Biodiversity and Fisheries Management in the Paraná River Basin: Successes and Failures

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Abstract

Biodiversity and fishery management are topics not well considered in the upper Paraná River. Biodiversity losses have been, in large part, due to anthropogenic actions, such as overfishing and dam construction. Unfortunately, in the past, fisheries management decisions were not evaluated or monitored for success. Recent studies have shown that if several of these management actions had been abandoned at an earlier date, considerable money, time and effort would have been saved. In this paper we presents the main fishery management actions taken in the Paraná River and link them to biodiversity concerns.

If biodiversity is to be maintained in the upper Paraná River, fisheries management will need to shift to an ecosystem approach. This will require:

1) Consideration of biological and ecosystem factors including, water quality, the food web, biotic and abiotic interactions, and population and communities structures.

2) Regularization of dam discharge to levels similar to observed natural levels.

3) Protection of the river, including all the different areas of the basin needed by different species to complete their life cycle.

Introduction

Biodiversity, a term introduced in the mid-1980´s, is defined as the total richness and varieties of life on earth (Lowe McConnell 1999). Approximately 7,000 freshwater fish species (Matthews 1998) have been identified, over 20% of which are extinct, endangered or vulnerable (McAllister 1999). There is clearly a need for the sustainable use of fish biodiversity. From an ecological perspective, any type of fishery, including the most selective (based on a single species), causes the alteration of ecosystems (King 1995). Multi-species fisheries, or less selective fishery methods, tend to catch species that have secondary or no economic importance, and small stock sizes, potentially leading them to extinction. Some management programs therefore strive to develop and enforce more selective fisheries methods.

Many fish species have had their stocks reduced by overfishing and fisheries management has therefore been blamed for impacts to biodiversity. For example, in the Black Sea, 21 of 26 major species have become “commercially extinct” (not profitable for commercial fishery) (McNeely 1999). Okada (2001) reported the reduction of the stocks of an armored catfish and the resulting collapses of its fishery in the upper Paraná River. Agostinho *et al.* (in press a) reported that migratory species in the same river also had their stocks reduced. It is important to note that fisheries are not the sole problem. Others activities, such as habitat alteration, species introductions and pollution, may have played an even more important role in the process.

Several management techniques have been employed to minimize these problems. The history of natural resource management is full of spectacular mistakes and, unfortunately, managers rarely change their approaches according to past experiences (Ludwig *et al*. 1993). These mistakes are unavoidable consequences of the contradiction between human aspirations (no limit on exploitation) and his/her capacity of achieving them (limited resources) (Ludwig *et al*. 1993). The lack of information about the systems being managed, the absence or inadequacy of monitoring and the high natural variability of the resource abundance are, in general, the main problems that affect the efficiency of management (Agostinho & Gomes 1997). In spite of this, the fishery is an important economic activity and an important source of protein for many people in several regions of Brazil. The fishery requires sound sustainable policies and management actions, but the paucity of accurate information makes evaluation of the resource difficult (Agostinho 1994a, Petrere Jr. 1996).

This paper addresses fish biodiversity and management in the upper Paraná River. First, the upper Paraná River basin is characterized, including a broad description of its fish biodiversity. The next section is devoted to fisheries, a history of fisheries management and its main management actions (results and lessons learned). A case study of the Itaipu Reservoir, the reservoir for which the most information is available, reviews its management history. In conclusion, recommendations are made that, in our view, need to be considered if the sustainable use of the biodiversity in the upper Paraná River is to be maintain.

Upper Paraná River Basin Characterization

The Paraná River is formed by the junction of the Grande and Paranaíba rivers in South-central Brazil and flows into the La Plata River in northern Argentina. It is the tenth longest river in the world (4,695 km), and has a 2.8×10^8 ha 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). The upper Paraná River basin includes approximately the upper third of the Paraná River basin down to the Itaipu Dam. The basin is all in Brazilian territory, except for a stretch within the Itaipu Reservoir that borders with Paraguay (Figure 1).

The main impacts on the upper Paraná River ichthyofauna include several anthropogenic actions. The most conspicuous of these actions is the construction of dams, especially after the 1960's. Damming has affected virtually all the principal affluents, especially those situated in the upper half of the upper Paraná River. In this region, there are 130 dams greater than 10 meters in height, twenty-six of which have an area bigger than 100 km^2. These large reservoirs are distributed among the Grande River (13 reservoirs), Tiête River (9 reservoirs), Paranaíba River (7 reservoirs), Paranapanema River (6 reservoirs), Iguaçu River (4 reservoirs) and the main channel of the Paraná River (4 reservoirs).

Fish fauna diversity of the Upper Paraná River

Ichthyofauna surveys conducted in the upper Paraná River remain incomplete and no consensus has been reached on the taxonomic position of many species collected in these surveys. These factors reflect the lack of systematic studies on freshwater fishes in Brazil and any list of species presented will therefore have some mistakes (Agostinho & Julio Jr. 1999).

Surveys thus far, indicate there are at least 250 species of fish in the upper Paraná River. Among them, 107 are Characiformes, 91 are Siluriformes, 20 are Perciformes, 3 are Rajiformes, 1 is Cypriniformes, 1 is Pleuronectiformes, 2 are Clupeiformes, 5 are Cyprinodontiformes, and 1 is Synbranchiformes. However, due to identification problem, these numbers do not included approximately 16 species of *Hypostomus* and a number of species of *Rivulus*. In general, these numbers are similar to those found in other Neo-tropical rivers (Lowe-McConnell 1987; Matthews 1998), but are much greater than the value of 130 species previously cited by Bonetto for the same region (1986).

The expansion in the area of the upper Paraná (the barrier was moved 150 km downstream from the Sete Quedas Falls, by the construction of the Itaipu Dam) and the introduction of several species from below the falls have certainly contributed to this increased number of species. In addition to these factors, increasing survey intensity, the survey of new areas (especially streams and creeks) and the revisions of some genus will likely increase the number of species in the upper Paraná even more (Agostinho *et al.* 1995, 2000).

Fishery Resources

Surveys, in the Upper Paraná basin, have identified three types of fishery, which have been characterized in reservoirs and rivers:

1) *Artisanal* - conducted by fishers who live in small towns along the river bank,

2) *Subsistence* - undertaken by small farmers or day workers who live on islands or along the rivers and reservoirs, and

3) *Recreational* or *sport* – conducted by inhabitants of major cities in the region.

Artisanal fisheries

Characterized as multi-specific fisheries, artisinal fisheries are practiced primarily in reservoirs and to a lesser extent in rivers. The most important artisanal fisheries in the basin is recorded in the Itaipu Reservoir, having the largest number of fish species and capture per effort unit, as described in the case study to follow.

Reservoir fisheries are conducted mainly using gillnets, with trammel net, cast nets and long lines sometimes used for certain species. In the artisanal fishery the most important upper Paraná River species are *Plagioscion squamosissimus, Pimelodus maculatus, Iheringichthys labrosus* and *Prochilodus lineatus.* In the reservoirs of the Tiête River, such as the Barra Bonita Reservoir, 39 species are exploited commercially, yielding approximately 230 tons/year (Table1). In the Ibitinga Reservoir 46 are fished with a yield of approximately 42 tons/year (Petrere Jr. & Agostinho 1993). In the Promissão Reservoir, the fishery exploits some 48 species. In the Nova Avanhandava Reservoir, 45 species are fished, yielding approximately 43 tons/year.

Information on lotic fisheries in the Upper Paraná is sparse. Preliminary surveys indicate that artisanal fisheries in rivers differ from those in reservoirs, with river fishers targeting mainly migratory species, such as large catfishes (pimelodids, such as *Pseudoplatystoma corruscans*), characids (*Salminus maxillosus*), anostomids (*Leporinus elongatus* and *L. obtusidens*) and prochilodontid (*P. lineatus*). River artisinal fisheries also differ in that they use mainly hand lines (poles), long lines and sometimes gillnets (Petere & Agostinho 1993).

Subsistence fisheries

Virtually all islanders and a considerable portion of the riverine population fish for subsistence, as fish is their main protein source. They employ basic gillnets, and to a lesser extent hook and line or poles, to catch medium-sized species, including some migratory species such as *Salminus maxillosus*, *Pseudoplatystoma corruscans*, *Piaractus mesopotamicus*, *Leporinus obtusidens*, *Leporinus elongatus*, and *Pterodas granulosus*.

Sport fisheries

The sport fishery along rivers occurs throughout the year, primarily on the weekends. The river anglers target mainly *Salminus maxillosus*, *Brycon orbignynus*, *Piaractus mesopotamicus*, *Leporinus elongatus*, *Leporinus obtusidens*, *Pseudoplatystoma corruscans*, and *Paulicea luetkeni*, and are restricted to the main channel and major tributaries. The technique used is hook and line (poles) baited with live fish for catching *Salminus maxillosus* and *Pseudoplatystoma corruscans*, pieces of fish for *Paulicea luetkeni*, seasonal fruit for *Piaractus mesopotamicus*, and worms for the remaining species. Some tournaments are held in cities along the riverbank, especially to catch *Leporinus elongatus*, *Plagioscion squamosissimus* and *Cichla ocellaris*. There is no information on their yields. The sport fishery in reservoirs is practiced on small and medium sized sedentary fish by fishers from local and neighboring cities.

Management: History and Legislation

The first legislation related to fishery management was São Paulo State Law Number 2250, dated December 28, 1927, Article 16 of which mandated the installation of fish ladders on all dams. In 1934 a Federal Law was passed requiring all hydroelectric dams to have mechanisms to allow for the preservation and movement of fish upstream. In 1938 a new law stated that dams must allow for the preservation of ichthyofauna, either by the use of fish ladders or hatcheries. This law prompted hydroelectric companies to build several hatcheries, a decision influenced in part by the inefficiency of fish ladders. In 1967, Decree Law 221 (28/02/67) delegated to SUDEPE (Federal Agency for the Development of Fisheries) the task of determining the best mechanism for the protection of the aquatic fauna. This agency, whose main purpose was the development of fish culture, made mandatory, through Resolution 46 (27/01/71), that one hatchery be built in every sub-basin containing a dam (Azulguir 1994).

Environmental Impacts Studies were first conducted in 1981 and in 1983 it became mandatory for hydroelectric companies to submit environmental impact reports. These reports included a survey of the area, a description of the proposed actions and alternative actions, and an identification, analysis and prediction of the major positive and negative impacts of the proposed actions. Article 11 of The Decree Law Number 2179, dated September 21, 1999, made it a crime to kill, hunt, take or use wild fauna, either native to the location or in migration, without official permission, license or authorization.

Legislation to reduce exploitation of juvenile fish (mainly migratory) and to protect spawning grounds has prohibited fisheries during the spawning season and has restricted net mesh-size and effort (number of hooks) used by fishers. In addition, regulations, to control fisheries during spawning ("piracema"), are published annually by federal agencies, for rivers which border states, and by state agencies, for rivers within a given state. These regulations are enforced by State Environmental Agencies.

Management Activities

Fishery management actions are infrequent in Brazil and are not usually evaluated or monitored (Agostinho 1994a). Until 1950's, the main purpose of Brazilian management programs was to ensure fish migration in low order rivers, where most of the small power plants were constructed. These programs, thought to implicitly conserve migratory fishes and maintain biodiversity, did not work. During the following decades the goal of these programs became to increase fishery yield by stocking of exotic and native species and to control the fishery. In the 1990's this management trend was also abandoned because of its failures. The importance of biodiversity was not considered during this period.

Fish passages

Fish passage facilities, the first fishery management action taken in the Paraná River basin, were constructed in an attempt to lessen the impact of dams on the upward migration of fish (usually large species). More than a dozen fish ladders were constructed, and rarely evaluated, in Brazilian small rivers before the 60's. Recently, as a result of public pressure, fish ladders were constructed close to large dams (Canoas I, Canoas II, Porto Primavera and Jaguara dams). At Porto Primavera, the biggest reservoir in the upper Paraná River, a fish elevator was constructed, in addition to the fish ladder.

Studies conducted on these facilities have, so far, been restricted to determining the efficiency of the ladders at transporting fish, and have not considered their effectiveness at conserving fish stocks (Agostinho & Gomes 1997). Agostinho *et al.* (in press b) has recognized some critical, and as yet unknown, aspects of fish passage efficiency. These include:

1) appropriate design for attraction and ascendant movements,

2) continuity of the migration after entering the reservoir, and

3) the most critical aspect of fish ladder success, descending migration and passage through the dam.

Fishery control

Licensing, equipment and net mesh size restrictions, length limits and season restrictions are used to control the fisheries. Both professional and recreational fishers require a license, which is provided by the Ministry of Agriculture. Equipment and mesh sizes are regulated by IBAMA (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis) through Resolution No. 021/93. This resolution allows for the use, in reservoirs, of gillnets and trammel nets (internal net) with mesh sizes bigger than 70 mm stretched. In the Paraná River main channel, the use of gillnets (with mesh sizes bigger than 120 mm stretched), trammel nets (with mesh sizes bigger than 70 mm stretched), and cast nets (with mesh sizes bigger than 80 mm) is allowed.

Specific regulations, detailing areas and season restrictions, are published annually. For the year 2000 (Resolution No. 73/2000) fisheries using nets and long-lines were forbidden between November 1st, 2000 and January 1st, 2001. This restriction was extended to February 28th, 2001, due to an exceptional lack of rain and the closure of Porto Primavera Dam. Some details of this Resolution included:

- All types of fishery in marginal lagoons along the Paraná River bank were forbidden.
- Fishing without boats, using hand-lines and/or fishing poles, respecting the length limits established by law (Resolution No. 21-N/93) was allowed.
- Fisheries (artisinal or sport) of introduced species was allowed.

Stocking

Stocking of native and non-native species, especially in reservoirs, is another management tool, which was used intensely in previous decades. It was considered an alternative for fish ladders, which were viewed as expensive and inefficient. Other alternatives, based on resource exploitation and environmental data, were refused on the basis that fish production in the reservoirs could not wait for research results.

This resulted in the widespread construction of hatcheries, at huge expense, with the hope that they would improve fisheries in the reservoirs. When these hatcheries experienced technical difficulties in their fry production of native species the hatchery managers elected to initially produce non-native species. As a result, as many as twenty species were introduced between 1970 and 1990 in south and southeastern Brazilian reservoirs (Agostinho *et al*. 2000). Although non-natives species still are stocked, this trend has decreased in recent years.

Fish cultivation

Although aquaculture in confined environments is not directly related to fisheries management, Brazilian environmental agencies and hydropower companies stress its development as a management alternative. Aquaculture is seen to reduce the pressure on natural fish stocks and to generate job for artisanal fishers that have been impoverished by stock depletion. Practiced in ponds, usually installed at the river levees, or in cages, placed into lentic environments, especially reservoirs, fish cultivation is considered the most important dispersion avenue of exotic species (Welcomme 1988, Agostinho & Julio Jr. 1996).

Results of Management Activities

Despite recent monitoring program, the low yield of artisanal fisheries in South-Southeast Brazilian reservoirs (Petrere & Agostinho 1993, Petrere *et al*., in press, CESP 1996, Gomes & Miranda 2001) and the virtual absence of large fish species in the high parts of the upper Paraná River basin, where some management actions were taken (Agostinho et al 1994a), indicate the results have not been satisfactory. In general, this is because management actions lack a clear purpose and are based on poor technical and scientific information (Agostinho & Gomes 1997).

Fish passages

Some studies have found fish ladders to be highly efficient. These include Godoy (1957,1975), which studied the Cachoeiras das Emas fish ladder (5m, Pirassununga, São Paulo), and Borghetti *et al.* (1993, 1994), which reported a high number of species on an experimental fish ladder in Itaipu Dam (27m). Godinho *et al.* (1991), on the other hand, considered the fish ladder in the Salto Morais Reservoir (10.5m, Tijuco River) to have a low efficiency. Quirós (1988) reviewed the theme and found that only three of Brazil's13 fish ladders were not efficient. The fact that ladders are considered to be, in general, selective is only superficially broached in existing studies (Agostinho *et al*., in press b).

There is no doubt, however, that large migratory fish can ascend fish ladders and others facilities, with an efficiency depending on the adequacy of the design (Quirós 1988, Convênio SECYT 1996, CESP 2000). The capacity of a fish to continue upstream migration, after being caught downstream of the dam and transported to the reservoir, was reported by Agostinho *et al*. (1993, 1994b). The main restriction to migratory fishes of the Paraná River basin remains, due to their dispersion strategies, the descendent movement of eggs, larvae and adults throughout the reservoir and their ability to get to the downstream stretch of the river (Agostinho *et al.* in press b).

Fishery control

Regulations, with the purpose of protecting juveniles, spawning grounds and spawning season, have not been efficient and have been limited by a lack of information on fish populations, financial resources, and an enforcement workforce. The absence of monitoring and clear protection goals should also be listed among regulation problems (Agostinho & Gomes 1997).

In the un-impounded stretch of the upper Paraná where migratory fish, such as *Salminus maxillosus*, *Piaractus mesopotamicus* and *Leporinus elongatus,* are valuable to the sport fishery, the ban on fishing during spawning (November to February) is rarely enforced. No information exists on the number of illegally fishers and the number fish harvested during this time. In years when floods are delayed, the fishery is commonly reopened just when fish are beginning to migrate or spawn.

In tributaries of the upper Paraná, fisheries are regulated by different legislation. Artisanal fishing is not permitted in the Goiás, Mato Grosso do Sul and Minas Gerais states and is regulated in the Paraná and São Paulo states. Differing state legislation create difficulties for fisheries officials trying to control fisheries in rivers that border these states. Recreational fisheries however, are permitted in all of the mentioned states.

Stocking

Many attempts to create self-sustaining populations through stocking have been unsuccessfully. Stocking efforts have been successful only when species introduced from the Amazon River basin, such as *Plagioscion squamosissimus* and *Cichla monoculus*, both piscivores, were used. *P. squamosissimus* is now the most abundant predator in large reservoirs of the basin. Successful colonization of *P. squamosissimus*, because of its use of shallow and near-shore areas for spawning and its developed parental care (Williams *et al.* 1998), depends on the presence of vast littoral zones and water level stability (Agostinho *et al.* 1999a).

The impacts of stocking of exotic species on the biodiversity of others fish stocks are not well known. Studies conducted in the Itaipu reservoir have shown that *P. squamosissimus* prey on more than 50 fish species (Hahn *et al.* 1997), especially the young of mapará *Hypophthalmus edentatus*, the main species in the artisanal fisheries of that reservoir. Santos *et al.* (1994) analyzed the impact of two introduced piscivores (*Cichla ocellaris* and *Plagioscion squamosissimus*) on zooplankton and forage fish in reservoirs of the Grande River (Paraná River Basin) and concluded that these species promoted an increase in zooplankton and a decrease in forage fish.

The constant failures of the stocking programs of exotic species, easily detected by the absence of target fish in the environment, led the power companies to develop hatcheries and stocking programs with native species, begging after 1980 and continuing today. However, stocking efficiency and the possible impacts of the poor genetic quality of parental fishes, characteristic of many Brazilian hatcheries, has not been evaluated (Toledo Filho *et al.*1991).

According to data, collected from six reservoirs operated by the Company of Electricity of the São Paulo State, there is no relationship between the number of fry released and the yield from artisanal fisheries (Torloni *et al.*1993, CESP 1996) (Figure 2). Despite these results, stocking is the main management strategy used by hydropower companies and environmental agencies and is most requested by stakeholders. Political influence is a large factor in the continued operation of most of these stocking programs. De Silva (1987) stated that, similarly, stocking programs in Thailand were done more for political reasons than enhancement reasons and, since returns of stocked fish were very low, fisheries continued to rely on endemic species.

Fish cultivation

An inventory conducted by Orsi & Agostinho (1999) in a fish farm located along the Paranapanema River, revealed that during a catastrophic flood in January, 1997 more than 1,292,000 adult fishes escaped from the farm and were introduced into the basin. Among the 12 species that escaped, 10 were exotic, one was a hybrid, and one was native. The most abundant of these was *Clarias gariepinnus* (African- 655,000 individuals), *Oreochromis niloticus* (African- 315,000), *Piaractus mesopotamicus* (native- 93,500), *Cyprinus carpio* (Asian- 76,000), *Leporinus macrocephalus* (Paraguay River- 74,000), and *Micropterus salmooides* (North American- 19,000). This disaster was attributed to the illegal occupation of the riverbank, and the non-observance of standard measures designed to avoid escapement. A survey conducted before and after this massive introduction revealed that the parasite *Laernea cyprinacea*, very common in fish farms, which was introduced in Brazil by Hungarian carp and found in only two native species before the disaster, occurred in seven native species after the disaster (Gabrielli & Orsi, 2000). Increases were also seen in the infestation intensity of the parasite (Gabrielli & Orsi, 2000).

This situation becomes more complex as the number of fish cages in the upper Paraná River reservoirs increases. Although the use of exotic species is not forbidden, providing the species does not become established in the water body (Federal Decree 2869, December 09, 1998), free interpretation is used to define the term “established”. The illegal use of exotic species has been recorded in the Itaipu Reservoir and others (Agostinho, personal observation). In addition to the introduction of exotic species, other effects of fish culture, including alterations to water quality, habitat and biota, are relevant and must be considered (Agostinho *et al.* 1999b).

Lessons Learned

Fishery control

The absence of data on catch and effort of the fishery, except for in specific places (Okada *et al.* 1996), makes the calculation of maximum sustainable yield, which would be helpful in identifying the status of the exploited stocks and providing a basis for fishery regulations, difficult. Recent participation of the universities and research institutes in the definition of polices is improving this situation (Agostinho 1994a), but the absence of data will be solved only with new research programs and monitoring studies. The effectiveness of fishery regulatory controls will depend on the level of enforcement applied. Enforcement should be lead by the Federal Agency (IBAMA) and State Agencies.

Stocking

The failure of stocking programs can be attributed to the their ignorance. In general, stocking decisions were made without consideration of the status of natural stocks, environmental restrictions or of target species requirement. There was uncertainty about species selection, adequate size, habitat and stocking seasons. Recent efforts in the Jupiá and Três Irmãos reservoirs have been more successful. These results were obtained by improving genetic control at the hatchery, stocking with larger sized (>10cm) individuals and using a native species (*Piaractus mesopotamicus*) whose natural stocks were depleted (CESP 2000). However, at this time, there is no information as to whether these stocks will reproduce in the reservoirs or if continuous stocking will be required.

Fish passages

Lessons related to fish passages have not yet been learned. Construction of fish ladders have not, in general, considered the technical characteristics of the dam (type, slope, water discharge, position in relation to the dam) and the nature of the ichthyofauna. This approach has resulted in increased risks of failure.

Fish passages, recently constructed in large dams, are generating controversy. Most of these dams were built in series, so that their backwaters are too close to another dam to allow for sufficient nursery areas. The fish ladder, currently under construction, and the functioning elevator at the Porto Primavera Dam will, in all probability, have a large impact on the downstream recruitment of fish fauna and fisheries. Six out of ten main species in the Itaipu fishery use this area to spawn and grow (Agostinho & Zalewski 1996). A large number of these fish, that could be reproducing in the free stretch below the Dam, are now passing upward where the spawning and nursery areas are restrict (CESP 2000). Similar situation could be occurring with the fish ladder located at Canoas I Dam, in the Paranapanema River, operated by the Duke Company.

Despite this scarcity and incompleteness of knowledge, results published thus far indicate that Brazilian fish passages, in contrast to North American salmonid models, have not been economically viable. Not only have these passages wasted money and effort and caused valuable study opportunities to be lost, they are possibly responsible for a variety of environmental impacts.

Fish cultivation

Fish cultivation is another activity for which lessons have not yet been learned. Despite several introductions (fish and other organisms) that may have created long term problems for biodiversity, this activity continues to receive support from the Federal Government. Without organization and training in this sector, problems relating to fish cultivation it will continue to get worst.

Case Study: Itaipu Reservoir

The construction of the Itaipu Reservoir involved both Brazil and Paraguay and, consequently, the management actions taken in the reservoir have not followed those taken in other parts of the basin. Due to the lack of information on fish stocks, environment and life cycle of the main species, no fishery was planned. The Itaipu Bi-national decided on a different management approach to those described above, especially stocking, and began in 1983 to collect biological, limnological and social information to better understand the fishery system. Collection of data relating to landings and social-economic aspects of the fishery was begun in 1986.

Characterization of Itaipu Reservoir

The filling of the reservoir began in October of 1982, and was completed in November of that same year. Located in the main channel of the Paraná River (along the border between Brazil and Paraguay), the reservoir is 151km long and covers an area of 1350km^2. Its average depth is 22m, reaching 170m near the dam. Hydraulic retention time is approximately 40 days in the reservoir, in contrast to the main channel, where it is only 29 days. Limnological studies indicate that the central part of the reservoir annually, over the spring and summer, becomes thermally stratified (Brunkow *et al.* 1988, Pagioro 1999).

Fish fauna

Surveys conducted since 1983 have registered more than a hundred species, 83 of which were found in the lentic portion of the reservoir. A strong spatial gradient of the fish fauna composition and abundance was verified by Agostinho *et al.* (1999a). This gradient, which causes strong zones of primary and secondary production, has resulted from a sedimentation process and is related to other physical and chemical variables (Pagioro 1999, Okada 2001). The riverine zone of the Itaipu Reservoir includes all the species that occur in the transitional and lacustrine zones (Thornton 1990), plus species that are typical to the lotic stretches upstream, such as large migratory fishes (Agostinho *et al.* 1994a). Higher diversity in this zone is likely due to the retention of characteristics of the original lotic environment.

On a latitudinal and vertical basis, the littoral zone has higher species diversity and is more productive than the epipelagic or bathypelagic zones. Enhanced productivity is associated with the input of nutrients and food from riparian areas, low reservoir depth, and increased habitat structure and diversity. These differences tend to be accentuated by reservoir age (Figure3). Fifteen years after the filling of the Itaipu Reservoir, 64 out of 67 species were caught in gill nets in the littoral zone. In the epipelagic and bathypelagic zones, 20 and 22 species were distinguished, respectively. The number of individuals caught per 1,000 m^2 of net, in a 24-hour period, were 388 in the littoral zone, 22 in the epipelagic zone and 20 in the bathypelagic zone (Agostinho *et al.* 1999a). These gradients are reflected in the use of different fishery strategies (see next topic). The dominant species in the experimental fisheries are *Hypophthalmus edentatus*, *Auchenipterus nuchalis*, and *Plagioscion squamosissimus* (Agostinho & Julio Jr. 1999).

The fishery resources and its exploitation:

The Itaipu Reservoir was opened to fishing 28 months (March 1985) after the dam was closed. Over 60 species, out of the more than 100 species that have been identified, are exploited in the fishery, with an average landing of 1,560 tons/year (Agostinho *et al.* 1999c).

The longitudinal gradient of the reservoir, mentioned above, relates to the longitudinal variation of species richness, composition of the landed fish and fishing strategies employed (Okada 2001). In the upper half of the reservoir the fisheries is practiced essentially with longlines and castnets, capturing mainly migratory species, such as *Pterodoras granulosus*, *Paulicea luetkeni*, *Pimelodus maculatus*, *Pinirampu pirinampu* and *Rhinelepis aspera.* Gillnets, not important in this zone, are used to catch *Prochilodus lineatus.* Species exploited in this region utilize the lotic stretch of the Paraná River upstream (230km) as spawning and nursery areas. In the inner part of the reservoir the fisheries is based on *Hypophthalmus edentatus*, a filtering zooplanktivore species, and *Plagioscion squamosissimus*, a piscivore introduced in the basin before the dam closure. Both species spend their entire life cycle inside the reservoir (including arms). Fishing in the inner zone of the reservoir is performed with gillnets. These findings reveal a need for management to realize the complex nature of the reservoir and to consider the peculiarities of each zone.

Summary of status and trends of target species

The most important of the species captured in the reservoir are *Hypophthalmus edentatus*, *Plagioscion squamosissimus*, *Prochilodus lineatus* and *Pterodoras granulosus*. *H. edentatus*, a middle-sized catfish, was very abundant after the formation of the reservoir (Okada *et al*. 1996), but recently, its contribution to landed fish has decreased sharply (Ambrósio 2000). In the Itaipu Reservoir, six out of the ten principal species in the artisanal fishery use the upstream floodplain for spawning and nurturing (Agostinho *et al*. 1994a). Annual failures in recruitment, caused by the absence of floods (upstream impoundment regulations are, in general, based on previous drought years), are related to stock depletion of this group of species (Agostinho *et al*. 1999a,c). This relation is particularly clear for *P. lineatus,* which saw a sharp decrease from 500 tons in 1987 to 220 tons in 1988, due to an absence of flood (failing recruitment) (Gomes & Agostinho 1997).

The fishery in the Itaipu Reservoir can be characterized by its low profitability and over exploitation. The CPUE reduced from 21.7 kg/fishers-day in 1987 to 15.5 kg/fishers-day in 1992 and 11.5 kg/fishers-day in 1998 (Okada 2001). Growth overfishing was identified for *P. granulosus*, *Paulicea luetkeni* and *Pseudoplatystoma corruscans* (fished mainly with longlines). Stocks exploited in the inner part of the reservoir (*H. edentatus*) are probably affected by recruitment overfishing. Both recruitment and growth overfishing were identified for the stocks of *Rhinelepis aspera* (armored catfish fished with cast nets), whose catches declined by 70% (Okada *et al*. 1996, Miranda *et al*. 2000) causing the recent collapsed of its fishery (Okada 2001). In addition, the landings of the introduced piscivore *P. squamosissimus* are composed essentially of juveniles.

Agostinho *et al*. (1997) reviewed the main factors influencing fish biodiversity in the upper Paraná River basin and concluded that habitat changes (especially damming) have immediate and direct effect on species and that it is the most important factor effecting biodiversity. Among the species considered endangered or threatened in the upper Paraná River (Enger *et al*. 1989) several, including *Brycon orbignyanus*, *Leporinus elongatus*, *Paulicea luetkeni*, *Piaractus mesopotamicus*, *Pseudoplatystoma corruscans*, *Rhinelepis aspera* and *Salminus maxillosus,* continue to be exploited by a variety of fisheries (Agostinho *et al*. 1997). This exploitation, secondary to the effects of habitat loss, could potentially have a great affect on these species.

Management history, successes and failures

The first management action taken in the Itaipu Reservoir, mandatory by law, was the construction of a hatchery on the Paraguayan side of the reservoir. Initially, the main goal of the hatchery was to produce fry of native species for stocking purposes. Some of their attempts, mainly with *Piaractus mesopotamicus,* were not successful. Currently the hatchery is devoted to developing technologies for artificial reproduction of native species and to producing fry **(Ed Note: native or non-native?)**, to be raised in ponds by local farmers. Additional management actions, taken to directly control the fishery, include licensing, mesh size restrictions and season restrictions.

Licensing

Due to the ease of access to the fishing grounds, especially in the superior half of the reservoir, and increased unemployment during the last decade, the number of fishers in the Itaipu Reservoir has increased. Fuem.Itaipu Binacional (1999) reported fishing effort in the reservoir to be 120,000 in 1993, rising from only 67,500 fishing days in 1987. In order to regulate the fisheries, licenses were issued only to those that depend on the fishery as their main work activity and, beginning in 1993, these licences were reviewed on a regular basis. Any license found to be irregular was cancelled. This procedure, which continues today, resulted in fishing effort being reduced to 106,500 fishing days in 1998 (Fuem.Itaipu Binacional 1999). Unfortunately, this level of fishing effort still exceeds the optimal level, of 95,900 fishing days/year, estimated by Okada *et al.* (1996) using the Schaeffer model.

Mesh sizes

Until 1998 mesh sizes less than 80 mm were not allowed in the reservoir. Due to decreased catch rates experienced after the initial upsurge period (Agostinho *et al*. 1999a,c) and a high abundance of *H. edentatus* in the epipelagic zone, a smaller mesh size of 70 mm was allowed for the first time in 1998, with the limitation that it could only be fished in the epipelagic zone (Agostinho *et al.* 1999a). As a result, fishers used mostly 70 and 80 mm meshes to capture *P. squamosissimus* and *H. edentatus* and 100, 120, 140, and 160 mm meshes to capture *P. lineatus* (Agostinho *et al.* 1994a, Petrere Jr. 1996). Unfortunately, this restriction was not effective, as fishers did not respect it and used 70 mm mesh outside the epipelagic zone. Local social problems, including the frequently theft of nets, led fishers to set their 70 mm nets in deeper regions, increasing the capture of juveniles of non-target species. Discussions among fishers, fishery control agencies and scientists led to the decision, in 1995, to increase the minimum mesh size back to 80 mm. This mesh size restriction is still in place in the reservoir.

Season restriction

Since most of the main species exploited by the reservoir fishery utilize areas outside of the reservoir for reproduction, the fishery in the reservoir was not seasonally restricted until 1997. At which time, the need to reduce effort and to protect the exit of migratory fishes to spawning ground was considered. Fisheries were, consequently, forbidden to operate between November 01 and January 31. The positive impacts of this decision on the reservoir stocks can not, as yet, be evaluated. This decision has, however, caused a large social and economic problem. Some fishers, it is believed, who no longer have a means to support their families during this three-month period have turned to illegal activities, such as smuggling, transport of stolen automobiles and the traffic of drugs through the Brazilian-Paraguayan border (personal information).

Importance of biodiversity in the fishery

The multi-species fisheries conducted in the Itaipu, and other reservoirs of the basin, reflect the great fish biodiversity in the upper Paraná River, which is estimated at 250 species (Agostinho & Julio Jr. 1999). Comparison of the artisanal fisheries before and after the dam construction revealed a remarkable change in the landing composition (Figure 4). The large migratory fishes were replaced by sedentary species (inner portion) and medium-sized migratory species (riverine zone, Agostinho *et al.* 1999a). Before the construction of the reservoir, artisanal fisheries were based on a more specialized and more profitable fishing method, using baited hooks to catch large migratory piscivores (about ten species, in general reofilic). The lacustrine conditions, found in the reservoir, have caused a depletion of large piscivores stocks and an increased density of piranhas (*Serrasalmus marginatus*), which eat the bait. This compels the fishers to use gillnets, increasing both the number of species exploited and the amount of by-catch.

The fish fauna of the Itaipu reservoir is the richest of the upper Paraná River and the reservoir has the largest number of exploited species (Table 1). This great diversity seems to be a result of a large un-dammed stretch (240Km) of river upstream of the reservoir. The Barra Bonita Reservoir, which also has a free stretch upstream, has the second highest level of species richness. These two reservoirs have the highest yields and the largest contribution of migratory species to their landings (Agostinho 1994b).

During its fishery history, the Itaipu Reservoir has experienced shifts in its main species. One conspicuous example of this was the decrease of *Prochilodus lineatus* stock, due to a lack of flood in its upstream nursery and spawning areas (Gomes & Agostinho 1997), and the subsequent exploitation of the new resources by *Pterodoras granulosus* (Agostinho *et al.* 1999c). In spite of these variations and their implications for fishing strategies, the reservoir was able to maintain an approximately constant level of yield during the period. This was due, possibly, to the high diversity of the fish fauna in this reservoir. Itaipu reservoir has, thus far, been able to sustain fair sized migratory fish stocks. This fact may indicate a strong link between the maintenance of the biodiversity and the maintenance of reasonable levels of yields.

Non-target biodiversity patterns

Approximately 40 non-target species are caught in the reservoir and about 30% of them are of no commercial value. The most frequently caught non-commercial species are *Potamotrygon* spp. (stingrays), *Catathyridium jenynsii* (flounder), *Gymnotus carapo*, *Ramphichthys rostratus* and *Apteronotus albifrons* (knife-fishes), *Loricariichthys* spp. and *Loricaria* spp (armoured catfishes), *Satanoperca pappaterra* (cichlid), *Raphiodon vulpinus* (cynodontid) and *Serrasalmus marginatus.*

For cultural reasons, Brazilians, including fishers, do not eat stingrays or *C. jenynsii.* In general, they are released live, after the fisher has cut off the sting of the first fish caught. The other species mentioned above are either released alive, used as bait or eaten by the fisher families. The exception to this rule is *S. marginatus* (piranha), considered by the fishers to be an undesirable species. *S. marginatus* is normally killed and discarded into the water due to the damage it causes to the fishers gillnets and the other fish caught in the net.

These species may be considered of commercial value in the inner areas (lacustrine region) of the reservoir where catches are very low. Stock assessment surveys conducted in the Itaipu Reservoir indicate that there are no problems with the stocks of these species and that they are still very abundant in the reservoir.

Incorporation of biodiversity in fisheries management

As mentioned above, it seems clear that migratory species are important to the maintenance of reasonable fish yields. For example, even thought it is over fished, the Itaipu Reservoir has the greatest yield (12 kg/ha) of reservoirs in the upper Paraná River basin (Agostinho *et al.* 1995). Six of the ten most important species in the reservoir leave the reservoir to spawn. It therefore follows that, by preserving nurseries and spawning grounds outside the reservoirs and allowing migratory fish to spawn and grow, biodiversity will be maintained and a good fishery will be sustained.

In an attempt to avoid losses of biodiversity, stocking with exotic species was not allowed in the Itaipu Reservoir. Efforts to stock the reservoir with the native fish *Piaractus mesopotamicus* failed. Regardless, some exotic species, such as *P. squamosissimus* and *Cichla monoculus,* two predators from the Amazon, introduced into other reservoirs upstream of Itaipu have been caught in the reservoir. *P. squamosissimus* is now very abundant in the reservoir and dominates the artisinal fishery, while *C. monoculus* continues to increase in abundance. The ecological cost of these introductions are not known, but it seems, as mentioned above, that *P. squamosissimus* has contributed to decreasing *Hypophthalmus edentatus* stocks, its main prey (Hahn 1997, Agostinho *et al.* 1995, Ambrósio 2000)

Results and lessons learned

Unfortunately, many of the management actions taken in the Itaipu Reservoir have not had the desired results. For example, attempts to increase yield by decreasing minimum mesh size to exploit a new stock (*Hypophthalmus edentatus*) were problematic and taught fisheries management of the need to consider the human dimensions when making management decisions. Today, in order to minimize possible weak points in management plans, all stakeholders are consulted before any actions are taken related to the management of the reservoir.

Management actions related to the maintenance of the biodiversity have been, on the other hand, very successful. Fish life history studies have indicated that protection of critical habitats is the most important management consideration. As of yet, only the first step toward this goal has been taken - the legal creation of three conservation units:

1) The Area of Environmental Protection (APA) of the Islands and Várzeas of the Paraná River (10,031 km^2), extending from the mouth of Paranapanema River to the Itaipu reservoir,

2) The Ilha Grande National Park (788 km^2), including the lower stretch of the former Area of Environmental Protection, and

3) The State Park of Ivinheima River (700 km^2), which includes the floodplain of the lower stretch of the Ivinheima River.

The effective conservation of the upper Paraná River floodplain and its biological diversity will therefore depend on the prompt and effective management of these conservation areas. The integrity and functionality of this stretch will also depend on the maintenance of the hydrological regime of the Paraná River (affected by the operation of upstream reservoirs) as close as possible to its natural state.

An additional measure, possibly related to the conservation of biodiversity, is the fish ladder, currently under construction in a lateral tributary near the Itaipu Dam. The purpose of this facility is to improve the genetic quality of the natural populations in the reservoir and upstream stretch.

Guidelines

The following guidelines have been consolidated according to the results obtained from life history studies and surveys and fisheries-system monitoring programs conducted in the Itaipu Reservoir, which collected data on environmental, landing and socioeconomic aspects:

1) Fishery management in reservoirs needs to consider, with equal emphasis, both fish production (social reasons) and the maintenance of biodiversity (ethical reasons).

2) The focus of management actions must be the integrity of the critical areas upstream the reservoir (spawning and nursery areas), including the flood regime.

3) Fishery control and its legal regulation need to be defined with the participation of the fisher community.

4) No management action should be carried out without monitoring.

Perspectives and Recommendations

The construction of hydroelectric dams has changed the upper Paraná River by compartmentalizing it and regulating its water flow. This fact is especially relevant to the preservation of migratory fish populations, which includes all the largest, and therefore commercially important, fish in the basin (at least 16 species, Agostinho *et al.*, in press a). These endangered species need different compartments of the basin for their development and generally occupy a spawning place (upper part of the tributaries), a nursery (usually lagoons and secondary channels of the floodplain) and a feeding place (tributaries, main channel and reservoirs). Management must therefore use more complex protection actions and planning initiatives, such as cyclical variation of water level and flooding of marginal lagoons, which tend to interfere with the structure of the system as a whole. The preservation of the remaining floodplain is essential for the maintenance of both the diversity and the production level of fishery stocks (Agostinho *et al.* 1995, Gomes & Agostinho 1997, Gomes & Miranda 2001).

Ideally, management employs an ecosystem approach (Likens 1992, Beverton 1998, Pauly 1998), taking into account water quality, food web, biotic and abiotic interactions and population and community structure. Unfortunately, knowledge about the response of aquatic resources to fishery exploitation is poor and the situation becomes more precarious as more ecosystem components are brought into the equation. Therefore, to promote both biodiversity development and sustainable exploitation, it will be necessary to establish a good level of knowledge about aquatic resources. This can be done through biodiversity surveys, which include species distribution and requirements as well as ecological process and function, and the development of a database, which makes this information accessible to researchers and decision-makers.

In addition, it will be necessary to understand the pattern of fish markets (for consumption), social perceptions and economic constrains. Management will need to be flexible and willing to interrupt the fisheries when necessary. Fishery legislation and control requires realism and clarity of objective, efficient social communication, and the involvement of fisher organizations in the decision-making process. It must be made clear to the public and all groups involved in the fishery and its management that the fishery is an indicator of environmental change and it plays an important role in conservation of biodiversity. Communication between scientists, managers, fishers and other stakeholders must be improved. Other uses of the water, such as power generation (hydrological regulation) and aquaculture, need to be rationally considered along with fisheries and conservation interests.

Traditionally, management actions in the Paraná River basin, and in Brazil as a whole, have not been properly evaluated or followed by appropriate monitoring. This, in large part, explains why many unsuccessful management techniques (i.e. stocking and fish passages) were not abandoned or corrected sooner. Monitoring and evaluation allows mangers to improve their knowledge of fishery systems they are managing and to make appropriate modifications to their programs. Environmental Impact Reports, legally required for all development actions, usually recommend the use of monitoring and researching programs to provide the information necessary for the correct evaluation of those impacts.

More integration of monitoring, management and research is necessary. For example, research indicates that the young of certain target species sometimes grow in marginal lagoons and although fisheries monitoring results show no increases in fish stock over several years, stocking programs continue to add fry into the river channel or the main body of a reservoir. Monitoring and management results can indicate what areas require investigation and, in turn, research results can be used to improve monitoring and management methods.

In conclusion, the fishery management program in the upper Paraná River must begin to incorporate a wider perspective of the fishery system, including environment, fishers and fish. Management must also pursue continued self-evaluation through monitoring programs, the results of which can be feed back into the management system. In addition, the hydrographic dimension and multiples uses of the basin must be considered and the biological, political and socio-economics constrains of management must be recognized.

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Figures and Tables

Figure 1. Map of the upper Paraná River basin.

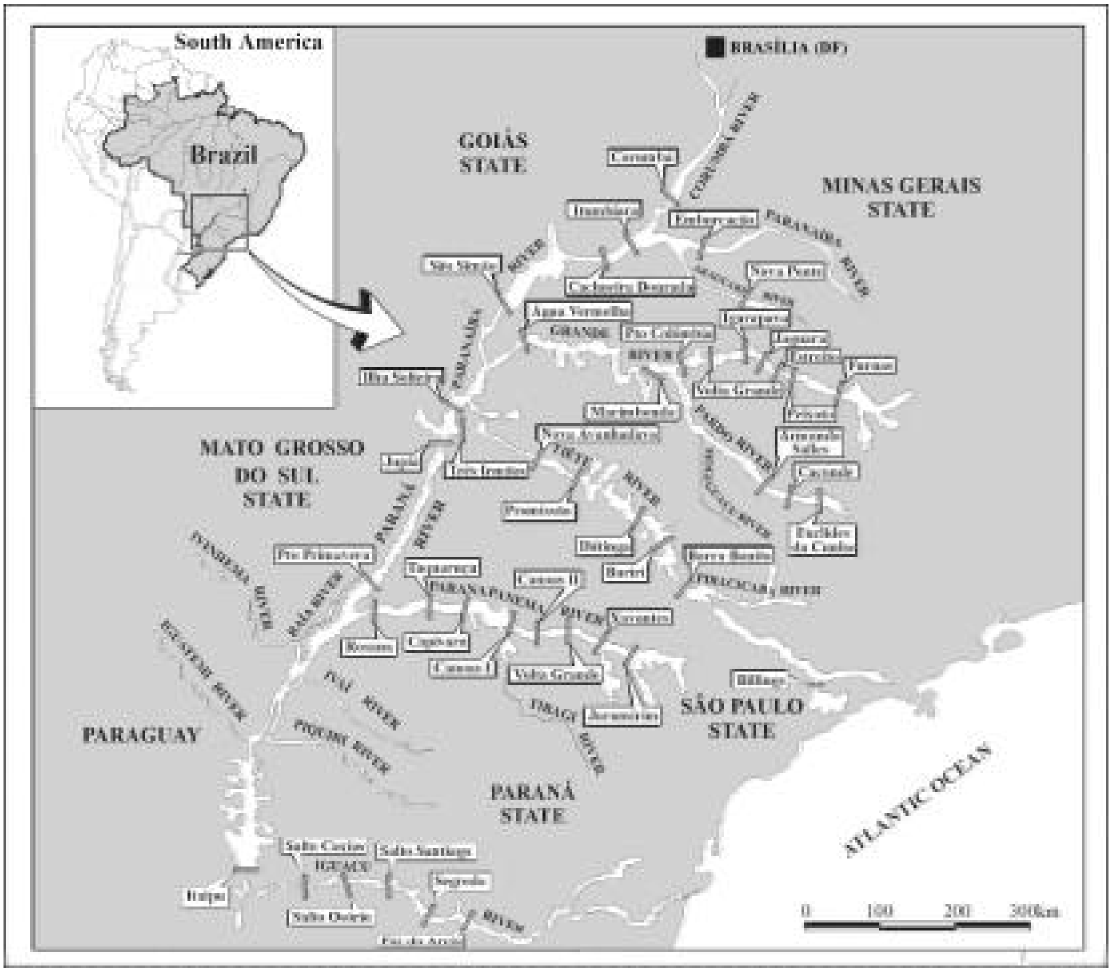


Figure 2. Relationship between the artisanal fishery yield and stocking effort during 15 years in six reservoir located in the upper Paraná basin, considering native and exotic species of fishes.[1]

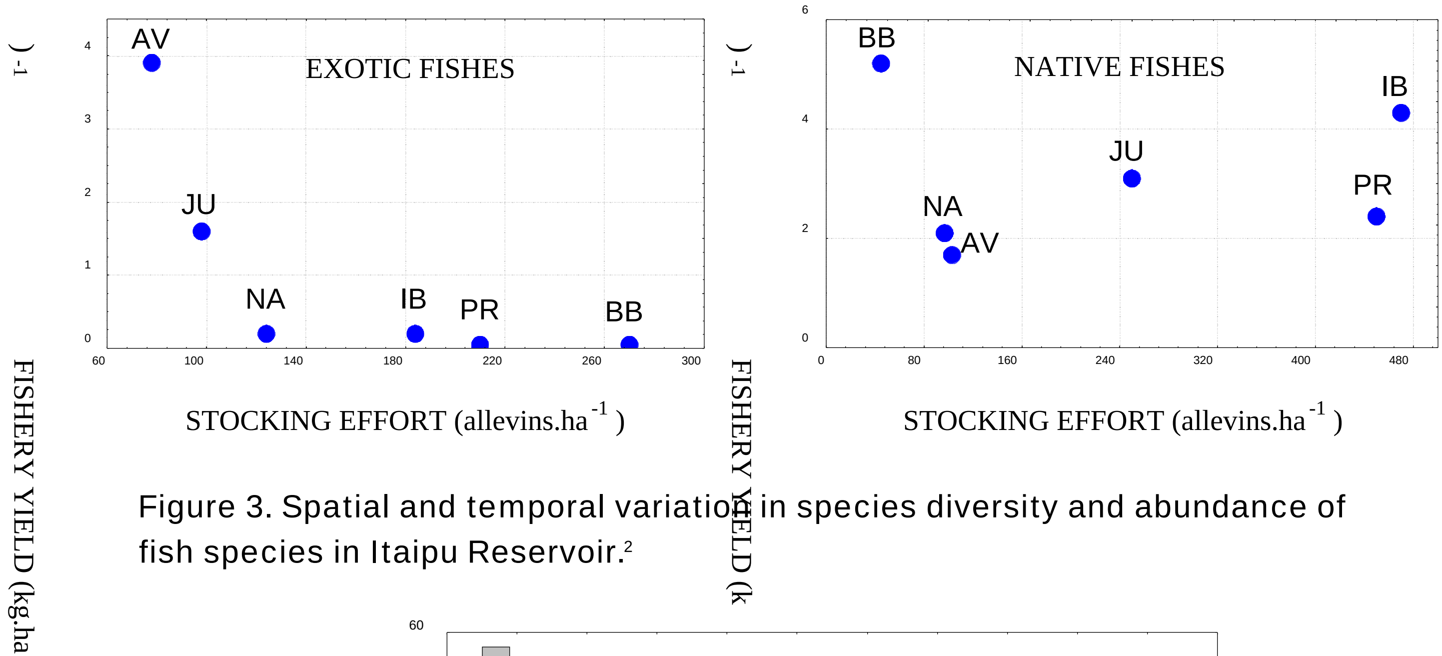
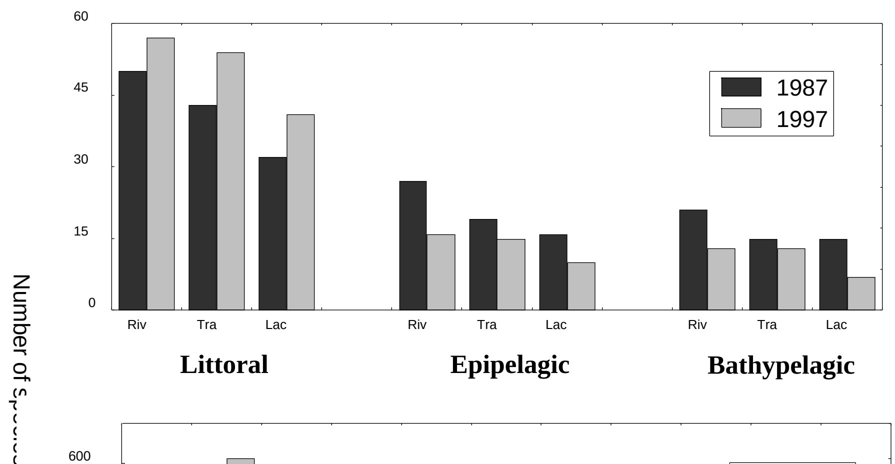
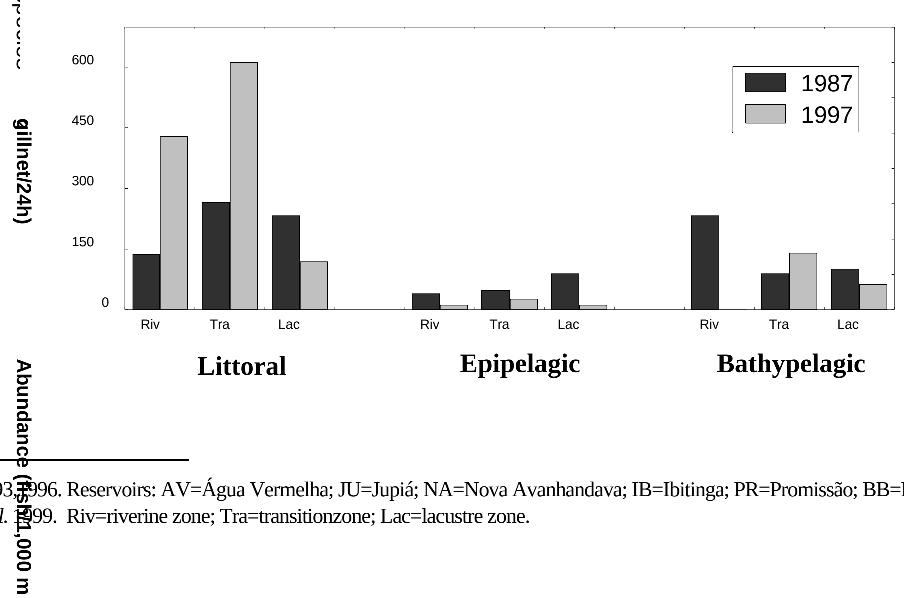


Figure 3. Spatial and temporal variation in species diversity and abundance of fish species in Itaipu Reservoir.[2]





[1] Data source: CESP 1993, 1996. Reservoirs: AV=Água Vermelha; JU=Jupiá; NA=Nova Avanhandava; IB=Ibitinga; PR=Promissão; BB=Barra Bonita.
[2] Source: Agostinho *et al.* 1999. Riv=riverine zone; Tra=transitionzone; Lac=lacustre zone.

Figure 4. Fish species composition in the landing of artisanal fishery in Itaipu Reservoir, before (1977) and after impoundment (1987 and 1997). [3]

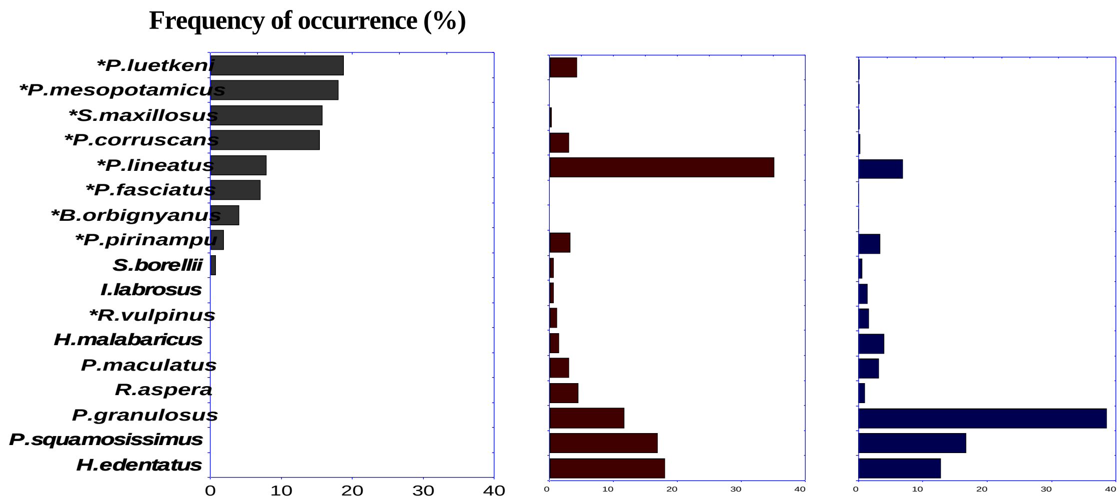


Table 1. Species richness and fishery yield in seven reservoir in the upper Paraná River.[4]

Reservoirs	Itaipu	Barra Bonita	Jupiá	Ibitinga	Promissão	Água Vermelha	Nova Avanhadava
General Information							
River	Paraná	Tietê	Paraná	Tietê	Tietê	Grande	Tietê
Closing	1982	1962	1968	1969	1974	1978	1982
Area (Km^2)	1350	334	352	114	530	644	217
Water turnover (day)	40.0	90.3	6.9	21.6	134.1	62.1	45.0
Species richness	100	70	46	53	54	59	59
Artisanal Fisheries							
Annual yield (t/year)	1600	229	166	42	173	184	43
Capture per effort unit (kg/ha/year)	12.0	7.0	4.7	3.7	3.3	2.9	2.0
Species landed	52	39	38	46	48	34	45
Composition of the Artisanal Fishery Landing (%)							
Introduced species	20.1	28.3	16.2	25.9	23.8	43.4	34.9
Plagioscion squamosissimus - curvina	20.1	28.3	11.9	25.4	23.8	30.8	34.7
Cichla monoculus - tucunaré			4.3	0.5	0.02	2.9	0.2
Oreochromis + *Tilapia* - tilapias						9.7	

[3] Source: Agostinho *et al.* 2000. Species names in bold are long distance migrators; asterisks identifies the species reach lengths over 60cm.
[4] data sources: CESP 1993, 1996, 1998; Petrere & Agostinho 1993.

Native species	79.9	71.7	83.8	74.1	76.2	56.6	65.1