Reproduction, food dynamics and exploitation level of *Oreochromis niloticus* (Perciformes: Cichlidae) from artisanal fisheries in Barra Bonita Reservoir, Brazil

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Abstract: Nile tilapia (*Oreochromis niloticus*), which is exotic to South America, is the most common species caught in artisanal fisheries at the Barra Bonita Reservoir, Southeastern Brazil. This species is of great socio-economic importance for the region and keeps active a population of about 500 fishers. In the present study we assess reproduction, food dynamics and level of exploitation of *O. niloticus*, caught by artisanal fisheries in the Barra Bonita Reservoir. Specimens were collected monthly, from July 2004-June 2005, and a total of 1 715 specimens were analyzed. Each specimen was examined to obtain biological and biometric data: standard length (cm), total weight (g), reproductive data (sex and stage of maturation), and stomach contents (empty, partly full, and full). We also estimated the sex ratio (by macroscopic observation of gonads), reproductive period (by ovarian development and seasonal average of gonadosomatic index in females), and feeding habits (by stomach contents). The possible relationship between abiotic factors and the reproductive period was statistically verified using Spearman's Rank Correlation. The FiSAT (ELEFAN I) package was used to assess growth parameters, mortality rates and to infer exploitation rate from standard length frequencies. The *O. niloticus* population had a sex ratio of 1.3:1 (M:F). Results indicated that ripe females were captured throughout the year, with a higher frequency during the winter-2004 (with a frequency of 59%, at a mean temperature of 20.5°C), and in spring-2004 (with a frequency of 60.5% at a mean temperature of 21.18°C). The GSI mean values obtained by season were: winter-2004: 1.71; spring-2004: 1.72; summer-2005: 0.80, and autumn-2005: 1.19. The Spearman correlation indicated positive values with respect to pH, dissolved oxygen, electric conductivity, transparency and chlorophyll *a*, and negative values with respect to temperature, accumulated rainfall and altimetric benchmark. The main food items were phytoplankton and periphytic algae, observed in 99.6% of the analyzed stomachs. The estimated growth and mortality parameters were: L∞=33.60cm, k=0.63/year, longevity= 4.76years, Z=2.81/year, M=1.20/year and F=1.61/year. The weight-length relationship was Ln Wt=–2.8532+2.8835 Ln Lp. The estimated yield per recruit values were as follows: E=0.570, E_{max}=0.776, $E_{0.1}$=0.604 and $E_{0.5}$=0.349. These results indicate that a well established population of *O. niloticus* is present at Barra Bonita Reservoir; with an active reproduction throughout the year, more intense during winter and spring, and that *O. niloticus* is a phyto-planktophagus species. There were no indications that this species is being overfished, we therefore recommend that, due to its exotic condition, no restrictions need to be taken on its fishing activities. Rev. Biol. Trop. 60 (2): 721-734. Epub 2012 June 01.

Key words: Tietê river, exotic species, Nile tilapia, *Oreochromis niloticus*, fisheries, stock.

Oreochromis niloticus (Linnaeus 1758) (Nile tilapia), with a known ability to adjust to various environmental conditions and its high potential for aquaculture, can now be found in many reservoirs in almost all continents (McCrary *et al*. 2007). In Brazil, *O. niloticus* was first introduced in the 1930s to increase fish production in the Northeastern dams (Lovshin *et al*. 1976), and into the upper Paraná River in the 1950s, also with the purpose of increasing

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fish production (Carvalho *et al.* 2005). In the 1970s, following legal requirements, the Energetic Company of São Paulo (Companhia Energética de São Paulo-CESP) began a fish stocking program in the reservoirs under its grant, introducing a number of tilapia species, including *O. niloticus* and other exotic species, into ten reservoirs of the Tietê, Paranapanema, and Grande Rivers (CESP 1998).

Oreochromis niloticus is now well established in a number of Brazilian reservoirs that are of prime importance to artisanal fisheries: dams in the Northeast (Paiva *et al.* 1994), at the Billings Reservoir (Minte-Vera & Petrere Jr. 2000), in Pampulha Lagoon (Alvares *et al.* 2000), Paranoá Lake (Walter & Petrere Jr. 2007) and in the Barra Bonita Reservoir (Petesse *et al.* 2007). *Oreochromis niloticus* is the most important species of the artisanal fisheries in the Barra Bonita Reservoir, producing a yield estimated at 15tons per day. This supports the livelihoods of about 500 fishers and has great socioeconomic relevance for the region (Novaes 2008). It is thus important to understand the biology of this species and to evaluate its stock in the reservoir. The elimination of *O. niloticus* from the reservoir would be extremely difficult, if not impossible. Results from this study may, however, assist in the management and control the species in order to ameliorate environmental impacts.

The objective of this paper was to characterize the population dynamics of *O. niloticus* in the Barra Bonita Reservoir. The artisanal fishery landings, and the population reproduction (reproductive period and sex ratio), feeding, and growth were studied. Besides, parameters associated with mortality (total mortality, natural mortality, and fishing mortality) were analyzed and the current status of the stock was assessed, using Beverton & Holt's model of analysis of yield per recruit.

MATERIALS AND METHODS

Data collection: Sampling was conducted at the Barra Bonita Reservoir (22°31'10'' S - 48°32'03'' W), for which the Tietê and Piracicaba Rivers are the main tributaries (Fig. 1). Due to ongoing releases of high volumes of untreated domestic sewage, the reservoir is currently considered as hypertrophic (Straškraba & Tundisi 2000). Monthly samples were collected from July 2004 to June 2005 at two fish landing sites: in Rio Bonito (22°40'52.1'' S - 48°18'16.2 W) and in Anhembi (22°47'10''S - 48°07'27'') (Fig. 1). After the arrival of fishers, a total of 20kg (about 80 individuals)
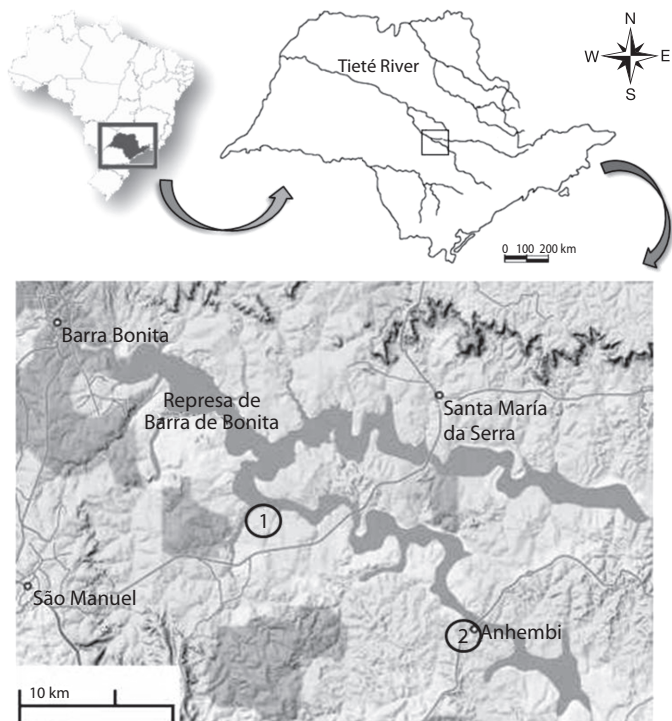
Fig. 1. Barra Bonita Reservoir with detail for the fishing landing sites where the samples were made: **(1)** Rio Bonito and **(2)** Anhembi.

of *O. niloticus* caught in lacustrine environment was randomly chosen for analysis and included in a box for transportation. For each specimen, total weight (g), standard length (cm), sex, and maturation status (according to the scale described in Helfman *et al*. 2007) were recorded. Besides, full stomachs were fixed in 5% formaldehyde for later analysis of stomach contents. A total of 1 715 specimens were analyzed. Data was grouped by to analyze reproduction and feeding by season: winter-2004 (July, August, September); spring-2004 (October, November, December); summer-2005 (January, February, March), and autumn-2005 (April, May, June).

Reproductive dynamics: The sex ratio and the sex frequency determined (N=1 687, immature specimens) were obtained by macroscopic observation of gonads. For the reproductive biology analysis only females (N=744) were used, because they are better indicators of the reproductive period (Wootton 1995). The reproductive period was evaluated using the following techniques: distribution and frequency of macroscopic stages ('immature', 'mature', 'ripe', 'spent' and 'at rest') of the ovarian development, and seasonal average of the gonadosomatic index in females (GSI=the gonad weight, expressed as a percentage of body weight).

Physicochemical parameters: These were considered to determine possible influences of the environmental and/or limnological variables on the reproduction dynamics of this species. Limnological variables and water samples were obtained at a distance of approximately 50m from the river bank. A water quality analyzer (Horiba model U22) was used to measure *in situ* the following parameters: pH, water temperature, dissolved oxygen, and electrical conductivity. Water transparency was also determined with a Secchi disk. Additionally, water samples (of about 500mL) were collected in appropriate bottles for total alkalinity and chlorophyll *a* (Chl *a*) content determination. In the laboratory, total alkalinity

was estimated by titration with 0.1 N H_2SO_4, and Chl *a;* was determined using Millipore AP20 membranes and cold acetone (90%) extraction (see Nogueira *et al*. 1999). Information about the monthly accumulated rainfall and the reservoir's water level benchmark were obtained from the concessionaire of Barra Bonita Hydroelectric Plant (AES Tietê S/A). Results from the limnological and environmental monitoring programme were correlated with the GSI of females (N=744).

Feeding: The contents of 180 stomachs were analyzed using the Neubauer chamber, according to Tavares & Rocha (2001). To quantify food items we followed the method of frequency of occurrence by Hyslop (1980). The classification of microscopic algae followed Round's system, using the classification key described in Bicudo & Menezes (2006). Algae were identified to the Division taxonomic level.

Length-weight relationship: For this and the following analysis, all available specimens (N=1 715) were used. The length-weight relationship was calculated with the next mathematical expression, after a logarithmic transformation of the data:

$$\ln Wt = a + b \ln Lp,$$

where Wt=total weight, Lp=standard length, a=a constant and b=inclination of slope.

Growth parameters and mortality estimates: Based on monthly distributions of standard length frequency, the following growth parameters were obtained: L¥ =asymptotic standard length (cm), and k=growth coefficient (year). These parameters were evaluated using the ELEFAN I routine within the computer program FiSAT II (Gayanilo *et al*. 2005), which is based on the von Bertalanffy equation:

$$L_t = L¥ \left[1 - \exp^{(-k\,(t - t0))}\right]$$

where L_t =length in age t, L¥=asymptotic standard length, k=growth coefficient and t_0=fish length at birth.

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The index of growth performance (Φ') was quantified using the model proposed by Pauly & Munro (1984):

$$\Phi'=\log_{10} k+2 \log_{10} L¥$$

where k is a growth constant per year and L¥ is the asymptotic length in cm.

The longevity potential was estimated according to the equation of Pauly (1980): $T_{max}=3/K$. The length-age structure was evaluated using the von Bertalanffy equation (described above). We used the parameters L∞ and K calculated in this paper, and replaced t with ages ranging from 0-5 years. The parameter t_0 was considered as zero, because it is not biologically significant (Sparre & Venema 1997).

The natural mortality rate was evaluated using Pauly's (1980) empirical model:

$$\ln M=-0.0152-0.279\ln L¥ +0.6543 \ln K+0.4634 \ln T$$

where L¥ and k are the growth parameters obtained from the von Bertalanffy equation and T=mean water temperature (°C), which was 24.6°C.

Total mortality rate (Z) was estimated using Beverton and Holt's model:

$$Z=k*(L∞-L_m)/(L_m-Lc)$$

where Lc=mean length at first capture, and L_m =mean length starting from Lc.

For the purpose of this study, Lc was taken as 15.0cm and L_m was 18.7cm. The mortality rate due to fishing (F) was calculated as the difference between the total mortality rate (Z) and the natural mortality rate (M) (i.e., F=Z-M).

Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R): Y'/R was calculated using Beverton & Holt's method, modified by Pauly & Soriano (1986), and the Knife Edges option of the program FiSAT II (Gayanilo *et al*. 2005), according to the following model:

$$Y'/R=EU^{M/K} [1-(3U/1+m)+(3U^2/1+2m)-U^3/1+3m)],$$

where m=(1-E)/(M/k)=k/Z, U=1-(Lc/L¥) and E=F/Z (exploitation rate).

We also calculated E_{max} (exploitation rate of maximum sustainable yield), $E_{0.1}$ (exploitation rate at which the marginal increment of Y'/R is 10% of its virgin stock) and $E_{0.5}$ (exploitation rate that will result in a 50% reduction of the non-exploited biomass). The relative biomass per recruit (B'/R) was estimated as B'/R=(Y'/R)/F. For these estimates we used the routine ELEFAN I in the program FiSAT II (Gaynilo *et al*. 2005).

The χ^2 test was used to evaluate if the male to female ratio of the population was 1:1. Before applying parametric tests, the data were transformed (ln) and their normality and homogeneity were analyzed using Kolmogorov-Smirnov's and Bartlett's tests, respectively. A one-way ANOVA was applied to test the null hypothesis of equal GSI values for different periods of the year and Tukey test was used to detect statistical differences. The t-test was applied to test whether the value of *b* of the length-weight relationship was equal to zero and whether *b*=3 (the condition of isometric growth). Because the data for the abiotic factors did not meet the assumption of variance normality and homogeneity, Spearman's non-parametric correlation test was applied to examine possible relationships between abiotic factors and reproductive period, through values of GSI. For all statistical analyses p<0.05.

RESULTS

Reproductive dynamics: Males comprised 56.1% (n=946) and females 43.9% (n=741) of the catches, with a sex ratio (M:F) of 1.3:1 (χ^2=24.911, d.f.=1, p<0.000). Seasonally, females predominated in winter-2004, comprising 251 (61.5%) and males 157 (38.5%) of the total; M:F=0.6:1, χ^2=21.657, d.f.=1, p<0.0000. Nevertheless, males predominated in the other seasons. In spring-2004 males comprised 246 (62.6%) and females 147 (37.4%) with M:F=1.7:1, χ^2=24.939, d.f.=1

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and p< 0.0000. In summer-2005, males represented 316 (69.5%) and females 139 (30.5%), M:F=2.3:1, χ^2=68.855, d.f.=1 and p <0.0000. In autumn-2005, males were 227 (52.7%) and females 204 (47.3%), M:F=1.1:1, χ=1.227, d.f.=1 and p<0.2893.

The distribution frequency of gonadal stages indicated that ripe females were present throughout the year, but relative frequencies of females were higher in the winter-2004

(N=148, 59.0%) and in spring-2004 (N=89, 60.5%) (Fig. 2a). Average values of GSI were as follows: winter-2004: 1.71, spring-2004: 1.72, summer-2005: 0.80 and autumn-2005: 1.19. The ANOVA showed statistical differences between GSI values among seasons ($F_{(3;733)}$=30.754, p<0.0000) (Fig. 2b).

Physicochemical parameters: Spearman correlation analysis indicated that average values of GSI were positively related to pH,
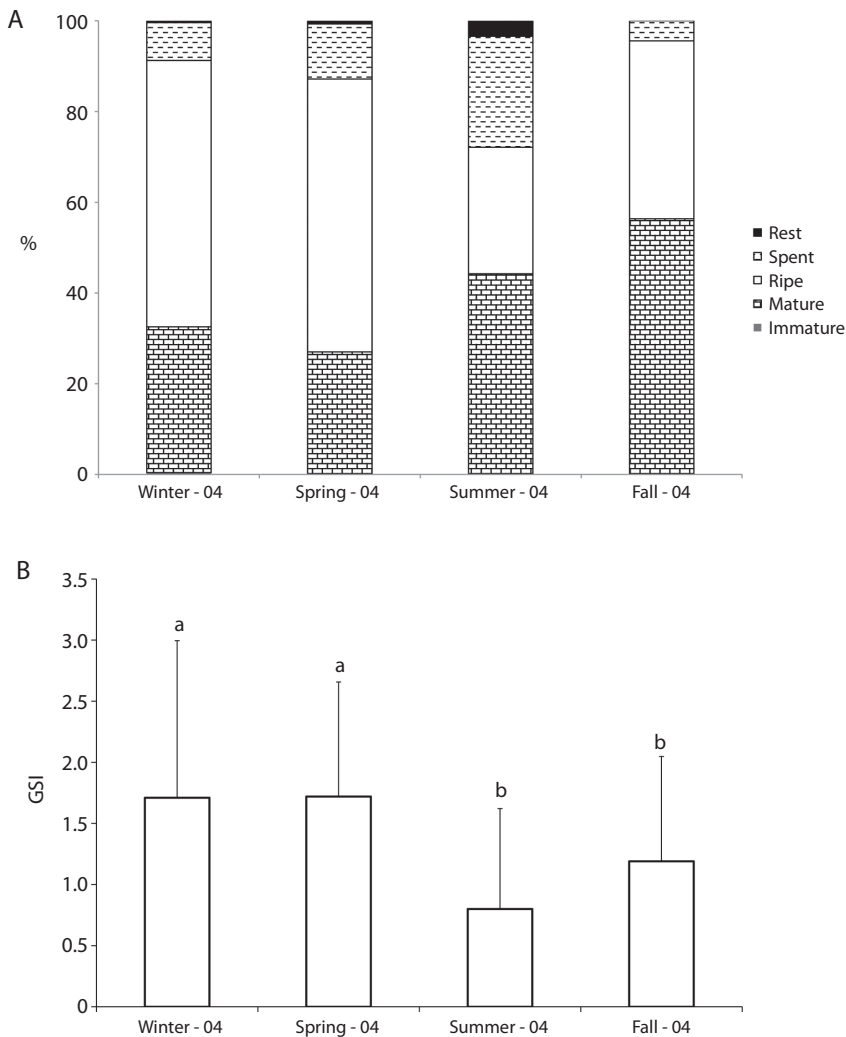
Fig. 2. (a) Frequency of gonad development stages of *Oreochromis niloticus* females at Barra Bonita Reservoir, sampled from artisanal fishery, (b) Gonadosomatic index (GSI) for *Oreochromis niloticus* females at Barra Bonita Reservoir, sampled from artisanal fishery. Different letters indicate the statistical differences (p<0.05), in b) vertical bars indicate standard deviation.

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dissolved oxygen, conductivity, water transparency and Chl *a;* and negatively correlated to temperature, precipitation, and water level benchmark altimetry (Table 1). When water level was plotted against GSI, it was observed that GSI values presented a response to the hydrologic cycle at Barra Bonita Reservoir, with a two month delay for both increases and decreases of values (Fig. 3).

Feeding: Dietary items found in the stomachs of *O. niloticus* consisted almost exclusively of phytoplankton and periphytic algae (99.6%) with a low presence of zooplankton (0.4%). The algae group Crysophyta was predominant in winter-2004 (64.9%) and moderately high in spring-2004 (39.1%). The Cyanophyta, particularly the filamentous types, predominated in summer-2005 (41.3%) and autumn-2005

TABLE 1

Mean value and standard deviation (SD) of limnological and environmental variables measured at
Barra Bonita Reservoir during study period and result of Spearman correlation

| Variables	Mean value ± SD	Spearman correlation
pH	7.0±0.75	0.2809*
Temperature (ºC)	25.4±3.60	-0.2286*
Dissolved oxygen (mg/L)	6.47±2.75	0.2191*
Electric conductivity (µs.cm)	319.17±68.19	0.2936*
Transparency (m)	0.73±0.20	0.2875*
Alkalinity (mEQ/L)	0.92±0.19	0.0516
Chlorophyll *a* (µg/L)	384.3±238.3	0,2404*
Monthly accumulated pluviosity (mm)	86.17±70.78	-0.0751*
Altimetric benchmark (m)	449.66±1.45	-0.1945*

* statistical differences (p<0.05).
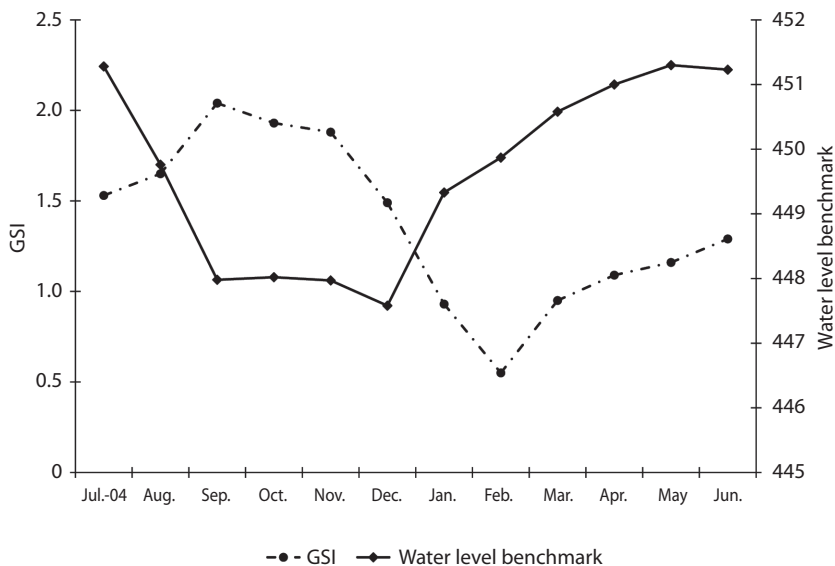
Fig. 3. Relationship between the monthly mean values of GSI for *Oreochromis niloticus* females sampled form artisanal fishery and water level benchmark at Barra Bonita Reservoir.

(62.9%) (Fig. 4). A large amount of sediment was present in fish stomachs, suggesting that *O. niloticus* may search for food along the bottom of the reservoir.

Length-weight relationship: The standard length of *O. niloticus* varied from 11.0cm-31.2cm (Lp$_{maen}$=18.3cm, SD=2.1), but most of the specimens were between 17.0cm-17.9cm. The length-weight relationship can be described by the formula: ln Wt=-2.8532+2.8835 ln Lp, where R^2=0.8941. The *t*-test indicated a value of *b* that differed from zero ($t_{(1:1713)}$=119.28, p=0.00) and three (the condition of isometric growth) ($t_{(1:1713)}$=75.76, p=0.00), thus indicating negative allometric growth.

Parameters of growth and mortality estimates: Growth parameters were as follows: L∞=33.60cm, k=0.63/year (Table 2). The length growth equation was as follows: L_t=33.60[1exp$^{(0.63 (t-t0))}$]. The length growth curve suggested the presence of two well-defined cohorts (Fig. 5). The index of growth performance was estimated to be Φ'=2.85 (Table 2).

TABLE 2

Estimates of parameters of growth, longevity, natural mortality (M), total mortality (Z), fish mortality (F) and relative yield per recruit of *Oreochromis niloticus*, sampled from artisanal fishery at Barra Bonita Reservoir

Parameters	Estimated values
L∞ (cm)	33.60
k (year)	0.63
Longevity (years)	4.76
M (year)	1.20
Z (year) Beverton & Holt model	2.81
F (year)	1.61
E	0.570
E$_{max}$	0.776
E$_{0.1}$	0.604
E$_{0.5}$	0.349

Longevity potential was estimated to be t_{max}=4.76 years (Table 2). The length-age structure analysis indicated that most *O. niloticus* caught in this fishery were 1-2 years old (98.5%), of which 81.2% were about 1.5 years old (Table 3).

The values for instantaneous total mortality rate (Z), natural mortality rate (M) and fishing mortality rate (F) were estimated to be
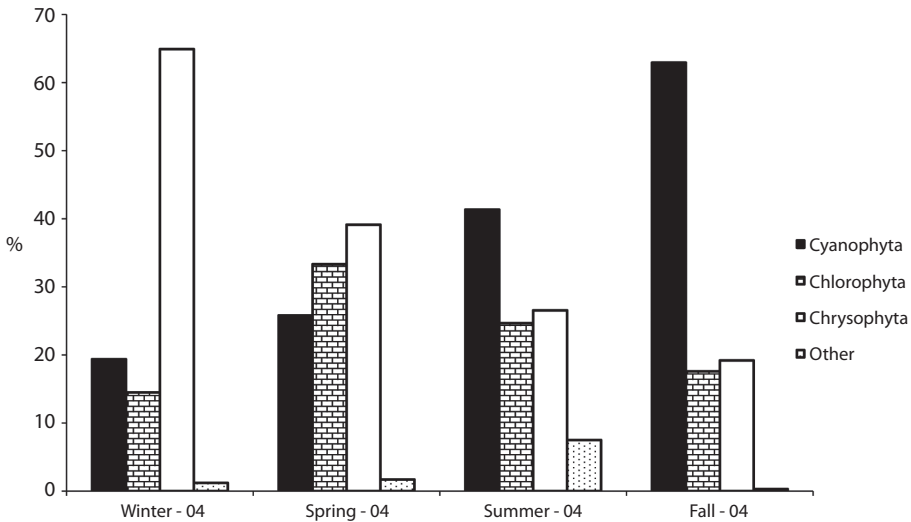

Fig. 4. Food item frequency distribution of *Oreochromis niloticus* at Barra Bonita Reservoir, sampled per season from subsistence fishery.

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Relative age (Years)	Standard length (cm)	N	%
0	0.0	0	0.0
0.5	9.08	0	0.0
1.0	15.70	88	5.1
1.5	20.54	1392	81.2
2.0	24.07	210	12.2
2.5	26.64	18	1.0
3.0	28.52	4	0.2
3.5	29.90	2	0.1
4.0	30.90	0	0.0
4.5	31.63	1	0.1

2.81/year, 1.20/year and 1.61/year, respectively (Table 2). Mortality due to fishing was more important than the other causes of mortality (F>M). Table 4 provides a comparison, based on parameters for growth and mortality, between this study and other studies in *O. niloticus*.

Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R): The values of E (0.570) and E_{max} (0.776) (Table 2) indicate that overfishing of *O. niloticus* is not occurring in the Barra Bonita Reservoir (i.e.,

$E < E_{max}$). It was, however, noted that the value of E exceeded the value of $E_{0.5}$ (0.349) and was very close to $E_{0.1}$ (0.604) (Table 2).

DISCUSSION

Reproductive dynamics: The sex ratio of most fish species in the wild tends to be 1:1, but deviations can occur and seasonal variations are common (Helfman *et al.* 2007). The sex ratio is influenced by several factors, including mortality, longevity and growth rate; these in turn lead to differences in the catch rate (King & Etim 2004). Differences in sex ratio for tilapia species have been verified in introduced populations such as *O. niloticus* in Mexico (Peña-Mendoza *et al.* 2005) and in Lake Victoria, Kenya (Njiru *et al.* 2006) and in natural populations, such as *Tilapia mariae* in Nigeria (King & Etim 2004) and *O. esculentus* in Lake Victoria and Lake Kyoga (Nagayi-Yawe *et al.* 2006). Two possible reasons may account for the sex ratio observed in our study. Firstly, it may relate to the reproductive strategies of the population and to differences in the dispersal of males and females after completion of the reproductive process. Lowe-McConnell (1987) reported that males make nests in shallow water during the reproductive process. Females release the eggs immediately after spawning (the eggs are usually fertilized in
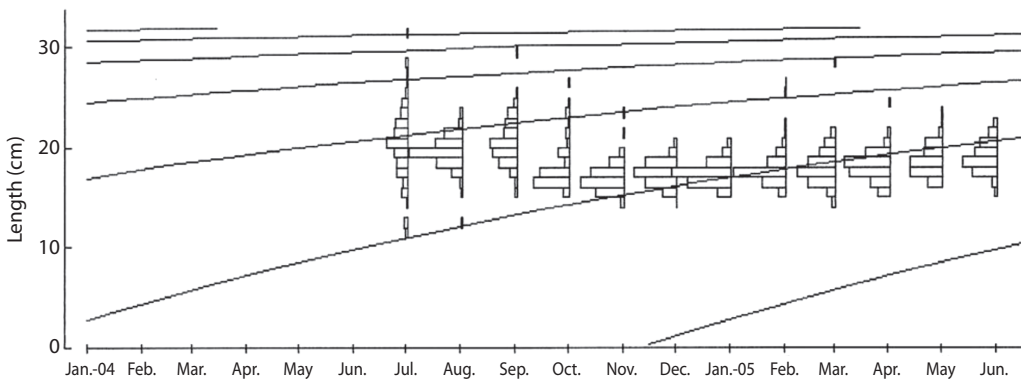

Fig. 5. Length frequency distribution and growth curve in standard length evaluated for *Oreochromis niloticus*, sampled from artisanal fishery at Barra Bonita Reservoir.

TABLE 4

Comparative data for growth (L∞, k), natural mortality (M), total mortality (Z) and fish mortality (F) parameters of *Oreochromis niloticus* from other and the present investigation

Reservoir	L∞ (cm)	k/year	M/year	Z/year	F/year	Reference
Tabbowa (Sri Lanka)	50.7	0.64	1.96	1,17	0.79	Amarasinghe (2002)
Kaudulla (Sri Lanka)	54.5	0.35	1.95	0,75	1.07	Amarasinghe & De Silva (1992)
Minneriya (Sri Lanka)	54.5	0.43	3.57	0.87	2.61	Amarasinghe & De Silva (1992)
Bontanga (Ghana)	23.6	0.58	1.35	1.90	0.55	Ofori-Danson & Kwarfo-Apegyah 2008)
Bontanga (Ghana)	23.6	0.58		1.90		Kwarfo-Apegyah *et al.* (2008)
Guarapiranga (Brazil)	28.7 (female)					Barbieri *et al.* (2000b)
Guarapiranga (Brazil)	33.0 (male)					Barbieri *et al.* (2000b)
Barra Bonita (Brazil)	33.60	0.63	1.20	2.81	1.61	Present investigation

their mouth) and remain in the beds, or move to safer places for incubation and protection of the spawn. The males are, however, more likely to be caught because they disperse when searching for food. This hypothesis might explain the differences in sex ratio of *O. niloticus* in Lake Victoria (Njiru *et al.* 2006) and in the Emiliano Zapata Reservoir in Mexico (Peña-Mendoza *et al.* 2005). Secondly, differential growth rates in males and females (Wootton 1995, King & Etim 2004), with higher rates being found in males, may mean that males are more susceptible than females to capture by fishing gears (10cm mesh with opposite knots). We performed exploratory data analysis, which did not reveal significant differences in the growth rates of *O. niloticus* males and females, in the Barra Bonita Reservoir. Thus, the differences in the sex ratio observed in this study are likely to relate more to reproductive behavior than to growth rates.

An analysis of average values of GSI and the frequency distribution of maturation stages indicated that *O. niloticus* reproduced throughout the year in the Barra Bonita Reservoir, with reproduction peaks in winter and spring. A long reproductive period for this species was reported in other ecosystems in which it was introduced, although reproductive peaks varied among localities (Cala & Bernal 1997, Barbieri *et al.* 2000a, Duponchelle *et al.* 2000, Gómez-Márquez *et al.* 2003, Peterson *et al.* 2004, Pena-Mendonza *et al.* 2005, Njiru *et al.* 2006,

Komolafe & Arawono 2007, Kwarfo-Apegyah & Ofori-Danson 2010).

Physicochemical parameters: Exogenous factors sometimes influence endogenous reproductive processes. Some of these, such as temperature, water flow, water level, and precipitation, can serve as triggers for tropical fish reproduction (Lowe-McConnell 1987, Wootton 1995). In reservoirs in the Ivory Coast (Duponchelle *et al.* 2000) and Ghana (Kwarfo-Apegyah & Ofori-Danson 2010), the reproductive period of *O. niloticus* is associated with high temperature, precipitation, water level, and higher photoperiod during summer. In the rivers of the state of Mississippi in the USA, the reproductive peak occurs in spring, when the temperature is over 22°C (Peterson *et al.* 2004). In the Guarapiranga Reservoir (Brazil), greater reproductive activity is associated with the rainy season and higher temperatures in summer (Barbieri *et al.* 2000a). Our results did not identify a positive relationship between average values of GSI in females and the water level, we believe that this variable is one of the main triggers of the increase in reproductive activity of *O. niloticus* in the Barra Bonita Reservoir during winter and spring. Because, of its position, the Barra Bonita Reservoir controls water levels in other reservoirs of the cascade system, resulting in a reversal of water flow regime compared to that found in natural environments, i.e. the lowest water levels in

the reservoir occur between September and December. The water level of the reservoir began to rise in January 2005 and reached maximum capacity from June to July, 2005. The values of GSI were a response to this hydrologic cycle, with a two-month delay in the case of both increasing and decreasing values.

Feeding: Our analyses revealed that *O. niloticus* in the Barra Bonita Reservoir is phytoplanktophagus, which is in agreement with results from African (Bwanika *et al.* 2004, Njiru *et al.* 2004) and Asian reservoirs and lakes (Weliange & Amarasinghe 2003). The presence of large quantities of sediment in the stomach contents suggests, however, that *O. niloticus* may also be taking food from the bottom of the reservoir, where accumulated organic matter is available, often in large quantities (Hahn & Fugi, 2007, Vidotto & Carvalho 2009). Thus in addition to phytoplankton and periphytic algae, bacteria, protozoa and fungi from the sediment may also be a source of food for *O. niloticus*.

Dietary analysis indicated seasonal differences in diet, with a predominance of chrysophytes during winter and spring-2004 and cyanophytes in summer and autumn-2005. Seasonality in diet is a result of variation in the availability of food in the environment. These variations can occur for many reasons, including life cycle changes of prey, changes in the predators preying on the food item, and changes in the foraging habitat (Wootton 1995). In Sri Lankan reservoirs, the diet of *O. niloticus* varied from phytoplankton to zooplankton to detritus, depending on the availability of these items in the environment (Weliange & Amarasinghe 2003). In Lake Victoria, phytoplankton and zooplankton, insects, vegetation, and fish were also part of the diet of this species (Njiru *et al.* 2004). The phytoplankton community in the Barra Bonita Reservoir consisted mainly of chrysophytes, cyanophytes, and chlorophytes and the availability of these algal groups varied seasonally (Matsumura-Tundisi & Tundisi 2005). Although *O. niloticus* feeds mostly on phytoplankton throughout the year, it is also

well adapted to seasonal variations in the availability of various food items. Thus, we inferred that the population of *O. niloticus* was able to survive on food resources available at Barra Bonita Reservoir along the year.

Length-weight relationship: Samples caught in the fishery were mainly adult and they had probably already reproduced at least once; few young individuals were caught. The *O. niloticus* fishery does not focus on young fish. Accordingly, fishery pressure does not yet seem to be a threat to the stock. On the other hand, fishery pressure on larger individuals may result in genetic degradation in the population. The removal of larger individuals favors the survival of smaller individuals and those that grow more slowly. This changes the genetic variability of the population, because it eliminates genes that promote rapid growth (Conover & Munch 2002). Furthermore, older and larger females tend to spawn earlier and lay more eggs. Larvae from these eggs grow three times faster, and are more resistant to periods of low food availability, than those born from young females (Berkeley *et al.* 2004). Thus the conservation of larger individuals, which are currently the target of the fishery due to fisheries legislation, is crucial for the maintenance of fish stocks.

The *b* value of *O. niloticus* (2.8838) was statistically different from three. This is an indicative of negative allometric growth (i.e. the species exhibited faster gains in length-growth than in weight). In contrast, Njiru *et al.* (2006) reported positive allometric growth in this species in Lake Victoria, and in the Betania Reservoir in Colombia (Cala & Bernal 1997), and the Guarapiranga Reservoir in Brazil (Barbieri *et al.* 2000b), isometric growths were reported. Values of *b* often oscillate between 2.5 and 3.5, depending on the species. Natural intraspecific variation, in terms of sex and age and the influence of season, type and availability of food and reproductive period, has been observed (Lalèyè 2006). For these reasons research workers need to be cautious when interpreting the meaning of *b*, because

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temporal variations in the value may occur naturally. Santos *et al*. (2004) studied *Geophagus brasiliensis* (a Brazilian cichlid) in reservoirs and concluded that stress caused by variations in the reservoir level, may have contributed to the negative allometric growth observed for this species. Water level fluctuations in the Barra Bonita Reservoir were estimated at about five meter. The hypothesis that stress, induced by variation in the fluctuation of the reservoir's water level, affected *O. niloticus* growth is thus feasible. This could be due to more energy being allocated to reproduction than to growth, causing a decrease in the weight of individuals.

Parameters of growth and mortality estimates: Growth parameters for *O. niloticus,* estimated using FiSAT, were biologically feasible, because the growth performance rate (Φ'=2.85) was within the range estimated for other cichlid populations (Moreau *et al*. 1986, De Silva *et al*. 1988, Amarasinghe & De Silva 1992, Amarasinghe 2002, King & Etim 2004). The growth parameters estimated for the species ($L\infty$=33.6cm, k=0.63/year and longevity 4.7 years) indicated rapid growth. According to some authors (Lowe-McConnell 1987, Winemiller 1989) species at a low trophic level, such as *O. niloticus*, tend to have rapid growth, short longevity, and early sexual maturation, that applies to the present results. When we compared the growth parameters ($L\infty$ and k) and the mortality rates (Z, M and F) estimated for *O. niloticus* in our study, with those estimated in other studies, several differences were apparent. Various endogenous and exogenous factors influence fish growth (Helfman *et al*. 2007) and these may be responsible for the observed differences. The level of fishing effort is a variable that clearly affects growth and mortality rates (Sparre & Venema 1997). This factor was identified as the cause of differences (in terms of growth and mortality rates) between species of *Oreochromis* in two Asian lakes (Amarasinghe 2002). It is likely that high fishing efforts (Maruyama *et al*. 2009) will affect the growth and mortality rates of *O. niloticus* in the Barra Bonita Reservoir.

Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R): The value of Y/R' in our study indicates that stock is not being over-fished. The observations that E is greater than $E_{0,5}$, that E is very close to $E_{0,1}$, and that F is greater than M, all suggest that the current fishing effort is very close to the maximum sustainable level. The artisanal fishing effort in the Barra Bonita Reservoir currently includes a contingent of about 500 fishers and 200 boats (Maruyama *et al*. 2009), which represents the maximum effort for the artisanal fisheries in this reservoir. It is necessary to take appropriate management steps so that the artisanal fishery does not decline in the reservoir.

Based on present results, we came to a number of conclusions: (i) *O. niloticus* is well established in the studied areas of the reservoir; (ii) The long reproductive period (more intense in winter and spring) and the phytoplankton feeding habit characterized in this study agree with results from other studies on *O. niloticus*; (iii) The fish stock is not currently over-fished, but the level of exploitation by the artisanal fisheries is close to the maximum sustainable level. Since *O. niloticus* is exotic to the Barra Bonita Reservoir, conservation measures to protect this species, such as temporary prohibition of fishing, prohibition of fishing gear, controls of fish size caught and control of fishing effort, are not recommended for this locality.

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RESUMEN

La exótica tilapia del Nilo (*Oreochromis niloticus*) es la especie mayormente capturada en la pesquería artesanal del embalse de Barra Bonita, sudeste de Brasil, de gran importancia socioeconómica para la región y para una población de unos 500 pescadores. El estudio analizó: la

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reproducción, la dinámica alimentaria y la explotación de *O. niloticus*, la cual fue capturada en la pesquería del embalse de Barra Bonita. Asimismo, se tomaron muestras mensuales y se analizó un total de 1 715 animales desde julio-2004 a junio-2005. De cada espécimen, se obtuvieron los siguientes datos biológicos y biométricos: longitud estándar (cm), peso total (g), datos reproductivos (sexo y estadio de maduración), contenido estomacal (vacio, parcialmente lleno y lleno). Estos datos fueron utilizados para estimar la proporción de sexo (a través de la observación macroscópica de las gónadas), el período reproductivo (a través de la distribución de la frecuencia de los estadios macroscópicos del desarrollo de los ovarios), y la media de la proporción del índice gonadosomático IGS de hembras, así como los hábitos alimentarios (a través de la observación del contenido estomacal). Para verificar las posibles relaciones entre los factores abióticos y el período reproductivo fue aplicada la correlación de Spearman. El software FiSAT (ELEFAN I) fue utilizado para evaluar los parámetros de crecimiento, tasa de mortalidad e inferir el grado de explotación, en donde se usaron los datos de frecuencia de longitud estándar. La población de *O. niloticus* presentó una proporción de sexo 1.3:1 (M:H). Los resultados indicaron que hembras fueron muestreadas durante todo el año, pero ha sido más frecuente en el invierno-2004-59.0% (temperatura media=20.05°C) y primavera-2004-60.5% (temperatura media=21.18°C). Los valores medios del IGS fueron: invierno-2004=1.71, primavera-2004=1.72, verano-2005=0.80 y otoño-2005=1.19. La correlación de Spearman fue positiva para pH, oxígeno disuelto, conductividad eléctrica, transparencia y clorofila *a*, y negativo para temperatura, pluviosidad acumulada y variación del nivel del agua en el embalse. Los principales ítems de alimentación fueron fitoplancton y algas perifiticas observadas en 99.6% de los estómagos analizados. Los parámetros estimados del crecimiento y mortalidad fueron los siguientes: L∞=33.60cm, k=0.63/año, longevidad=4.76 años, Z= 2.81/año, M=1.20/año y F=1.61año. La relación peso-longitud fue Ln Wt=-2.8532+2.8835 Ln Lp. Los valores de producción por reclutamiento estimado fueron=0.570, E_{max}=0.776, $E_{0.1}$=0.604 y $E_{0.5}$=0.349. Estos resultados indican que la población de *O. niloticus* está bien establecida en el embalse de Barra Bonita. Además, su reproducción ocurre durante todo el año, pero es más intensa en el invierno y primavera; su dieta tiene como base el fitoplancton. Los resultados indican que no está ocurriendo sobrepesca de *O. niloticus*, por tanto, recomendamos que, debido a su naturaleza exótica, no se tomen restricciones a la hora de su pesca.

Palabras clave: Rio Tietê, especie exótica, tilapia del Nilo, *Oreochromis niloticus*, poblaciones de peces.

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