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Age, growth, mortality and yield per recruit of the dourado *Salminus brasiliensis*, Corumbá Reservoir, Goiás State, Brazil

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In order to evaluate the fate of the migratory species dourado *Salminus brasiliensis* in the first years of impoundment in Corumbá Reservoir we estimated age, growth, mortality and yield per recruit. Samplings were carried out monthly in Corumbá Reservoir and its main tributaries (Goiás State) from March 1998 to February 1999 using gillnets. After one year of impoundment, age was estimated from scales and the maximum number of rings was six for males and five for females. Rings are formed annually in May and June. The asymptotic length and growth rate for males and females were 37.1 cm and 0.77 and 56.6 cm and 0.52, respectively. A dominance of juveniles was verified in the reservoir and its tributaries. The instantaneous total mortality rate (*Z*) was 1.59 and the annual total mortality rate (*A*) was 79.6%. The highest yield per recruit (1200g) and the highest average weight (1900g) were obtained in simulations with low values of fishing (*F*) and natural (*M*) mortalities. Based on the above information we describe the Corumbá Reservoir impoundment has influenced the growth of the dourado. As regards this study, we recommend that the fishing effort not be applied during the trophic upsurge period and that the monitoring of the dourado assemblage continue. Fishery programs management for this species should be carried out with subsequent monitoring involving efficient communication, realistic practices and involvement of fisher organizations.

Com o propósito de avaliar o destino da espécie migradora dourado *Salminus brasiliensis* no primeiro ano de represamento do reservatório de Corumbá foi estimado a idade, crescimento, mortalidade e rendimento por recruta. As amostras foram capturadas no reservatório de Corumbá e seus principais tributários (Estado de Goiás) mensalmente de março de 1988 a fevereiro de 1999 usando-se redes de espera. Após um ano do represamento, a idade foi estimada das escamas e o número máximo de anéis foi seis para machos e cinco para fêmeas. Os anéis são formados anualmente de maio a junho. O comprimento assintótico e a taxa de crescimento para machos e fêmeas foram 37,1 cm e 0,77 e 56,6 cm e 0,52 cm, respectivamente. A dominância de juvenis foi constatada no reservatório e seus tributários. A taxa de mortalidade total instantânea (*Z*) foi 1,59 e a taxa de mortalidade total (A) foi 79,6%. O mais elevado rendimento por recrutamento (1200g) e peso médio (1900g) foi obtido em simulações com baixo valor de pesca (*F*) e mortalidade natural (*M*). Baseado nas informações acima foi determinado se o represamento do reservatório de Corumbá tem influenciado o crescimento do dourado. Como recomendação para este estudo, sugere-se que o esforço de pesca não seja aplicado durante o período de elevada produtividade trófica e que o monitoramento da assembleia de dourado continue. O programa de manejo para esta espécie deve ser conduzido com subsequente monitoramento envolvendo comunicação eficiente, práticas realistas e envolvimento das organizações de pesca.

Key words: Growth model, Mortality, Fishery yield, Dam, Characidae.

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Introduction

The dourado from upper rio Paraná was formerly identified as *Salminus maxillosus*, but this is actually a junior synonym of *S. brasiliensis*, the valid name for that species. According to Lima *et al*. (2003) it is distributed in the Paraná, Paraguay and Uruguay river basins, Laguna dos Patos drainage basin and the upper Chaparé and Mamoré river basin in Bolivia. It is the largest characin of the Paraná basin and could reach more than one meter in length (Godoy, 1975; Britski *et al*., 1999).

The diet of this piscivore includes a great variety of prey, which reflects its relative abundance in the environment. In its adult phase on the upper Paraná River floodplain it fed on mainly corimba *Prochilodus lineatus*, piau-bosteiro *Schizodon altoparanae* and lambari *Moenkhausia intermedia* (Almeida *et al*., 1997). It is the most valuable in the artisanal and sport fishing of the upper Paraná River basin (Agostinho *et al*., 2003). Given its popularity for all types of fishing, Agostinho *et al*. (2005) consider it a good candidate for an umbrella species in conservations strategies. *Salminus brasiliensis* has been impacted by the construction of dams because it can migrate up to 1000 km to spawn (Petrere Jr., 1985) and needs floodplains and marginal lagoons for the larvae to complete development and the juveniles to find food and shelter (Agostinho *et al*., 2004).

This study examines growth parameters from an assemblage of *S. brasiliensis* after the first year of the impoundment of Corumbá Reservoir. Considering this fact, the objective of this paper is a) to determine periodicity and time of age ring formation, b) to estimate age and growth parameters (length) for each sex, c) to determine age structure for the different environments sampled in the reservoir area (the reservoir itself, upstream, downstream and the tributaries), d) to estimate the mortality rate and e) to evaluate yield using yield per recruitment models. Based on the aims above we expect to describe how the Corumbá Reservoir impoundment has influenced the growth of the dourado.

Material and Methods

Study area

The Corumbá River (500 km long with a 34,000 km^2 drainage area) is the second most important tributary of the Paranaíba River, which, along with the Grande River, form the Paraná River (Paiva, 1982). Corumbá Reservoir is located in the upper third of the Corumbá River and was closed in September 1996. It does not have a fish ladder. Its surface has an area of 65 km^2 and an average depth of 23 m. Average hydraulic retention time is 30 days. Annual precipitation is above 1,500 mm, with maximum values in January and minimum values in June. The dry period is from April to September, with a minimum annual temperature of 10ºC in July and a maximum of 31.5ºC in October.

Samplings were carried out from March 1998 to February 1999 in 12 sites distributed in the Corumbá River and Corumbá Reservoir and their main tributaries. Five sites were located in the reservoir (Pedra Lisa - LISA, Jacuba - JACU, Pirapitinga - CPIR, Ponte - PONT and Peixe - COPE), two upstream from the reservoir (Porto das Moitas - MOIT and Areia - AREI) and one downstream (JUSA). Four sites were located in the tributaries (two in the Pirapitinga River - PIRA and SAPE; two in the Peixe River - PFOZ and LINI) (Fig. 1 and Table 1).

Sampling Methodology

Salminus brasiliensis individuals were collected monthly from an experimental fishery conducted in the 12 sites in Corumbá Reservoir (grouped into reservoir, downstream, upstream and main tributaries) (Fig. 1). Three gangs of 15 gillnets with different mesh sizes (varying from 2.4 to 16.0 cm

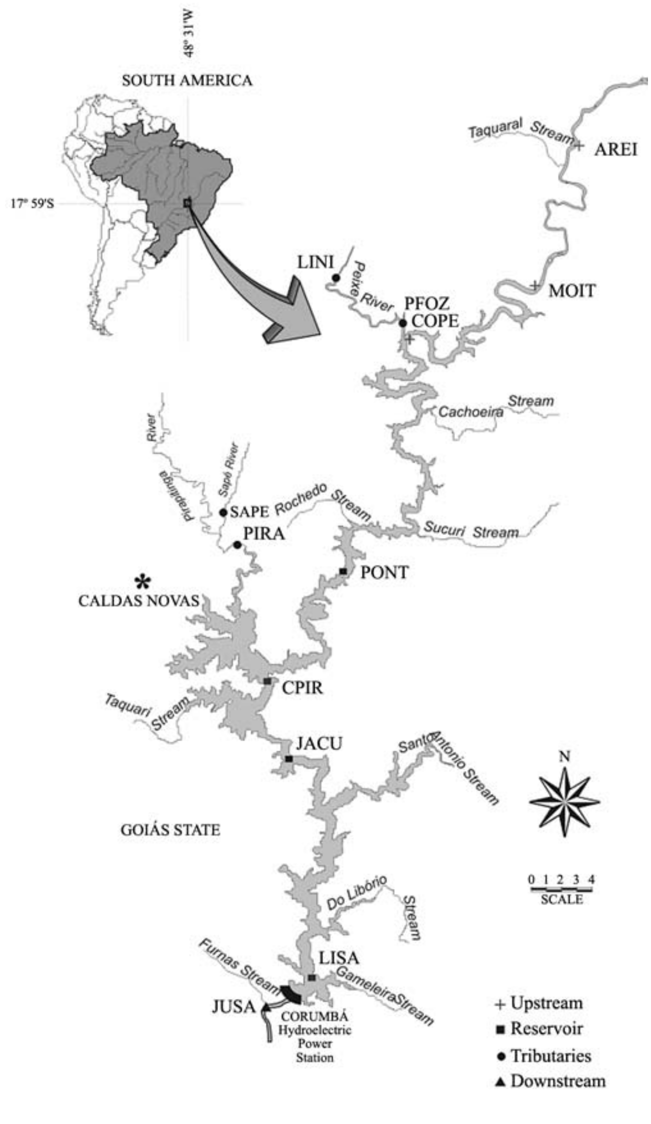

Fig. 1. Location of the sampling sites in the area of Corumbá Reservoir.

Table 1. Morphometric and physiographic characteristics of the sampling sites.

Sites	Code	Characteristics			
		width (m)	depth (m)	bottom	banks
Corumbá Reservoir					
Pedra Lisa	lisa		90	Clayey-sandy; predominance of organic detritus and some small stones	Scrub intermingled with pastures
Jacuba	jacu			Heterogeneous, with a predominance of rocks, fine pebbles and a small quantity of clay	Scrub intermingled with pastures
Corumbá Pirapitinga	cpir	940	30	Predominance of clay and a few pebbles	Scrub intermingled with pastures
Ponte	pont	430	37	Sandy-clayey with large quantities of detritus	Scrub intermingled with pastures
Corumbá Peixe	cope	110		Rocky	Narrow strip (10 m) with large trees, shrubs and creepers
Upstream Corumbá Reservoir					
Porto das Moitas	moit	120	6	Flagstone and accumulations of gravel and sand	Clean and dirty pastures with some trees, a lot shrubs and mainly grasses
Areia	arei	90	9	Rocky with deposition of sandy material and fine gravel	Heterogeneous vegetation; some sectors with large trees and others with shrubs and grasses
Downstream Corumbá Reservoir					
Downstream	jusa	110	9	Rocky with deposits of gravel and sand	Steep; arboreal and shrubby (high density of palms intermingled with pastures)
Tributaries					
Pirapitinga River					
Ponte	pira	35	5	Rocky with deposits of coarse sand and fine gravel	Riparian vegetation surrounded by a large scrub area and cattle
Sapé River (tributary)	sape	13	1.5	Rocky with deposits of sand and gravel	Scrub and pastures
Peixe River					
Foz	pfoz	40	4	Sandy-clayey with deposits of leaves and mud cover	Arboreal vegetation and empty area with grasses
Linígrafo	lini	28	4.5	Rocky with areas of gravel and coarse sand, with a little clay	Predominance of cattle-raising activity

stretched mesh) and longlines with 50 and 20 hooks (2/0 and 7/0, respectively) were used. These gears were set for 24 hours and checked periodically: in the morning (8:00 to 9:00), in the afternoon (16:00 to 17:30) and at night (22:00 to 23:30).

Date and sampling site, standard length (Ls) in centimeters, total weight (Wt) in grams and sex of each individual were recorded. Five individuals were sampled from each length class by sex. About 10 scales from the region immediately posterior to the insertion of the left pectoral fin were taken from each individual and stored in an envelope. Scales were cleaned and sterilized and placed between glass slides, according to the methodology of Vazzoler (1982). The reader counted three times and measured age rings using a stereomicroscope. In the case of different results, the data were not considered. Measurements were taken in mm between the center and the edge of the scale and between the center and each ring using an ocular micrometer.

Data analysis

The coefficient of variation (CV) of the standard length per growth ring was used to determine age precision for males and females (Witherel & Burnett, 1993).

The period of age ring formation was determined using analysis of the marginal increment of the scales per month, considering 2 to 6 year olds (Lai *et al*., 1996; Campana, 2001; Isely & Grabowski, 2007).

Growth in length was modeled for the sexes separately using the von Bertalanffy equation (Beverton & Holt, 1957). In order to adjust the von Bertalanffy model, a non-linear procedure was carried out (King, 1995). Seed values were obtained using the Ford-Walford protocol (Walford, 1946). The von Bertalanffy growth equation is:

$$L_s = L_\infty[1 - e^{-k(t-t_0)}]$$

Where: L_s = average standard length (cm) of the individuals with age t; L_∞ = maximum standard length (cm) that, on average, the individuals can reach, also called asymptotic length; k = refers to the growth rate (year^{-1}); t = age of the individuals; t_0 = parameter related to the average standard length of the individuals at hatching.

The value of t_0 was zero, given that this parameter does not have biological relevance (Moreau, 1987).

The age structure was established using the frequency distribution of the ages per environment (reservoir, upstream and tributaries). A total of 254 individuals were considered for this analysis. The individuals were deposited in a museum collection and were not part the analyses.

Instantaneous total mortality (Z) was obtained converting the length of each individual into age using the formula $t = \ln_e(1 - L/L_\infty)\, k$. Later, a linear regression was applied, with age (x axis) and Ln_e of the abundance per age class (y axis). The slope of this relationship corresponds to Z (Van Den Avyle, 1993). Annual mortality (A), *i.e*. the number of fish that die during a year, was obtained using the formula $A = 1 - e^{-Z}$ (Ricker, 1975).

The model proposed by Beverton & Holt (1957) and modified by Jones (Ricker, 1975) was used to simulate the yield per recruit. This model is based on the premise that the stock biomass varies with the rates of growth and mortality. Thus, yield is obtained from variations in the available biomass or dynamic pool (Van Den Avyle, 1993). The model is expressed by the following equation:

$Y/R = [(FN_1 e^{Fr} W_\infty)/k]\,[H_1 - H_2]$

Where: F = instantaneous fishing mortality; N_1 = number of individuals recruited to age 1 (in years); r = time (in years) between age 1 and when the fish becomes susceptible to the fishing gear; W_∞ = asymptotic average weight; k = growth coefficient; $H_1 = \beta(X_1,P,Q) / (1/((\Gamma(P) \times \Gamma(Q))/\Gamma(P+Q)))$; $H_2 = \beta(X_2,P,Q) / (1/((\Gamma(P) \times \Gamma(Q))/\Gamma(P+Q)))$; β = probability of the beta distribution; Γ = complete gamma function (fully defined); $X_1 = e^{-kr}$; $X_2 = e^{-kl}$; l = time (in years) between age 1 and when the fish are no longer susceptible to the fishery; $P = Z/k$; Z = instantaneous total mortality; $Q = b + 1$; b = angular coefficient of the weight-length relationship; $R = N_1 e^{-Mr}$; M = instantaneous natural mortality.

We arbitrarily set N_1 = 1000, but then adjusted these values multiplying by the representation (*i.e*. proportion) of the species at age 1 relative to the other species (Miranda *et al*., 2000).

The main information necessary to calculate yield per recruit and average weight were the parameters (*a* and *b*) of the weight-length relationship (0.0118 and 3.1616, respectively), von Bertalanffy growth equation parameters, asymptotic length (L_∞= 47.2cm) and weight (W_∞= 2331.0g), standard length of first maturation (L_{50} = 32.0cm) and age of first sexual maturation (tL_{50} = 1.82 years), obtained solving the von Bertalanffy equation for L_{50}.

Simulations of yield per recruit were conducted varying instantaneous natural mortality (*M*), fixed arbitrarily from 0.1 (low) to 0.6 (high), and instantaneous fishing mortality (*F*), ranging from 0.1 to 0.6. Instantaneous total mortality (*Z*) was computed as the sum of *M* and *F* (Ricker, 1975). The yield simulations were carried out using the package SAS (SAS Institute Inc., 2000).

Results

A total of 195 (100 males and 95 females) *Salminus brasiliensis* individuals out of 300 caught was analyzed. In the downstream site only one individual was sampled and in the Piratininga River the dourado was not caught during this sampling period. Standard length of caught individuals varied from 8.5 cm to 41.2 cm for males and 8.5 cm to 63.5 cm for females. Maximum number of rings observed was 6 for males and 5 for females (Table 2).

Formation of the age rings for *S. brasiliensis* occurred in March through August since the lowest marginal increment averages were found in this period (Fig. 2). It is evident from these data that formation of age rings follows an annual periodicity and indicates that the scales of the dourado are adequate to estimate age.

Table 2. Sample size (N), average standard length (Ls, cm) and coefficient of variation (CV) of the standard length per growth ring in *Salminus brasiliensis* scales from the area of influence of Corumbá Reservoir.

	Males			Females		
Rings	N	Ls	CV	N	Ls	CV
0	34	17.6	22.3	38	21.3	18.5
1	23	23.9	19.9	28	29.4	17.7
2	30	27.7	10.3	16	33.2	12.6
3	7	29.9	9.0	7	38.8	10.1
4	3	33.0	15.3	5	52.9	17.4
5	2	36.4	0.8	1	53.6	
6	1	41.2				
Total	100			95		

Salminus brasiliensis presented values of L_∞ equal to 37.1 cm for males and 56.6 cm for females and growth rates *k* equal to 0.77 and 0.52 for males and females, respectively (Table 3). Females presented larger sizes and higher growth rates than males.

A dominance of juveniles, particularly females less than one year of age and one-year-old males, was verified in Corumbá Reservoir (Fig. 3). In addition, adults up to 4 years of age were also caught. There was a dominance of juveniles upstream and in the tributaries; however, they were in lower quantities when compared to the reservoir.

Causes of mortality of the fish stock in Corumbá Reservoir are only natural, since fishing is prohibited. The total instantaneous mortality rate *Z* was 1.59, which corresponds to an annual total mortality rate *A* of 79.6%, with Ln (N) = -1.5864 (age) + 6.03 (R^2 = 0.96); N=4.

The best yield per recruit and average weight were obtained in the simulations with low values of fishing mortality *F* and natural mortality *M* (Figs. 4 a and b).

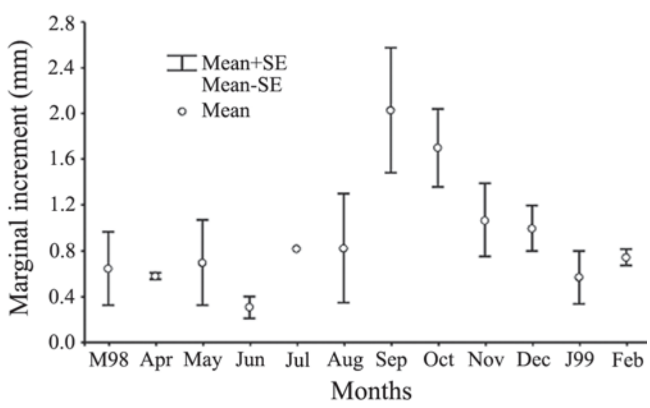

Fig. 2. Monthly average (mean ± standard error; SE) of the marginal increment in scales of the dourado *Salminus brasiliensis* in the area of influence of Corumbá Reservoir.

Table 3. Parameters estimated for the von Bertalanffy model using non-linear procedure (L_∞ = asymptotic length (cm), k = growth rate (year^{-1}), F = Fisher Statistic, P = level of significance, SST = sum of the corrected total squares) for *S. brasiliensis* males and females in the area of influence of Corumbá Reservoir.

	L_∞	K	F	P	SST
Males	37.1	0.7687	32.62	0.0033	841.7
Females	56.6	0.5174	42.98	0.0007	371.7

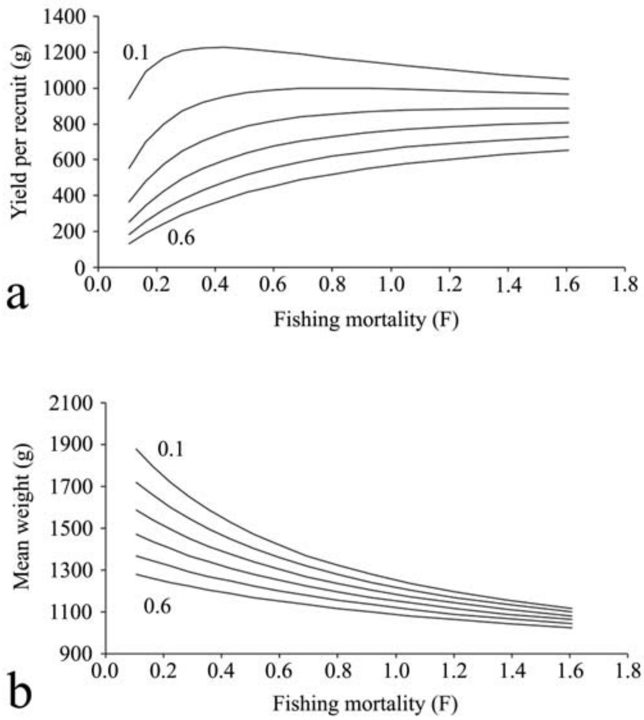

Fig. 4. (a) Simulation of the yield per recruit (g) in different scenarios of fishing mortality (year^{-1}). Each curve represents a natural mortality rate (year^{-1}) (0.1 to 0.6 with intervals of 0.1) for *S. brasiliensis* in the area of influence of Corumbá Reservoir. (b) Simulation of the average weight (g) in different scenarios of fishing mortality (year^{-1}). Each curve represents a natural mortality rate (year^{-1}) (0.1 to 0.6 with intervals of 0.1) for *S. brasiliensis* in the area of influence of Corumbá Reservoir.

Discussion

Calcified structures present periodic growth and are useful in determining age in fish. Scales were chosen in this study because they are easy to collect and prepare, and have given satisfactory results for the Neotropical region (Castagnolli, 1971; Sverlij & Espinach-Ros, 1986; Barbieri *et al*., 2001; Feitosa *et al*., 2004). Variability in age determination may be due to difficulty in distinguishing between false and true rings. This is associated with errors in the criteria used to determine age and due to the subjectivity existing in every age estimate (Casselman, 1983; Kimura & Lyons, 1991; Campana, 2001; Fernandes *et al*., 2002). Another difficulty was the sample. Few large-sized individuals were caught. Thus, the precise age (for purposes of validating the formation periodicity of the ring) was evaluated using the coefficient of variation, which reached a maximum value of 22.3% for males and 18.5% for females. These values show good precision in the reading of the growth rings. The high degree (82%) of agreement between the readers also suggests that scales can reliably estimate age. This was also verified for *S. brasiliensis* studied in the Paraná River near the municipality of Porto Rico (Paraná State). For that study, the coefficient of variation was not above 20% either (Feitosa *et al*., 2004).

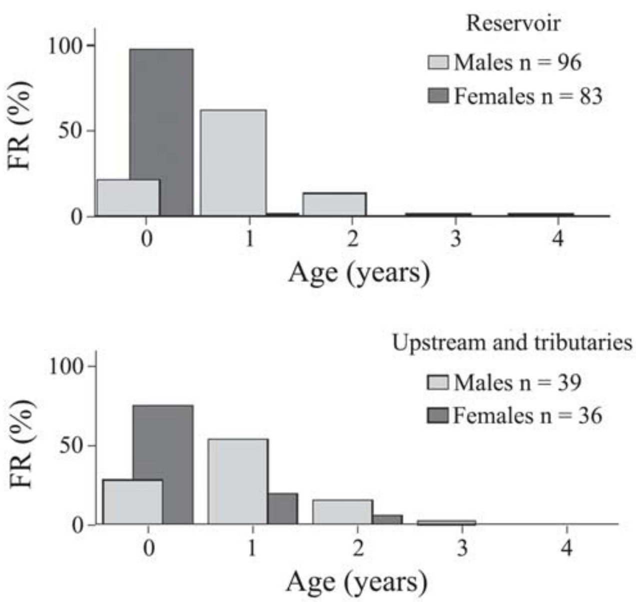

Fig. 3. Frequency per age (years) of *Salminus brasiliensis* individuals from Corumbá Reservoir, upstream and tributaries.

There is some controversy in the literature about which factors could create growth marks in tropical fish. Various authors consider multiple causes (Brett, 1979; Ambrósio & Hayashi, 1997; Jepsen *et al*., 1999; Ambrósio *et al*., 2003). Formation of rings in *S. brasiliensis* coincides with the period of low precipitation, low temperatures, short daylight and high water transparency in the region. The seasonal growth linked to mark formation indicates that the former two variables are the most important but, as emphasized by Fontoura & Agostinho (1996), they are not the only determining factors.

The studies carried out on this species in the Mogi-Guaçu River (São Paulo State) show that the formation of age rings occurs in December and January. This is related to the high precipitation, air and water temperatures and photoperiod, in addition to coinciding with the spawning period (Barbieri *et al*., 2000). However, *Leporinus acutidens* studies carried in middle Paraná River stretches report growth mark formation during autumn/winter before the damming and during spring after it (Araya *et al*., 2008).

Studies developed in the Mogi-Guaçu River for *S. brasiliensis* reveal asymptotic lengths of 71.0 cm for males and 87.4 cm for females (Barbieri *et al*., 2001). In the Paraná River, asymptotic length was found to be 76.7 cm for males and 81.1 cm for females (Feitosa *et al*., 2004). This study agrees in general that females reach greater asymptotic length than males. The value of *k* estimated for *S. brasiliensis* in Corumbá Reservoir was high and indicates fast growth. High growth rates of the dourado in the first year have been determined in Corumbá Reservoir. This is due to the fact that the reservoir is now (trophic upsurge period) and, therefore, allows rapid colonization and high reproductive and recruitment success (Kimmel and Groeger, 1986; Agostinho *et al*., 1999). This strategy seems to enable piscivores to feed on other fish and this resource had the highest availability in Corumbá Reservoir (Luz-Agostinho *et al*., 2006).

Like other characins, *S. brasiliensis* eggs drift to the lower parts of the tributaries while undergoing embryonic development and are washed into floodplains and marginal lagoons where the larvae complete development and juveniles find food and shelter (Agostinho *et al*., 2004). Our study shows the high frequency of juveniles in Corumbá Reservoir, just after its impoundment, and indicates that this species exploits its abundant but temporary resources (food and shelter) to complete its development. A similar result is reported for *Leporinus* species in Yacyretá (Araya *et al*., 2005, 2008). The high mortality of the dourado in the first and second year could be because open areas with low turbidity can increase predation on eggs and larvae. Studies carried out in the Tocantins River after the impoundment of Lajeado Reservoir found a reduction in the density of fish eggs and larvae (Agostinho *et al*., 2007) and demonstrated that the changes in the transport-sedimentation process led to an increase in water transparency (especially in the reservoir), which influenced predation on eggs and larvae. According to Luz-Agostinho *et al*. (2006), *Galeocharax knerii*, *Serrasalmus spilopleura* (actually *S. maculatus*), *Cichla monoculus* (actually *C. kelberi*), *Cichlasoma paranense*, *Pseudoplatystoma corruscans*, *Rhamdia quelen* and *Hoplias malabaricus* from Corumbá Reservoir mainly eat fish (forager species and the younger of other species).

The values found for yield per recruitment and per weight show that this species has the economic potential to lead a fishery in Corumbá Reservoir as long as the fishing effort is maintained at low levels. In spite of this economic potential, as the reservoir ages this stage of high production (trophic upsurge period) will tend towards trophic depletion and migratory and large-bodied fish which reached peak abundance shortly after impoundment will decrease, and assemblages shifted towards a dominance of sedentary, medium-sized species, as mentioned by Agostinho *et al*. (1999). Consequently, we recommend that the fishing effort not be applied during the trophic upsurge period and that the monitoring of the dourado assemblage continue. Fishery programs management for this species should be carried out with subsequent monitoring involving efficient communication, realistic practices and involvement of fisher organizations.

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