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Threats for biodiversity in the floodplain of the Upper Paraná River: effects of hydrological regulation by dams

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Abstract

The Paraná River is the main tributary of the La Plata River and runs through 4,695 km. Its third upper part, the Upper Paraná River, is almost completely inside the Brazilian territory. In this area, there are more than 130 major reservoirs that inundated most of the river-floodplain system. The stretch left, about 230 km, is the area where a Long Term Ecological Research (LTER; Site 6) is developed. The floodplain presents itself as a mosaic of habitats (river channels, secondary channels and lagoons) with peculiar characteristics, depending on local and/or regional processes. Surveys conducted in the area since 1986 registered about 2,920 species (745 of terrestrial plants; 60 of macrophytes; 543 of phytoplankton; 385 of zooplankton; 188 of benthos; 176 of fish and 417 of vertebrates). Besides the intense regulation by dams, the flood pulse is still the main function force working on the floodplain. Then, the flood pulse plays important role determining the dynamic of abiotic factors and organisms that live or use the plain for at least one stage of the life cycle. Main impacts in the area are natural, such as climatic (effects of "El Nińo") and anthropogenic, such as damming (the most conspicuous), cattle raising and removal of riparian vegetation. It is concluded that the maintenance of the biodiversity of the area will depend on the integrity of the land-inland water ecotone, represented by the floodplain, especially for large migratory fish species. Then, it is suggested a creation of a permanent floodplain reserve, according to biosphere reserve from MAB/UNESCO.

Key words: Neotropical, Reservoir, Connectivity, Flood Regime.

1. Introduction

The Paraná River is formed by junction of the Grande and Paranaíba rivers in south-central Brazil, and discharges into the La Plata River in Argentina. It is 4695 km long and has a 2.8 10^6 km^2 drainage area that includes most of the south-central part of South America (18^o to 34^o S; 45^o to 68^o W) from the Andes to the Serra do Mar near the Atlantic Ocean. The Upper Paraná River includes approximately one third of the Paraná River basin, and includes itself completely within the Brazilian territory. Its basin has an area of 891 000 km^2 (10.5% of Brazil), comprising the region with the highest population density (from 10 to 100 inhabitants.km^{-2}; 36% of the Brazilian population), the main industrial centers and the most intensive agriculture in Brazil. However, dams are the most common human interference on the physiography of the region. They are present in all major tributaries (Grande, Paranaíba, Tiete, and Paranapanema rivers) and the Paraná River main channel. In this region there are more than 130 major reservoirs (dam > 10 m high); among these, 20% are larger than 100 km^2 and four are located in the main channel of the Paraná River and have areas ranging from 482 to 2250 km^2.

Before the construction of Porto Primavera Dam, the Upper Paraná River had an extensive floodplain (a 480 km stretch, more than 20 km wide). This section was the only remaining dam-free stretch of the Paraná River in Brazil. Despite being one of the most regulated river stretches in the world, the flood regime was still predictable because of several important tributaries in this reach. In 1998, the Porto Primavera Dam, located in the middle part of this dam-free stretch, was closed, which reduced the floodplain to 230 km between the Itaipu Reservoir and Porto Primavera Dam. Despite of the anthropogenic occupation of part of the Paraná River floodplain and some regulation of water discharge by dams upstream, the area still plays fundamental role in the maintenance of the regional biodiversity.

This stretch presents high habitat heterogeneity and still maintains a great biodiversity of terrestrial and aquatic organisms. In the area, the flood pulse is the main force function that regulates the structure of communities and functioning of the ecosystem. Due to its importance as representative of a river-floodplain system, three conservation units were created in this stretch, i.e. Area de Proteçao Ambiental das Ilhas e Várzeas do Rio Paraná (1 000 310 ha), Parque Nacional de Ilha Grande (78 800 ha) and Parque Estadual do Ivinheima (70 000 ha) - Fig. 1. In this area is located also one site of the national program "Long Term Ecological Research" (LTER site 6).

In the present paper the area is described and characterized in relation to biodiversity status. We emphasize its functional characteristics in order to identify potential risks to its maintenance and finally, we consider some perspectives for conservation.

2. Description of the area and main environmental conditions

The Upper Paraná River runs north-south/southwest (1800km), draining areas with tropical and subtropical climates. Mean monthly temperatures area above 15^{o}C and precipitations above 1500 mm.year^{-1} (IBGE 1990).

In the last remaining stretch of the Paraná River floodplain in Brazil, the river presents an anostomosed channel, with low declivity (0.09 m.km^{-1}). Common features of the landscape are the extensive alluvial plain, with great sedimentation, forming sand bars and small islands (more than 300) and big islands and more restricted wetlands (Agostinho *et al.* 1994). The stretch is 230 km long and the floodplain may reach 20 km wide, with numerous secondary channels, lagoons, the Baia River and the lower parts of the Ivai and Ivinheima rivers.

The main channel of the Paraná River, secondary channels and tributaries compose the drainage network in this stretch. On the eastern margin, the main tributaries there are the

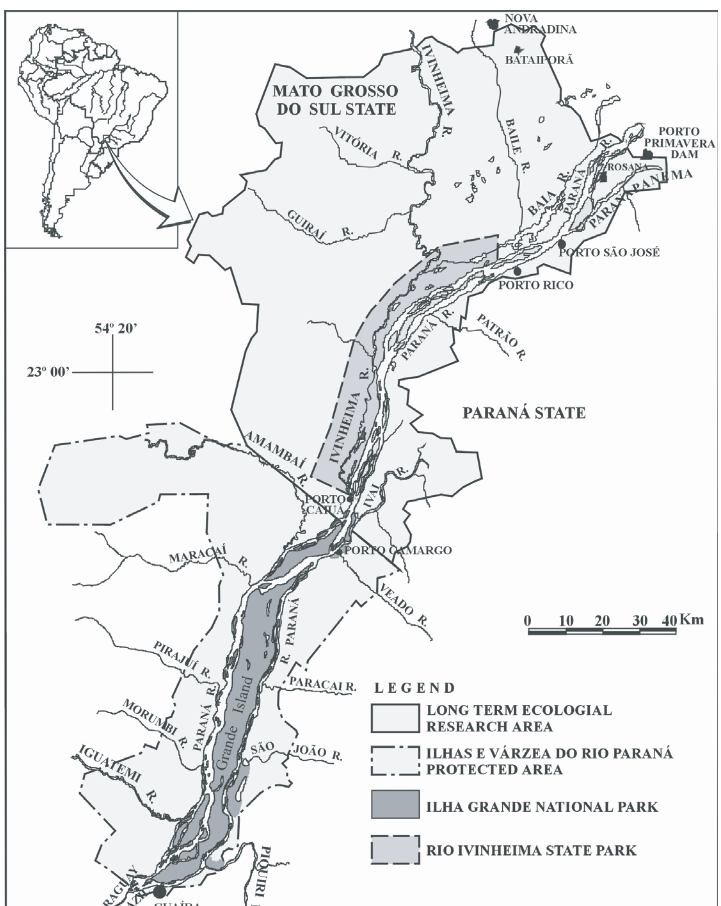

Fig. 1. The upper Paraná River floodplain showing the Area of Long Term Ecological Research (ALTER) and the conservation units of the region.

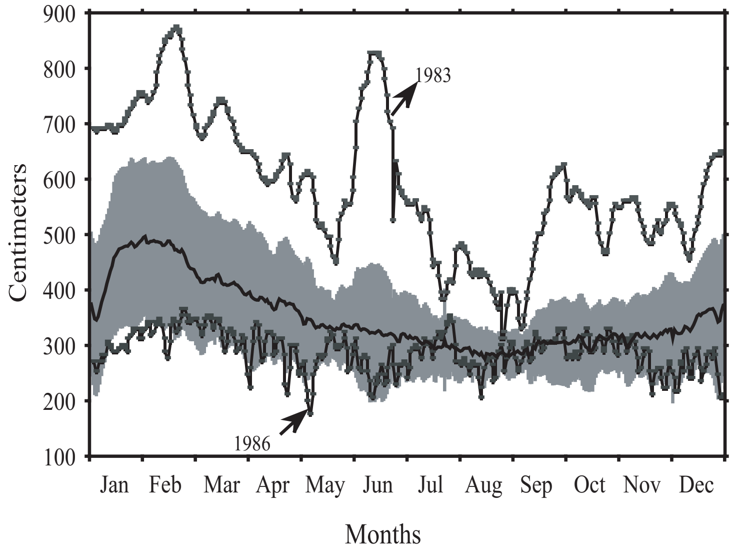

Fig. 2. Mean water level (standard deviation - grey) of the Paraná River during the period of 1978 and 1997, measured in Porto Sao Jose. Lower and upper curves show annual cycles with greatest water levels (1983) and lowest water levels (1986).

Paranapanema, Ivai and Piquiri rivers, whereas in the western margin, the Ivinheima, Amambai and Iguatemi rivers. All tributaries of the western margin discharge in a network of secondary channels.

Besides the dams constructed upstream from the area, fluctuations in the water level are still seasonal and may reach up to 2.5 m (Fig. 2). Studies in the area show that the floodplain presents high biodiversity and it is fundamental for the maintenance of self-sustained population of species already absent in the upper reaches of the basin, especially large sized fish species that develop long reproductive migration (Agostinho *et al.* 2000a).

Lagoons on the floodplain differentiate themselves according to limnological conditions. These conditions are determined by regional (water inflow from the Paraná River, for instance) and/or local processes (wind, precipitation, inflow of small tributaries, for example). In the lagoons, electrical conductivity ranges between 16 and 55 $\mu S.cm^{-1}$, dissolved oxygen between 0 and 116% and high amounts of chlorophyll-a (up to 70 $\mu g\ dm^{-3}$) are found, specially during low water levels (dry season). Lagoons may present relatively stable thermal stratification during high water levels (wet season), causing absence of oxygen near the bottom. However, during low water levels, diel circulation occurs, especially at night (Thomaz *et al.* 1997). Values of pH also vary considerably, ranging from 5 to 9, due to inflow of humic compounds, addition of carbon dioxide from decomposition of aquatic plants, inflow of water from the Paraná River rich in bicarbonate and from photosynthesis of the phytoplankton.

Temporal and spatial variations of the abiotic factors are more conspicuous in temporary lagoons. During low water levels, remaining lagoons are shallow (less than 0.5 m deep) and usually fragmented. Consequently, they are easily affected by wind and stepping of cattle or other animals. In a given year, in these lagoons, electrical conductivity may range from 24 go 131 $\mu S.cm^{-1}$, total phosphorus from 28 to 348 $\mu g\ dm^{-3}$ and alkalinity from 0.06 to 0.87 meq dm^{-3} (Okada 1995; Pagioro *et al.* 1997).

Low concentration of phosphorus (between 5 and 56 g dm-3) is usually found in the Paraná River whereas nitrate is higher (25-232 $\mu g\ dm^{-3}$) than in lagoons (< 25 $\mu g\ dm^{-3}$). The Paraná River channel presents greater values of electrical conductivity (42-74 $\mu S.cm^{-1}$) and total alkalinity (0.27-0.57 meq dm^{-3}) (Thomaz *et al.* 1997).

The Baia River is a typical semi-lotic environment, with intermediate limnological conditions between the Paraná River and lagoons. But the Ivinheima River is different due to loads of phosphorus, that are on average, twice as the ones registered in the Paraná River (28 to 132 $\mu g\ dm^{-3}$) (Thomaz *et al.* 1992a). Therefore, the Ivinheima River is an important source of phosphorus for floodplain lagoons.

3. Species richness

The surveys concerning species richness of the different groups, in terrestrial and aquatic habitats of the Upper Paraná River floodplain are still incomplete. Most of the studies in this stretch were dealt with terrestrial vegetation and aquatic communities. The terrestrial vertebrates surveys used to characterize the area were carried out by previous studies in the upstream portion of the site, in the area now flooded by the Porto Primavera Reservoir (Mussara 1994). Nevertheless, since that area had the same characteristics as the remaining floodplain described in this study and both areas were continuously connected, with no barriers, the terrestrial species can found in the upstream portion of the floodplain, its terrestrial vertebrate fauna is probably similar to the one found in the remaining floodplain.

Considering the surveys carried out since 1986, about 2920 species were already registered in the Upper Paraná River floodplain system (Fig. 3). The Long Term Ecological Research, started in 1999, was conducted initially to increment species surveys, sampling in stations not still considered in previous investigations, which were restricted to few sampling stations in the river channel and in four lagoons. The sampling efforts were increased and 36 stations, among lagoons, channels, backwaters and the main channel of the Paraná, Baía and Ivinheima rivers were sampled. Considering only the terrestrial and aquatic vegetation, phytoplankton, zooplankton, zoobenthos and periphytic algae, a survey carried out in 2000, in the new sites, increased the number of taxa registered in 11.4% (from 2159 species registered between 1986 and 1999 to 2406 species recorded after the intensive sampling). In addition, several species are still being identified, which will increase the species richness. Such results show clearly that the number of species recorded in this last undammed stretch of the Paraná River is still far from the true value. To overcome problems with species richness underestimation, rarefaction curves and several statistics estimators of species richness have been applied to different groups (Machado-Velho *et al.* 2001; Bini *et al.* 2001), when the main intention is to search for patterns and comparisons among stations or with other systems.

The importance of the area for biodiversity conservation is also indicated by comparisons of the number of species recorded in the river-floodplain with the numbers presented by the Ministério do Meio Ambiente (2002) for the Atlantic Forest domain ("Floresta Atlântica"), in which edge it is included. This biome covers about 136,000,000 ha of the Brazilian territory, extending from the Northeast to the extreme south of Brazil. Although the Upper Paraná River floodplain has an area of only 526,000 ha (ca. 0.4% of the biome area), it contains about 50% of the fish species, 35% of the birds, 24% of mammals, 6% of amphibians and 4% of the terrestrial plants recorded at the Atlantic Forest biome.

Concerning the terrestrial vegetation, about 745 species were already recorded, belonging to 410 genera and 119 families, which are spread over an area of approximately 120,000 km^2 of mainly forest and rural vegetation (Souza, Romagnolo, in press). Herbaceous species are the most important in the area (Souza *et al.* 1997). Wide natural areas are colonized by this type of vegetation and such areas used to be reached yearly by the Paraná, Ivinheima and Baía rivers floods, although the water retention by upstream reservoirs have prevented these events in recent years (see bellow). In these fields, grasses (*Panicum prionitis*, *P. mertensii*, *P. maximum*), Cyperaceae (*Cyperus digitatus*, *C. difusus*) and Amarantaceae (*Pfaffia glomerata*) are predominant. In the riparian zone, which were deeply impacted by deforestation and catastrophic floods, *Cecropia pachystachya*, *Croton urucurana*, *Lonchocarpus guilliminianus* and *L. muhelbergianus* are the dominant species (M.C.Souza-Stevaux, unpubl.). The riparian forests contain elements of the vegetation from two domains (the tropical Atlantic and "cerrado") (Souza, Romagnolo, in press). According to these authors, the similarity among forest fragments is rather low (Sorensen Index from 13.33% to 72.72%), despite

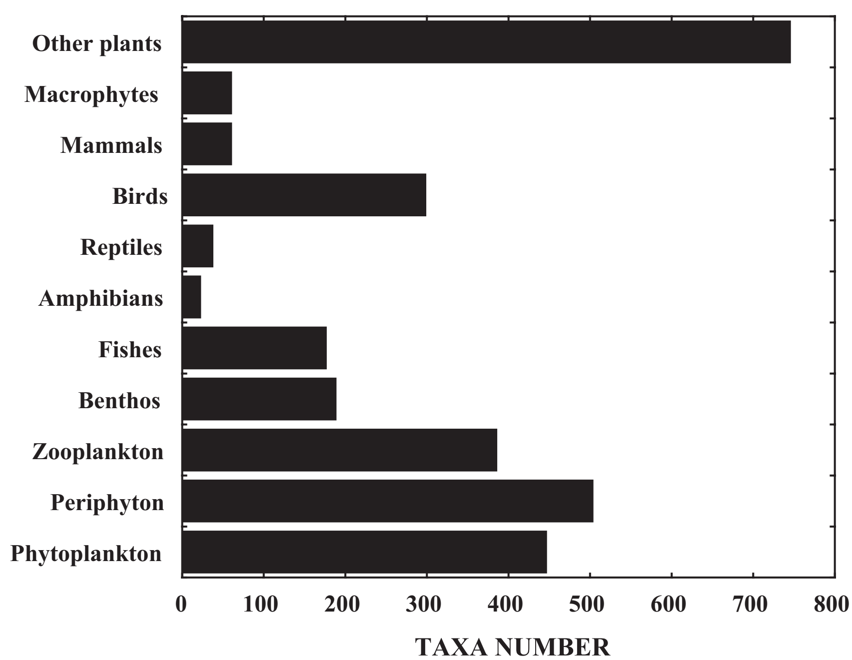

Fig. 3. Number of species identified in the Area of Long Term Ecological Research (Upper Paraná River floodplain) during the period of 1986 to 2000. For most of the groups, surveys are still incomplete.

their close proximity to each other and relatively low species richness. The low similarity among fragments indicates a high β, or among habitat, diversity in the forests of this area.

The aquatic vegetation is composed of about 60 species. Emergent species are dominant (37 species) followed by free-floating and rooted submerged (10 species), free submerged (2 species) and rooted with floating leaves (1 species). The most important species, considering the abundance and frequency of occurrence, is *Eichhornia azurea*, which is found in marginal areas of the river main channels, secondary channels, temporary and permanent lagoons. Other species associated with *E. azurea* stands are *Eichhornia crassipes*, *Salvinia auritulata*, *S. herzog*, *S. minima*, *Pistia stratiotes*, *Utricularia foliosa* and *U. gibba*, among others (Bini *et al.* 2001; Souza *et al.* 2002). Rivers that arrive in the floodplain determine the species composition of the littoral regions. In other words, the lagoons connected to Paraná, Ivinheima and Baía rivers have different aquatic plant assemblages (Bini *et al.* 2001).

The species richness of other aquatic assemblages has been assessed in different habitats of the floodplain in surveys carried out in distinct hydrological phase. Despite the impacts affecting the Upper Paraná River floodplain, the results indicate that phytoplankton, periphytic algae, zooplankton, zoobenthos and fishes are highly diverse.

About 446 species of phytoplankton were recorded in the Upper Paraná Floodplain (Oliveira *et al.* 1994; Jati, Train 1994; Train, Rodrigues 1998; Train 1998; Rodrigues 1998; Train, Rodrigues, in press). According to these authors, most species belong to Chlorophyceae. In the Paraná main channel, Bacillariophyceae are also important (e.g., *Aulacoseira granulata* and *Cyclotella* spp.). In the lagoons, blooms of Cyanophyceae, commonly dominated by *Anabaena solitaria* or *A. spiroides*, occur especially during the low water periods (Train 1998; Rodrigues 1998). Considering species richness, Euglenophyceae is also an important group, and its species are recorded especially in temporary lagoons, which are very common habitats in islands (Jati, Train 1994). Cryptophyceae (e.g., *Cryptomonas brasiliensis*) are important in the more turbid waters of Ivinheima River (Rodrigues 1998).

The high phytoplanktonic species richness of the Upper Paraná River lagoons is clearly demonstrated when individual habitats are considered. Surveys carried out in Guaraná lagoon (area of ca. 4 ha) registered 220 species (Train 1998) and in Patos lagoon (area of ca. 114 ha) 272 species were recorded (Rodrigues 1998). These numbers are higher than the ones recorded in other lagoons of the Paraná River in Argentina or even in Amazonian "várzea" lakes (Train, Rodrigues, in press).

Studies of the attached algae in the region were done with both artificial and natural (especially *Eichhornia azurea* petioles) substrates. The total number of periphyton recorded by Rodrigues *et al.* (in press) was 503. The Bacillariophyceae was the algal class dominant qualitatively and quantitatively. The composition of periphyton in the Paraná River main channel is clearly different from the one recorded in lagoons and semi-lentic habitats in the floodplain (Rodrigues, Bicudo 2001). The lowest species richness is observed in the river substrates, where diatoms are dominant (Rodrigues, Bicudo, in press).

The zooplankton of the different habitats in the floodplain is composed of ca. 385 species among rotifers (230), testate amoeba (74), cladocerans (64) and copepods (17) (Bonecker *et al.* 1994; Bonecker, Lansac-Tôha 1996; Lima *et al.* 1996; Lansac-Tôha *et al.* 1997; Garcia *et al.* 1998). Among the most frequent species of rotifers are *Keratella Americana*, *K. cochlearis*, *K. tropica*, *Lecane bulla*, *Conochilus unicornis* and *Polyarthra vulgaris*. The most frequent cladocerans are *Bosminopsis deitersi*, *Bosmina hagmani*, *Ceriodaphnia cornuta*, *Moina minuta* and *Diaphanosoma birgei* and the most frequent copepods are the cyclopoids *Thermocyclops minutos*, *T. decipiens*, *Mesocyclops meridianus* and the calanoids *Argyrodiaptumus furcatus*, *Notodiaptomus isabelae* and *N. amazonicus*. In general, the highest number of species of rotifers, cladocerans and copepods are found in lagoons (Lansac-Tôha *et al.*, in press).

Some zooplankton species have distribution restricted to certain habitats. For example, the testate amoebae *Arcella rota*, *A. nordestina* and *Suiadifflugia multipora* occurred only in lagoons, *Heleopera petricola*, only in channels and *D. kempnyi* and *Pontigulasia compressa* have been found only in rivers. The rotifers *Brachionus urceolaris amazonicus*, *Lepadella rhomboides*, *Notommata tripus*, *Trocosphaera aequatorialis* and *Horäella thomasoni*, the cladoceran *Macrothrix triserialis*, and the copepod *Microcyclops* sp. have been recorded only in lagoons. Differently, the rotifers *Monommata mucronata*, *Notommata glyphura* and *Rotatoria tardigrada* are found only in channels whereas the rotifers *Lophocaris salpina* and *Pompholyx* sp. only in river main channels (Bonecker *et al.* 1994; in press; Bonecker, Lansac-Tôha 1996; Lima *et al.* 1996; Lansac-Tôha *et al.* 1997).

Among the 188 taxons of benthic invertebrates recorded, higher densities are found for gastropods, chironomids, nematods, tubicificids and ostracods. In the main channel of the Paraná, interstitial species dominate (e.g., the nematode *Narapa bonettoi*) and in muddy bottoms, mainly in the lagoons, burrowers (e.g., *Campsurus*) are dominant (Higuti *et al.* 1993; Takeda *et al.* 1997). High abundances of the invasive *Corbicula fluminea* and

Limnoperna fortunei have been recorded in the main channel of the Paraná River and secondary channels in the last 5 years, in detriment of the native species (Takeda, Fujita, in press). It is suggested that the introduction of the former in the floodplain occurred by downstream dispersion through the Paraná main channel, differently from the invasive species, *Limnoperna fortunei* that is migrating upstream the Paraná River, from the Plata River (Argentina).

In the stretch, 176 fish species were registered. Among them, resident species (opportunistic and equilibrium strategies; according to Winemiller 1989) that develop entire life cycle in the floodplain and migratory species (seasonal strategy; according to Winemiller 1989), that use the floodplain only during a certain stage of the life cycle. There are considerable differences in fish assemblages that occupy the diverse habitats of the floodplain. Then, in lagoons (usually shallow, daily stratified and with abundant macrophytes), *Loricariichtys platymetopon*, *Hoplosternum litoralle*, *Acestrorhynchus lacustris*, juveniles of *Prochilodus lineatus* and other migratory species, *Hoplias malabaricus* and *Leporinus lacustris* are dominant. In secondary channels (semi-lotic environments), besides the above mentioned species, Iheringichthys labrosus, *Pimelodus maculatus*, *Trachydoras paraguayensis* and *Serrasalmus* spp are also abundant. In the Paraná River channel, characteristic species are *Paulicea luetkeni*, *Pseudoplatystoma corruscans* (largest fish of the basin), *Raphiodon vulpinus*, *Loricaria* spp, *Salminus maxillosus* (largest characid) and some apteronotids. In the meandering part of large tributaries, predominate anostomids (*Schizodon borelli* and *Leporinus obtusidens*), auchenipterids and doradids. Fish fauna in creaks and streams that empties in the area present high number of small sized species (tetragonopterids, cheirodontids, some pimelodids, loricarids and trycomicterids) (Agostinho *et al.* 2000a). In the remaining lagoons (almost dried up), species such as *Astyanax altiparanae*, *Cheirodon notomelas*, *P. lineatus*, *Characidium fasciatus* (Verissimo 1994), cichlids and other small tetragonopterids (Okada 1995) are common.

Macrophytes have been considered very important concerning biodiversity conservation of aquatic groups in the Upper Paraná River floodplain. Studies on zooplankton showed higher number of species of rotifers, testate amoeba and cladocerans in stands dominated by *Eichhornia azurea* (Lansac-Tôha *et al.* 2003). In the littoral regions of lagoons, a great number of non-planktonic species are found (Bonecker *et al.* 1998; Lansac-Tôha *et al.* in press), what contributes to such increase in species richness. In addition, the littoral region has been demonstrated to decrease the temporal turnover of species (β diversity) of testate amoeba, indicating that the presence of plants lead to low temporal heterogeneity of the planktonic community (Lansac-Tôha *et al.* 2003; Machado-Velho *et al.* 2001).

Floating species are also considered important habitats for meso and macro invertebrates, and the composition of this community changes according to the species of aquatic plant considered (Takeda *et al.* 2003). Regarding fish fauna, studies using simultaneous samplings in the pelagic zone of lagoons, inside macrophytes stands and in their borders, showed significant increment of species richness, equitability and Shannon Index in this last region (Agostinho *et al.* 2002b). In addition, smaller individuals were caught at the stand borders, indicating that the importance of such habitats for juveniles survival and conservation of short-sized species.

Surveys carried out before the construction of Porto Primavera Dam (Mussara 1994) registered 417 species of vertebrates. Among them, 22 were amphibians, 37 reptiles, 298 birds and 60 mammals. Most common amphibians were members of the families Hylidae (9 species) and Leptodactylidae (8 species). Thirteen families of reptiles were registered, predominating Colubridae (16 species) and Teiidae (6 species). For this group, 27% of the species presented preference for aquatic habitats. Among them, three species of caiman (*Caiman latirostris* is the most common) are found in the area. Most of the snakes found are non venomous, with Chironius and Phylodryas the most common genus.

Among the 58 families of birds, 19 were Passeriformes. In this group, Tyrannidae (48 species), Emberizidae (32 species) and Icteridae (11 species) presented greater number of species. Other non-Passeriformes (39 families), such as Ardeidae, Accipitridae and Picidae presented great number of species (Mussarra 1994). Only 3.8% of the avifauna are common to other continents and 6.6% are restricted to southeastern Brazil. About 18% of the total number of species are aquatic. Among them, some large sized species, as the ciconids (*Mycteria americana*, *Ciconia maguari* and *Jabiru mycteria*), the bigua tinga *Anhinga anhinga*, the ardeids (*Ardea cocoi*, *Egretta alba*, *E. thula*, *Nycticorax nycticorax* and *Tigrisoma lineatum*) and the threskiornitids (*Theristicus caudatus* and *Ajaia ajaia*). Other common aquatic species are the anatids (*Dendrocygna viduata*, *D. autumnalis* and *Cairina moschata*). Some species found in the ALTER are listed as threatened, such as the macuco *Tinnamus solitarius* and the bicudo *Oryzoborus maximiliani* (Portaria number 1522 of the Brazilian Institute of the Environment - IBAMA).

The 60 species of vertebrates belonged to 25 families. Phyllostomitadae (12 species), Felidae (6 species) and Cricetidae (4 species) were the families with more species. *Felis concolor* and *Panthera onca* (Felidae) are large predators considered threatened. Capybaras *Hydrochaeris hydrochaeris* (large sized rodent) are quite common in the region. Cateto *Tayassu tajacu*, cachorro do mato *Dusicyon dichtomus*, tapir *Tapirus terrestris*, marsh deer *Blastocerus dichotomus*, veado mateiro *Maxama* spp, armadillos (*Dasypus* spp, *Euphractus* sp. and *Priodontes* spp), anteaters (*Tamandua tetradactyla* and *Myrmecophaga tridactyla*), monkeys (*Alouatta caraya* and *Cebus* spp), coati *Nasua nasua*, mao pelada *Procyon cancrivorus*, irara *Eira barbara* are also common. It is important to emphasize that 7% of the mammals species registered in the region are considered threatened (Portaria Number 1522/89 -- IBAMA).

Although the terrestrial vertebrates were focused by few researches, carried out in the upstream part of the floodplain, where now exists the Porto Primavera Dam, results available indicate that the Upper Paraná River floodplain is an important site for conservation of large terrestrial vertebrates in South Brazil. A survey on marsh deer *Blastocerus dichotomus*, in the adjacent area to the remaining floodplain, which is now flooded by Porto Primavera Reservoir, found mean densities of 0.50-0.54 deer.km^{-2} and a population of approximately 950 individuals, which is considered among the largest populations reported for this threatened species in Brazil (Pinder 1996). Before inundation, other surveys estimated 630 caiman nests per year, 650 marsh deer, and 200 groups of capybaras in the area (Mourao, Campos 1995). Although there was no data available after the formation of Porto Primavera, probably part of these populations migrated to the remaining stretch of floodplain.

Recent evaluation and identification of priorities areas for conservation, done by the Environmental Ministry of Brazil, pointed out this stretch of the Upper Paraná River basin as an area of extreme biological importance for fish, amphibian, reptilian, bird and mammal (Ministério do Meio Ambiente. 2002).

4. Functional characteristics of the area

The biogeochemical cycles in the floodplain are highly dependent upon the water level fluctuations, which regulate the exchange of water between the floodplain habitats and the rivers Paraná, Ivinheima and Baía. The dynamic of these rivers are complex and the floods of each one may occur in different periods of the year. The Paraná water level controls the water level in the floodplain, but in Baía River area the local rain produce local variations of the water level by the water table (Souza Filho, Stevaux, 1997; Comunello 2001). Similar effect occurs in the Ivinheima River area by regional rainfall. The rainfall in this river increases its debit, flooding the Paraná floodplain, close the lower Ivinheima River (Souza- Filho, Stevaux 1997; Columello 2001).

This dynamic aspect makes the floodplain connected to every river and they functionally differ along a seasonal cycle and they have different chemical features and assemblage structures. For example, lagoons connected to the Ivinheima River are usually richer in phosphate than the ones connected to the Paraná (Thomaz *et al.* 1992; 1997). This is due to the Ivinheima that is an undammed river, transporting higher loads of solids and nutrients than the Paraná. The differences in water quality are probably a factor that explains the distinct aquatic flora found in Ivinheima, when compared to the Paraná and Baía rivers (Bini *et al.* 2001). Thus, this complexity, generated by different contributions of water from different rivers may be important to keep a high degree of spatial heterogeneity and habitat diversity in the whole area.

Besides the exchanges associated with such dynamic, floods increase nutrient inputs from decomposition of detritus accumulated in the floodplain during the low water periods (Thomaz *et al.* 1992b; Pagioro, Thomaz 1999a). Such pulses are important to keep the high productivity of the aquatic community all over the year.

Nevertheless, the biogeochemical cycles have been intensively altered in the river-floodplain system due to the operation of the dams located upstream. We identified basically two general processes, associated with reservoirs operation, acting upon nutrient cycling: (i) changes in the natural flood pulses (i.e., changes in the water level fluctuation), which affect the water exchange between the river main channel and the floodplain; in extreme situations, frequent recently, the absence of floods is observed and (ii) retention of solids and nutrients, especially phosphorus, by the reservoirs (Agostinho *et al.* 1995; Souza-Filho *et al.* in press). Despite the lack of previous data, we believe that this process is probably the main cause for the low phosphorus concentrations registered in the Paraná River waters (usually lower than 20 μg P-total dm^{-3}; atomic relations inorganic-N:inorganic-P between 62 and 95; Agostinho *et al.* 2000c). These results strongly suggest that differently from other large rivers, Paraná is diluting the aquatic habitats in its floodplain, concerning phosphorus. On the other hand, the nitrogen dynamic is very different, since its concentrations in the Paraná River waters are always higher than the ones found in the floodplain habitats (Thomaz *et al.* in press). The long term impacts of such phosphorus shortage, relative to nitrogen, is difficult to assess at present.

Despite the scarce data obtained before 1986, when several reservoirs were already operating, a good opportunity to test the impacts

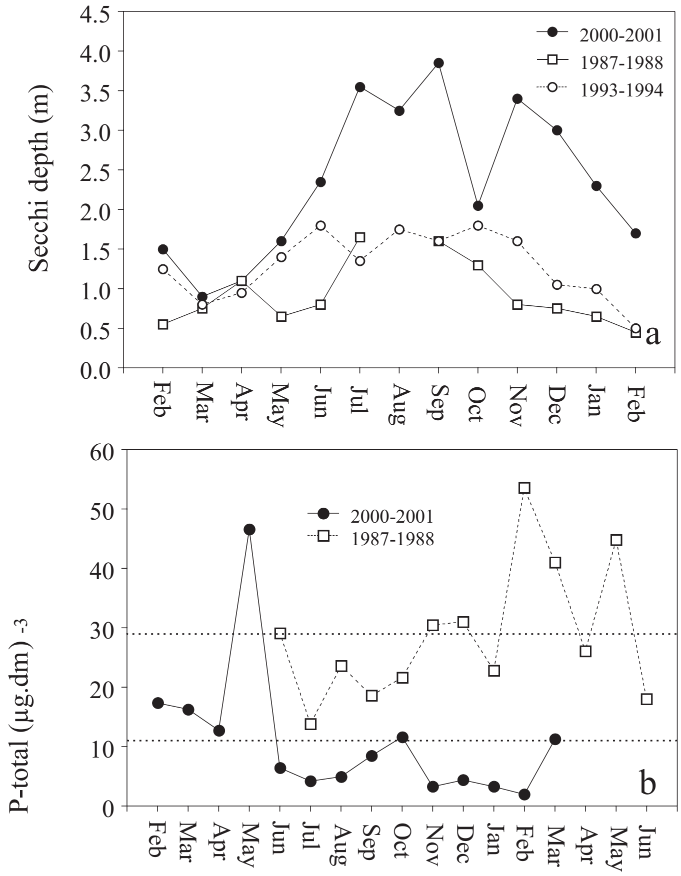

Fig. 4. Comparison of the monthly fluctuations of the Secchi depth (a) and total phosphorus concentrations (b) in the water of the Paraná River before (1987-1988; 1993-1994) and after Porto Primavera dam construction (2000-2001).

derived from reservoirs occurred after 1998, when Porto Primavera Dam was closed. Studies carried out in the floodplain showed that after the formation of the reservoir, a significant decrease in the suspended solids (Souza Filho *et al.* in press) and in an increase of water transparency, measured by Secchi disk (Fig. 4a), were observed in the Paraná main channel. Simultaneously, a decrease in total phosphorus concentration was registered (Fig. 4b), what was expected in view of the well-known trapping effect of reservoirs (Agostinho *et al.* 1995; Barbosa *et al.* 1999; Pagioro, Thomaz 2002).

The phytoplankton primary productivity in the lagoons is usually higher during the low water periods. It is indicated by higher metabolism (measured through oxygen and inorganic carbon diel cycles) and by higher phytoplankton densities and chlorophyll-*a* concentrations during this phase (Thomaz *et al.* 1997; Train, Rodrigues 1998; in press). During these periods, chlorophyll-a concentrations of up to 70 μg dm^{-3} have been registered (Thomaz *et al.* 1997). The increase of primary productivity during low waters are caused by a combination of factors associated with the characteristically shallowness of the lagoons during this phase, such as nutrient inputs from sediment (caused by wind) and diel mixing of the water column (Thomaz *et al.* 1992b, 1997).

The primary productivity of aquatic plants also responds to the hydrological cycle. Data about this community are still scarce, but results of biomass obtained for the three main species showed that they did not respond similarly to water level fluctuations (Bini 1996). The higher growth of the floating-emergent *Eichhornia azurea*, for example, was observed during the low water period. On the other hand, the growth of the emergent *Polygonum* sp. occurred simultaneously to water level increase while no pattern was observed to *Salvinia auriculata* (Bini 1996).

Experiments of decomposition in the floodplain have been carried out basically with respect to the dominant species *E. azurea*. The decomposition of this species is relatively slow (50% of dry weight lost ranged from 67 and 102 days) (Pagioro, Thomaz 1998; 1999b). The decomposition is affected by detritus chemical and water characteristics (Pagioro, Thomaz 1999b). In view of the high habitat diversity in the floodplain, it is expected that the dynamic of the decomposition and the nutrient cycling associated with plant detritus present a considerable variability in the area.

Detritus from aquatic and amphibian vegetation hypothetically are important food resource in the floodplain. Several species of detritivorous and bottom feeding fishes are found in the region and they are abundant in terms of biomass (Fugi *et al.* 1996; Hahn *et al.* 1997), which is also common in other floodplains (Araújo Lima *et al.* 1995). Among the species that feed on detritus, *Prochilodus lineatus* is the most important (Hahn *et al.* 1997). Several rotifers (e.g. *Lecane*) and chironomids, which are very common in the floodplain aquatic habitats, also feed on detritus and bacteria (Garcia *et al.* 1998; Higuti, in press).

The effects of the flood regime on the availability of food and refuge against predation provide ideal condition to the initial development of fishes. Similar to other South American basins (Welcomme 1979; Lowe-McConnell 1987; Machado-Allison 1990; Vazzoler, Menezes 1992), the seasonal variations in the water level is the factor in the Upper Paraná River basin with the greatest relevance in controlling fish reproduction and recruitment success. This may be established not only by the high synchronism between floods and the principal events of the reproductive cycle (maturation of oocytes, migration, spawning and initial development of juveniles), but also by the relationships between recruitment success and the time, duration and amplitude of the floods (Gomes, Agostinho 1997; Agostinho *et al.* 2000b). These relationships are more evident in long distance migratory species that, in general includes large fishes (maximum standard length higher than 40 cm) with seasonal and total spawning, small eggs, and high fecundity (Suzuki 1992). This group constitutes about 19% of the regional species richness and 21% of the total catch numerically. Three of these fishes (*Prochilodus lineatus*, *Rhaphiodon vulpinus*, *Leporinus obtusidens*) are among the most abundant. These fishes show a pattern of seasonal occurrence of adults in floodplain habitats. Some of them (e.g., *Brycon*, *Salminus*) reproduce in the upper reaches of major tributaries, whereas others (e.g., *Pseudoplatystoma*, *Pterodoras*) spawn in rivers along the margins of the floodplain, and all of them use the floodplain as nursery habitat (Agostinho *et al.* 1993). Migratory fishes depend on large stretches of free-flowing river and are the most affected by the series of impoundments constructed on the upper Paraná River (Agostinho *et al.* 2000b).

5. The main natural and anthropogenic impacts

The Upper Paraná floodplain is submitted to several natural and anthropogenic disturbances, which affect the ecosystem locally and/or regionally. Among the natural ones, are those associated with "El Nińo" that result on floods with high amplitude and duration with periodicity close to seven years. The effects of this phenomenon were not still evaluated, but, apparently great floods alter population structure of all aquatic organisms.

As mentioned, the occupation of the uppermost stretch of the basin impacts indirectly the area under study and its biota. This stretch drains the region with great urban and industrial centers and intensive agriculture as well. In the Sao Paulo State, where cities are bigger, urban demand of water is greater than 87 $m^3.s^{-1}$, with 50% returning to rivers. Only 8% of these receive some type of treatment. For 2300 industries out of 4300 registered by the "Departamento Nacional de Águas e Energia Elétrica" (National Department of Water and Electricity), estimated water demand is 113 $m^3.s^{-1}$, with return of 68% (Sao Paulo 1990). Water demand for irrigation is also high, but there is no information available. The ever increasing demand for water, the intense use of chemicals, inadequate soil management, removal of riparian vegetation and the poor quality of the water that return to rivers are worsening the situation.

These impacts reach alarming proportion in some stretches of the basin, especially where there are big cities. Water in those is inadequate for consumption and costs for treatment are high. Between the source of the Tiete River and the Upper Paraná floodplain there are seven big dams which contribute to improve water quality (Esteves 1983; Mussara 1994).

The direct anthropogenic activities in the area which have greatest potential impacts are those related to cattle raising, rice agriculture, *Pfaffia* extraction (a shrub used in the cosmetic industry), sand extraction and navigation. Islands have been extensively used for cattle raising during the low water periods (dry period), when farmers find difficulties to feed cattle in the fields outside the islands. Although specific data concerning this impact are lacking, it is expected that the stepping produces soil compactation, marginal erosion in the islands and destruction of the saplings and herbaceous vegetation. This situation is even worse after burnings caused to accelerate the grasses and herbaceous vegetation growth. The severe impact of deforestation was quantified at Porto Rico Island, a small island with ca. 100 ha. Aerial images show that 92% of this island was covered by forests in 1952, 42% in 1965, 23% in 1970, 17% in 1980 and only 6% in 1996 (Campos 1999). Although it was not quantified, it seems that other islands in the region suffered the same fast deforestation process in recent decades.

Persons who collect *Pfaffia* in the floodplain also commonly cause burnings to facilitate the localization of such plants (this species is the first to sprout after burning). Another impact is the dredging and, sometimes, use of biocides in rice agriculture in the floodplain. The incorporation of the floodplain into the agriculture productive system is increasing in the region and it subtracts important areas for initial fish development leading to negative impacts upon the conservation of fish populations and fishery stocks.

Navigation projects are being planned in the Paraná basin and they will increase the traffic of barges to transport the harvest of grains from the west of the State of Paraná and south of the State of Mato Grosso do Sul to Santos Harbor (Sao Paulo). Most of the barges start their trips in the Itaipu Reservoir, navigate upriver, passing trough locks in the dams located in the Paraná and the Tiete rivers. Marginal erosion and pollution are probable impacts caused by this activity.

Among all perturbations, the effect of the operation of the upstream dams seems to cause the most severe impacts observed in the river-floodplain system. Such perturbations can be included in the category of "downstream impacts of reservoirs chains" and they affect the physical and biological environment, interfering direct or indirectly upon the habitat structure, communities composition and functional aspects of the system. In addition to the impacts upon nutrient cycling and solid concentrations, considered previously, other impacts associated with the alterations of the water level were identified:

(i) Changes of the natural hydrological regime, with direct impacts upon species whose life cycles depend on such fluctuations and upon the connectivity among habitats;

(ii) Presence of barriers to migratory fishes, which spawn upstream the floodplain but use its habitats as nursery and feeding sites.

These impacts has potential do lead to biodiversity losses in the ALTER and main tributaries because several species that live in the region, as mentioned, use the floodplain during a certain stage of the life cycle.

6. Perspectives for conservation and management

Besides the human occupation of part of the Upper Paraná River floodplain and discharge regulation by dams located upstream, this area still plays important role in the maintenance of the regional biodiversity. For example, in the Itaipu Reservoir, located downstream from the floodplain, the fishery is at least twice more profitable than in any other reservoir of the Upper Paraná River basin and some large migratory species are still captured in the fisheries.

Using the criteria employed by Welcomme (1979) to determine the stage of modification in floodplain rivers, the Upper Paraná River floodplain can be classified as slightly modified, with some areas not modified. Removal of trees located in some islands, levees of secondary channels and on the eastern margin of the Paraná River is common. These areas are used for cattle raising or subsistence agriculture (corn, bean and rice). The area that is seasonal inundated is covered by bushes and, during the dry season, it is used for agriculture and cattle raising. Fish stocks are altered but the fishery of large sized species (Pseudoplatystoma corruscans - may reach up to 150 cm; *Salminus maxillosus* - up to 100 cm) is still relevant.

The state of preservation is spatially heterogeneous. Then, areas near urban centers are altered, whereas those far maintain pristine conditions. In the region, the area near the mouth of the Ivinheima River is the most pristine. Surveys of eggs and larvae of fish conducted in the five rivers in this region demonstrated that higher densities are found in the Ivinheima, suggesting the importance of this river as spawning ground (Nakatani *et al.* 1993). This fact is supported by the high capture of individuals with ripe gonads (*S. maxillosus*, *P. corruscans*, *Brycon orbignyanus* and *Piaractus mesopotamicus*; all migratory), in the upper part of this river. As mentioned before, these species are the most impacted by the dams, and they are virtually absent in the dammed stretches of the superior part of the upper Paraná River basin.

Because most of the activities developed in the area are conflicting with environmental legislation, several prosecutors in the region are pressuring farmers to remove cattle from the islands and the floodplain, and prohibiting the extraction of *Pfaffia*. Following the same, state agencies are discussing with researchers and other governmental agencies, looking forward to find solution for a sustainable development of the region, maintaining the integrity of the floodplain. Important steps for the conservation of the biodiversity associated with the floodplain occurred with the creation of three conservation units in the area.

It is concluded that the maintenance of fish diversity in the last dam-free segment of the Paraná River in Brazil, especially with regard to the populations of large migratory species, depends on the integrity of the land - inland water ecotone represented by the floodplain. The maintenance of this integrity should necessarily be linked to the disruption of the current process of human occupation in the region and especially to a greater rationalization of dam operation upstream. The artificial control of the floods by the dams upstream (controlling discharge) has a great potential to improve recruitment performance, particularly of large migratory fishes. Dam operation has some flexibility, but there are some pitfalls (e.g. the scarce information about fish biology and specific responses to the floods). More detailed studies are necessary in order to assess the biological requirements of the threatened species and to identify the minimum water level, duration and timing of the floods that trigger spawning and assure the viability of the eggs and larvae. Additionally, the establishment of a permanent floodplain reserve (core zone), with at least two concentric region with decreasing restriction of use (buffer and transition zones), according to biosphere reserves from MAB/UNESCO, encompassing the three areas already established for environmental protection in this stretch (National Park of Ilha Grande, State Park of Ivinheima River and Environmental Protected Area of Paraná River Várzea) is recommended.

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