Application of von Bertalanffy growth curves in a *Farfantepenaeus paulensis* (Decapoda, Penaeidae) captive broodstock.

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Abstract

The aim of the present study was to analyze the growth of *Farfantepenaeus paulensis* juveniles captured in the Patos Lagoon Estuary (Rio Grande do Sul, Brazil), by fitting the von Bertalanffy growth model. Estuary-caught juveniles with mean weight (±SD) of 9.7 ± 2.3g and 7.5 ± 2.3g for females and males, respectively, were maintained indoors at a density of 7.3 shrimp/m² for 279 days by which time they had exceeded the minimum size for reproduction (32.50 ± 5.14g for females and 21.55 ± 2.16g for males). Modal progression analysis and the von Bertalanffy growth model were used to estimate weight (W) and carapace length (Lc) growth curves for females and males, as follows:

$W_t = 42.39\,[1 - e^{-1.15\,(t + 0.0442)}]^{2.501}$ (Males)

$W_t = 55.74\,[1 - e^{-1.57\,(t - 0.0036)}]^{2.517}$ (Females)

$Lc_t = 38.60\,[1 - e^{-1.46\,(t + 0.0262)}]$ (Males)

$Lc_t = 47.28\,[1 - e^{-1.73\,(t - 0.0357)}]$ (Females)

The growth curves were coherent with published information for *F. paulensis* and other penaeids, and provide a tool for aquaculture management and research.

Key words: Growth, von Bertalanffy, penaeid, *F. paulensis*

Introduction

Aquaculturists generally use simple measures to describe shrimp growth and in most cases only the stocking and harvest data are used to calculate absolute growth rates (weight / time). However, discarding all information contained in the intermediate data implies that the relationship of weight to time is linear and the growth rate is the same regardless of shrimp size or life stage. Nevertheless, growth can be approximated by exponential, linear or asymptotic functions (Hopkins, 1992).

The von Bertalanffy growth model (VBGM) appropriately describes the growth of crustaceans and it has been widely used to represent the growth of penaeids (Garcia and Le Reste, 1981; D'Incao and Fonseca, 1999; Rothlisberg, 1998). Although this model is commonly adopted in field research, the application of growth curves in aquaculture in terms of length or weight could be useful to access reliable information of market-size shrimp or captive broodstock growth in different environmental conditions. Furthermore, this method represents an important link to compare shrimp growth under captive and natural conditions reported in aquaculture and field research, respectively.

Modal progression analysis (MPA) represents a simple approach to estimate growth curves based on VBGM, generally through size frequency distribution and cohort identification. This methodology was already applied for *Farfantepenaeus paulensis* juveniles in the Patos Lagoon estuary (D'Incao, 1984) and adults in the southern Brazilian coast (Mello, 1973; Zenger and Agnes, 1977), but it was never applied in aquaculture to describe growth of captive broodstocks.

The reproduction of *F. paulensis* under laboratory conditions has been successfully achieved for wild and pond-reared broodstock sources (Marchiori and Boff, 1983; Brisson, 1986; Petersen *et al.*, 1996; Cavalli *et al.*, 1997). Nevertheless, several studies reported that captive broodstock could be an effective alternative to nauplii production, due to their lower costs, year-round availability and acceptable reproductive performance (Menasveta *et al.*, 1994; Cavalli *et al.*, 1997; Palacios *et al.,* 1999; Preston *et al.*, 1999).

A predictable source of *F. paulensis* broodstock could be provided by the capture of juveniles in the Patos Lagoon estuary. Therefore, the present study was proposed to analyze the growth of estuary-caught shrimps by fitting the VBGM until they reached the minimal size for reproduction.

Materials and Methods

Juveniles of *F. paulensis* were captured using a beam trawl net in the Patos Lagoon estuary, Rio Grande do Sul, Brazil. Shrimps were transferred to two rectangular concrete tanks (8,500 l) enclosed in a greenhouse at the Marine Aquaculture Station, University of Rio Grande. A continuous recirculation system equipped with a 1,000 l biologic filter provided 2 turnovers per day. Water was exchanged at a mean rate of 3%/day. Water temperature was controlled by using submerged electrical heaters and monitored daily. Estimates of nitrogenous compounds were made weekly following the methodology of Unesco (1983) for total ammonia and Bendscheneider and Robinson (1952) for nitrite concentrations. Estimates of pH and salinity were also made weekly.

A total of 150 females and 100 males were stocked in each tank at an initial density of 7.3 shrimps/m^2. Animals were fed *ad libitum* once a day (1700 h) alternating fresh frozen crab (*Callinectes sp.*), squid (*Illex sp.*), shrimp (*Artemesia longinaris*), fish (several species) and a commercial diet (Purina®MR35).

Growth analysis

Shrimp growth was accompanied during 279 days (from May to February) by randomly sampling 30 females and 20 males at approximately 30-day intervals. Carapace length (mm) was measured as the distance from the postorbital margin to the mid-dorsal posterior edge of the carapace. Body wet weight (g) was measured directly in analytical balances. All individuals were returned to their original tanks after the mensurations.

The VBGM was used to represent carapace length and weight growth, according to the equations:

$$W_t = W_\infty\,[1 - e^{-k(t-to)}]^b$$

$$Lc_t = Lc_\infty\,[1 - e^{-k(t-to)}]$$

where W_t and Lc_t are weight and carapace length at time t, W_∞ and Lc_∞ are the asymptotic weight and carapace length, k is the growth coefficient, t is the age or time, t_0 is the time correction factor and b is the exponent of a length-weight relationship of the form $W = a\,(Lc)^b$.

Growth curves were calculated independently for length and weight, but following the same methodology. Frequency distributions were calculated for males and females samples during the experimental period, using one millimeter and one gram class intervals for length and weight, respectively. The equation described by Spiegel (1970) was used to calculate the modal values for each interval class of the frequency distribution:

$$\text{Modal value} = \text{class} + [(N_i - N_{i-1}) \,/\, (N_i - N_{i-1}) + (N_i - N_{i+1})]\ \text{interval};$$

where *class* is the class interval in question, N_i is the class frequency; N_{i-1} is the precedent class frequency, N_{i+1} is the posterior class frequency and *interval* is the interval adopted.

Modal values were plotted against time from the first data recorded (day zero) to the last one (day 279) for males and females. Modal progression analysis (MPA) was applied to choose which modal points should be related to a cohort (age groups). The VBGM parameters were calculated by least-squares residual sum of different modal points combinations, using Microsoft Excel® Solver tool.

Shrimp growth was also represented in absolute growth rate, because it has been widely used in aquaculture studies. Growth rates for weight and carapace length were determined by the formula:

$$G = (Mf - Mi) \,/\, t$$

where G is the absolute growth rate expressed in g or mm/week, Mf is the final mean weight (g) or carapace length (mm), Mi is the initial mean weight (g) or carapace length (mm) and t is the time in weeks.

Evaluation of curves adherence

In spite of the subjectivity associated to cohort determination by MPA, some approaches were adopted to choose the best fitting of curves. One of these approaches was the longevity estimates, calculated for each curve by the Bertalanffy's inverse equation:

$$t_{max} = t_0 - (1/k) \ln [1 - (W_t / W_\infty)^{(1/b)}]$$

$$t_{max} = t_0 - (1/k) \ln [1 - (Lc_t / Lc_\infty)]$$

where t_{max} is the longevity (years), W_t or Lc_t were considered equal to 99% of the asymptotic weight and carapace length, respectively and t_0 equal to zero.

The curves adherence were statistically tested using regression analysis between observed data and estimated curve points. A regression coefficient (r) was accepted when higher than or equal to 0.95. Asymptotic values (Lc_∞ and W_∞) and growth coefficients (k) were also analyzed to verify the curves adherence, based on published information available for *F. paulensis* (Zenger and Agnes, 1977; D'Incao, 1984) and other penaeids (Garcia and Le Reste, 1981; Pauly *et al.*, 1984; Dall *et al.*, 1990; D'Incao and Fonseca, 1999).

Statistical analysis

A Student's t-test was used to detect differences of water quality parameters between the two tanks at the 5% significance level. An F test was applied at the same significance level to compare growth curves parameters between males and females (Cerrato 1990).

Results

The mean stocking weight of estuary-caught shrimps were 9.67g and 7.52 g for females and males, respectively. At harvest, mean weight were 32.50g for females and 21.55g for males, resulting in an overall growth rate of 0.56 g/week and 0.35 g/week, respectively (Table I). Shrimps survival was similar between females and males (Table I).

Water quality during the experimental period was considered acceptable for shrimp culture and did not present significant differences (P>0.05) between tanks. Overall means (±SD) were: temperature 22 ± 4°C, salinity 33 ± 2, pH 8.02 ± 0.16, ammonia-nitrogen 0.37 ± 0.39 mg/l and nitrite-nitrogen 0.15 ± 0.21 mg/l.

The estimated growth equations for weight and carapace length according to the VBGM were:

(Males) $W_t = 42.39 [1 - e^{-1.15 (t + 0.0442)}]^{2.501}$ (Fig. 1a);

(Females) $W_t = 55.74 [1 - e^{-1.57 (t - 0.0036)}]^{2.517}$ (Fig. 1b);

(Males) $Lc_t = 38.60 [1 - e^{-1.46 (t + 0.0262)}]$ (Fig. 2a);

(Females) $Lc_t = 47.28 [1 - e^{-1.73 (t - 0.0357)}]$ (Fig. 2b).

These equations differ significantly (P<0.05) between males and females within each measure.

Table I: Mean values (±SD) of weight and carapace length (initial and final), growth rates and overall survival during 279 days for *F. paulensis* females and males.

	Females	Males
Initial weight (g)	9.67 ± 2.36	7.52 ± 1.06
Final weight (g)	32.50 ± 5.14	21.55 ± 2.16
Growth rate (g/week)	0.57	0.35
Initial length (mm)	23.22 ± 2.15	20.83 ± 1.28
Final length (mm)	36.31 ± 2.45	31.31 ± 1.15
Growth rate (mm/week)	0.33	0.26
Survival (%)	62.0	64.5

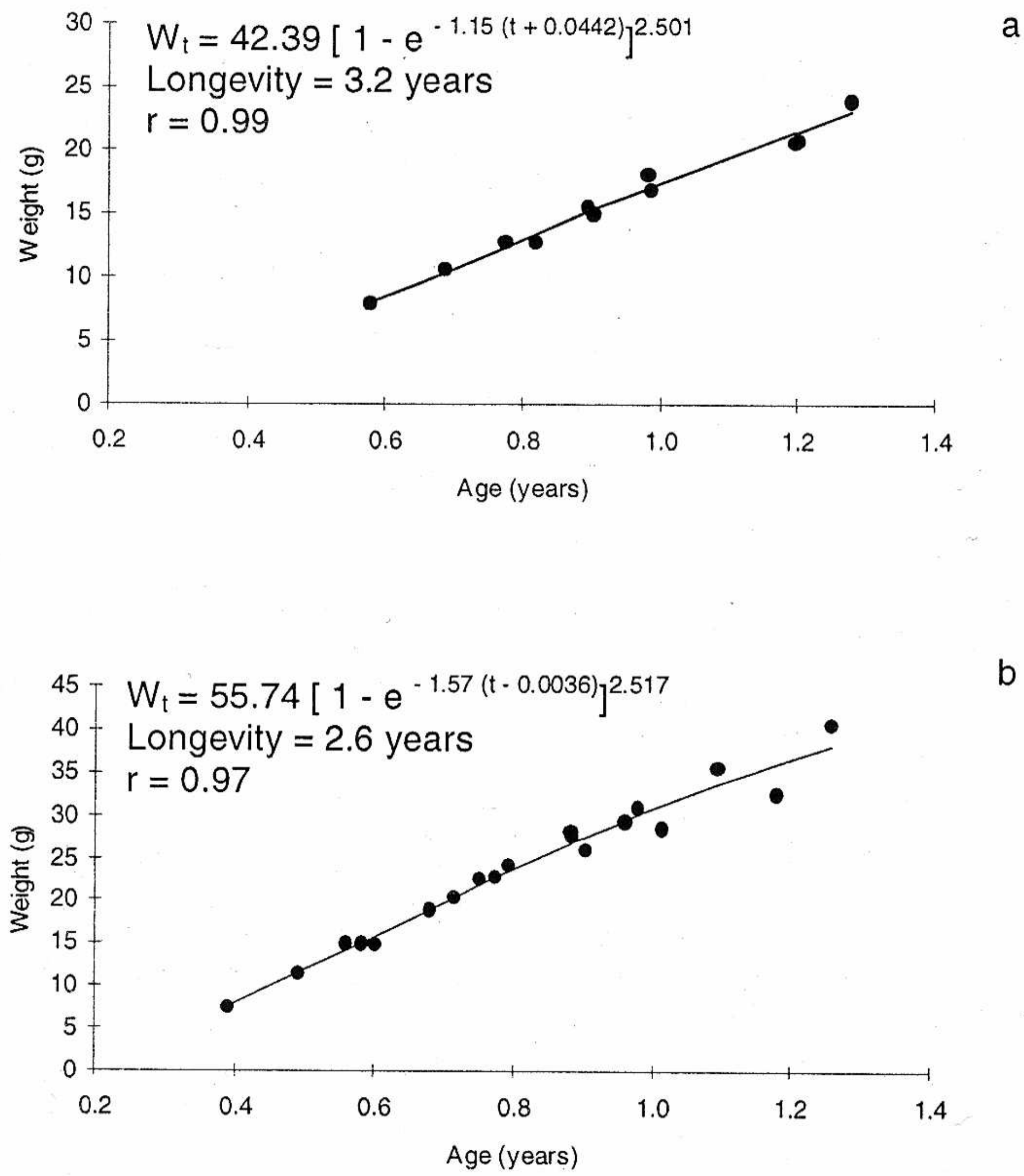

Figure 1: Weight growth curve for *F. paulensis* males (a) and females (b) using modal progression analysis and the von Bertalanffy growth model.

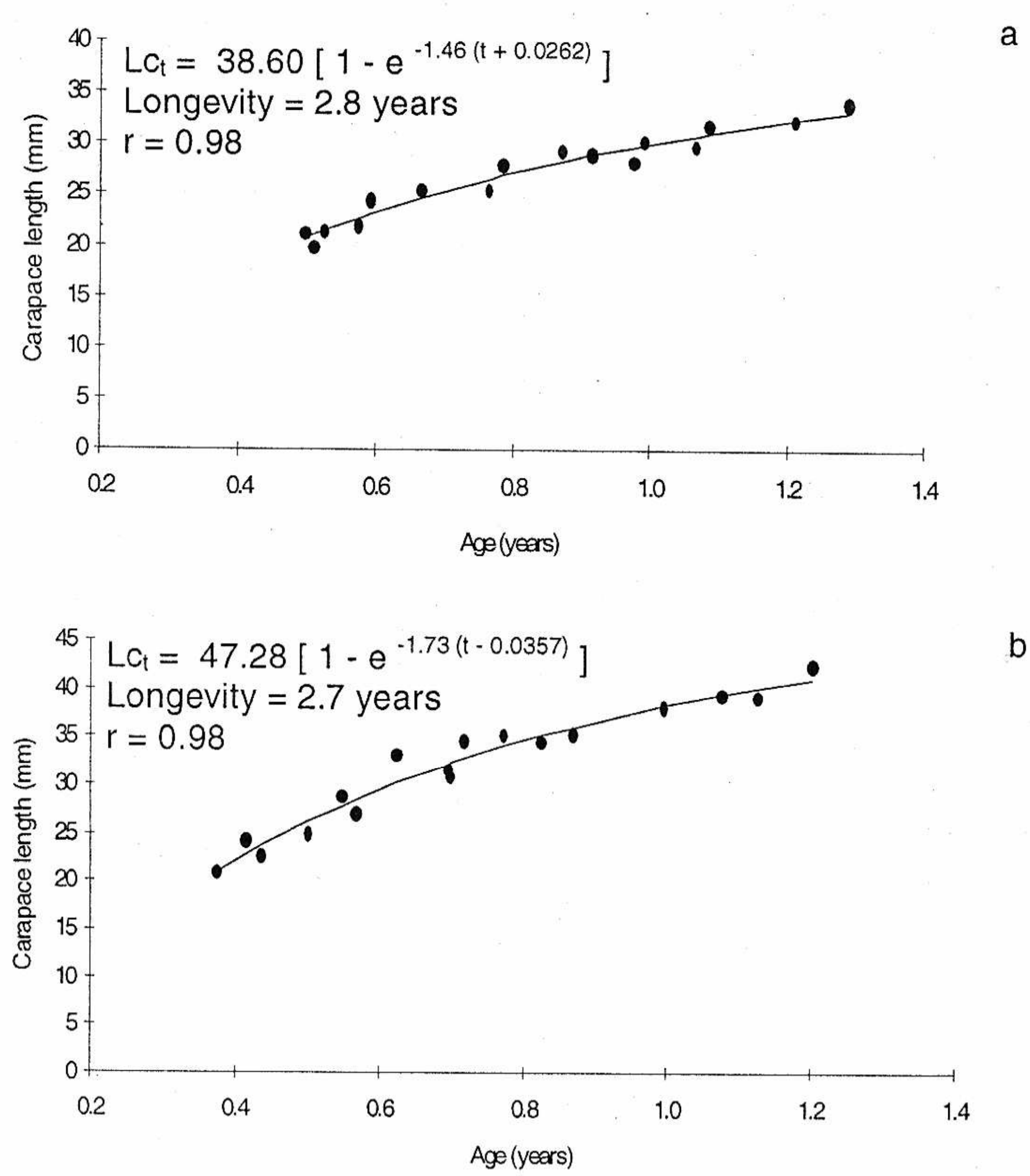

Figure 2: Carapace length growth curve for *F. paulensis* males (a) and females (b) using modal progression analysis and the von Bertalanffy growth model.

Discussion

In penaeids, as a consequence of their discontinuous growth pattern (molts separated by intermolt periods) and the absence of bony structures, traditional age determination methods can not be applied (Garcia and Le Rest, 1981). Thus, modal progression analysis and age associations are generally used to estimate growth curves. Variations in the MPA are usually related to identification of relationship among modal points, growth model adopted and different manners to evaluate the curves adherence (Gulland, 1987). More specific age determination methods by neuronal lipofuscin concentration are being developed (Sheehy, 1995; Medina *et al.*, 2000; Vila *et al.*, 2000), however it is not already widespread for penaeids.

Modal progression analysis rely on cohort identification, which brings uncertainty to growth analysis because there are no elements to test the accuracy of the growth parameters. D'Incao and Fonseca (1999) recommended a previous knowledge on life span to detect possible errors in growth analysis. These authors assumed that the asymptotic parameter of the VBGM has biological significance and recommended longevity estimates to validate growth curves.

Growth in penaeids is strongly influenced by environmental and biological factors. These factors must be considered in growth surveys to avoid generalizations and wrong comparisons as growth curve parameters could be influenced by local conditions, sex and life stage (Dall *et al.*, 1990). Theoretically, at higher temperatures the growth coefficient (k) and asymptotic length ($L\infty$) tend to increase and decrease, respectively (Pauly *et al.*, 1984). In penaeids, males exhibit lower $L\infty$ and higher k (Garcia and Le Reste 1981; Dall *et al.*, 1990). It has also been reported that, in adult shrimps, k values are usually lower than in juveniles (Dall *et al.*, 1990; D'Incao, 1984). Nevertheless, curve parameters reported in previous studies could be useful to indicate if the estimated parameters are coherent with the biology of the species in consideration.

The annual growth coefficient could vary in penaeids from 0.25 to 2.5 (Pauly *et al.*, 1984) and longevity from 1.5 to 2.5 years (Garcia and Le Rest, 1981). D'Incao and Fonseca (1999) considered k values around 2 and longevity estimates ranging from 1.5 to 2.3 years, as well adjusted to the penaeid life span. The growth coefficients estimated by Mello (1973) for an adult population of *F. paulensis* in the southern Brazilian coast were 2.4 for males and 1.1 for females. D'Incao (1984), who studied the juvenile growth of *F. paulensis* in the Patos Lagoon estuary, reported k values of 1.27 and 1.04, for males and females, respectively. Based on the above, it is concluded that k and longevity values estimated in the present study are in agreement with published information available for *F. paulensis* and other penaeids.

Since k represents the rate at which $L\infty$ is reached, higher estimates of k will lead to lower estimates of $L\infty$. This problem could be minimized if reliable information on the variation of these parameters are known for this species and other penaeids. Mean asymptotic carapace length for penaeids was reported as 47.8 and 40.2 mm for females and males, respectively (Dall *et al.*, 1990). For *F. paulensis* these values were estimated to be 56 mm for females and 41 mm for males (Zenger and Agnes, 1977; D'Incao, 1984). In accordance, the asymptotic length estimated in our study for males and females are well within these ranges.

Carapace growth rate of *Penaeus merguiensis* varied from 0.63 to 1.65 mm/week in juveniles under a temperature between 24 and 31°C (Haywood and Staples, 1993). Benfield *et al.* (1989) reported carapace growth rate for *Penaeus indicus* as varying from 0.2 and 0.4 mm/week at temperatures around 26°C and absence of growth at temperatures below 22°C. The carapace growth observed here for *F. paulensis* is coherent with these values. Moreover, *F. paulensis* is a subtropical species and growth takes place even at temperatures below 19°C, as observed here during the winter. However, further studies are necessary to analyze growth of *F. paulensis* captive broodstocks in outdoor tanks, where low temperatures during the winter could affect growth and survival.

The minimal size for reproduction of pond-reared *F. paulensis* broodstock was established as 30g for females and 18g for males (Cavalli *et al.*, 1997), but no information about growth until reached this broodstock size is available. Luis and Ponte (1993) reared *Penaeus kerathurus* at a density of 10/m² during 10 months to reach broodstock size. Under our conditions, the minimal broodstock size was attained after approximately 9 months of the juveniles capture in the Patos Lagoon estuary. Nevertheless, based on the present results, it is suggested that the growth equations according VBGM could be applied in the future for better management of *F. paulensis* captive broodstock.

Studies on the biology of coastal penaeids may provide reliable indications on the potential growth rates under culture (Rothlisberg, 1998). Although, aquaculture and field research are difficult to compare mostly because they are based on different approaches as a means to describe shrimp growth. An important link could be provided by the application of growth models in aquaculture. Therefore, we hope to have improved the outlook for the applicability of growth curves and to have encouraged aquaculturists to examine shrimp growth more precisely.

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