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Patterns of reproduction and growth of the catfish *Iheringichthys labrosus* (Lütken, 1874) after a reservoir formation

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Summary

This work contributes to the knowledge of the reproduction, growth parameters and mortality rates of *Iheringichthys labrosus* in a newly-formed reservoir. A total of 554 males and 1227 females were collected over 12 consecutive months, 1998–1999, from sites in the Corumbá Reservoir, Brazil, using gillnets (meshes: 2.4–16 cm). Information on each individual, i.e. standard length (cm), weight (g), sex, and gonadal development phase was recorded. The pectoral spines were removed to estimate age. The number of juveniles and adults, males and females, reproductive sites and seasons were estimated. First maturation length was estimated using a likelihood function fitted by binomial distribution. Growth parameters were estimated using the von Bertalanffy equation. Total instantaneous mortality was obtained through a linearized catch curve method. Standard length varied from 6.0 to 20.5 cm. Growth showed negative allometry for both sexes. The reproduction period was August to December in all environments sampled and first maturation length was 11.5 cm. All individuals were adults with 17.0 cm standard length. Ages varied from zero to 7 years. Asymptotic length, growth coefficient and t_0 for the entire population were 27.79 cm, 0.12 and −2.64, respectively. Instantaneous and annual mortality rates were 0.90 and 0.59, respectively.

Introduction

Most rivers are currently fragmented or are included in dam-building projects. In Brazil, reservoir construction is for hydropower generation, and the Paraná Basin is the most impacted (Agostinho et al., 2008). Plans are to build dams in several regions of the country, including the Amazon (Castello et al., 2013).

In this context, new environmental conditions can act as environmental filters for the establishment of new species and the population dynamics of existing species, since the construction of dams can lead to the loss of biodiversity (Santos et al., 2016), and even the displacement of sensitive species to headwater regions (Oliveira et al., 2004). The ichthyofauna is recognized as one of the assemblies most impacted by habitat fragmentation caused by the construction of reservoirs (Agostinho et al., 2007; Barletta et al., 2010), mainly due to the sudden change of lotic to lentic environments. This scenario is worsened because most Brazilian fish species are not pre-adapted to this kind of environment, since there are virtually no lakes of natural origin in Brazil, i.e. there is no evolutionary history that allows these species to possess characteristics enabling them to live in artificial lakes. Thus, pre-adapted species will colonize and succeed in this new landscape and environment (Agostinho et al., 2016). To understand the population and colonization patterns of these species it is essential to provide knowledge on the basic population parameters, such as reproduction period, first maturation size, reproduction areas, growth rates, maximum length and mortality rate, which are often basic entry parameters in population and assessment models (Dei Tos et al., 2002; Zhang and Megrey, 2006; Maunder and Punt, 2013; Methot and Wetzel, 2013).

One way to obtain these parameters is to carry out growth studies, which involve age estimates from bony structures or even length-frequencies (Campana and Thorrold, 2001; El-Haweet et al., 2005; Cunha et al., 2007; Romo-Curiel et al., 2015), but only a small percentage of South American species has been studied (Dei Tos et al., 2010). Together with growth and reproduction studies, mortality rates are essential to understand the production dynamics of populations. Moreover, they furnish indications of the level of fishery exploitation. From these estimates, possible management actions and restoration alternatives for the exploited species can be identified (Araújo and Haimovici, 2000; Feitosa et al., 2004; Murie et al., 2009).

There are three main definitions of mortality: Mortality by fishery (F), which acts on individuals recruited from commercially-exploited populations; natural mortality (M), which reflects the conditions of life intrinsic to each species; and total mortality (Z), which results from the equation $Z = M + F$ (Pauly, 1984; Sparre and Venema, 1997). These three parameters present different models to be estimated. Ricker (1975) and Pauly (1983) presented a catch curve method to find total mortality (Z) by means of the abundance of individuals in each age group. Pauly (1980) reported the growth rate, the asymptotic growth and the average temperature of the environment to determine natural mortality (M). Lastly, the fishing mortality rate is generally estimated by the difference between total and natural mortality.

Iheringichthys labrosus (Lütken, 1874), popularly known as 'mandi', belongs to Pimelodidae and is widely found in rivers of the Prata Basin, mainly in Brazil, Uruguay and Argentina. This species has shown significant increases in abundance in artisanal fisheries in recent years after the closure of the Itaipu Reservoir in 1982 (Okada et al., 2005; Hoeinghaus et al., 2009). Thus, this work aimed to describe the reproduction patterns and estimate the growth parameters and mortality rates of *I. labrosus* just 2 years after the formation of the Corumbá Reservoir.

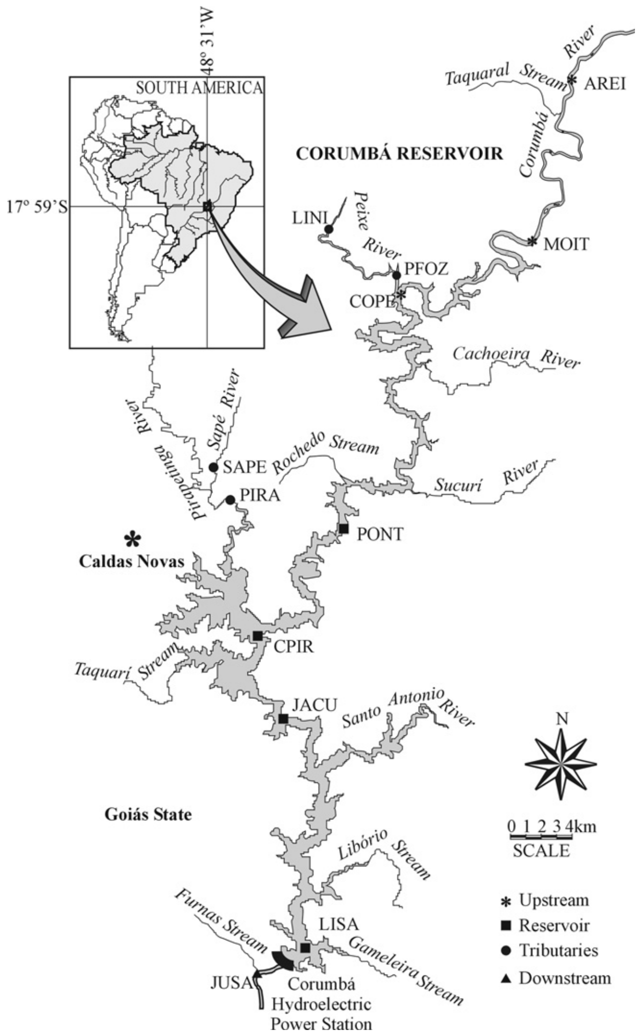

Fig. 1. Sampling sites, Corumbá Reservoir and tributaries, 1998 and 1999. LISA = Pedra Lisa; JACU = Jacuba; CPIR = Pirapitinga, PONT = Ponte; COPE = Peixe, MOIT = Porto das Moitas; AREI = Areia, JUSA = downstream; PFOZ = Peixe River; LINI = upstream stretch, Peixe River; PIRA = Pirapitinga River and SAPE = Sapé affluent.

Materials and methods

Study area

The study was carried out in the Corumbá Reservoir (Fig. 1; state of Goiás, Brazil). This reservoir has an area of 65 km^2 and a total volume of 1.5×10^9 m^3, an average depth of 23 m and an average residence time of 30 days. Its main affluent is the Corumbá River, which starts near Distrito Federal and is 580 km long. Closing of the floodgates to form the reservoir was on 7 September 1996; filling was concluded in March 1997, when the normal maximum level (595 m) was reached.

Sampling

Samples were collected for 12 consecutive months (March 1998 to February 1999) in 12 sites (Fig. 1) in the main body of the reservoir (Pedra Lisa – LISA, Jacuba – JACU, Pirapitinga – CPIR, Ponte – PONT and Peixe – COPE), upstream (Porto das Moitas – MOIT and Areia – AREI), downstream (JUSA) and four points in the main tributaries (one in the mouth of the Peixe River – PFOZ, one in the upstream stretch of the Peixe River – LINI, one in the Pirapitinga River – PIRA, and one in its affluent Sapé – SAPE). The fish were collected using gillnets that remained at each site for 24 h (checked every eight hours). Three sets of 15 gillnets (meshes: 2.4–16 cm) were used at each site. Sampling effort was the same at all sampling points. The gillnets were placed in locations with similar structures (such as depth, marginal area and time of day), making the results comparable between different locations.

Each individual was recorded for: standard length (cm), weight (g), sex, gonadal development phase, date and collection site. In addition, in order to estimate age, the pectoral fin spines were removed. The right spine of each individual was cross-sectioned at the base and mounted on slides for age readings (Fig. 2). Three independent readings were done for each structure.

The phases of gonadal development (immature, developing, spawning capable, regressing and regenerating) were classified according to Brown-Peterson et al. (2011).

Data analysis

The weight–length relationship was fitted according to the equation WT = a*LS^b, proposed by Le Cren (1951), in which 'a' represents the intercept and 'b' the slope. The values of 'b' serve as a parameter to infer the growth type of the fish (allometric or isometric) (Froese, 2006).

The number of juveniles and adults, males and females and reproductive sites and season was estimated. The sexual proportion was tested using the chi-square test for males and females.

First maturation length was estimated using a logistic function:

$$1/(1 + \mathrm{EXP}\ (\mathrm{alpha} + \mathrm{beta} * \mathrm{length}))$$

fitted by maximum likelihood using binomial distribution (Roa, 1993; Freitas et al., 2011):

$$L(\widehat{\mathrm{p}}^{\circ}|\mathrm{x}) = \sum_{i=1}^{M} x_i \ln\ \widehat{(p)} + (n_i - x_i) \ln\ (1 - \hat{p}_i),$$

Fig. 2. Cross-section, right pectoral fin spine, *Iheringichthys labrosus* specimen, Corumbá Reservoir, bar = 1 mm.

where $\hat{p}$ is the predicted maturation in each length class (i) from the logistic function; x_i is the number of mature fishes, n_i is the total number of fishes of each class (i), and M is the number of length classes. The L_{50} is:

$$L_{50} = -\frac{\text{alpha}}{\text{beta}}$$

The precision of the age readings was tested using the Bowker test (Bowker, 1948), paired between the three readings. The null hypothesis is that there are no differences between the readings and the significance is estimated by means of an approximation of the chi-square test. Moreover, bias between the readings was verified through the average percent error (APE) and the average coefficient of variation (ACV). See Campana et al. (1995) for more details.

Growth parameters were estimated using the von Bertalanffy growth equation as a reference:

$$L_s = L\infty[1 - \exp(-K^*(t - t_0))]$$

where: L_s = standard length at age t (cm); $L\infty$ = asymptotic length (cm); K = growth coefficient (year^{-1}); t = age; t_0 = theoretical age at which length is zero.

The estimates were made using the 'nls' function in the software R (R Core Team, 2015), which estimates the least squares by means of nonlinear models. In addition, the seed values for the fit were obtained using the function 'vbStarts' of the package FSA (Ogle, 2015). Confidence intervals for the growth parameters were obtained by means of bootstrap permutations using the function 'nlsBoot' of the nlstools package.

Total instantaneous mortality (Z) measures the rate at which the individuals of a population are lost in a unit of time. This was obtained through a linearized catch curve method (Ricker, 1975; Pauly, 1983; Miranda and Bettoli, 2007). It was estimated through a linear regression, plotting the natural logarithm of the abundance in relation to age for the two grouped sexes. In the fit of the regression, only the data from the descending part of the catch curve were used, since the rising part of the curve represents age classes that were not completely caught (Ricker, 1975). The estimate of total instantaneous mortality (Z) was determined by the slope, according to the equation:

$$\text{Log}_e N = a - Z^*\text{age}$$

where: Log_e = natural logarithm; N = number of individuals per age; a = intercept of the linear regression; Z = slope.

The annual mortality rate was calculated from the value of Z ($A = 1 - e^{-Z}$), according to Ricker (1975).

Results

During this research, 1791 individuals of *I. labrosus* were sampled (1534 adults; 257 juveniles). However, for the growth and mortality analyses, 395 were used (251 females; 143 males; one individual of indeterminate sex). Standard length of this species varied from 6.0 to 20.5 cm. The weight–length relationship indicated a negative allometric ($b < 3$) growth for both males and females (Fig. 3).

Based on the spatial distribution, more individuals were sampled in the reservoir and upstream regions, where the predominant reproductive stages were spawning capable and regenerating (Fig. 4). However, the number of juveniles independent of the sampling site was very low, and the reservoir and downstream stretches had the smallest juvenile/adult proportions. The sexual proportion was tested using the chi-square test and was statistically different ($\chi^2 = 61.455$, $P < 0.000001$).

The reproductive peak of *I. labrosus* is from August to December (Fig. 5), when there are high proportions of individuals in the spawning-capable stage, indicating highly seasonal reproduction.

Through the proportion of adult individuals per length class (Fig. 6), the standard length of the first maturation was estimated at 8.6 cm (11.5 cm total length), and all individuals larger than 17 cm standard length were adults.

The three age readings carried out for each individual were similar and presented a high degree of agreement (Table 1). The high values of agreement resulted in low values of average coefficient of variation and average percent error.

Ages for *I. labrosus* varied from zero to 7 years old; moreover, there was a high predominance of fish aged one and two, and few records of individuals above 4 years of age (Table 2).

As there were no differences between readings, the growth parameters of the von Bertalanffy equation were estimated using the average age of the three readings. In addition, since the oldest individuals were all female, it was not possible to estimate for separate sexes. Thus, the values presented in Fig. 7 refer to the entire population. Asymptotic length was 27.79 cm, the growth coefficient 0.12 and t_0 −2.64 (Fig. 7).

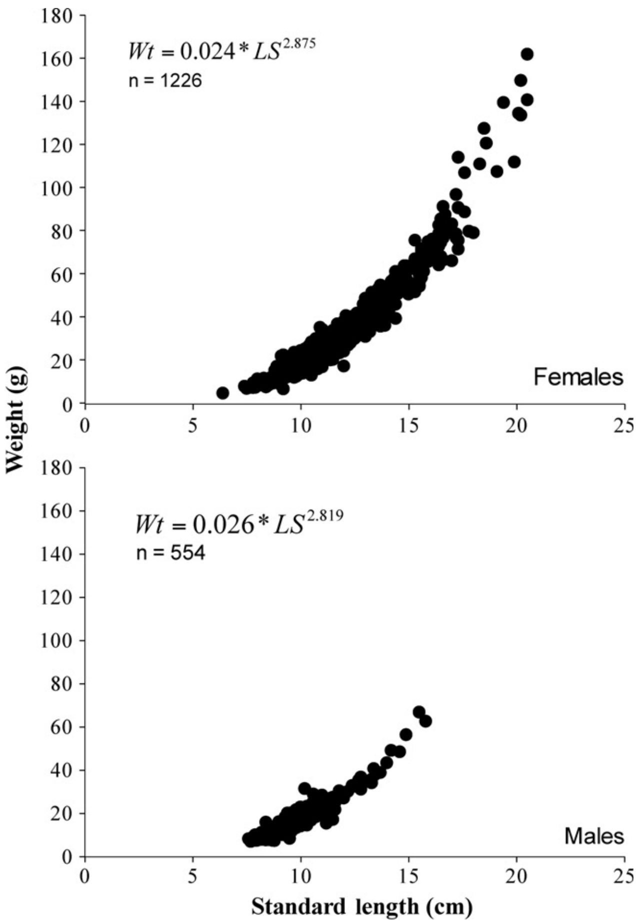

Fig. 3. Weight–length relationships for male (n = 554) and female (n = 1226) *Iheringichthys labrosus*, Corumbá Reservoir, 1998 and 1999.

The total instantaneous mortality rate (Z) for *I. labrosus* was determined by a linearized catch curve, considering a maximum age of 7 years for the combined sexes. The estimate obtained through the descending part of the catch curve was $Z = 0.90$ (± 0.09) (Fig. 8). Based on this value, the annual mortality rate (A) was 0.59.

Discussion

Iheringichthys labrosus, which was not among the most abundant species before the Itaipu Reservoir damming, gradually became one of the most frequent species in the experimental and commercial fishery in the upper dam section (Agostinho et al., 1994; Okada et al., 2005). A higher proportion of *I. labrosus* females relative to males in the Piquiri River (state of Paraná) was also reported by Holzbach et al. (2009). The ratio between males and females can indicate the reproductive potential of the species, including estimates of stock size. Maximum lengths obtained for *I. labrosus* 'mandi' generally vary between 25 and 40 cm (Holzbach et al., 2009).

Reproductive activity of *I. labrosus* is from August to December, with the largest number of immature individuals recorded in March, May and June. Migratory species generally tend to intensify reproductive activity in the last months of the year because this coincides with the beginning of the rainy season and the consequential increase in water levels (Agostinho et al., 1993).

Carefully analyzing the reproductive pattern of *I. labrosus*, some contrasting results can be seen in the high proportions of reproductively active adults. However, there are few juveniles, indicating that the species is able to reproduce but that the juveniles fail to remain in the environment, indicative of the high mortality values. Another important conclusion regarding the reproductive pattern of the species is that despite the small number of juveniles in relation to adults, most juveniles were found upstream and in the tributaries. Agostinho et al. (2016) clearly highlighted the spatial displacement that building a reservoir can impose on species, since there is a natural tendency for individuals to seek more suitable locations similar to their environmental profile prior to the formation of the reservoir. The importance of maintaining dam-free tributaries is widely proven, not only for fish but for other assemblages such as macroinvertebrates and zooplankton (Ragonha et al., 2014; Braghin et al., 2015).

The three age readings of the spines were very consistent and presented low APE values. Reading precision is generally associated with factors such as reader experience, the preparation process of the material (possible damage to growth rings) and type of structure used (Campana, 2001; Zymonas and McMahon, 2009). Some authors have pointed out that otoliths are more precise and reliable structures for age and growth studies because they are indifferent to the reabsorption processes (Khan et al., 2011; Van der Meulen et al., 2013); however, other structures such as scales, vertebrae and spines are used frequently and successfully (Campana, 2001; Megalofonou et al., 2003; Koch and Quist, 2007; Albuquerque et al., 2011). The maximum age recorded was 7 years (one individual); however most individuals were 3 years of age or less. In the present work, similar length values were found only in initial ages (Table 2), but the length-frequency distributions demonstrated that the individuals caught in the Corumbá Reservoir were systematically smaller than those caught in the Paraná River Basin (Holzbach et al., 2009).

No other studies refer to the mortality of *I. labrosus*, therefore it is not possible to ascertain if the values found in this study are high or low for the species, based on its biology. However, comparing the mortality in this work (0.90) with that of another catfish species *Calophysus macropterus* (Lichtenstein, 1819) on an Amazon floodplain belonging to the same family (0.42 for females and 0.40 for males) (Pérez and Fabré, 2009), our value is quite high. The reasons why mortality was high range from stochastic events that occurred at the study site to impacts caused by the damming (the reservoir was closed in 1996). Dei Tos et al. (2009) reported that the high mortality found for the dourado *Salminus brasiliensis* in the first and second years after damming might be due to increased predation of the eggs and larvae, as areas such as reservoirs have low turbidity.

Moreover, we believe that the value of estimated total mortality is near the value of natural mortality, as fishery

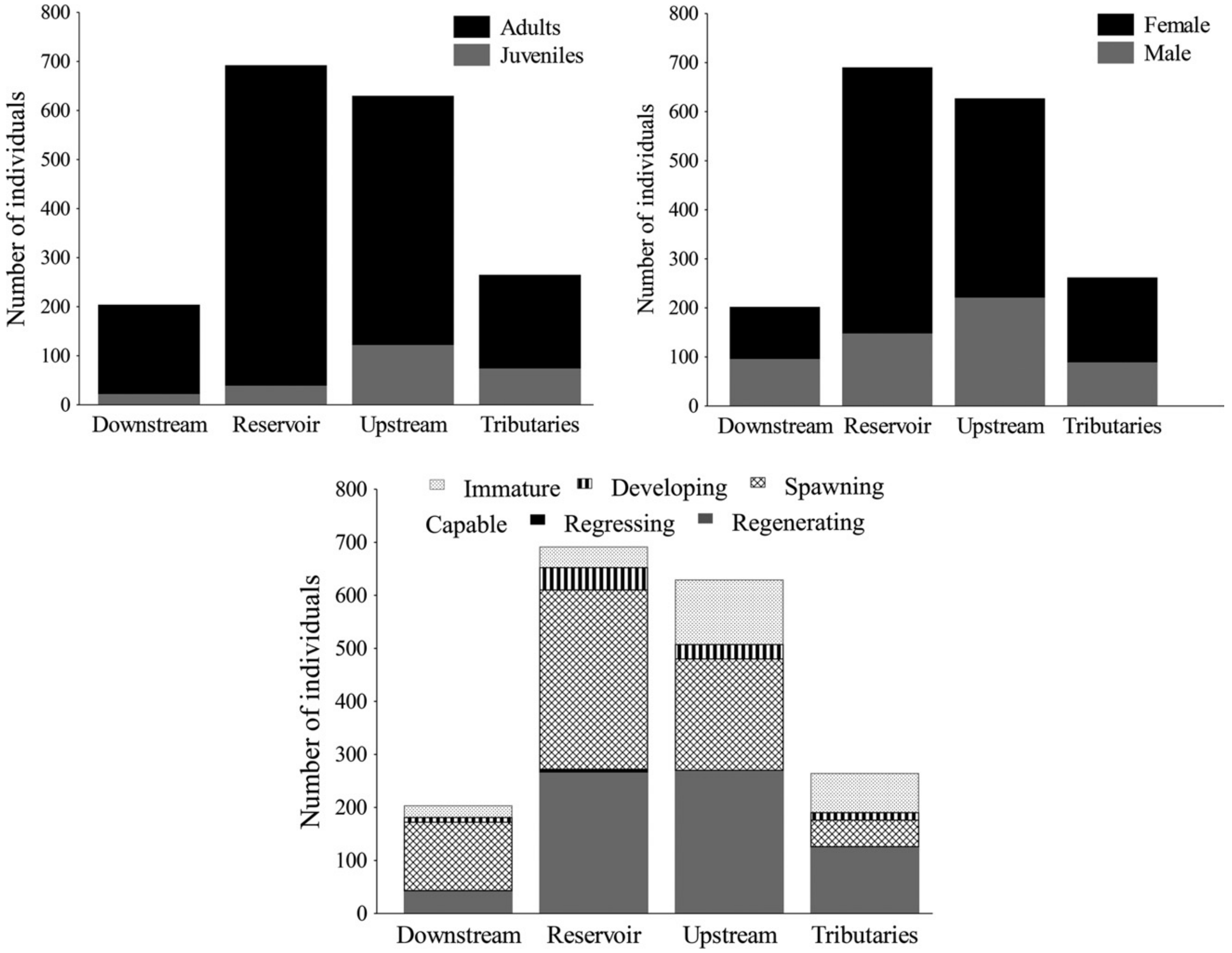

Fig. 4. Spatial distribution of juveniles and adults, males and females, and reproductive stages of *Iheringichthys labrosus* in Corumbá Reservoir and surroundings (downstream, upstream and tributaries), 1998 and 1999.

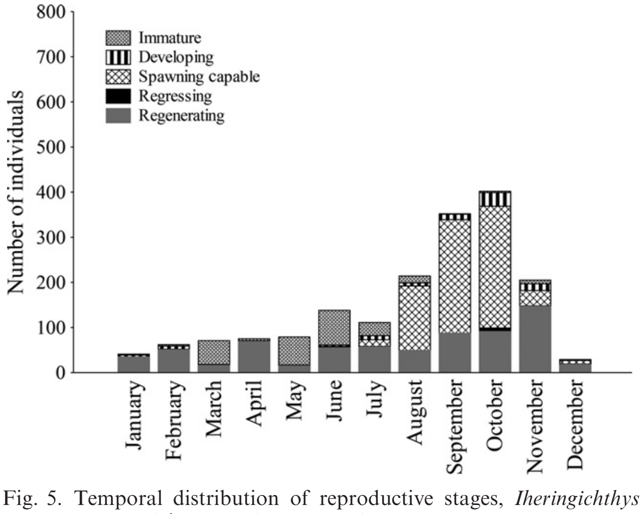

Fig. 5. Temporal distribution of reproductive stages, *Iheringichthys labrosus,* Corumbá Reservoir, 1998 and 1999.

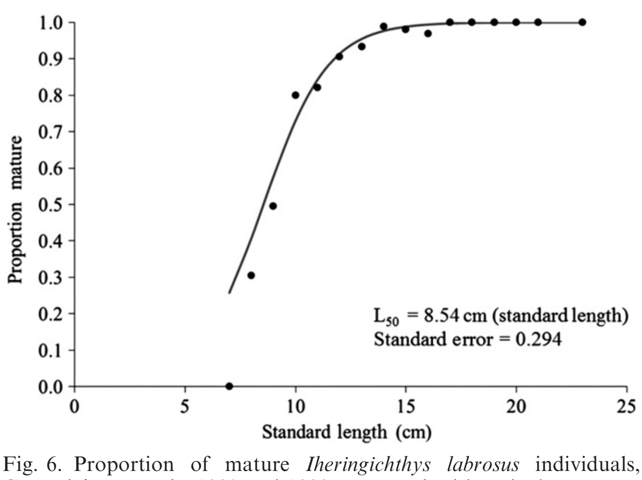

Fig. 6. Proportion of mature *Iheringichthys labrosus* individuals, Corumbá Reservoir, 1998 and 1999, per standard length class.

Table 1
Age comparisons in three independent readings

	n	d.f.	χ^2	Bowkers (p)	ACV	APE	Agreement (%)
R1–R2	146	15	10.20	0.80	12.27	8.67	74.5
R1–R3	146	15	12.00	0.67	14.14	9.99	72.5
R2–R3	146	14	16.17	0.30	9.16	6.48	79.0

N, number of samples; d.f., degrees of freedom; ACV, average coefficient of variation; APE, average percent error; R1, Reading 1; R2, Reading 2; R3, Reading 3 of *Iheringichthys labrosus*, Corumbá Reservoir, Brazil, 1998 and 1999.

Table 2
Range, mean and standard deviation of standard length measured for each age

Age +	n	LS Range (cm)	Mean (±SD; cm)
0	8	6.1–10.5	8.4 ± 1.8
1	132	6.0–16.4	9.8 ± 2.0
2	194	8.2–19.1	11.2 ± 2.1
3	43	9.6–20.2	13.2 ± 2.6
4	10	11.9–20.5	16.5 ± 2.2
5	5	14.4–17.6	16.2 ± 1.2
6	3	15.5–20.1	17.6 ± 2.3
7	1	18	18

LS, standard length; SD, standard deviation of *Iheringichthys labrosus*, Corumbá Reservoir, Brazil, 1998 and 1999.

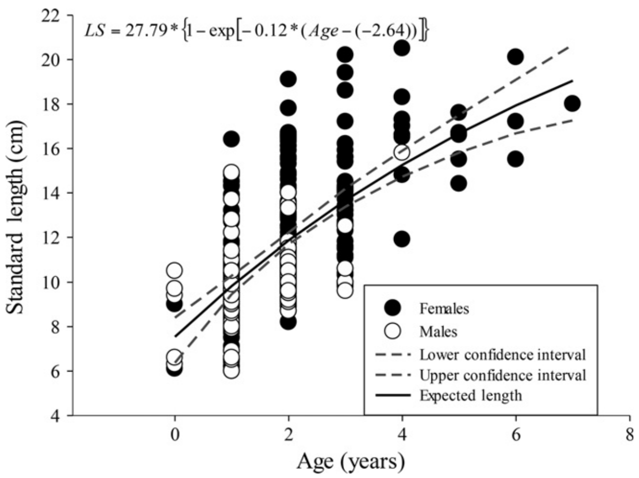

Fig. 7. Growth curve of *Iheringichthys labrosus*, Corumbá Reservoir, with respective to confidence intervals of estimated parameters. LS = standard length; Age = estimated age from spines, 1998 and 1999. Open dots = Males; Solid dots = Females.

mortality is almost zero because professional fishery activity at the study site was greatly affected by the publication of Law (‘Lei’) No. 13,025 (January 1997), in which the quota (in kg) per fisher was reduced. This law was later broadened by Decree (‘Portaria’) No. 50 (February 2003), which limited this quota even more to 5 kg per fishery license (per fishing trip). Transport of fish is prohibited until 2016 [see Normative Ruling (‘Instrução Normativa’) No. 0002/2013 of the Secretary of the Environment and Water Resources of the state of Goiás (‘Secretaria do Meio Ambiente e dos

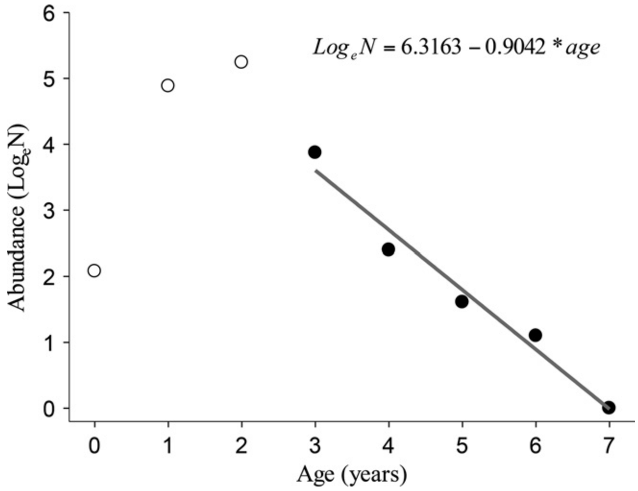

Fig. 8. Catch-curve and total mortality estimate, *Iheringichthys labrosus*, Corumbá Reservoir, Brazil, 1998 and 1999.

Recursos Hídricos de Goiás’)], although sport fishing is permitted.

Despite being an abundant species in several places (mainly the Paraná River) (Agostinho et al., 1997; Benedito-Cecilio and Agostinho, 2000), little is known about its population dynamics. In addition, despite the difficulty in obtaining actual estimates of mortality, the values presented here can be used as a first indication of the total mortality of the ‘mandi’, since the catches per fishery are infrequent and not motivated by profit. Although we did not perform a temporal analysis, these results clearly demonstrate how the population of a short-distance migratory species is structured after the formation of a reservoir. In addition, the distribution of juveniles and adults, and the reproductive stages, emphasizes the importance of the maintenance of tributaries, because dam-free stretches are fundamental to the establishment and growth of numerous species.

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