Growth and first sexual maturation size of *Salminus maxillosus* Valenciennes, 1849 (Characiformes, Characidae), in Mogi Guaçu river, state of São Paulo, Brazil

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ABSTRACT. Age and growth were estimated from counts of hyaline zones in scales of dourado, *Salminus maxillosus* Valenciennes, 1849, of Mogi-Guaçu River, state of São Paulo. The time of annuli formation was established by the scales' marginal growth quotient variation. The first sexual maturation size was determined, and the reproductive period was defined by the analysis of the maturation curve, based on the gonadosomatic index variation, the relative frequency of the maturation stages and of the hepatosomatic index. Annulus formation is annual, occurring during the spawning period. The first annulus formation was observed in the second year of the fish life, corresponding to 346.7 mm and 447.4 mm for males and females, respectively. Up to seven annulus for males and eight for females were observed. The growth curve in length were adjusted by the mathematical expression of von Bertalanffy (1938) and the growth curve in weight by the deductive method from the expressions of the length growth curve and weight/length relationship. The L_∞ and W_∞ values were 874.0 mm and 8804 g for females and 713.0 mm and 4416.0 g for males. The growth rates were 0.3917 and 0.3572 for females and males, respectively.

Key words: *Salminus maxillosus,* Mogi-Guaçu river, fish, growth, first sexual maturation size.

RESUMO. Crescimento e tamanho de primeira maturação gonadal de *Salminus maxillosus* Valenciennes, 1849 (Characiformes, Characidae), no rio Mogi Guaçu, Estado de São Paulo, Brasil. Estimativas de idade e crescimento do dourado, *Salminus maxillosus* Valenciennes, 1849, do Rio Mogi-Guaçu, estado de São Paulo, foram feitas a partir de anéis de crescimento presentes nas escamas. O estabelecimento da época de formação dos anéis foi baseado na variação do quociente de crescimento marginal das escamas e foi determinado o tamanho de primeira maturação gonadal. O período reprodutivo foi estabelecido pela análise da curva de maturação baseada na variação do índice gonadossomático, da freqüência relativa dos estádios de maturação gonadal e do índice hepatossomático. A formação do anel mostrou-se anual, ocorrendo por ocasião do período reprodutivo. O primeiro anel se forma no 2º. ano de vida, correspondendo a 346,7 mm para machos e 447,4 mm para fêmeas. Foram detectados até 7 anéis etários para machos e 8 para fêmeas. As curvas de crescimento em comprimento foram ajustadas pela expressão de von Bertalanffy (1938) e as curvas de crescimento em peso pelo método dedutivo, a partir das expressões das curvas de crescimento em comprimento e das relações peso/comprimento. Os valores de L_∞ e W_∞ encontrados foram 874,0 mm e 8804 g e 713,0 mm e 4416 g para fêmeas e machos respectivamente. A taxa de crescimento para fêmeas foi calculada em 0,3917 e 0,3572 para machos.

Palavras-chave: *Salminus maxillosus,* rio Mogi-Guaçu, peixe, crescimento, tamanho primeira maturação gonadal.

Determining the age of fish is an important tool in fishery biology. Age data, coupled to length and weight measurements, can give information on stock composition, age at sexual maturity, life span, mortality, growth and production (Ricker, 1971). *Salminus maxillosus* Valenciennes, 1849, commonly known as "dourado", is widely distributed in the Parana river basin, Pantanal/Mato Grosso and Amazon river basin. In Mogi-Guaçu river (Pirassununga, São Paulo) the species is commercially important. Systematics and taxonomy of the group were redefined by Britski (1972) and

Godoy (1975). *S. maxillosus* is a migratory species, carnivorous (Morais Filho and Schubart, 1955) and is regarded as tasty food (Rodrigues, 1999). In spite of its economical importance, few papers on *S. maxillosus* were found in the literature: Ihering (1930), Plaza (1950), Morais Filho and Schubart (1955), Cordiviola (1966), Castagnolli (1971), Godoy (1975), Fundação Universidade Estadual de Maringá-Nupélia/Finep (1989) and Rodrigues (1999).

The method of age determination from scales, otholits, opercula and other bones is well-know for temperate fishes (Ricker, 1971). In spite of the suggestion on its application in tropical and subtropical fishes (Menon, 1951, De Bont 1967), it was applied with good results to some species of these regions (Barbieri and Barbieri, 1983, 1988, 1989; Barbieri and Santos, 1988; Santos and Barbieri, 1991; Agostinho *et al.*, 1991; Barbieri, 1992, 1995a,b; Santos and Barbieri, 1993; Hartz and Barbieri,1993, 1995; Barbieri *et al*., 2000).

The objectives of the present investigation were to study the growth of *Salminus maxillosus* by the annual ring method and to determine the size and age at first sexual maturation.

Material and methods

A total of 327 specimens (195 females, 132 males) was monthly collected in the Mogi-Guaçu River (Pirassununga SP Brazil) during a period of one year (from August 1996 to July 1997). Specimens were analyzed to record the following parameters: total length (L_t) in mm; total weight (W_t) in g, gonad weight (wg) in g, liver weight (wf) in g, and gonadal maturation stage.

Five to six scales were collected from each specimen and prepared by the method of Oosten (Ricker, 1971).

Gonadal maturation stages were defined from macroscopic aspects (size, colour, presence of egg and egg size). The following stages were established: stage I (immature or virgin), II (maturing), III (mature), IV (spent) and V (resting).

The time of annulus formation on the scales was obtained by plotting bimonthly variations in the marginal growth coefficient of the scale. The growth coefficient (Qm) as given by Matsuura (1961), is represented by:

$Qm = R - r_n / R - r_{n-1}$

where R is the total scale radius, and r_n and r_{n-1} are the radii of the ultimate and penultimate annuli, respectively. Mean coefficients (Qm) are presented with 95% confidence intervals.

Maturation curves were established by the monthly variation of gonadosomatic index (Igs = $wg/ W_t.100$), hepatosomatic index (Ihs= $wf/W_t.100$) and relative frequencies of gonadal maturity stages.

The growth curve in length was established by using the mathematical expression of Bertalanffy (Bertalanffy, 1938; Gulland, 1977; Santos, 1978):

$$L_t = L_\infty [1 - e^{-K(t-to)}] \quad (1)$$

where

L_t = average fish length at age t

L_∞ = average maximum length attained by the fish, corresponding to the asymptotic value of L_t

K = rate at which length approaches L_∞

t_o = a parameter related to average fish length at birth ($t_o \cong 0$)

t = fish age.

The value of the mathematic expression for our analysis study was detected by the Ford-Walford transformation (Walford, 1946). The K and L_∞ values were determined by linear regression coefficients (Sparre and Venema, 1992).

The correction factor of relative age (t_1) was estimated by attributing relative age (t^*) to the individuals with the same number of annuli on the scales. The relative age (L_t^*) values were estimated by the following expression:

$$L_t^* = \ln (L_\infty - L_t / L_\infty)$$

The t_1 value was estimated from the linear relationship between t^* and L_t^*. By estimating the average weight (W_t) / average length (L_t) ratio, we can describe the relationship between these two variables, while individual condition can be determined by estimating values of the condition factor ($\varnothing$) in a single expression (Le Cren, 1951). This relationship is one of the basic premises of the deductive method required to obtain the growth curve in weight. The tendency of the empirical points in dispersion graphs suggests that the relationship is given by the expression:

$$W_t = \varnothing L_t^{\theta}, \quad (2)$$

where

$\varnothing$ = condition factor related to individual fatness;

θ = constant related to individual growth type.

Empirical data were then transformed logarithmically to ascertain the linear relationship between the two variables, which were transformed by the expression:

$$\ln W_t = \ln \varnothing + \theta \ln L_t,$$

where ∅ and θ were estimated by the linear regression method. The linear coefficient of correlation of Pearson was estimated.

Once the expressions for the growth curve in length (1) and the weight/length relationship (2) were known, the growth curve in weight was determined by the deductive method:

$W_t = W_\infty (1 - e^{-Kt})^\theta$,

where W_∞ = average maximum weight reached by the individuals.

The size of the first sexual maturation (Lpm) and L_{100} were determined by the distribution of the relative frequency (fr) of adults (stages II, III, IV and V) in each total length class (Santos, 1978). The relationship is given by the expression:

$$fr = 1 - e^{-aL_t^b}$$

$fr = 1 - e$,

where

fr = relative frequency

a,b = parameters relation

L_t = total length

Results

The time of annulus formation in *Salminus maxillosus* estimated from bimonthly variations of marginal growth coefficient is given in Figure 1. Results show that the annuli are formed during the spawning season (December-January).

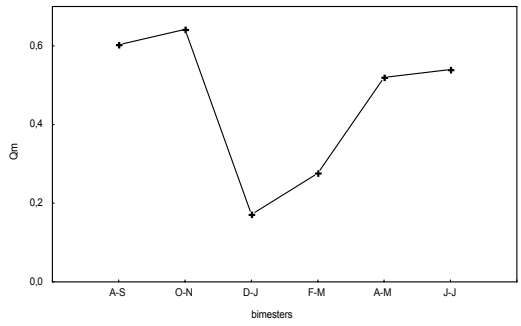

Figure 1. Time of annulus formation in the scales (Qm = marginal growth coefficient)

The Igs and Ihs values were plotted graphically and the results are shown in Figure 2. It can be observed that the reproductive period for males and females occurs from November to January (highest values are recorded in December). Figures 3 and 4 exhibit the relative frequency distribuition of maturity stages and show the higher frequencies of mature individuals in October-December for females and males.

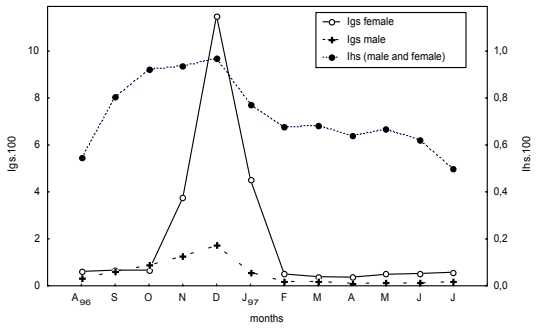

Figure 2. Monthly variation of average gonadosomatic index (Igs) and hepatosomatic index (Ihs)

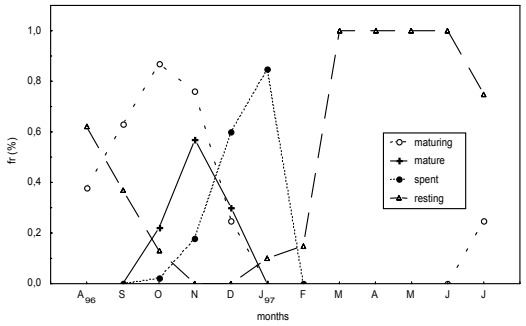

Figure 3. Monthly variation of relative frequency of maturation stages for females

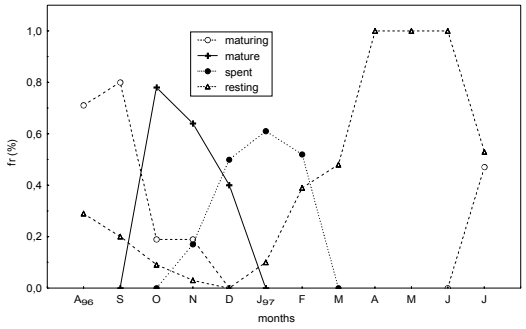

Figure 4. Monthly variation of relative frequency of maturation stages for males

The validity of the von Bertalanffy expression was confirmed by the Ford-Walford transformation (Figure 5). The growth curves in total length (Figure 6).

The theoretical curves obtained by these expressions agreed with the empirical data.

The weight (W_t) was plotted in relation to length (L_t) for males and females (Figure 7), which were defined by the linear relationship expressions:

$\ln W_t = - 11.97 + 3.104 \ln L_t$ (males)

$r^2 = 0.9973$
$\ln W_t = - 12.52 + 3.190 \ln L_t$ (females)
$r^2 = 0.9904$

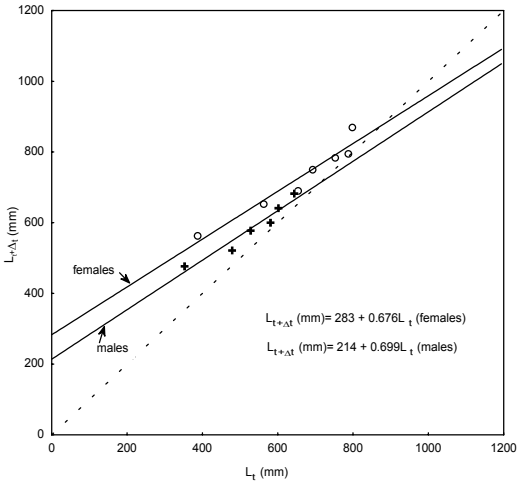

Figure 5. Linear relationship between L_t and $L_{t + \Delta t}$ (Ford-Walford transformation)

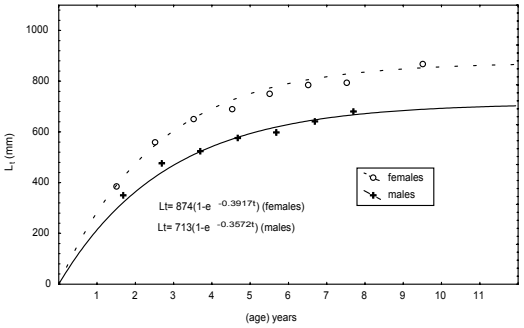

Figure 6. Length growth curve adjusted by the von Bertalanffy expression

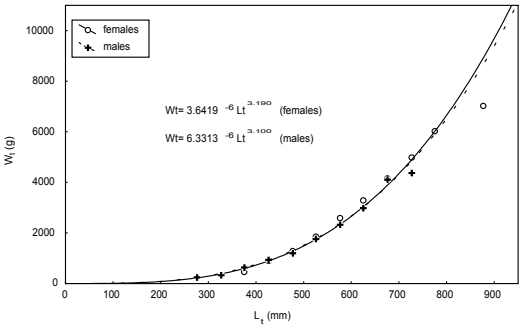

Figure 7. Length / weight relationship

The weight/length relationship shows that *S. maxillosus* has a positive allometric growth, since θ were significantly different and larger than 3.0 (t-test; p= 0.05).

Based on these expressions, the growth curves in weight (Figure 8) were established by the deductive method that permits calculating total fish weight as a function of age.

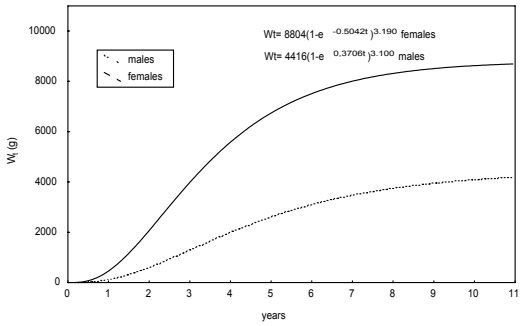

Figure 8. Weight growth curve

Figure 9 shows the relative frequencies (fr) of adults by total length class. The mathematical expressions obtained were:

$$fr = 1 - e^{-1.532^{-10} L_t^{3.801}} \quad \text{for males}$$

$$fr = 1 - e^{-3.009^{-21} L_t^{7.681}} \quad \text{for males}$$

fr = 1 - e for females, which were defined by the linearity of the logarithmic form of these variables:
Y = - 22.59 + 3.801 X (males)
Y = - 47.25 + 7.681 X (females)

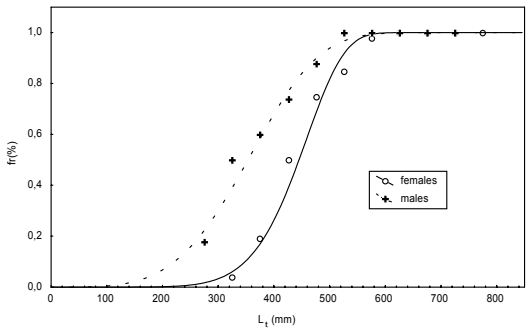

Figure 9. Relative frequency of adults by total length (Lpm= first sexual maturation)

The size of *S. maxillosus* at first sexual maturation (L_{50}) was calculated to be 346.7 mm (males) and 447.4 mm (females). The L_{100} values calculated were 525.0 mm for males and 625.0 mm for females, respectively. The formation of first annulus occurs during the second year of life and corresponds to the first sexual maturation size (Lpm).

Discussion

Several studies on fish age and growth by the annual ring method have been reported in the literature. The validity of this method for tropical fishes, however, is still a matter of controversy (Ricker, 1971). Menon (1953) reported that determination of age and growth is difficult in tropical and sub-tropical regions because the scales may show rings that are not necessarily annual. Contrastingly, Nekrasov (1979) reported that annulus formation occurs once a year in tropical fishes and is linked to spawning. In this study on *S. maxillosus* Valenciennes,1849, it was found that ring formation occurs during the last quarter of the year and coincides with the spawning season in the Mogi-Guaçu River.

The Igs (gonadosomatic index) and Ihs (hepatosomatic index) show increasing values from the gonadal maturation stages onwards. This condition suggests that the decreasing relative weight of the liver is related to vitelogenesis process, migration and spawning. Similar results were reported by Fundação Universidade Estadual de Maringá-Nupélia/Finep (1989), for *S. maxillosus* of Parana river basin.

In the present study the formation of the first annulus in *S. maxillous* occurs during the second year of life. A number of 7 and 8 rings on the scales for males and females respectively was confirmed. Barbieri *et al*. (1978), Barbieri and Barbieri (1983), working with *Geophagus brasiliensis* and *Gymnotus carapo* of Lobo Reservoir (São Paulo), *Parodon affinis* of Passa Cinco River (Barbieri and Barbieri, 1989) and *Cyphocharax voga* of Emboaba Lagoon Rio Grande do Sul (Hartz and Barbieri, 1993) confirmed the validity of the methodology for the studied specimens. However, other results were obtained for *S. maxillosus* at Mogi-Guaçu river. Morais Filho and Schubart (1955) found up to 10 rings (females, L_t= 910 mm) and 8 rings (males, L_t= 730 mm); Castagnolli (1971) found up to 6 (females, L_t= 812 mm) and 5 rings (males, L_t= 615 mm). Cordiviola (1966) found up to 9 rings (females, L_t=830 mm) and 8 rings (males, L_t= 730 mm) for the same species caught in the Paraná river.

The value of K is a parameter related to the velocity of growth and has a physiological meaning as a measure of metabolic rate or the destruction of the body matter per unity of time. According to Beverton and Holt (1957), this parameter has a genetic and physiological determinant and puts in evidence the mathematical interaction with the L_∞ value. Grimes (1978) associates K with the trophic level occupied by the species and suggests that, in the same community, species which feed on higher trophic levels have higher values of K. On the other hand, Beverton and Holt (1957) assert that L_∞ values may be affected by factors such as density and food supply.

In *S. maxillosus,* rapid growth in length occurs during the first year of life and before the fish reaches first sexual maturation size. However, the opposite occurs for increase in weight. Lowe-McConnell (1987, 1991, 1994) attributes an adaptative meaning to the rapid growth in the first year of life for a great number of fish, mainly among those living in rivers subject to floods. Welcomme (1985) believes that fishes grow up quickly during the flood; thus, they can reach a suitable size and begin migration after the flood.

The L_∞ and W_∞ values estimated were 874.0 mm and 8804 g for females and 713.0 mm and 4416 g for males.The highest L_∞ and W_∞ values recorded in the samples were 870 mm and 7030 g for females and 710 mm and 4400 g for males, respectively. The empiric values obtained from the monthly samples corroborate the validity of the von Bertalanffy methodology for the L_∞ and W_∞ calculation applied in natural populations.

The differences in L_∞ between sexes indicate that *S. maxillosus* females attained greater sizes. However, this does not mean that the females live longer, since their K value was also higher.

The weight/length relationship has been used to estimate the growth curve in weight and to define fish condition and the kind of growth. According to Le Cren (1951), the condition factor (∅) is related to the physiological condition of fishes and may vary according to fatness, suitability of environment or gonad development. On the other hand, the θ parameter, which is a constant for the species, defines the type of growth peculiar to the species (Bagenal and Tesch, 1978). *S. maxillosus* of the Mogi-Guaçu river has a θ value estimated in 3.10 (males) and 3.19 (females), which characterizes an allometric type of growth. Increase in weight for *S. maxillosus* is inverse to the growth in length, which is low in the first year of its life. The mean length of first maturity (L_{50}) is very important in rational stock assessment, fixing the minimum length of permitted capture. According to Santos (1978), there is no fixed size at which each individual begin to reproduce, but frequency increases gradually with fish length. Thus, the first sexual maturation size is defined as the size that corresponds to 50% frequency. The first sexual maturation size (Lpm) of *S. maxillosus* is 447.4 mm for females and 346.7 mm for males. Based on the growth curve in length, this

is the size of individuals in the second year of life. Hundred percent of the adults occurred at 625.0 mm and 525.0 mm for females and males, respectively.

However, the first sexual maturation age is nearly the same for both males and females (second year of life). This is explained by the fact that the females grow more rapidly than the males. The estimated values of Lpm obtained from *S. maxillosus* of Paraná river basin (Fundação Universidade Estadual de Maringá-Nupélia/Finep, 1989), were 356 mm for males and 411 mm for females and the parameter θ values were 3.124 and 3.178 respectively for females and males.

According to these results, it may be concluded that the annuli encountered in the scales of *Salminus maxillosus* Valenciennes, 1849, of Mogi-Guaçu river are formed during the last quarter of the year, corresponding to the spawning period, which starts at the second year of life, when the fish attains first sexual maturation size (Lpm). Females reach higher asymptotic values and have faster growth than males. The value of θ estimated characterizes an allometric type of growth. The first sexual maturation size was determined in 447.4 mm and 346.7 mm for females and males, respectively.

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