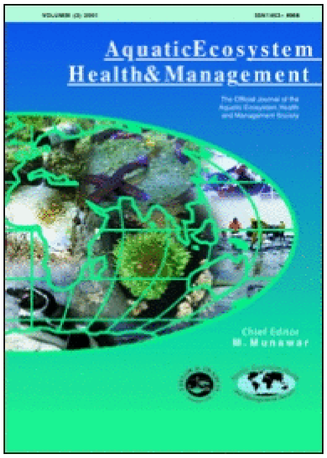

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Fish diversity in the upper Paraná River basin: habitats, fisheries, management and conservation

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The Paraná River is the second longest river in South America and the tenth largest river in the world in water discharge. The upper stretches are characterized by high human occupation and intense anthropogenic activities, and few areas are still in pristine conditions. Despite this, fish diversity is remarkably high in the upper Paraná River basin, and the existence of different habitats greatly influences fish biodiversity. Although most species are sedentary, migratory species are considered the most important, since they have historically sustained commercial and recreational fisheries. Recently, stocks of migratory species have diminished in many rivers due to overfishing and habitat modifications caused by dams. Impoundments have a long history in the basin and constitute the main source of impacts for both sedentary and migratory fish species. Government agencies have implemented management actions to mitigate the effects of damming on fish populations, which included fish stocking (using native and non-native species), the construction of transposition mechanisms and fishery control. However, their efficacy for conservation has been severely questioned and, in many instances, these actions have produced negative outcomes to biodiversity. The lack of studies and monitoring programs contributed to the uncritical adoption of some dubious management actions. Inevitably, management plans directed to conserve fish biodiversity in the basin need urgent revision.

Keywords: South America, ecology, reservoir, migratory fishes, ladder, non-native species

Introduction

The Paraná River is the second longest river in South America (4,695 km), the tenth largest river in the world in water discharge and the fourth in drainage area (Agostinho et al., 1995). Its basin, including the Paraguay River occupies most of the central-south part of South America (2.8×10^6 km^2) (Brazil, Paraguay and Argentina).

The upper Paraná River basin includes the former upper Paraná Province (the stretch between Sete Quedas and Itaipu Dam, described by Ringuelet (1975)), and the Iguaçu River. It drains an area of $880,000$ km^2, and it represents 10.3% of

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the Brazilian territory. The most important feature of this basin is the presence of the highest human occupation in the country (54,640,000 inhabitants; 32% of the population), and several industrialized centers. In addition, agriculture, ranching and construction of dams are historical widespread activities. Consequently, few areas are still found in pristine conditions.

Compared to other large Brazilian basins, the upper Paraná River is considered one of the most intensively studied. Surveys started during the first half of the 20th century as observation of fish migrations (for spawning) in some tributaries (Godoy, 1957). Other studies have shown that a major part of the biological diversity found in the Atlantic Forest biome is found in the upper Paraná River basin, although the overall number of species is certainly underestimated (Thomaz et al., 2004a; Agostinho et al., 2005; www.biota.org.br).

Fishes are considered the most intensively studied taxonomic group. However, they are a good example of the underestimated trend observed in species number of aquatic biodiversity. New fish species are still discovered and many others are currently being described. In addition, improvements in genetic techniques are revealing that some species are actually species complexes.

Despite this, fish diversity is remarkably high in the upper Paraná River basin, and the existence of different types of habitats greatly influences fish biodiversity (Agostinho et al., 1995). Although most species are sedentary, migratory species are considered the most important feature, since they have historically sustained commercial and recreational fisheries.

Impoundments have a long history in the basin and constitute the main source of impacts for both sedentary and migratory fish species. In addition, government agencies have implemented dubious management actions to mitigate the effects of damming on fish populations and fishery stocks. Efficacy of these actions has been severely questioned and in many instances, they have produced negative outcomes on biodiversity (Agostinho et al., 2005). Inevitably, it created a great debate and measures toward conservation of fish species and maintenance of fish stocks in the basin need urgent revision.

In this paper we present a synthesis on aspects of fish taxonomy and ecology, main biotopes used by fish, environmental impacts and fisheries from the upper Paraná River basin. Additionally, actions taken towards management of fishes are presented and discussed. Finally, we identify some priorities for further studies.

Fish fauna and ecology

Several taxonomic orders characterize fish assemblages in the upper Paraná River basin, which is composed of about 270 fish species (Pavanelli et al., 2001; Shibatta et al., 2002; Castro et al., 2003, 2004; Graça, 2004). Two orders, Characiformes and Siluriformes (characins and catfishes, respectively), usually predominate in number of species and abundance, comprising approximately 80% of all fish species. These orders also have the highest number of families, and species are characterized by an immense diversity in color, body shape, size and behavior. Other taxonomic groups are Gymnotiformes (knife fishes), Cyprinodontiformes (killifishes), Perciformes (cichlids and sciaenids), Synbranchiformes (swamp eel), Pleuronectiformes (flat fishes), and Myliobatiformes (stingrays).

Fish species of the upper Paraná River basin can be divided into two major groups based on their life history strategies: sedentary/short migratory; and migratory. Most species belong to the first group (∼88%), characterized by a relatively short lifespan, small to medium size, and a variety of reproductive strategies (Agostinho et al., 2003; Suzuki et al., 2004), which contributes to the dynamic aspect of populations and assemblages. Depending on the species considered, one or a few habitats are needed to complete the life cycle, including short migrations (< 100 km). Some species (∼8%) have internal fertilization, and may have external or internal development of young. The remaining species have external fertilization, with varying degrees of parental care (Figure 1). On the other hand, migratory species (∼11% of all species) require different habitats during their life cycle, traveling long distances to reach distinct sites for spawning, early development and feeding (Agostinho et al., 2003). Migratory species have larger size, longer lifespan, external fertilization and do not exhibit parental care (Figure 1).

Information on life-history strategies and habitat preferences are well known, especially for economically important migratory species. A widely recognized pattern for both migratory and sedentary species is the close association between life cycles and seasonal hydrological dynamics. The reproductive period of many species is synchronized with the occurrence of floods and stimulated by rising river levels. Therefore, the reproductive success of

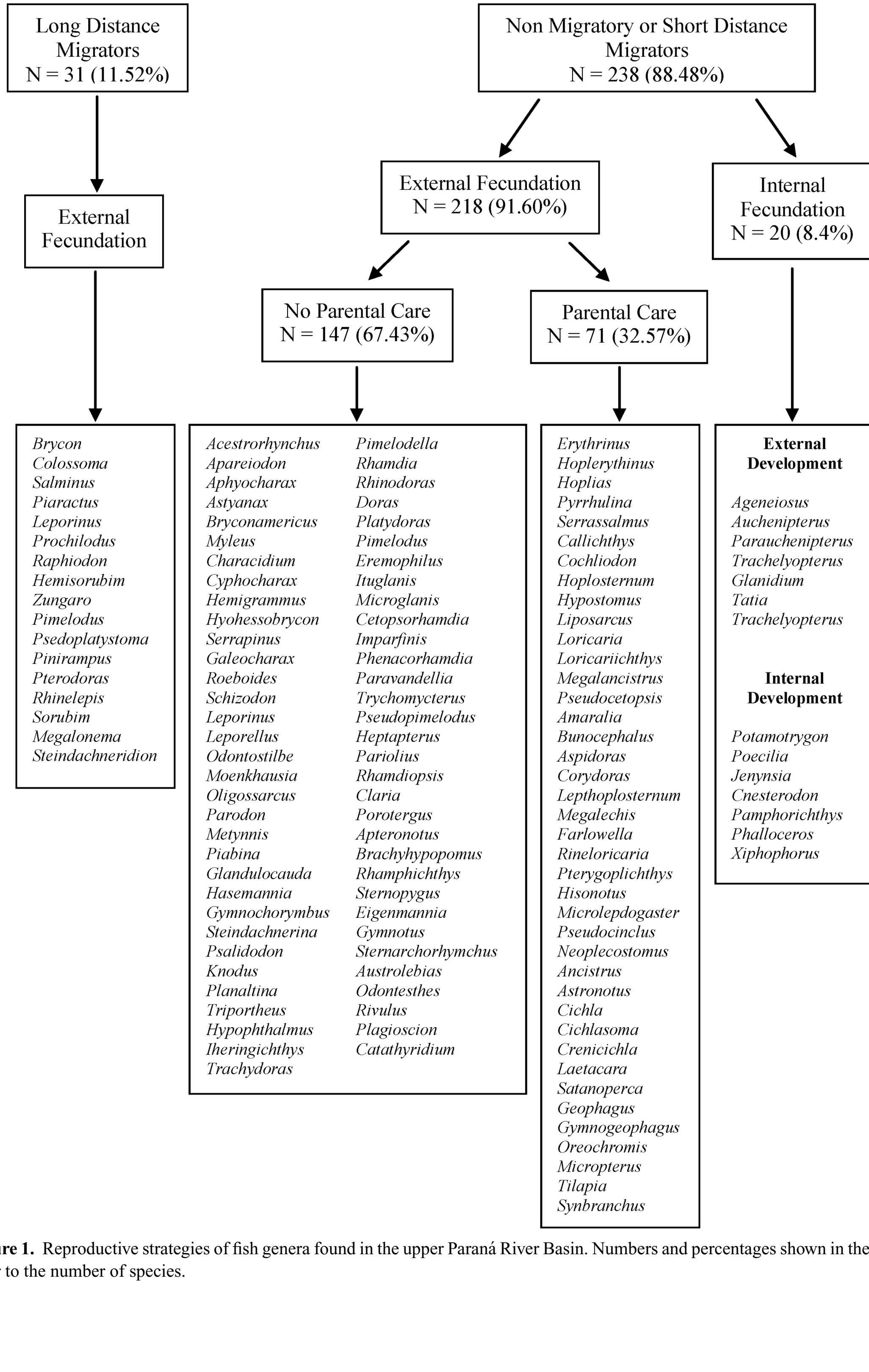

Figure 1. Reproductive strategies of fish genera found in the upper Paraná River Basin. Numbers and percentages shown in the boxes refer to the number of species.

riverine migratory species is associated with timing, intensity and duration of floods (Gomes and Agostinho, 1997; Agostinho et al., 2003).

Depending on the hydrological phase in the basin, three different fish movements can be distinguished: i) upstream reproductive migration, named *piracema*, that occurs with rising water levels (usually October and November); ii) lateral movement among habitats during the flooding period (between January and March), which constitutes an opportunity for small-sized species, eggs, and YOY to reach marginal lagoons; and iii) backward movement towards the main river channel, by species that spent initial phases of their life cycles in disconnected marginal lagoons and occurs during decreasing water levels (∼March to May).

Considering feeding ecology, an important characteristic is the high plasticity observed in most species, although some trophic specializations may occur (Araújo-Lima et al., 1995; Abelha et al., 2001). Detritus and invertebrates constitute an important and abundant resource in all habitats and form the base of most food webs. Algae and fishes are other important resources. Despite abundant and widely distributed, aquatic macrophytes are rarely consumed by fish.

Small-sized species, abundant in lagoons, creeks and littoral habitats, consume mostly filamentous algae, plant matter, crustaceans, insect larvae and other aquatic/terrestrial invertebrates (Hahn et al., 2004). Consumption of these items depends on fish species, habitats, season and availability. Piscivores are a diversified group and represent the higher fish biomass in many assemblages. Most migratory species are strictly piscivores, such as large catfishes, but a number of sedentary piscivores, such as *Hoplias*, *Acestrorhynchus*, *Serrassalmus* and the introduced *Plagioscion*, exhibit some degree of plasticity and may intake invertebrates. According to the tactic used for predation, fishes may be categorized as ambushers (e.g., Erythrinidae), shoaling (e.g., Characidae and Cichlidae), and opportunistic (e.g., Serrassalmidae).

Feeding specialists are less common (Hahn et al., 2004). True planktivores include catfishes of the family Hypophthalmidae, which use their long gill rakers to filter zooplankton. Another group of specialists include illiophagous species, belonging to Prochilodontidae, Curimatidae and Loricariidae, with well-developed suctorial lips, and Parodontidae, whose jaws are shovel-shaped. Detritivores and illiophagues may constitute the higher fish biomass in rivers and lagoons and, because they consume algae, bacteria and detritus, they are important in cycling of nutrients, transferring energy to higher trophic levels, and sustaining some fisheries (Fugi et al., 1996).

Studies on fish growth in the upper Paraná River basin have considered only about 10% of fish species (Agostinho et al., 1995). Some growth parameters were already estimated, allowing some generalization on growth patterns and life-history strategies. Although greatly influenced by abiotic (temperature) and biotic (food availability) factors, small-sized species (e.g., characins, curimatids) tend to have higher growth rates, whereas medium to large-sized species (e.g., cichlids, large characins and catfishes) grow more slowly. However, considering the high spatial-temporal variability in growth aspects, in addition to the fact that most research was conducted during the 70s and 80s, specific predictions of growth at age may be imprecise in some circumstances. For example, it is common that the individuals of the same species present significant difference in growth when inhabiting different habitats, such as reservoirs and floodplain areas (Agostinho et al., 1995).

Main biotopes

The upper Paraná River basin includes several large tributaries, such as the Tietê, Paranapanema, Ivinheima, Ivaí and Iguaçu (Figure 2). These rivers run through the Atlantic Forest and Savannah biomes, both in advanced stages of fragmentation. The existence of different types of habitats along the tributaries and the Paraná River main channel enhances environmental heterogeneity and, consequently, regional biodiversity (Agostinho et al., 1995).

These habitats include creeks, rivers, floodplains, lakes, temporary lagoons and reservoirs, which have distinct and characteristic fish assemblages (Agostinho et al., 2004a). The amount of each habitat is difficult to estimate due to the large size of this basin and the lack of specific studies. Low-order rivers are abundant, while floodplains are found in lower stretches of the upper Paraná River and its tributaries. Reservoirs are located along the main channel of medium and large rivers and, in most cases, disposed in chains.

In **creeks**, pool and riffle stretches contain a high number of small-sized fish species (∼150 species), depending on the availability of underwa-

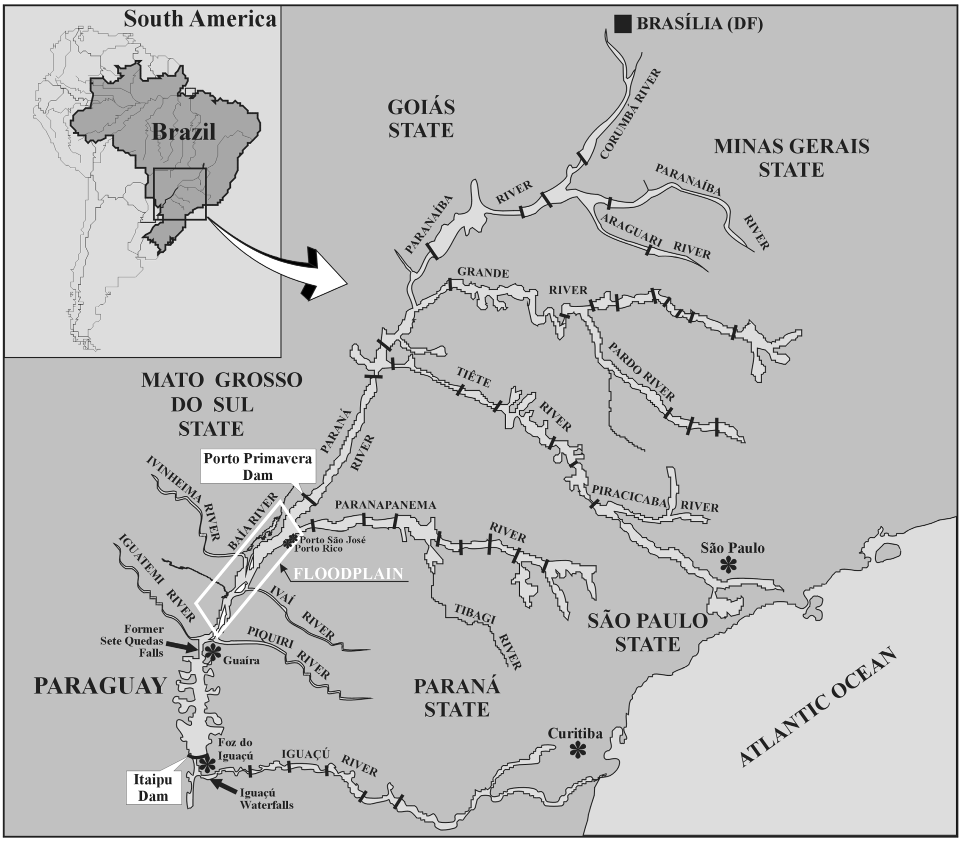

Figure 2. Map of the upper Paraná River Basin, Brazil, with main tributaries and the last un-impounded stretch (rectangle indicates the floodplain). Each transversal dash in the rivers indicates the presence of a dam.

ter shelter and the presence of riparian canopy (see Agostinho et al., 1995; Castro et al., 2003, 2004 for details). Recent efforts have concentrated on the biodiversity of creeks (www.biota.org.br), which have several endemic species and are extremely sensitive to impacts. The fish fauna is unique, composed mainly by small characins, pimelodids, loricarids and poecilids, such as *Astyanax*, *Characidium*, *Rhamdia*, *Pimelodella*, *Rhineloricaria*, *Hypostomus* and *Phalocerus* (Agostinho et al., 1995).

Rivers present a high diversity of physical characteristics, varying from rapids with rocky bottoms (*High Gradient Tributaries*), such as Piquiri, Tibagi and Iguaçu rivers, to meandering rivers with low water velocity and sandy-clay bottom (*Low Gradient Tributaries*), such as Piracicaba and Ivinheima rivers. The tabarana *Salminus hillari* and the catfish *Steindachneridium* are restricted to medium sized rivers. Doradids, ageneiosids and erithrinids are frequent in meandering rivers, where species richness is also high (more than 100 species). Some anostomids (piaus) and darter characins, such as *Leporinus amblirhynchus*, *Schizodon nasutus* and *Apareiodon affinis*, are typical of rapid rivers (Agostinho, 1994). Unimpounded tributaries are of great importance as routes to reach spawning sites, usually located in upper sections of the basin (Suzuki et al., 2004). Although the Iguaçu River does not function as a dispersal route, it deserves special attention because of its high number of endemic species (80% of its fish fauna; Garavello et al., 1997). This is a result of regional processes: the presence of several cascades along the river and the huge Iguaçu Falls in the lower reach, which acted as natural barriers to dispersion, limiting populations to short stretches.

The **main channel** of the upper Paraná River has lotic characteristics, variable depths and dominance of sandy bottom. Deeper areas of the river are the preferred habitat of the biggest fish in this basin, the jaú *Zungaro zungaro*. In general, however, the fauna in the main channel is similar to that found in larger tributaries, including many adult migratory species. Unfortunately, the Paraná River main channel, as well as the channel of larger tributaries (such as Paranaíba, Grande, Tietê, Paranapanema and Iguaçu), have lost much of their lotic characteristics and are, today, altered by impoundments. The last stretch of the upper Paraná River with lotic characteristic is less than 250 km long. This stretch presents a floodplain area, located mostly in the west margin, between Porto Primavera Dam and Itaipu Reservoir (Figure 2).

This **Floodplain** represents a mosaic of waterbodies that experience reductions in water volume during dry periods, although regulation is promoted by upstream dams. Conspicuous habitats in the floodplain are shallow **lagoons** and **temporary pools**, with muddy or sandy bottom, covered with many species of aquatic vegetation (Thomaz et al., 2004b). Lagoons remain connected most part of the year to the main river by small channels, or may be supplied by groundwater, while temporary pools can undergo drastic reductions in water volume during dry seasons. These habitat types harbor more than 100 fish species; most of them presents morphological, physiological or behavioral adaptations to drastic variations in dissolved oxygen content and water temperature. Because these lagoons function as nursery areas for juveniles of many migratory species (e.g., *Prochilodus*, *Pseudoplatystoma*, *Leporinus*), and constitute the main habitat for several sedentary species (e.g., *Hyphessobrycon*, *Hemigrammus*, *Moenkhausia*, *Pyrrhulina*, *Astyanax*, *Loricariichthys*), they play a key role in maintaining high levels of biodiversity (Gomes and Agostinho, 1997; Okada et al., 2003).

Reservoirs are a conspicuous feature of the basin landscape. Currently, there are about 150 large reservoirs in the basin, four of them in the Paraná River main channel (Agostinho et al., 1995). Impoundments on rivers constitute the main threat to biodiversity conservation, due to habitat losses and severe environmental changes. Fish communities in reservoirs represent a combination of the original species pool (common species belong to *Astyanax*, *Serrassalmus*, *Schizodon*, *Hoplias*, *Steindachnerina* and *Geophagus*), and introduced species (such as *Plagioscion, Cichla* and, in some cases,*Tilapia*) (Agostinho et al., 1999a; Gomes and Miranda, 2001). Migratory species are usually absent or in very low abundances.

Main impacts

Since the second half of the 19th century, the Paraná River and its main tributaries have been increasingly used for hydropower generation, through the construction of dams. Impoundments affected mainly migratory species due to habitat fragmentation and regulation of floods. The closure of Itaipu Dam (October 1982), for example, modified a narrow stretch of the Paraná River (170 km long), forming a lake of 1350 km^2. As a consequence, riverine and highly valuable commercial species, like *Salminus brasiliensis*, *Pseudoplatystoma corruscans* and *Piaractus mesopotamicus* virtually disappeared in the new semi-lentic environment. This impoundment drowned Sete Quedas Falls, which constituted a natural barrier for fish movement, allowing upward dispersions of at least 17 species (Agostinho et al., 1995). Some of these (*Serrasalmus marginatus*, *Loricariichthys platymetopon* and *Parauchenipterus galeatus*) are now widespread in the floodplain located above Itaipu (Agostinho et al., 2004a).

Porto Primavera Dam, completed in 1998, formed the Porto Primavera Reservoir (area of 2,200 km^2). This dam, located immediately above the upper Paraná River floodplain area, interrupted fish migration routes and altered hydrological dynamics. Impacts related to its operation have affected floodplain assemblages and have been documented in some recent studies (Agostinho et al., 2004b). This dam drastically altered the river dynamic, interrupting floods in some periods or leading to severe decreases in flood intensity, duration and amplitude (Figure 3). The lack of flooding during the spawning period of most fish species is a great concern, since recruitment may not occur due to inaccessibility to marginal lagoons. Fish abundance and species richness in experimental fisheries decreased in years marked by low water levels, especially for migratory species (Agostinho et al., 2004c). After the closure of Porto Primavera Dam, water transparency increased, submerged macrophytes proliferated and the introduced peacock bass (*Cichla* spp.), a visual predator, became abundant downstream of the dam.

Waterbodies in the upper Paraná River basin are also subjected to pollution. Paraná River tributaries run across the most developed metropolitan and agricultural regions of Brazil, and, consequently, receive large amounts of domestic-industrial sewage (especially in São Paulo State) and pesticides (used on soybean, cotton and sugar cane fields). For example, the Tietê River basin harbors a population

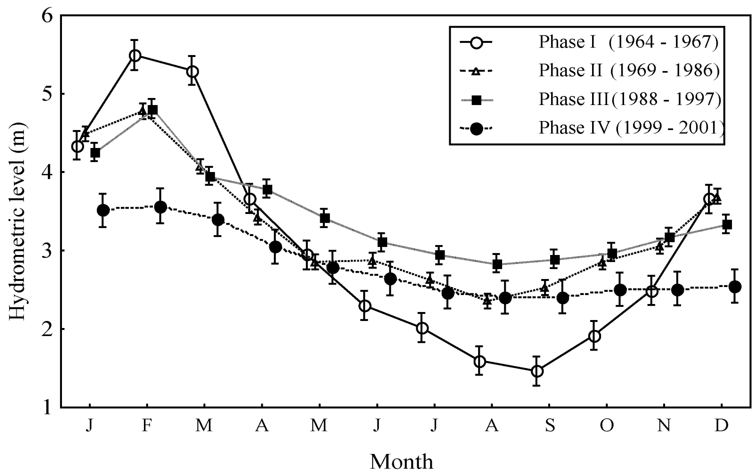

Figure 3. Variation in water level of the upper Paraná River, from 1964 to 2001, measured at Porto São José municipality, located just below Porto Primavera Dam. Points are monthly averages and bars represent standard errors. Phase I: before the closure of Jupiá Dam; Phase II: before the closure of Rosana Dam; Phase III: before the closure of Porto Primavera Dam; Phase IV: after Porto Primavera.

of 24 million people, with 71% of them in the São Paulo metropolitan region. According to Barrella and Petrere Jr. (2003), longitudinal patterns of the fish fauna in this river are strongly affected by pollution, and only one or two species may dominate assemblages in polluted headwaters.

However, the increased sedimentation rates and retention of matter and energy upstream, prompted by cascade of dams, lead to a pattern of decreasing primary productivity toward lower stretches (Barbosa et al., 1999). Based on recent evidence, the impoverished waters that reach the upper Paraná River floodplain are removing nutrients (mainly phosphorus) and organic matter from its habitats. Therefore, the upper Paraná River no longer acts as a source of nutrients for floodplains (Agostinho et al., 1995), differing from the dynamics observed in other large rivers (Junk et al., 1989).

Another threat to aquatic biodiversity in this basin is the introduction of non-native species. Stocking programs used to be the principal way for fish introduction. Most common species added from these actions is *Plagioscion squamosissimus*, introduced from the Amazon basin. Currently, aquaculture is the main source of introductions. Orsi and Agostinho (1999) estimated that 1.3 million individuals (belonging to ten non-native species) escaped into natural waters in one sub-basin of the Paranapanema River, during the catastrophic flooding of January 1997. Aquaculture using cages, from which escapes are unavoidable, is increasing in reservoirs of the basin, supported by governmental agencies. Also, ponds constructed by damming small rivers used to fish-and-pay are becoming abundant in the basin (2000 only in São Paulo State). The risk of non-native species escaping from these ponds is the same as those for aquaculture (Fernandes et al., 2003). Finally, stocking non-native fishes to develop recreational fisheries, especially the piscivorous peacock bass (*Cichla* spp.), is illegal but occurs frequently.

Fisheries

Similar to other regions of the Brazilian territory (e.g. Amazon and Pantanal), multi-species fisheries represent a traditional and important social/economic activity in the upper Paraná River basin. Three kinds of fishers are found in the region (Petrere Jr., 1989; Petrere Jr., 1996). *Commercial fishers* are concentrated mainly in reservoirs and they live exclusively from the fisheries. They use motorized aluminum boats and a wide range of gears and methods, including seines, gill nets and hooks. *Artisanal fishers* are found mainly in rivers (remaining lotic stretches) and floodplain areas, practicing small-scale agriculture during periods when fishery is prohibited. They use simple gears, such as hook and lines but may also use nets and wooden boats. The catch is usually sold, but some fishes may be kept for family consumption. *Recreational fishers* increased in number in reservoirs and floodplain areas in recent years. They are better equipped, using rods, hooks and line, and motorized boats. They usually live in urban centers and fish recreationally during weekends.

Historically, migratory species constituted the main catches, such as *Salminus*, *Prochilodus*, *Piaractus* and several catfish species. These species are highly appreciated in regional markets, especially because of their excellent flesh. However, overfishing and especially dam construction have negatively impacted the population of these species, and catches decreased substantially over the years (Agostinho et al., 1999b; Petrere Jr. et al., 2002). Currently, fisheries are developed basically in reservoirs and because the decreasing harvest of migratory species, fisheries are based on non-migratory species. These species are generally smaller in size with shorter life span and lower commercial value, such as *Astyanax*, *Schizodon*, *Cyphocharax*, *Hoplias, Pimelodus, Iheringichthys* and *Geophagus* (Agostinho et al., 1995; Petrere Jr. et al., 2002). In addition, non-native species have become important in commercial and recreational fisheries, such as in reservoirs of the Grande and Tietê basins (e.g. capture of *Plagioscion*, *Cichla*, *Oreochromis* and *Tilapia*).

In the upper Paraná River basin, fishery yields are considered low, a situation commonly found in Brazilian waters. Petrere Jr. et al. (2002) presented data from some of the reservoirs in this basin. Yield varied from 37 t year^{-1} in Ibitinga Reservoir to 1,800 t year^{-1} in Itaipu Reservoir. Most of the fishes caught in commercial fisheries comes from the Paraná River, followed respectively by Grande, Tietê and Paranapanema rivers (Santos et al., 1995; Vermulm Jr. et al., 2001).

Mean yield values for some reservoirs ranged from 2.2 to 24 kg ha^{-1} year^{-1}, with most mean values falling bellow 10 kg ha^{-1} year^{-1} (Gomes et al., 2002). Petrere Jr. et al. (2002) estimated an overall average of 4.5 kg ha^{-1} year^{-1}. Capture per unit of effort (CPUE; kg fisher^{-1} day^{-1}) from 1994 to 1999 has not varied significantly in the Paraná and Paranapanema rivers, but has declined progressively in the Grande River (Vermulm Jr. et al., 2001). The low fish yield in the upper Paraná River basin is evidenced when compared to fisheries in the northeast Brazil, or to other continents such as Asia and Africa, where catches may exceed 100 kg ha^{-1} year^{-1} (Fernando and Holcik, 1991; Paiva et al., 1994). This difference is associated to physical characteristics of reservoirs in the upper Paraná River basin, which are neither lacustrine nor riverine environments. Species usually are maladapted to these new conditions and, therefore, cannot thrive and maintain high fishery yield (Gomes and Miranda, 2001).

Recreational fisheries are increasing in floodplain and reservoir areas. This activity contributes to develop regional tourism, supported by local authorities, but without adequate planning. These fisheries also promote the development of fishery for bait. Although without scientific evaluation, the bait fishery constitutes an important economic activity for floodplain inhabitants, especially for women. They catch *Gymnotus* spp. and small characins in floodplain lagoons using sieves in stands of aquatic macrophytes. In addition, ornamental fisheries has a tremendous potential in the basin (Pelicice & Agostinho, 2005).

Management actions

Management actions taken in the upper Paraná River basin were based on trial and error methodologies, since adequate scientific and technical information was not available in the past, or neglected more recently. Spectacular failures accompanied the history of fish management in the upper Paraná River basin. The preferable actions taken by managers involved basically fishery management objectives, such as stocking with native and non-native species, construction of fish ladders and fishery control.

Stocking

Stocking in the upper Paraná River basin was conducted mainly in reservoirs (Agostinho et al., 1995; Agostinho et al., 2004d). Due to a multitude of factors Neotropical reservoirs show low fishery yields within a few years after formation (Gomes and Miranda, 2001). Stocking was considered an action necessary to recover fisheries and started some years after reservoirs were filled. However, some mistakes led to total failure, such as using the wrong species, releasing fishes in inappropriate sites, size or seasons and, the low stocking effort. In fact, stocking was carried out with clear political objectives and pseudo-conservationists institutional marketing (Agostinho et al., 2005). These stockings, performed without a clear objective or sound planning, were never monitored. Therefore, people involved recently began to realize that expected results were never met and fisheries did not improve. Astonishingly, these negative results have not impeded this practice from extending to rivers and lakes and, in many cases, released species were never caught.

These introductions (stocking) included species from other continents, such as the opportunistic *Oreochromis niloticus* and *Tilapia rendalli* (Agostinho and Júlio Jr., 1996). Species from other neotropical basins were also introduced, such as the piscivorous *Cichla* and *Plagioscion*, from the Amazon and Northeastern basins, respectively. As mentioned before, these non-native species are dominating fish assemblages and fishery landings in many reservoirs of the upper Paraná River basin. In addition, they have been registered in environments formerly considered more pristine, for example the floodplain located in the longest stretch not impounded of this basin (Agostinho et al., 1995). Several other species were introduced (stocked) but did not become established.

During the past decade, stocking programs switched to include native fishes. However, evaluation of stocking efficiency has not been performed as well as the possible impacts related to the poor genetic quality of the parental fish that usually characterizes some Brazilian hatcheries (Toledo-Filho et al., 1992).

Fish ladders

As the main courses of all large rivers in the upper Paraná River basin are interrupted by series of dams, another common management action taken was the construction of fish passages. Construction of fish ladders started almost simultaneously with dam construction, using techniques imported from Europe and North America. During the first half of the 20th century, fish ladders were mandatory and they were constructed in several small reservoirs. In most cases, they were not effective. The main problem was that functioning of fish ladder depends on their technical features (type, slope, discharge, position in relation to other components of the dam) and the nature of the fish fauna (Agostinho et al., 2002a).

Recently, structures for fish passage were reconsidered and, again, became mandatory in some Brazilian states. However, their importance for fish conservation is contested (Agostinho et al., 2002a). In the upper Paraná basin, most of the reservoirs are in cascades and they do not have relevant nursery areas.

Studies observed that some fish species are able to ascend ladders, but selectivity is high (Fernandez et al., 2004). Also, the success in passage can not be used to evaluate the efficacy of a ladder, because downstream movement of fishes after spawning is low, and eggs, larvae and YOY cannot drift in the lentic and clear water of a reservoir without increasing mortality rates by predation, sinking to low oxygenated water near the bottom or passing through the turbines and spillway (Agostinho et al., 2002a). Research is still needed, but these preliminary observations have led scientists to consider Brazilian ladders as devices with questionable positive effects and with great potential to cause negative impacts on biodiversity. Agostinho et al. (2002a) suggest that the emphasis of the studies on fish passages need to change the approach, from demography to genetics.

Fishery control

This action has a long history of controversy. Brazilian legislation is severe and restricts fisheries by imposing limits on quantities, gears employed, habitats and seasons. In the upper Paraná River basin, limits on quantity are imposed on recreational fishers (10 kg $fisher^{-1}$). No limit of fish quantity restricts commercial/artisanal fisheries, which are always targeting higher yields. Overfishing is a constant issue and sometimes operates synergistically with other disturbances (e.g., impoundments), resulting in severe stock depletions. For example, large migratory species, the most appreciated in the market that historically constituted the main landings, are rare and disappearing in commercial catches in many areas.

There are three levels in which the control has been more directed: licenses, gear, and minimum fish size. Fishing licenses are needed to practice any type of fishery, and are issued by government agencies, which help to control the number of fishermen. The number and type of gears employed by commercial and recreational fishers also have restrictions, including the use of boats. Minimum fish size is the most controlled aspect in fisheries. Legislation determines a minimum catch-size, which is species-dependent and is based on length at which fish are adults (at least spawned once). Although these aspects are considered the most important by authorities, the lack of constant supervision and enforcement makes any type of control difficult, and it is common for fishermen to employ prohibited gears, such as cast-nets and seines, or to capture juvenile fishes. Furthermore, a minimum catch-size does not appear to be the best strategy, once populations of commercially important species are exhibiting problems of size-structure, because larger individuals have been selectively and intensively removed over the years (Feitosa et al., 2004).

Legislation also prohibits fishing in important habitats, such as marginal lagoons (nurseries), close to dams, waterfalls and river mouths. In some cases, fishery is prohibited in entire rivers, such as Iguaçu and Tibagi. Total prohibitions are controversial, because enforcement is impossible, and, in some cases, unjustified.

Seasonal prohibitions are no less controversial. The legal fishing period is fixed and extends annually from March to October, because the rainy warm season (∼November to February) is when several species spawn. Seasonal prohibitions are questionable because, as already discussed, the reproductive cycle of many Neotropical species depends intensely on the water regime, following closely rising river levels. Floods are not fixed and the attributes depend on the amount and period of rains, which vary among years. For example, the opening of the fishing season in a year with delayed floods may affect the reproduction success of commercially important species, reducing recruitment in following years. Unquestionably, the fishing period must be controlled, but the adoption of flexible procedures may be more effective and realistic.

Conclusions

The fish fauna of the upper Paraná River basin is remarkably diverse and employed efforts towards its management and conservation are far from adequate. Practically all environments have suffered one or more impacts, and few areas are left in pristine conditions. In addition, lotic stretches of some rivers are still considered for future impoundments.

The most important scientific achievements, which, at some degree, characterize Neotropical fishes, are the understanding of some aspects on fish migration, the close association between life cycles and hydrological seasonal dynamics, behavioral plasticity (including feeding), multiple-habitat requirements, and the diverse life-history strategies demonstrated by the species. This understanding indicates that fish conservation in this basin will be an extremely difficult task and will require complex actions.

Fish conservation in this basin is synonymous with fisheries conservation. For many years, managers tried to improve fisheries, as a compensatory measure to all negative impacts resulting from reservoirs, or simply as an attempt to increase catches. Nevertheless, spectacular failures characterized almost all attempts, including stockings, fish passages and fishery control. The main reasons for the failures include: i) inadequacy and insufficient data availability; ii) inappropriate approach used to perform management (trial and error); iii) absence of monitoring studies; iv) police inadequacies; and, v) deficiencies in integration among hydroelectric companies (Agostinho, 1994). There has been too much exhaustive discussion about the inadequacies of these actions, but in Brazil, short-term political and economical objectives overcome any prudent and more reliable alternatives, with critical consequences on poorer social classes and, inevitably, on biodiversity conservation.

According to Agostinho et al. (2005), this history of failure is an important lesson for politicians, managers, technicians and scientists, and now objectives/actions must be urgently reformulated. Importance should be given to both fish production and biodiversity conservation, focusing mainly on habitat management and conservation, since it tends to guarantee the protection of the whole system. Another relevant point is the need for monitoring after management. Traditionally, monitoring in the Paraná River basin, as well as in Brazil, does not follow management actions. This explains why some management actions took a long time to be abandoned or corrected (i.e., stocking, fish ladders). Lastly, interaction among the components involved (social, economic, political and environmental) must be considered when proposing any management plan.

Adoption of the bio-manipulation paradigm (Miranda, 1996; Agostinho et al., 2004d) seems to be a promising perspective. This paradigm conveys an ecosystem approach to achieve maximum fisheries benefits, including information about water quality, food web, abiotic and biotic interactions, population and community structure. In addition, human dimensions must be a central theme for future management plans, since fishers (commercial, artisanal and recreational) are a common feature in the upper Paraná River basin, and they may play a key role in its management.

There is a tendency to create conservation units and protect critical areas, considered by scientists a more appropriate procedure to protect biodiversity and natural resources (Agostinho et al., 2002b; Agostinho et al., 2004b). Although being a difficult task, some areas in the upper Paraná River basin are under legal protection as State and National Parks (e.g. Morro do Diabo State Park, 338 km^2; Rio Ivinheima State Park, 700 km^2; Ilha Grande National Park, 788 km^2), and Protected Areas (e.g. Protected Area of Ilhas e Várzeas do Rio Paraná, 10,031 km^2).

The protection of vast areas that embody different habitats appears to be a good tool to protect natural resources, including fishes. But this option conflicts sharply with the Brazilian bureaucratic system, besides being an obstacle to the economic "development" desired by politicians and economists. It is important to say that the "development" desired includes more hydroelectric generation, ranching, expansion of agriculture, production of timber and industrialization. If the Brazilian government does not change its directions, the loss of freshwater resources will continue, as is evident today when dams are completed or riparian forests are removed. A promising alternative is the conservation of migratory fish species, since it may facilitate the conservation of habitats and a number of other species. Long distance migratory species, such as *S. brasiliensis*, *Prochilodus lineatus* and *Pseudoplatystoma corruscans* use different habitats during their life cycle, making them umbrella species in conservation strategies. This practice, however, has seldom been applied to Brazilian aquatic ecosystems. Concluding, the replacement of policies directed to give immediate outcomes with long-term perspectives is a promising and prudent initiative, not only for the upper Paraná River basin, but also for Neotropical freshwaters in general.

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