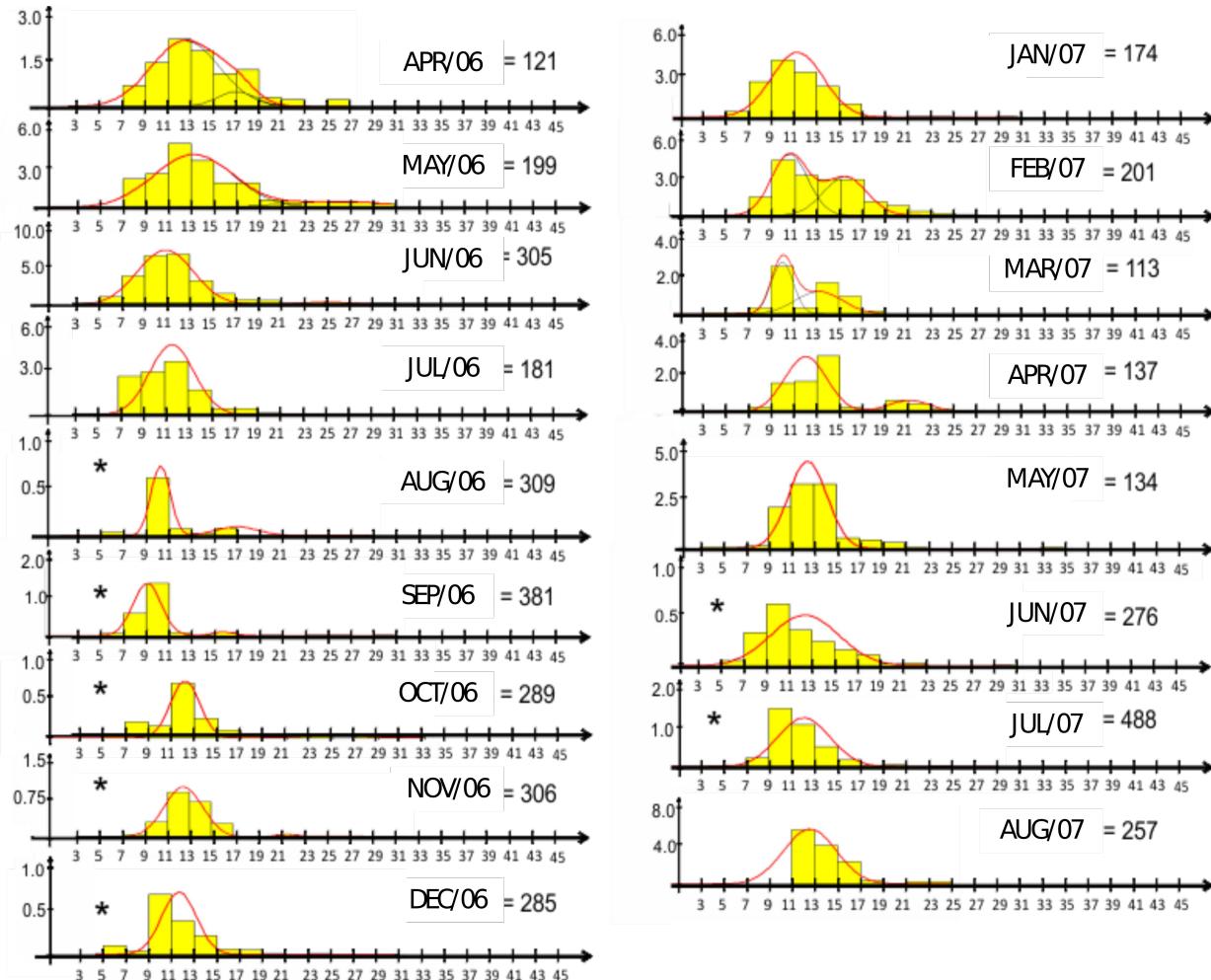
Sex	CL (mm)					Mass (g)			
	N	Min	Max	Mean	SD	Min	Max	Mean	SD
F	4471	2.57	44.72	14.80	2.84	0.04	13.80	2.88	1.37
M	4181	1.55	34.23	12.95	1.78	0.02	22.07	1.96	0.91
IND	465	3.09	30.22	11.36	3.39	0.02	12.37	1.27	1.09
T	9117	1.55	44.72	12.88	3.68	0.02	22.07	1.97	1.69



**Figure 2.** Absolute frequency (A.F.) of *M. amazonicum* carapace length (CL - in mm) collected from April 2006 to August 2007. F = females, M = males.



**Figure 3.** Monthly frequencies of carapace length (CL - mm) by length class of females *M. amazonicum*, calculated by Bhattacharya's method of mode decomposition. The specimens were collected in the Guajará Bay and on Mosqueiro Island from April 2006 to August 2007. Y axis frequencies calculated are represented as  $10^1$  and those highlighted with \* have Y scale = frequency  $10^2$ .



**Figure 4.** Monthly frequencies of carapace length (CL - mm) by males *M. amazonicum* length class calculated by the Bhattacharya's mode decomposition method. The specimens were collected in the Guajará Bay and on Mosqueiro Island from April 2006 to August 2007. Y axis frequencies calculated are represented as 10 to the first ( $10^1$ ) and those highlighted with \* have Y scale =  $10^2$  frequency.

The follow-up of the corresponding modes and subsequent adjustments provided growth parameters similar to the two cohorts of each sex recruited per year. The analyses of CL sequences performed by ELEFAN also confirmed this pattern (Figure 5).

Similarly, von Bertalanffy's curve growth parameters estimated were similar among the methods used. The asymptotic maximum length ( $L_\infty$ ) estimated by the methods was almost always greater for females and the individual growth constant ( $K$ ) was higher for males in most cases (Table II).  $L_\infty$  ranged from 36.5 to 46.9 mm of CL or 152.8 to 193.23 mm pf TL; and  $K$  from 0.20 to 0.44 year $^{-1}$  for both the two cohorts as among the different methods used for obtaining estimates. Among all methods used, ELEFAN seemed to be the most adjusted to the data. For this reason, it was used to obtain estimates of mortality and growth performance rate.

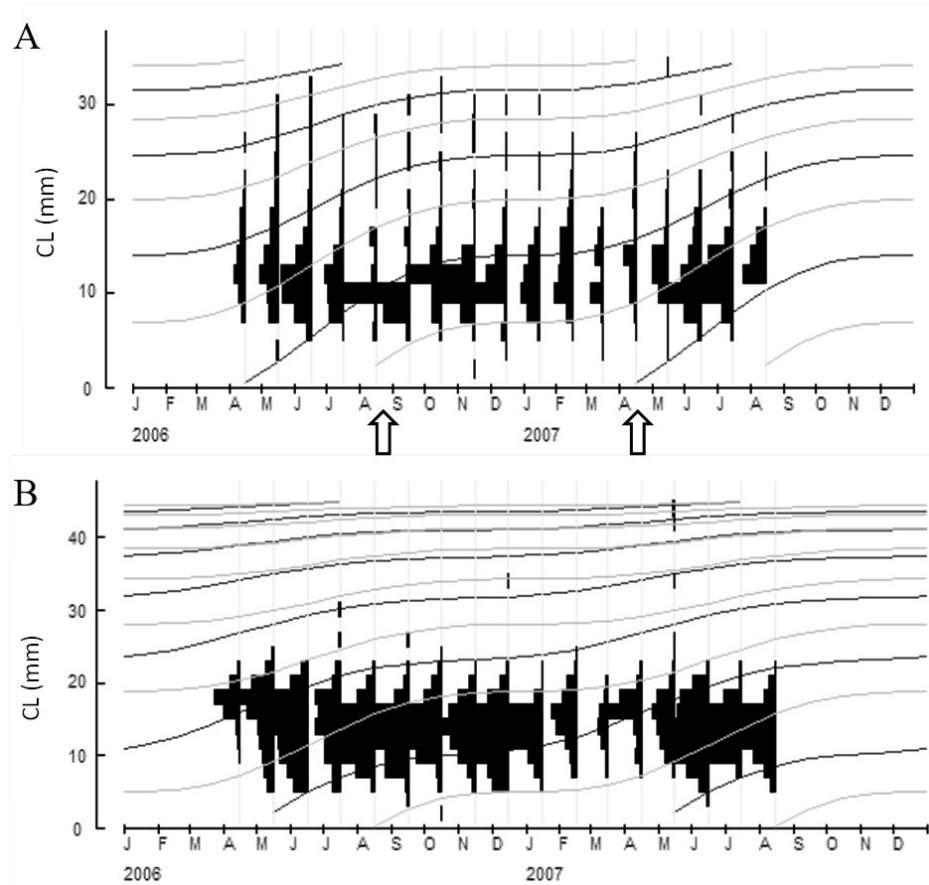
Growth curve oscillation intensity, represented by C and WP values, were estimated in routines where these values could be calculated. Growth was slower almost always in the second half of the year, except for Appeldoorn's routine, in which WP was smaller (Table II).

Values  $t_0$  found for females were -0.139 years and 0.12 years for males, calculated assuming the use of growth parameters obtained through ELEFAN. By the observation of the graphs, it is concluded that longevity was approximately four years for males and six years for females. Growth performance rates ( $\Phi$ ) varied between 7.75 and 8.20. *Mortality and recruitment pattern:* Natural mortality rates ( $M$ ) estimated ranged from 0.77 (Pauly's method) up to 2.12 (Roff's equation) and were roughly similar between sexes (Table III).

Total mortality ( $Z$ ) was higher for males in most cases except when estimated by catch curve, which

was higher for females, ranging from 2.37 to 3.78 year<sup>-1</sup> for males; 2.04 to 3.55 year<sup>-1</sup> for females; and 2.86 to 3.74 year<sup>-1</sup> for sexes together (Table IV;

Figure 6). Fishing mortality rate varied from 0.39 to 2.75 for both sexes, and exploitation rate varied from 0.19 to 0.77.



**Figure 5.** Growth curves of two annual cohorts (gray and black lines) estimated by ELEFAN 1 for frequency data of carapace length (CL in mm) in *M. amazonicum* caught in the Guajará Bay between April 2006 and August 2007. The arrows indicate the recruitments. A- males, B- females.

**Table II.** Estimation of von Bertalanffy's growth curve parameters ( $\Phi'$ ) in *M. amazonicum* collected in the Guajará Bay from April 2006 to August 2007 for both cohorts identified and for males (M) and females (F).  $L_\infty$  = asymptotic length (mm); CL = carapace length (mm) converted to TL = total length (cm) by linear regression, CT = 3.8822\*CC+11,158 (Bentes et al. 2011); K = constant growth (year<sup>-1</sup>); C = growth rate oscillation amplitude; WP = winter point.

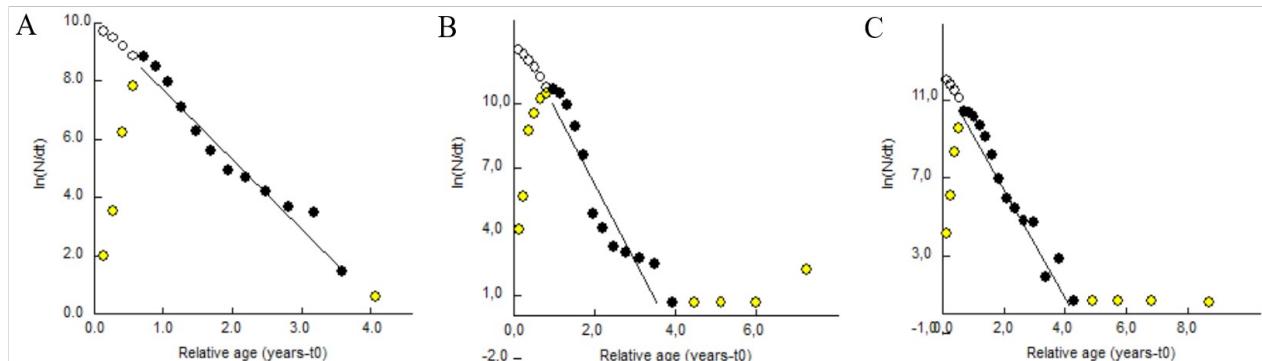
Method	Cohort	Sex	$L_\infty$ (CL - mm)	$L_\infty$ (TL - cm)	K (year <sup>-1</sup> )	C	WP (year)	$\Phi'$
Appeldoorn	1	M	42.14	17.47	0.23	1	0.4	7.846
		F	40.5	16.84	0.2	0.5	0.5	7.754
	2	M	44.8	18.51	0.21	1	0.34	7.857
		F	43.0	17.81	0.4	0.5	0.5	8.103
Length at age	1	M	-	-	-	-	-	-
		F	45.0	18.59	0.31	0.5	0.5	8.029
	2	M	-	-	-	-	-	-
		F	45.0	18.59	0.3	0.5	0.5	8.015
ELEFAN I	1	M	44.8	18.51	0.4	0.8	0.7	8.137
		F	46.6	19.21	0.31	0.7	0.9	8.058
	2	M	36.5	15.29	0.44	0.77	0.7	8.012
		F	46.9	19.32	0.4	1	1	8.174

**Table III.** Natural mortality rates (M) of Amazon Shrimp *M. amazonicum* Heller, 1862 – calculated by using indirect methods of analysis, whose description and parameters used for the estimates are discussed throughout the text.

Method	Males	Females	Grouped sexes
Rikhter & Efanov	2.03	1.93	1.98
Alverson & Carney (1975)	1.68	1.25	1.44
Pauly (1980)	0.85	0.8	0.77
Hoenig (1983)	2.34	1.96	2.12
Roff (1984)	2.31	2.07	2.10
Average	1.79	1.52	1.66

**Table IV.** *M. amazonicum* total mortality (Z) estimated for males (M), females (F) and sexes together (S.T.) of obtained through different methods. F# = fishing mortality; E = current exploitation rate; L medium = average length of experimental catches; L' (mm) = minimum length at which 100% of individuals are caught.

Method	Sex	Z year <sup>-1</sup>	F# year <sup>-1</sup>	E	L medium (mm)	L'(mm)
Catch curve	M	2.37	1.57	0.66	12.95	10
	F	3.55	2.75	0.77	14.8	10
	S.T.	2.86	2.06	0.72	12.88	10
Beverton & Holt	M	3.78	2.12	0.56	12.95	10
	F	2.05	0.39	0.19	14.8	10
	S.T.	2.92	1.26	0.43	12.88	10
Ault & Ehrhart	M	3.77	2.11	0.56	12.95	10
	F	2.04	0.38	0.19	14.8	10
	S.T.	3.74	2.08	0.56	12.88	10

**Figure 6.** Catch curve converted into lengths according to Ricker (1975) for *M. amazonicum* caught in an Amazon estuary from April 2006 to August 2007. The white dots represent the classes that were not used in the calculation. A- males, B- females, C- both sexes.

The pattern of recruitment for *M. amazonicum* through projection of all length classes' frequencies showed two annual peaks. One of the peaks was always more intense than the other, confirming the entry of two groups of young specimens per year in the adult population, at two different times (Figure 7).

**Yield per recruit:** In the current situation, with  $L_c = 8.65$  mm, which corresponds to 0.5 years and  $E = 0.50$ , fishing is at the maximum possible yield (approximately 0.51 g per recruit) for  $E_{Max} = 0.5$  and

$E_{0.10} = 0.41$ . In this situation, the shrimps' biomass in nature is only 26% of the virgin biomass, i.e., just over 1/4 of the biomass existing before fishing exploitation (Figure 11).

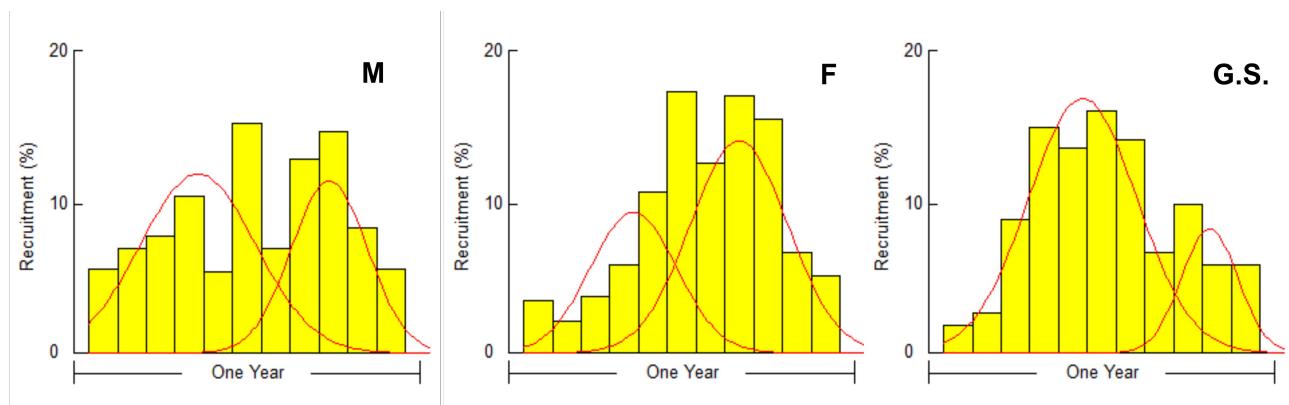
Therefore, to maintain a more sustainable situation, it would be necessary to increase the size of specimens in the first catch, allowing a larger yield without threatening the stock with a growth overfishing due to excess of little specimens in catches. If the increase were  $L_c = 10$  mm, which corresponds to  $t_c = 0.62$ , and keeping the current

fishing mortality pattern,  $E_{\text{optimum}}$  will be 0.5, considering that our current rate of exploitation is 0.5. In this case, we will have a yield increase of almost 9%, with a prediction of 0.54 g per recruit, after we have obtained the new balance. In this new situation, the biomass exploited will represent 28% of the virgin biomass (Figure 8).

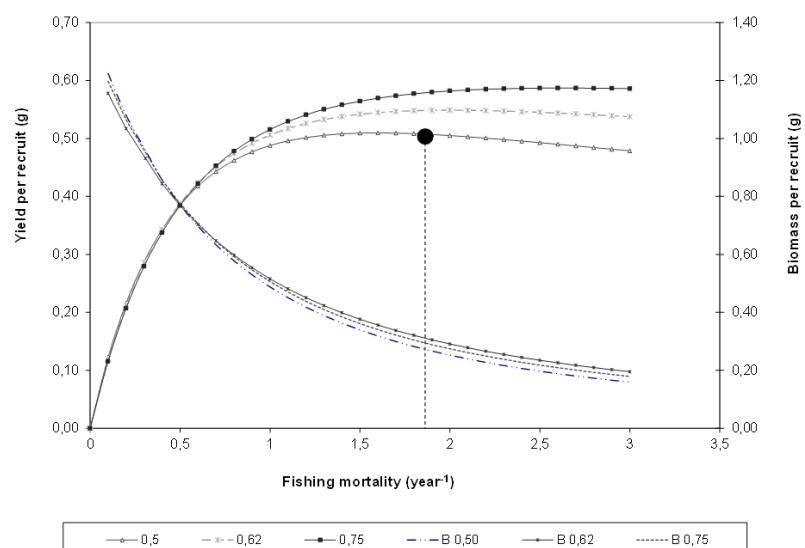
In a situation even more sustainable,  $L_c$  could be adjusted to 11.5 mm or its equivalent:  $t_c = 0.75$  years (Table V). This age corresponds to the estimation of first sexual maturation ( $t_{50}$ ). In this case, the maximum exploitation rate is 0.61 and our current rate (0.50) would coincide with the estimated value for  $E_{0.10}$ . Under these conditions, the fishing effort does not need to be changed and the yield balance would be 0.57 g per recruit, representing an increase of almost 9%, in relation to the current situation. Biomass exploited would be 31% of virgin biomass, which will allow an increase in the spawning stock and therefore the reproductive potential of the species.

increase in the spawning stock in nature and therefore in the reproductive potential of the species.

In a situation even more sustainable,  $L_c$  could be adjusted to 11.5 mm or its equivalent,  $t_c = 0.75$  years, which corresponds to the estimate of average size and age at first sexual maturation ( $L_{50}$  and  $t_{50}$ ). In this case, the maximum exploitation rate is 0.60 and our current rate (0.50) would coincide with the proposed value for  $E_{0.10}$ . Considered that  $E_{0.10}$  is a more conservative value and highly suggested for the regulation of fisheries, this situation is strongly recommended. Under these conditions, the fishing effort does not need to be changed and the yield of balance would be 0.69 g per recruit, representing an increase of 11% in relation to the current situation. Biomass exploited would be 31% of virgin biomass, which will allow an increase in the spawning stock and therefore the reproductive potential of the species.



**Figure 7.** Pattern of *M. amazonicum* recruitment caught in an Amazon estuary (Guará Bay) from April 2006 to August 2007 showing two pulses of recruits in a year. M = males; F = females; G.S.= grouped sexes.



**Figure 8.** Yield and biomass per *M. amazonicum* recruit depending on the fishing mortality (F), for three different ages of first catches, 0.50, 0.62 and 0.75, respectively.

**Table V.** Parameters of Beverton and Holt's yield analysis per recruit for sexes together of Amazon shrimp caught in an Amazon estuary from April 2006 to August 2007. Lc = average length of commercial catch (carapace length - mm) according to Lucena Frédou et al., (2010); E<sub>0,1</sub> = curve point in which yield per recruit is 10% of virgin biomass; E = current rate of exploitation from tc of commercial fishing.

Parameter	tc=0.50	tc=0.62	tc=0.75
F year <sup>-1</sup>	1.6	1.6	1.6
E	0.5	0.5	0.5
Lc	8.65	10.00	11.50
E <sub>max</sub>	0.503	0.557	0.617
E <sub>0,10</sub>	0.408	0.455	0.505
Yield per recruitment (g)	0.62	0.66	0.69
Biomass per recruitment (g)	0.39	0.41	0.43
Proportion of virgin biomass	0.26	0.28	0.31
Average weigh of caught specimens (g)	1.0	1.3	1.7
Average age of caught specimens (years)	0.8	0.9	1.1

## Discussion

The average size of the specimens collected is greater than most recorded in other studies in the Amazon and in other parts of Brazil (in natural environments). The highest carapace length average was recorded on Combu Island (13.75 mm). In this study, we obtained also the largest individual of *M. amazonicum* reported in the literature, with a female with 44.72 mm carapace length or 18.45 cm total length (Table VI).

The largest specimen collected was a female notably, this was the biggest shrimp of the species ever recorded in the literature.

Generally, the individuals caught in flowing waters of large rivers have greater lengths than shrimps collected in calmer waters of floodplain lakes and dams (Odinetz Collart 1993). The largest size of individuals observed in this study may be related to increased productivity in the Guajará Bay, with wide food availability and refuge, where individuals can optimize growth and fecundity (Paiva et al. 2006).

The population structure varied depending on the sex of the specimens. Females were always larger and heavier than males. Hartnoll (1982), Mantelatto and Martinelli (2001) state that body growth patterns among crustaceans is similar between the sexes until the individual reaches sexual maturity. From that stage, growth rate becomes smaller in females, which typically reach sizes lower than those of males in most species.

To obtain growth parameters of fish or other aquatic organisms, direct methods can be used, by reading age rings conformed in hard parts such as scales, otoliths and spines; and indirect methods, through length frequency data or capture and recapture experiments (Etim and Sankare 1998). The applicability of the first method is not possible for

shrimps, since they are organisms that do not develop calcified structures. In this case, only the analysis based on length frequencies can be used for this purpose. Many computational analysis tools have been developed to work with this type of data. The applicability of their results has been discussed (Isaac 1990; Defeo et al. 1992). However, Tomalin (1995) states that ELEFAN is the most widely used, because this method does not require advanced knowledge of statistics. The method does not require normality in the distribution of data to be used, which can be considered as an advantage. Studies on precision developed by Isaac (1990) show that this method is much more accurate for short-lived species, as in the case of shrimps.

Von Bertalanffy's growth curve parameters were similar among the methods used; however, the asymptotic maximum length ( $L_{\infty}$ ) estimated was almost always greater for females, unlike that found by Silva (2006). From all species of *Macrobrachium*, *M. fellicinum* (Inyang 1984), common in the Western region of the African continent, has the smallest asymptotic maximum size (total length) already estimated:  $L_{\infty} = 9.1$  cm (Etim and Sankare 1998).

The largest size reached by females favors the survival and reproduction through increased fecundity. In addition, their mortality may be decreasing by having cryptic habit, due to the fact that they incubate the eggs and seek protection to the litter.

*M. amazonicum* growth revealed common situations among most crustaceans: rapid growth, low longevity and more than one recruitment per year, as stated by Frédou et al. (2010). Recruitment during two peaks in a year corroborates with Silva (2002) who found recruits in rainy and less rainy periods, in catches performed in Vigia, State of

**Table VI.** Size variation of *M. amazonicum* in different sites. TL= Total Length (cm). Empty cells = information not recorded in the study. Sources: 1: This study; 2: Frédou, 2010; 3: Odinetz Collart, 1987; 4: Odinetz Collart, 1987; 5: Silva, 2002; 6: Borges, 2003; 7Odinetz Collart & Moreira, 1993; 8: Odinetz Collart & Enriconi; 9: Vargas & Paternina, 1977; 10: Guest, 1979; 11: Davant, 1963; 12: Coelho et al., 1982; 13: Romero, 1982.

Site	Environment	TL max	TL med	Author
Pará River (Pará - Brazil)	Natural (lotic)	18.45	6.2 (males) 6.8 (females)	1
Guamá River (Pará - Brazil)	Natural (lotic)	14.1	-	2
Tocantins River (Pará - Brazil)	Natural (lotic)	13.2	-	3
Tucuruí Lake (Pará - Brazil)	Reservoir (lentic)	8.0	5.5	4
Guajará-Mirim River (Pará - Brazil)	Swamp	14.4	7 (males) 7.6 (females)	5
Rômulo Dam Campos (Bahia - Brazil)	Reservoir (lentic)	17.8	-	6
Careiro Island (Amazonas -Brazil)	Natural (lotic)	10.6	6	7
Central Amazon – Brazil	Natural (lotic)	6,0	-	8
Colombia	Culture	6,8 (males) 7,7 (females)	-	9
Ceará - Brazil	Culture	10	6	10
Ceará - Brazil	-	11	-	11
Pernambuco - Brazil	Culture (lentic – culture ponds)	-	8 (commercial)	12
Venezuela	Culture (lentic – culture ponds)	-	6	13

Pará, Brazil, and Frédou et al. (2010) on Combu Island.

At the laboratory, Guest (1979) estimated the theoretical asymptotic length for this species in 102.5 mm total length. At that time, the largest specimen's measure recorded was 100 mm. This differentiation in estimating  $L_\infty$  in this work and others with the species is probably related to catching larger specimens in the Amazon estuary, taking advantage of the fact that it is a nutrient-rich environment, which justifies a greater growth of specimens caught in the area. The influence of increased growth density is manifested through increased intra-specific competition for food and space, in addition to other forms of interaction between the animals. When food or space becomes limited, growth will possibly be reduced as a way to save the accumulated energy (New and Singhalka 1982; Sandifer and Smith 1985).

The intensity of growth curve oscillation, represented by C and WP values suggest that growth decrease because of the reproduction, corroborating the result of smaller values of catabolic constant for females. Seasonality of growth in aquatic animals is a well-known phenomenon, primarily in temperate

environment. In the tropics, growth variations are more related to the seasonal rain pattern and/or reproduction (Etim and Sankare 1998; Bentes et al. 2011).

Growth performance rate ranged between 1.0 and 2.6. The value obtained in this study was the largest among the works with *M. amazonicum* and other species of the genus that demonstrate von Bertalanffy's growth curve parameters, which can also be interpreted as a result of the high productivity in the Guajarino estuary (Table 7).

Regarding the estimates of mortality rates, they are difficult to obtain, given the complexity of the necessary data and yet because the methods are inaccurate, especially in regard to natural mortality (Isaac et al. 1992). This way, the uncertainty in the values of natural mortality (M) is recognized. In an attempt to reduce this uncertainty, we chose to use several indirect methods, commonly used for crabs. Many empirical models were initially developed for fish and they include few data for invertebrates. However, the use of multiple methods can ensure better approximation to the parameter.

Natural mortality (M) coefficients were similar between sexes; however, total mortality (Z)

obtained by catch curve was greater for females. Noting that the catch curve showed a convex format, it is assumed that the mortality rate of females regarding the lowest classes of length is greater. On the other hand, the average size of males' catches was smaller than females', which can be linked to males' vulnerability to catches when they have smaller sizes than females, since the proportion of males is always greater than that of females in smaller length classes.

Similar results were found for males by Silva et al. (2007). Other works with species of the same genus show high mortality rates as  $Z = 10.6 \text{ year}^{-1}$ ,  $M = 3.36 \text{ year}^{-1}$  and  $F = 7.24 \text{ year}^{-1}$  for *M. macrobrachium* (Enim 1995);  $Z = 3.4 \text{ year}^{-1}$ ,  $M = 3.61 \text{ year}^{-1}$ , and  $F = 0.26 \text{ year}^{-1}$  (Gabche and Hockey 1995);  $Z = 3.69 \text{ year}^{-1}$ ,  $M = 1.97 \text{ year}^{-1}$  and  $F = 1.72 \text{ year}^{-1}$  (Etim and Sankare 1998) both for *M. vollenhovenii*. It is discussed that the methods used to obtain these parameters regard the values of  $M$  constant for all ages, but this fact is completely unreal. It is clear that a smaller individual is exposed to greater mortality from predation than a bigger individual, simply by the fact that smaller animals have more predators than larger animals. This difference in mortality from predation (which is perhaps the biggest cause of natural mortality in small aquatic animals) should be relatively high (Sparre and Venema 1992).

Recruitment has two annual peaks, one of which is always more intense than the other. The number of recruitment peaks somewhat compensates for the high rates of mortality recorded for the species. In any population, there is a certain amount of individuals that reproduce each period and these are the responsible for producing the sufficient amount of new specimens, so that a sufficient number of new individuals enter each time enabling to restock the population.

The optimum sustainable exploitation rates calculated ( $E_{\max}$ ) were close to the estimates of the current exploitation of *M. amazonicum*, i.e., the current rate of exploitation lies in the maximum sustainability. In this situation, any increase of effort may lead to growth overexploitation or overfishing. Catches, even in small-scale fishing, focus on the juveniles, whose lengths at first catches were lower than those at first maturity. This result is more evident regarding the males of the species.

It is assumed that larger males were not caught because they are no longer available in the population. These catches are characterized by high values of fishing mortality and by a catch with reduced weight. Because of this apparent reduction of stock, it is suggested to catch specimens with size greater than 4.5 cm ( $t_c > 0.75 \text{ year}$ ) total length. That is, given this data, by increasing the size of the first catch, we would have better fishing yield (increase of 14% if compared to current yield).

**Table VII.** *Macrobrachium* species values of growth performance rate ( $\Phi$ ). SX = sex of individuals; M = males; F = females; Mn = minimum; Mx = maximum; S.T. sexes together; TL total length; k = growth constant ( $\text{year}^{-1}$ ). Sources: 1: Silva et al., 2007 & Frédou et al., 2010; 2: Sampaio & Valenti, 1996; 3: Etim & Sankare, 1998; 4: Alhassan & Armah, 2011; 5: Deekae & Abowei, 2010; 6: Enim, 1995; 7: Khan et al., 2004; 8: Mantel & Dudgeon, 2004; 9: Román Contreras & Campos Lince, 1993

Species	Site	SX	L $\infty$						Source
			TL (cm)		K		$\Phi$		
			Mn	Mx	Mn	Mx	Mn	Mx	
<i>M. amazonicum</i>	Guajará Bay - Brazil	M	12.4	17.7	0.7	1.4	2.0	2.6	1
		F	12.7	14.1	0.7	0.9	2.0	2.3	
<i>M. rosenbergii</i>	Culture - Brazil	S.T.	18.4	23.4	0.2	0.4	1.9	2.3	2
<i>M. vollenhovenii</i>	Reservoir - Africa	S.T.	18.0		0.9		2.5		3
<i>M. vollenhovenii</i>	Reservoir - Africa	S.T.	14.2		1.0		2.3		4
<i>M. macrobrachium</i>	Streams - Nigeria	S.T.	8.3		2.0		2.1		5
<i>M. macrobrachium</i>	Estuary - Nigeria	S.T.	12.9		1.8		2.5		6
<i>M. malcolmsonii</i>	Reservoir - India	S.T.	20.3		0.6		2.4		7
<i>M. hainanensis</i>	Streams - China	S.T.	3.6		0.7		1.0		8
<i>M. acanthurus</i>	Mexico	S.T.	21.2		0.2		2.0		9

The decrease in average size of *M. amazonicum* in catches should be a research target, in view of the complaint by many fishermen regarding exponential increase in the number of fishermen and fishing traps used in small-scale fishing. Another discussion is the predation of Amazon shrimp by the Malaysian prawn (*M. rosenbergii*) also included in the region of study (Barros and Silva 1997). Additionally, the increase in fishing effort of catches has been occurring gradually. This is a fact observed by the amount of traps used by fishermen's families during the time of completion of this work, that is, fishing mortality seems to be the strongest interference in the continuity of stocks. Frédou et al. (2010) have already warned about this situation on Combu Island. Co-management initiatives could be discussed with the coastal communities in order to increase the selectivity of gear used, thus avoiding the increasing catch of shrimp that have not yet reproduced.

In terms of management, a priori, we suggest accurate analyses to assess the sustainability of Amazon shrimp farming in the State of Pará. Before being established, each enterprise must go through a thorough analysis of the likely impacts produced and hold a guarantee of economic and social sustainability. In Pará, this would possibly be an immediate solution to decrease fishing pressure in natural stocks; however, there should be ensuring access to credit for small local producers in particular, so that the goal can be reached as well as improvement of the living conditions of these workers.

Still, according to Martinelli (2005), referring to marine shrimps of the species *Farfantepenaeus subtilis* (pink shrimp), *Xiphopenaeus kroyeri* (seabob shrimp) and *Litopenaeus schmitti* (white shrimp), preserving estuaries, preventing intensive small-scale fisheries of younger shrimps and also ensuring the health of waters without pollutants of any nature is essential for the maintenance and survival of shrimps.

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