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Ecological Features of Large Neotropical Reservoirs and Its Relation to Health of Cage Reared Fish

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1. Introduction

Environmental Brazilian legislation allow the implementation of cage culture fish farm enterprises in large public reservoirs (Ayroza et. al., 2006), aiming a qualitative and quantitative increase of inland aquaculture, regarding concerns with environmental, economic and social sustainability (Costa-Pierce, 2002; Valente, 2000). Fish farming is an important activity for animal protein production, and if well planned, is benefic to the economic development of the country. However, it is necessary continuous assistance of appropriate expertise and scientific support in order to organize and improve fishery and aquaculture (Agostinho et al., 2007). Due to low productivity of inland native fish stocks, Brazilian government aquaculture programs initially focused on change artisanal fisher to fish farmers, assuming that this could improve their economic situation. This is a mistaken philosophy, since the extrativist way of life contradicts the planned life of a modern aquaculturist. This is especially applicable for Brazilian Southeastern region, where this activity is basically maintained by intensive culture of tilapia (Furlaneto et al., 2006) by capitalized stakeholders. Food and Agriculture Organization of the United Nations [FAO] (2010) and Rojas & Wadsworth (2007) highlight that aquaculture annual growth rate surpasses other zootechnical activities. Currently, annual fish yield in Brazil, by means of aquaculture and extractive fishing, has accomplished a 1,240,000 metric tons/year baseline, of which approximately 10% are related to tilapias (*Ministério da Pesca* [MPA], 2010), predominantly *Oreochromis niloticus* and derived hibrids Lovshin, 1982). Within this context, Brazil has been showing vigorous growth (over 25% per year) in this decade, however this growth is still modest considering the prodigious potential of water resources and suitable weather that Brazil offers (Godinho, 2007; MPA, 2010). It is evident that Brazilian aquaculture production is behind its potential comparing to Chinese fish yield, that produces approximately 47.5 millions of metric tons/year (FAO, 2010). Fitzsimmons (2006) highlights Brazil as a prominent country that could compete with China as biggest fish producer in the world. The Paraná River is the second largest catchment in South America, with 3,780 km of extension, and is the main River of La Plata

River basin originating at the confluence of Paranaíba and Grande Rivers and has a watershed area of 2,800,000 km², which consists chiefly of sedimentary and volcanic rocks. The Paraná River stretches are divided into an upper course, from its source to Itaipu reservoir; a middle course along Paraguay-Argentina border; and a lower course from Paraguay River confluence to La Plata River estuary. The Upper Paraná River basin, with an extension of 809 km and area 820,000 km², has about 250 km without impoundments, resulting in a deeply altered hydrological and limnological regime (Stevaux, 1994). Currently, Brazilian inland net cage aquaculture is integrated to these large reservoirs. Within this context, in the last five decades it is noticed that Brazilian large Rivers have been impounded to build dams and power-plants, aiming hidroelectricity as a priority (Tundisi, 1993; Zocchi, 2002), to meet the increasing demand for energy in the country. This way of producing hidroelectricity energy represents 14.8% of all Brazilian energy matrix (Ministério das Minas e Energia [MME], 2006), with São Paulo state responsible for over 22% of this type of energy. These impoundments were built as a cascade system in large rivers (Grande, Tietê, Paranapanema and Paraná Rivers) (Agência Nacional de Energia Elétrica [ANEEL], 2009; Agostinho et al., 2007). Under an ecological perspective and environmental legislation, a good water quality and aquatic ecosystem integrity are fundamental to allocate the multiple uses of these large reservoirs, especially to effective organization by policy makers for aquaculture and fishing activities. In limnological terms, the determination of trophic state index (TSI) *sensu* Carlson (1977), based upon phosphorus and *a* chlorophyll contents to a specific water body, is a satisfactory and practical tool as environmental indicator, considering different human interventions that induce artificial eutrophication process. Various studies in hydrographic sub-basins of Tietê and Paranapanema Rivers show that this index usually varies. As an example, the index varies between oligotrophic to mesotrophic state for upper and middle Paranapanema stretches (Nogueira et al. 2006), and also between oligotrophic to eutrophic for Tietê River (Barbosa et al. 1999; Moretto et al., 2008; Tundisi & Straškraba, 1999). These variations are mainly due to anthropogenic actions, such as occupation of lands for agriculture, livestock, increasing urbanization due to growth of human population, and emissions of organic wastes (Tundisi, 2005). Brazilian native ichthyofauna of large rivers has been subjected to negative impacts, such as these impoundments (Agostinho et al., 2007), introduction of non-native species (Brandão et al., 2009; Latini & Petrere, 2004; Orsi & Agostinho, 1999; Santos & Formagio, 2000; Souto et al., 2011), environmental contamination, loss of riparian vegetation, sedimentation, and erosion (Agostinho et al., 2007). Currently, a new form of impact in Brazil is the increasing development of fish farming in floating cages (Ramos et al., 2008). In cage systems, the input of organic matter and nutrients is done by artificial feeds, and output is done through the removal of fish produced, similar to what occurs in fish ponds (Beveridge, 2004). However, Beveridge (2004); Munday et al. (1992); Persson (1988); and Pillay (2004) report that in fish cage farming systems up to 30% of feed is lost into the aquatic environment, in the form of unconsumed feed and wastes. These feed losses can cause problems related to eutrophication (Beveridge, 1984) and/or be used as a food resource by local biota (Beveridge, 2004; Håkanson, 2005; Ramos et al., 2008; Vita et al., 2004), resulting in ecological changes around these systems (Beveridge, 2004; Håkanson, 2005; Ramos et al., 2008). Besides these impacts, several authors as Agostinho et al. (2007); Beveridge (1984, 1996 e 2004); Dempster et al. (2002); Håkanson (2005); Karakassis et al.

(2000, 2002 e 2005); Machias et al. (2004, 2005 e 2006); Pitta et al. (2005); Ramos et al. (2008); Yucel-Gier et al. (2007); and Zanatta et al. (2010) discuss the problems of this activity in coastal and inland waters. These authors cite impacts upon water quality and sediment which have implications on the structure of benthic communities, plankton and fish, and furthermore, the inherent scapes of caged fish. Thus, it is evident the necessity of developing new technologies aiming the enhancement of fish yield, associated to decrease of environmental impacts caused by this zootechnical activity. This is a big challenge for Brazilian aquaculture that needs to guarantee its economic and social sustainability with preservation of water resources and multiple uses of public reservoirs.

2. Situation of the aquaculture in cage farms in Brazilian Southeastern reservoirs: An overview

The effects of cage aquaculture enterprises in Brazilian inland waters upon the biota and water quality have not been satisfactory elucidated yet, thus these effects still require studies aiming a full comprehension to better ordinate these activities. However, despite divergent opinions of some sectors of Brazilian society, the Brazilian government has been sponsoring studies focusing on taking advantage of the potential for aquaculture of large public reservoirs (Ayroza et al., 2006). Thus, Brazilian government has been selecting, delimitating, and controlling areas to install Aquaculture Parks in different reservoirs, based upon premises that promote sustainable development, enhancement of Brazilian fish yield, social inclusion, and food safety. Effective success of production in aquaculture founds in limnological studies and environmental carrying capacity, regarding concerns with water quality and maintenance of water resources (Costa-Pierce, 2002; Tundisi, 2005), as well as its interference upon aquatic biota, through escapes of non-native species, and pathogen dispersion (Agostinho et al., 2007; Orsi & Agostinho, 1999). According to Dillon & Rigler (1975) and Beveridge (2004), the modeling of environmental carrying capacity is done based upon two fundamental equations, which define phosphorus emission to aquatic ecosystem without inducing eutrophication, and how much P is emitted per product unit. The lack of suitable information to define application values of this modeling has been repeatedly emphasized as the highest difficulty to appraise environmental impacts caused by aquaculture (Pillay, 2004). In Brazil, cage fish farming systems has gained impulse in the mid-90's, especially in Brazilian Southeastern (Medeiros, 2002; Ono, 1998; Rojas & Wadsworth, 2007). Nowadays, this activity is in accelerated expansion in Brazilian reservoirs, and at least 40 freshwater fish species are used in Brazil, considering all kinds of pisciculture (Godinho, 2007). However, despite this rich fish diversity, the most used species for inland aquaculture in Brazil is the non-native Nile tilapia (*O. niloticus*) due to its favorable zootechnical features (Castagnolli et al., 2000; David et al, 2006; Rojas & Wadsworth, 2007). The Middle Paranapanema River area has about 800 net-cages designated to Tilapia culture along its reservoirs and ponds. It is estimated in 200 kg of fish/m^3/cycle in small net-cages (up to 6m^3); and 100 kg of fish/m^3/cycle in net-cages of great capacity (over 10m^3) (Furlaneto et al., 2006). In this sense, three issues are eminent within this approach: 1) artificial eutrophication, which is interconnected with environmental carrying capacity; 2) dispersion of parasites and pathogens and; 3) escapes, relating to depletion of fish biodiversity *lato sensu* by ecological processes of competition and predation. Below, it is followed the results of our main researches aiming to identify and quantify the ecological interferences of tilapia farming.

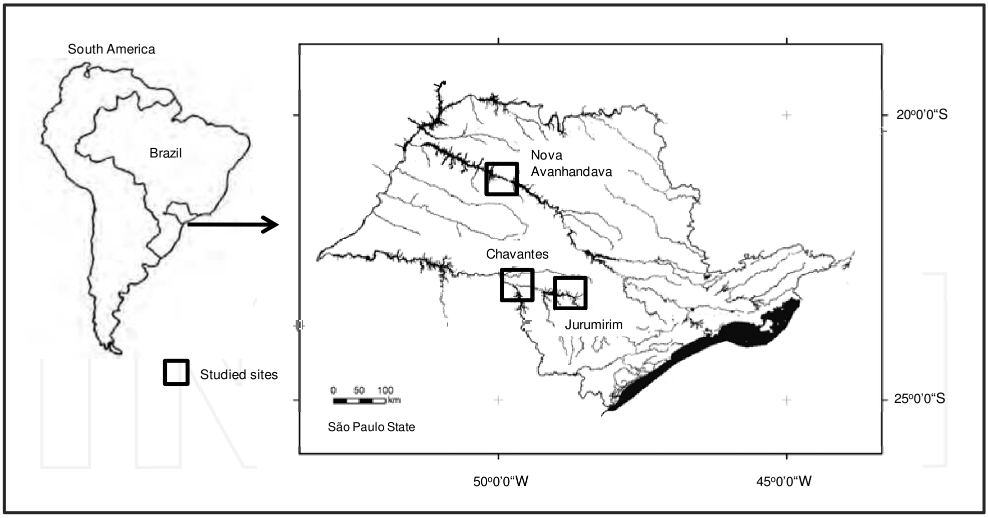

Fig. 1. Reservoirs studied in the Upper Paraná River Basin, São Paulo State, Brazil.

2.1 Limnological conditions and trophic state index

A comparative approach was used to evaluate the impact of three cage farms upon limnological conditions of the stretches were the cages are installed. These farms are located in three different reservoirs in the upper Paraná River Basin, São Paulo state, Brazil (fig. 1). The farms are small and medium-sized enterprises (ranging from 30 to 200 cages with 6 m^3 each), mainly for the culture of Nile tilapia (*O. niloticus*) using an intensive model, with high densities and fed with pelleted compound feed. An example of such farms is shown in fig. 2. Monthly surveys were performed in the farms in different years from 2003 to 2009, sampling limnological data and water samples inside the Farm Sites (referred as FS) and in similar Control areas sited upstream (CT). Differences among farm sites and control areas were regarded as effect of the nutrient loads from the farms. Limnological sampling included Secchi depth (Z_{DS}), water temperature, pH, dissolved oxygen (DO), electric conductivity (K_{25}) measured *in situ* using a water quality multiprobe Horiba model U-22; water samples were collected for nutrients (total Nitrogen - TN and total Phosphorus – TP following Valderrama, 1981; Strickland & Parsons, 1968), total suspended solids (Teixeira et al., 1978) and chlorophyll *a* (CHL, Golterman et al., 1978) analyses. TSI was determined based on CHL and TP by formulae 1 and 2, combined using formulae 3 (Carlson, 1996, as cited in Lin, 2001). The first reservoir studied by our research group was Nova Avanhandava, which is the fifth of a cascade of reservoirs on the Middle Tietê River, sampled from 2003 to 2004 (Paes, 2006). It is a run-of-river plant, that has been operated since 1982, located at 358 m above sea level, with surface area of 210 km^2, total water volume of 2,720 x 10^6 m^3, mean discharge rate of 688 m^3/s, maximum depth 30 m, level oscillation of less than 1 m throughout the year, and water residence time of 46 days (Torloni et al., 1993; Rodgher et al., 2002). The second reservoir was Jurumirim, where the surveys were done from 2004 to 2005; it is a storage plant at Upper Paranapanema River, operated since 1962, located at 568 m above sea level, total area 484 km^2, total volume of 7,900 x 10^6 m^3 mean discharge rate of 210

$m^3 s^{-1}$, mean depth 12.9 m, residence time 334 days (Henry et al., 2006) and significant level oscillation of 2.2 m along the year.

$$TSI\ (CHL) = 9.81*\ln(CHL)+30.60 \quad (1)$$

$$TSI\ (TP) = 14.42*\ln(TP)+4.15 \quad (2)$$

$$TSI = (TSI\ (CHL)+ TSI\ (TP))/2 \quad (3)$$

Fig. 2. Cage farm at Chavantes reservoir, Middle Paranapanema River Basin, São Paulo State, Brazil.

Lastly, it was studied Chavantes reservoir, that is also a storage plant in Paranapanema River, operating since 1970 in its middle stretch at 474 m above sea level. This reservoir area is 400 km^2, total volume of 8,800 x 10^6 m^3, maximum depth 80 m, residence time 281 days, mean outflow 322 $m^3 s^{-1}$, and seasonal water level oscillation is more than 3 m (Nogueira et al., 2006). The three reservoirs are in a region with annual precipitation above 1,500 mm, and with a rainy season from September to February and dry season from March to August. Limnological characterization of the three sites studied are shown in Table 1.

Limnological features of Tietê River basin are quite different from Paranapanema River basin (table 1). Ph values are higher in Tietê, reaching 9.6, while Paranapanema values were close to neutrality. Conductivity was three fold higher in Tietê, and CHL were almost ten fold higher. TP values were slightly higher at Tietê, and TN was two times higher in Nova Avanhandava than in Jurumirim, and five fold higher than Chavantes. OD mean values

Reservoirs	Nova Avanhandava[1]		Jurumirim[2]		Chavantes[3]	
Parameters/Sites	FS	CT	FS	CT	FS	CT
Temperature (°C)	20.3-31.3 (26.3±3.3)	20.0-31.2 (26.2±3.5)	18.9-27.4 (23.6±3.0)	18.4-28.2 (23.2±3.0)	19.3-27.4 (23.4±2.5)	19.6-28.7 (23.8±2.5)
pH	5.8-8.9 (8.0±0.7)	7.2-9.6 (8.2±0.8)	6.0-8.3 (6.8±0.6)	6.0-8.2 (6.7±0.8)	6.0-7.6 (7.0±0.4)	6.6-7.8 (7.1±0.3)
Dissolved Oxygen (mg/L)	6.4-9.9 (8.5±1.1)	7.0-10.0 (8.7±1.0))	6.5-8.9 (8.0±0.8)	6.8-9.0 (8.0±0.7)	6.5-11.4 (8.1±1.3)	2.2-11.5 (8.2±1.7)
Conductivity (µS/cm)	143.7-208.0 (184.8±18.5)	148.0-207.0 (183.9±19.0)	50.0-83.0 (59.3±9.4)	50.0-86.0 (59.8±9.1)	36.8-60.0 (40.5±6.0)	36.0-60.0 (40.3±6.2)
Secchi depth (m)	0.7-2.7 (1.4±0.6)	0.8-2.5 (1.3±0.5)	0.6-1.5 (0.9±0.2)	0.4-1.5 (1.0±0.3)	1.5-5.0 (3.1±0.7)	1.5-5.0 (3.1±0.8)
Chlorophyll a (µg/L)	2.2-30.5 (17.7±9.3)	5.1-30.1 (18.0±8.7)	0.5-8.0 (3.3±2.8)	0.9-3.8 (2.4±0.8)	0.9-2.3 (1.5±0.5)	0.7-5.4 (1.9±1.3)
Total dissolved solids (mg/L)	0.0-11.1 (3.8±2.8)	0.5-4.0 (2.7±1.1)	0.1-5.0 (2.0±1.5)	0.1-4.4 (1.3±1.4)	-	-
Total P (µg/L)	7.7-23.7 (14.1±3,7)	5.9-21.3 (12.7±4.3)	3.4-9.8 (7.0±2.0)	4.9-15.0 (8.2±3.6)	4.9-23.5 (11.1±5.2)	3.1-23.1 (9.7±4.1)
Total N (µg/L)	763.7-1950.2 (1282.6± 283.9)	871.0-1973.4 (1213.2± 342.5)	600.0-825.0 (669.4±72.0)	520.0-780.0 (621.3±83.5)	108.2-404.6 (244.9±74.0)	120.0-376.9 (236.0±78.7)

Table 1. Limnological characterization of surface waters of the three reservoirs studied in the Paranapanema and Tietê Rivers, Upper Paraná Watershed. Modified from [1]Paes (2006), [2]Zanatta (2007) and [3]David et al. (2011).

were above 6 mg/L in all sites, considered adequate for tilapia culture, and average Z_{DS} reached 3.1 m at Chavantes, while in the other sites were about 1 m. A concerning issue about the improvement of cage aquaculture in Upper and Middle Paranapanema reservoirs is that winter temperatures were far below 23°C (fig. 3) and in a less degree for Nova Avanhandava, assumed as a lower limit for efficient tilapia grow-out commercial systems (Shelton & Popma, 2006; Suresh, 2002). This fact can hinder aquaculture sustainability and profitability in this watershed, and suitable native species would be desirable. Paes (2006) studied a medium-sized farm, with 80 fish cages of six m³ volume, in Nova Avanhandava reservoir and concluded that the limnological variables measured showed no statistically significant differences between FS and CT (Table 1). Some of the variables were considered high, especially electrical conductivity and total nitrogen, indicating risks of water quality deterioration, a typical feature of Tietê River Watershed (Barbosa et al., 1999). The Trophic state index (TSI) was mesotrophic for both areas (fig. 4A). These conditions can be seriously aggravated by nutrient loads from cage farming activities, which can induce autopollution and loss of water quality for aquaculture purposes. Alves & Baccarin (2006) found similar values for these limnological variables, in a cage farm that uses more than 2 tons of feed per day to produce 1,500 to 1,800 kg of fish per cage per cycle. Water quality depletion is object of concerns in this basin because of widespread blooms of cyanobacteria (Fracácio et al., 2002, Tundisi, 2005). In Jurumirim reservoir, Zanatta (2007) studied a small farm with only 30 cages of six m³ volume, and no significant differences between FS and CT was found for all limnological parameters measured. The very limited scale of farming operations probably prevented impacts on water quality in this large reservoir. Thus, only natural

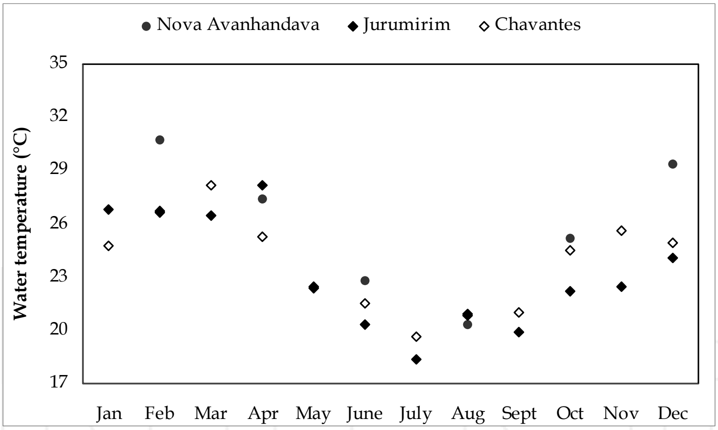

Fig. 3. Seasonal variation of water surface temperature in the studied sites.

and seasonal differences were reported. Jurumirim reservoir was oligotrophic in both areas throughout the year, except for FS (mesotrophic in August), (fig. 4B).

David et al. (2011) using data from a cage farm in Chavantes reservoir with 200 cages, found significant seasonal variation for all limnological parameters measured, but no significant differences among areas at monthly scale. In this same study, comparison of mean values (pooled data per year) of phosphorus in the water between FS and CT indicates that fish farming may be related to hipernutrification of FS in the euphotic layer ($\Delta TP=1.65 mg/m^3$, $p<0.05$), although no significant increase in chlorophyll *a* was detected. However, in the euphotic layer other limnological variables measured showed no significant differences between areas, even though depletion of dissolved oxygen in the bottom layer in FS was verified. Most of the year, oligotrophic conditions were also found in Chavantes, but switched to mesotrophic in January for CT, and in December/January for FS (fig. 4C). Simulations on the carrying capacity, due to availability of more detailed data on hydrodynamics and field farming practices in Chavantes reservoir, was also performed by 18 David et al. (2011). Data used for carrying capacity modelling were: Feed Conversion Rate (FCR): 1.5; feed total phosphorus content: 1.5%; whole fish phosphorus content: 0.9% (Dantas & Athayde, 2007), resulting on of 13.5 kg P/ton of fish produced. It is worth emphasizing that phosphorus loads can be greatly influenced by FCR (fig. 5), which itself is related to the welfare of fish and their physiological condition. In addition to unprofitability, the cultivation of tilapia at temperatures below the optimal nutrient emissions increases, which brings higher risks of eutrophication. Hydrological data of FS used in modelling were: original total phosphorus water content of 10.85 mg/m^3, maximum allowable TP water content of 30.0 mg/m^3, and sedimentation rate of 0.083 (Larsen & Mercier, 1976). Retention time used was 1 day for precautionary purposes, according to estimates of Persson et al. (1994) and direct ADCP measurements was less than 1 day, with measured water current velocity from 0.1 to 0.3 m/s.

Maximum allowable fish production in the area was estimated to be 1666 tons/year, while the theoretical fish production that would result on the observed increase of TP was 144 tons/year while total tilapia production of approximately 55 tons/year. These results

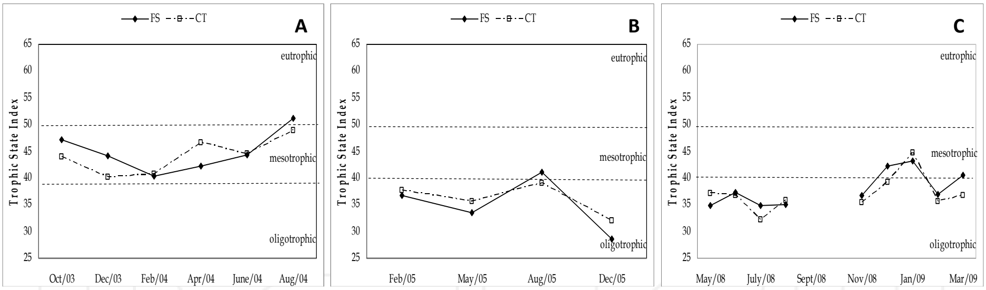

Fig. 4. Seasonal variation of Trophic State Index (TSI) for FS and CT for Nova Avanhandava (A), Jurumirim (B) and Chavantes (C) reservoirs.

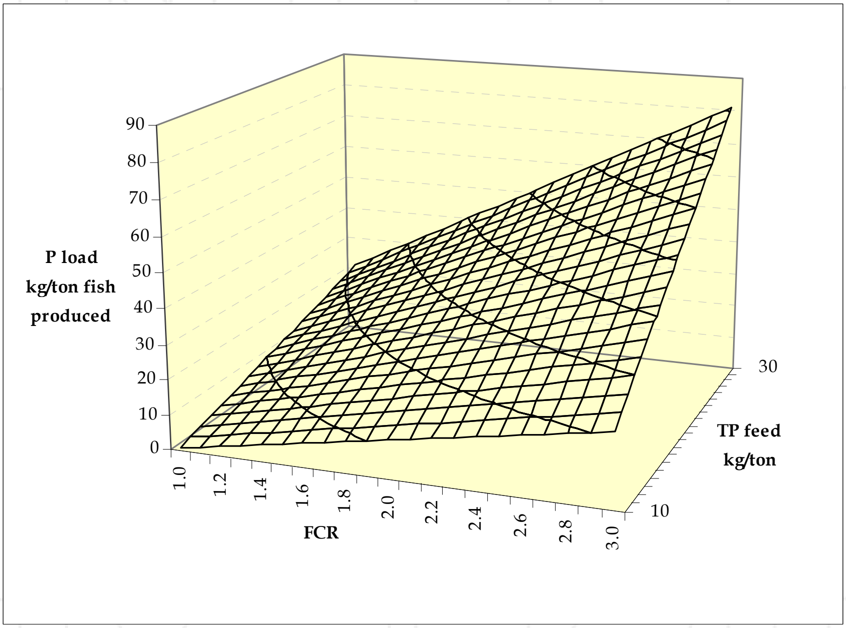

Fig. 5. Effect of FCR and feed composition on Phosphorus loads by fish cage culture

indicate that fish production at FS is compatible with the local carrying capacity for the assimilation and recycling of nutrients derived from aquaculture.

Regarding water quality, conditions may be considered adequate, with no signals of surpassing eutrophication thresholds. Dillon & Rigler mass balance model overestimated the fish production needed to cause the observed FS increase, indicating that specific models are needed for the management of aquaculture in the ecosystems studied here.

2.2 Main fish parasites in cage farms

The interest in fish parasites has increased in recent decades due to economic implications, particularly for intensive fish farms. The high rates of parasitic infestations or infections can cause considerable mortality in several species of farmed fish and its treatment in some cases is very difficult, while in others, there are no currently effective treatments. The economic losses caused by parasites can often be verified in an indirect way, either by reducing the rates of assimilation and growth of infected animals, or by decreasing the value of marketable final product (Eiras, 1993). Many organisms have been associated with fish diseases. Although parasites can occur in natural environments, these organisms become more abundant in conditions of intensive cultivation and depending on the conditions of culture, they can have a deleterious effect to fishes. In eutrophic environments this situation could worsen due to the presence of many intermediate host species, favouring the life cycle of many parasites (Pillay, 2004). Our studies performed with *O. niloticus* in cage farms have shown that the main parasites affecting fish health in intensive cage systems are monogenoids, *Trichodina* spp., *Ichthyophthirius multifiliis* and *Henneguya* sp. Monogeneans (fig. 6A) are ectoparasites responsible for the most important parasitic disease of fish farming in Brazil (Martins, 1998). They are characterized by the presence of a fixation structure generally located in the back of the body, called haptor, which contain hooks, bars and anchors, in different numbers and sizes according to the species and its function is the fixation of parasite in the hosts (Gerasev, 1990). The adult parasites are elongated, oval or round and measure one to 75 millimeters. The most important monogeneans in fish farms belong to the families Gyrodactylidae and Dactylogyridae. Gyrodactilids are viviparous species and they are mostly parasites of the body surface of fish. Dactylogirids are oviparous and are found in the gills, but can also become placed in the nasal cavities and, more rarely, other parts of the body (Kubtiza & Kubtiza, 1999). The studies performed with *O. niloticus* from fish farms from Chavantes reservoir showed that the dactylogyrids *Cichlidogyrus halli* (fig. 6B-C) and *Scutogyrus longicornis* were the most abundant monogeneans found in the gills of this fish species. Dactylogyrid monogeneans are hermaphrodites and have direct life cycle, which facilitates the parasitic re-infestation. Generally in monogeneans the eggs (dactylogyrids) or larvae (gyrodactylids) leave the uterus by the genital pore, attach to the host and develops in the same host (Cheng, 1986). According to Eiras (1993), pathogenesis caused by monogeneans varies with the species and the fixation site. Monogeneans which parasitize the gills frequently cause cell hyperplasia and mucus hypersecretion. The lesions are much more serious as the parasites are most abundant, which can reach high densities. When attached to the tegument, necrosis of cells, destruction of scales and mucus hypersecretion can be observed. In cases of high intensity of infection, monogeneans can cause mortalities especially in small fish (Noga, 1996), which has been recorded for numerous fish species (Cone et al., 1983; Ergens, 1983; Lester & Adams, 1974; Mackenzie, 1970). Considering the seriousness of this disease and also the difficulty of eradicating this disease in fish after installed, it is suggested that all new fish bought undergo to quarantine and prophylactic baths using commercial formalin diluted 1:4,000 for an hour or sodium chloride in 1 to 3% from 30 minutes to 3 hours (Pavanelli et al., 1999). Another important group of organisms that can affect fish health, especially those in breeding system, includes the protozoans of the phylum Ciliophora, highlighting, *Trichodina* spp. (fig. 6D) and *I. multifiliis* (fig. 6E). Apparently, these ciliates live as ectocomensal in the tegument and gills of the fish without causing major damage, except in cases of heavy infestations, which is particularly evident in species that multiply rapidly by successive binary divisions, especially in environments with excess of organic material and low amounts of dissolved oxygen in water (Eiras, 1993). The rearing of *O. niloticus* in cage farms in Chavantes reservoir have high infection rates by *Trichodina* spp. (fig. 6D), in some cases and periods, the prevalence is 100%. Trichodinids are ciliated protozoa commonly found in both freshwater and saltwater, and show no host specificity, which favors their widespread distribution. Their morphology is characteristic, with a circular shape and the presence of an adhesive disc with a series of denticles that help fix the parasites in the host. They are usually considered ectoparasites of skin and gills of the host and can rapidly proliferate in the presence of decaying material (Heckmann, 1996). The life cycle of *Trichodina* spp. occurs by binary fission, in which the parasite divides and fixes in the host's skin (Cheng, 1986). Its pathogenesis is related to the rotatory movements of these ciliates on the gills and tegument of the host, leading to an abrasive action of the skeletal structures and denticles present in the adhesive disk, which damage the epithelial cells. Trichodinidiasis signs include loss of appetite, lethargy, excessive mucus production in the gill epithelium and skin, erythema, and sometimes bleeding skin (Heckmann, 1996). This is more evident in cases of intense parasitism, which is observed when environmental conditions favour the reproduction of the parasite and weakens the host, which happens when there is a decline in water quality. These parasites are easily transmitted through infected fish, water, plants or utensils used on fish farms. The treatment can be accomplished by bath with malachite green 2-3 g/10 m^3, when the fish are not used for consumption, or a bath for two hours in commercial formalin 1:4.000-6.000 (Pavanelli et al., 1999). *Ichthyophthirius multifiliis* (fig. 6E) however, has not been frequently found in *O. niloticus* from Chavantes reservoir. It causes a disease commonly known as freshwater white spot disease. This protozoa is a ciliate parasite, ovoid, measuring 100-1000 µm, the cytoplasm is granular and contains numerous vacuoles and contractile structures. These protozoans are characterized by the presence of a horseshoe-shaped macronucleus and a micronucleus barely visible (Cheng, 1986). Although often cited as ectoparasites, it is located under the epidermis, presenting the appearance of small white spots on skin and gills of fish (Eiras, 1993). The life cycle of *I. multifiliis* is completed in 3-4 days at 25.5 °C, but can also occur in up to 5 weeks at 18 °C and in lower temperatures the parasite will remain dormant. The adult parasite called trophont reach the maturity, leaves the host as tomont forms and fixes in the substrate of fish cage forming a cyst. Inside it, multiple cell divisions form many tomites which are the infective forms to new fishes when the cyst breaks (Ewing & Kocani, 1987). Probably this protozoan is responsible for major economic losses in fish farms in the world. Young fish are usually more susceptible, and high infestations are usually associated with sudden drops in temperature in the water fish farm (Eiras, 1993). In Brazil, *I. multifiliis* was already reported infecting *Colossoma macropomum*; *Prochilodus cearensis*, *Cichla ocellaris*, *Piaractus mesopotamicus*; *Leporinus macrocephalus*; tambacu hybrid (*P. mesopotamicus* x *C. macropomum*); *Tilapia rendalli*; *O.niloticus* and *Cyprinus carpio* (Békési, 2002; Tavares-Dias et al., 2001).

The most appropriate way to avoid freshwater white spot disease is maintaining good water quality, adequate food, and avoiding stress, caused mainly by changes in temperature. In this case, fish are more sensitive to attack by parasites. It should be considered that freshwater white spot disease is difficult to treat, especially in large cages. Treatment should be done in special cages for therapeutic baths. One product that can be used is sodium chloride 0.3%, where the fish stay sunk for about 24 hours. More concentrated doses, 5% for example, may be used in severe cases, with the fish remaining in the solution for 30 minutes (Pavanelli et al., 1999). Myxozoa includes parasites frequently found in marine fish and freshwater. Currently the phylum Myxozoa includes the classes Myxosporea and Malacosporea, and almost all fish parasites belong to Myxosporea (Eiras et al., 2006). The life

Fig. 6. A) Monogenoid in the gill of *Oreochromis niloticus* (10x); B) *Cichlidogyrus halli* specimen (10x); C) detail of the haptor and sclerotized structures of *Cichlidogyrus halli* (40x); D) *Ichthyophthirius multifiliis* specimen (40x); E) *Trichodina* sp. specimen (40x); F) *Henneguya* sp. spores in fish tegument (100x).

cycle of mixosporeans occurs in two hosts: a vertebrate (fish) and invertebrates (oligochaete). The spore is released when infected fish dies and decomposes, or through contaminated faeces of a predator fish that have eaten infected fish. The oligochaetes are infected when they ingest the sporoplasms that fix to the intestinal wall using polar filaments; these proliferate and remain incubated for 3 months. After this period the Actinospore are released to infect the fish in the water column and deposit the sporoplasm within the epidermis which will migrate to the organs and gills (Stevens et al., 2001). The main genera of Myxozoa infecting fishes are *Myxobolus* and *Henneguya* (fig. 6F). In Brazil there are only reports on the occurrence of *Henneguya* sp. infecting *O. niloticus* (Ranzani-Paiva et al., 2005). Histopathological analysis of the gills of fish infected *Henneguya* sp. reveal the presence of severe bleeding and inflammatory foci in the gill epithelium, where the cysts are located. Lesions such as compression of capillaries causing edema in superficial lamellae more frequently in primary and secondary lamellae occasionally can be observed. In later stages, cysts dilate the respiratory lamellae decreasing respiratory efficiency of infected fish (Martins et al., 1999). The treatment of this disease has been carried out using 10 ml of formalin/m^3, which has been quite effective (Martins et al., 1999). Other studies have been conducted evaluating the oral administration of chemotherapeutics (quinine, salinomycin) that had significant effect on the treatment of infections in the gills of fish mixosporeans (Dohle et al., 2002). However, studies on the treatment of infections *Henneguya* spp. are still scarce. Our studies with *O. niloticus* in Chavantes reservoir have also demonstrated that the occurrence of parasites in cage farms is associated with environmental variables. Therefore, we have observed a higher prevalence, abundance and intensity of infection of parasites in the summer. No difference was noted in the parasitism levels among different fish tanks, considering the groups established by the zootechnical methods in fish farm. Depending on the parasite species, fish size also influences the parasitism. For example, a negative correlation was observed between monogenoids and fish size and a positive correlation between *Trichodina* sp. and fish size. This is important because demonstrates that some parasites are more important in the initial breeding phase while others are problems in the final stages. In conclusion, we can note that despite the wide distribution and incidence of parasites in fish rearing, there are few studies on the prevalence, pathogenesis, and potential biological cycle of transmission of these parasites in Brazilian cage fish farms. It is important to consider that in cage farming there must be a balance between the health of the host, the proliferation of pathogens and conditions of the aquatic environment. Thus, poor water quality, reduction of dissolved oxygen, changes in temperature, high fish density, inadequate management or unbalanced nutrition are factors able to induce stress to the animals, predisposing them to various types of infections, including parasites. Water offers an extremely favorable environment for the proliferation of these agents and the parasites are responsible for major losses in fish farms worldwide, with more relevance in the neotropics, due to the climatic characteristics of these regions (Martins, 1998; Thatcher, 1994).

2.3 Impacts on the resident ichthyofauna and fish feeding ecology

Brazilian freshwater fish fauna has been managing to adjust to continuous environmental impacts, such as damming and deforestation, due to its great diversity of species, with different tactics of life cycle (Agostinho et al., 2007). Currently, a new expanding form of impact is fish farming in floating cages. However, knowledge of the impacts from this activity on the ichthyofauna is still precarious. This activity provides food resources and shelter to resident fish fauna, attracting a large number of fish (Brandão, 2010; Nobile, 2010; Paes, 2006; Zanatta, 2007, 2011), which is also observed for marine fish farms (Boyra et al., 2004; Machias et al., 2004, 2005, 2006). This attraction is due to availability of food resources, such as feed losses, fish scales, and fish faeces. According to Beveridge (2004) and Pillay (2004), these losses can reach 30% of all feed used in aquaculture enterprises. Thus, the contribution of allochthonous energy in aquatic ecosystems can cause changes in the food chain, especially upon plankton community, benthic community, and fish fauna, interfering with the dynamics of the aquatic ecosystem. Our studies in the Paraná River basin (Middle Tietê River and Upper/Middle Paranapanema River) reported impacts on the ichthyofauna (Nobile, 2010; Paes, 2006; Zanatta, 2007, 2011) from this activity, such as changes in population structure of fish fauna (Ramos et al., 2008), changes in diet (Brandão, 2010; Ramos et al., 2008, 2009), and changes in bromatological composition of some fish species (Queiroz, 2010). A research made by Paes (2006) in 2003 and 2004 at Nova Avanhandava reservoir, evaluated some impacts of fish farms upon ichthyofauna. While in FS was recorded 18 species, a greater number of fish species (N=20) was recorded in CT. However, a greater number of individuals was captured in FS (n=684) than in CT (n=518). For species, the Shannon-Wiener diversity index H' (Krebs, 1999) showed no significant differences between these two sites (p> 0.05). For Simpson dominance 1/D (Krebs, 1999), similar values were recorded for FS (1/D = 5701) and CT (1/D = 5555). Even though this difference was small, the dominant species in the FS was *Metynnis maculatus*, an omnivorous species with tendency to herbivory, while in CT the dominant species was *Plagioscion squamosissimus*, a strict carnivore species. A study conducted by Ramos et al. (2008) aimed to compare the diet of the species *M. maculatus*, *Astyanax altiparanae* and *P. squamosissimus* between FS and CT. The results show that the omnivorous species *M. maculatus* changed its diet in FS. This species used a new alimentary source with high availability and low energy cost, and its diet consists almost exclusively of feed from fish farming (85%). Such a change in diet led to a change in population structure of this species, showing higher values of weight and length in FS (p <0.05). Similar results were found at Jurumirim by Zanatta (2007). A greater number of species (N=24) was captured in CT than in FS (N=21), and a greater number of individuals were captured in CT (n=1,601) than in FS (n=1,470). There was no significant differences for H ' (p> 0.05) between the two sites, and Pielou evenness E (Krebs, 1999) values were similar for FS (E = 0.73) and CT (E = 0.76). At Chavantes reservoir, Nobile (2010) showed differences only between the abundance of individuals in both sites, recording the 78% of the capture (n=3096) in FS. Furthermore, it was recorded introduction of the non-native fish *Ictalurus punctatus* by aquaculture activities, whose impacts upon native fish fauna of Brazilian reservoirs are still unknown (Zanatta et al., 2010). There was also the capture of *O. niloticus* juveniles, which we believe that they are recruited from reproductive processes occurring in the reservoir rather than escaped, due to its great abundance, and size smaller than juveniles stocked in the cages (fig. 7). If these recruits are born from adult scaped fish from fish farms, than efficiency of the sexual reversion process in use is not enough to avoid breeding in this aquatic ecosystem, which may lead to disruptions of ecological interactions with native fish assemblages. In Chavantes reservoir, Brandão (2010) and Ramos (2009) observed that the most abundant species showed differences in diet composition between the FS and CT. Remains of feed was major component of the diet of *Pimelodus maculatus* (98%) and *A. altiparanae* (99%) in FS. For CT, the diet of *P. maculatus* was composed of detritus (27%), aquatic insects (22%), vegetables (21%) and molluscs (21%); and *A. altiparanae* by terrestrial insects (61%) and vegetables (30%). Another species analyzed was *Apareiodon affinis*, which diet was composed of detritus (80%) and feed remains (20%) in FS, and only by detritus in CT. Moreover, two carnivorous species were analyzed (*Galeocharax knerii* and *P. squamosissimus*), and there was no differences in their diet between the sites studied. Comparative analysis of weight and length show that omnivorous species grows faster at FS due to use of remains of feed as main food source. In addition,

Fig. 7. *Oreochromis niloticus* juveniles captured around FS at Chavantes reservoir.

Queiroz (2010) observed change in bromatological composition of muscle tissue of *P. maculatus*.

Significant differences for total lipids and gross protein were observed between fish caught around FS and CT (p <0.05). It is evident that this type of fish farm attracts native ichthyofauna in these reservoirs. Attractiveness is directly related to availability of food resources, especially remains of feed. These are similar to the findings for marine aquaculture in coastal ecosystems, which also found the effect of attractiveness of these systems (Boyra et al., 2004; Dempster et al., 2002; Håkanson, 2005). The results presented allow the conclusion that remains of feed are used by omnivorous species with large feeding plasticity, which certainly justifies its dominance in sites used for cage aquaculture. Furthermore, the changes in the diet of these species have direct effects on their population structure, and the effects upon fish fauna still need to be clarified. Håkanson (2005) and Ramos et al. (2008) report that such changes in the diet of abundant species in aquatic ecosystems may affect the food chain in long term, and the effects upon ichthyofauna are still unknown. We conclude that where fish farms in cages are deployed, there is a change upon the population structure of fish communities, due to attractiveness and changes in the diet of omnivorous species in nearby sites, which may interfere in the local ecological dynamics, especially in the food web, altering ecological relationships between the components of local biota.

3. Conclusion

The results showed that cage aquaculture fish production in oligotrophic ecosystems, as Jurumirim and Chavantes reservoirs (Paranapanema River) is compatible with environmental carrying capacity, and wild fishes play a relevant role recycling nutrients derived from aquaculture. The main constraint to cultivation of tilapia in these reservoirs is the low temperatures during the winter months, with recent records of mass mortality of fish due to parasite infestation in this season. These aquaculture enterprises are an important source of dispersion of non-native fish species, as *O. niloticus* and *I. punctatus*. In Tietê river (Nova Avanhandava reservoir), the situation is more complex because of low water quality due to high nutrient loadings of sewage and agriculture runoff, related to the presence of cyanobacteria blooms, causing severe consequences for the environmental and economic sustainability of aquaculture. After some years operating cage farms in middle and lower Tietê River, events of fish mass mortality associated with eutrophication motivated fish farmers to move to sites with better water quality. It is also pertinent to note that fish farming in cages still need the development of scientific and technological knowledge, which besides basic technical support, could also allow the improvement of this activity. The lack of expertise and the inappropriate implementation of best management practices can lead to failure of these enterprises, making them economically unviable in the short and medium term. Measures for the effective planning for farming public waters require further discussion and guidance at governmental levels, in order to reach a truly sustainable aquaculture, in all its socioeconomic and environmental interfaces.

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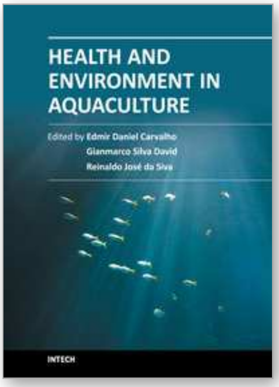

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Aquaculture has been expanding in a fast rate, and further development should rely on the assimilation of scientific knowledge of diverse areas such as molecular and cellular biology, and ecology. Understanding the relation between farmed species and their pathogens and parasites, and this relation to environment is a great challenge. Scientific community is involved in building a model for aquaculture that does not harm ecosystems and provides a reliable source of healthy seafood. This book features contributions from renowned international authors, presenting high quality scientific chapters addressing key issues for effective health management of cultured aquatic animals. Available for open internet access, this book is an effort to reach the broadest diffusion of knowledge useful for both academic and productive sector.

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