# THE PLATA RIVER BASIN: INTERNATIONAL BASIN DEVELOPMENT AND RIVERINE FISHERIES

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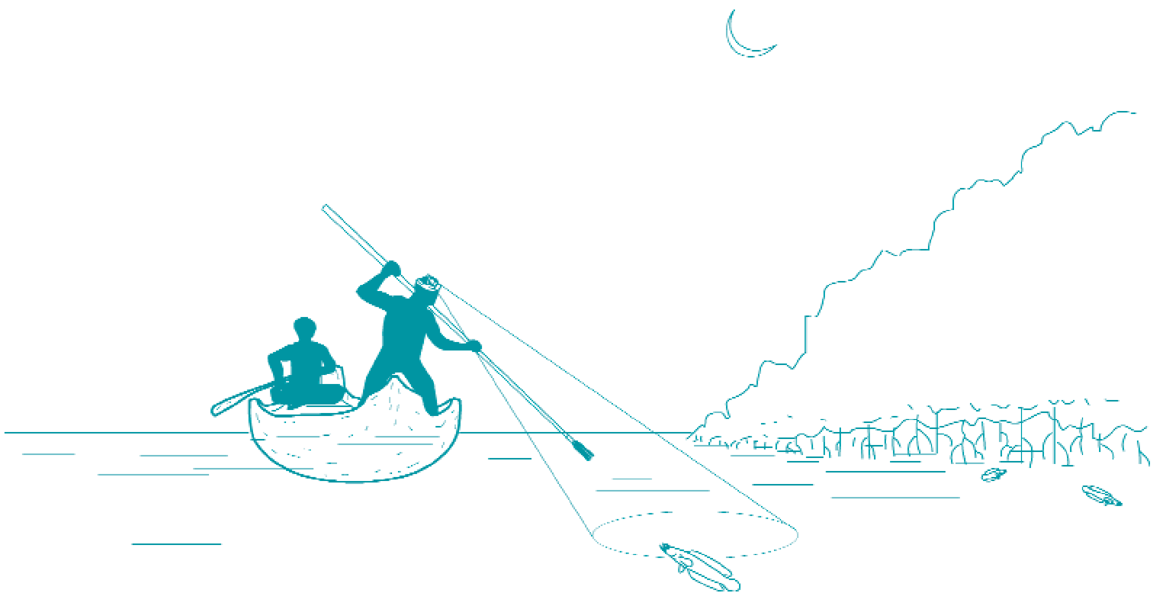


**ABSTRACT**

Environmental changes in large river basins are subject to forces external to the water and to biological issues. Before 1960, the Plata River Basin was almost undeveloped. The regulation of the Parana for hydroelectricity has been increasing since the early 1970s. Water in reservoirs of the upper Parana Basin currently comprises more than 70 percent of the mean annual discharge at its confluence with the Paraguay River. The expansion of hydroelectric generation in the upper basin brought with it an increase in industry, agriculture, transport and settlements. These in turn have resulted in significant increases in deforestation, soil erosion, changes in water quality and reduced fisheries opportunities in both the upper and lower basins.

Key words: Plata River, impacts, fisheries

The fisheries of the Plata Basin are lightly to moderately exploited compared to other subtropical and tropical floodplain fisheries. The fisheries were traditionally based on large potamodromous fish caught from a fish community containing a relatively high frequency of the detritivorous *Prochilodus*. The catch per fisher per day now ranges from 11 to 30 kg for reservoirs situated in the Brazilian upper basin to more than 110 kg in the lower middle Parana River. Catch rates drop to 8-10 kg of high value fish fisher$^{-1}$ day$^{-1}$ at the Parana-Paraguay confluence and for the Pantanal fishery. Striking differences in the fish species structure of the catch are noticeable between reservoir and floodplain fisheries and among floodplain fisheries themselves. We have identified three main fishery states in the Plata Basin across broad temporal and spatial scales. A relatively undisturbed state corresponds to the unregulated river, when fishing effort was relatively low to moderate. Here catch is mainly dominated by high value large siluroids and characins. This state is represented by fisheries at the Pantanal and the Parana-Paraguay confluence and to a lesser extent by some of the remnant lotic reaches at the upper Parana. A second fishery state corresponds to the developed river, with floodplains disturbed by river regulation and other developmental activities. Here the fisheries are still supported by potamodromous fish but fish size at capture is usually lower. Fishing effort is usually higher, the contribution by weight to the catch of less valuable *Prochilodus* has increased and exotics are usually included in fish catches. The disturbed floodplain fishery state is represented by fisheries of most of the lower basin and at the few unregulated reaches of the upper Parana. Fisheries in riverine reservoirs represent a third, relatively highly disturbed fishery state. The catch of potamodromous fish frequently descends well below 50 percent of the total catch and fish catches are often dominated by blackfish species, less dependent on river flows and with an increasing importance of exotic fish species. Fish size is lower as well as fish value at landing. The Plata Basin fisheries represent almost all of these states at the same time in different parts of the basin.

## INTRODUCTION

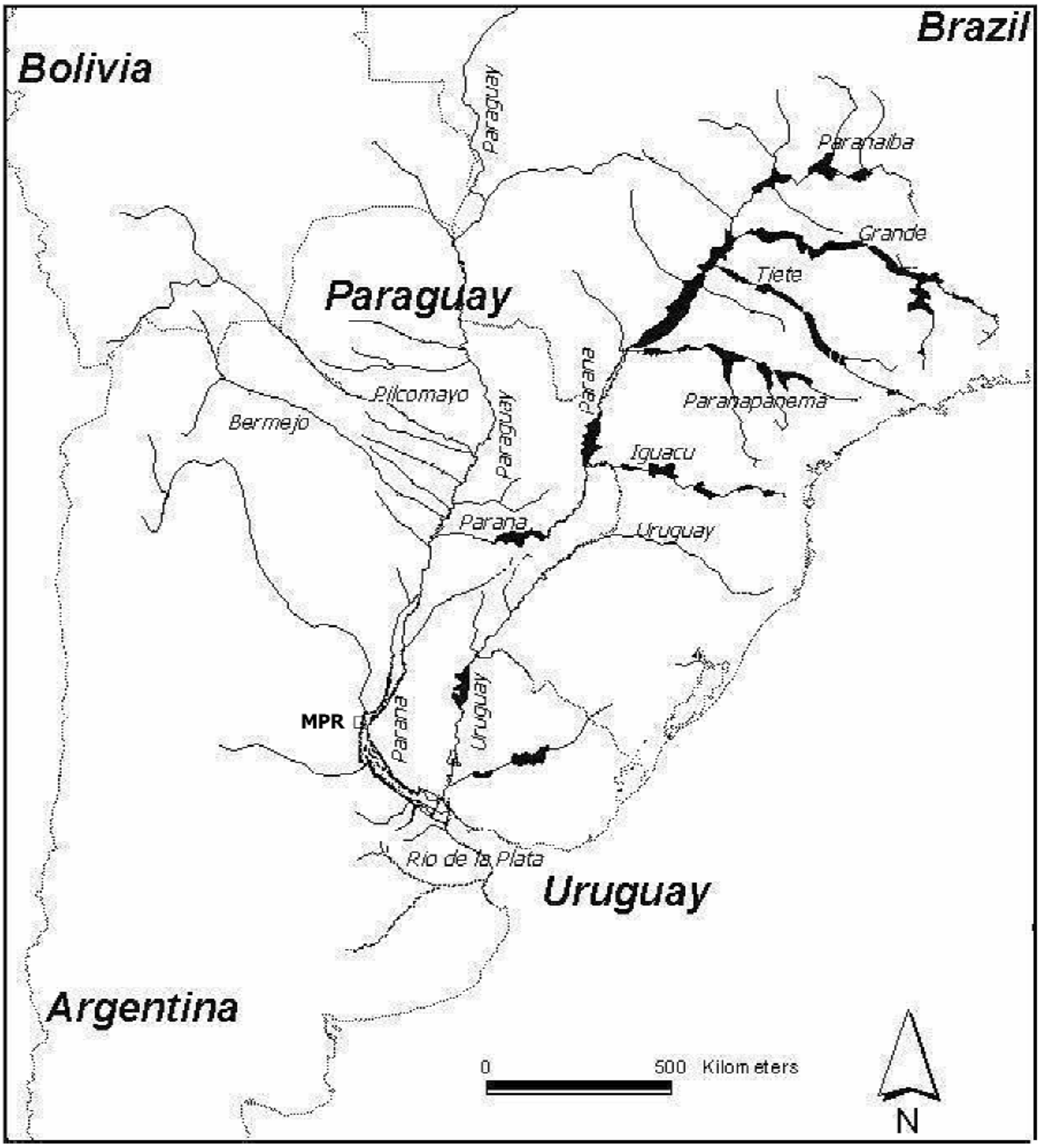
Development planners look to the unique hydrological characteristics of each river to determine the physical capability of the whole river, developed as a unit, to meet the needs of water-dependent users. For most planners the basin is the appropriate unit for thinking about development. Moreover, for international rivers integrated development provides an incentive for the basin countries to benefit from economies of scale. However, despite the economic incentives to co-operate, the technical, legal, institutional and above all political difficulties in the way of successful common development are formidable (UN 1990).

Most of the world's large rivers are greatly affected by human activity (Welcomme, Ryder and Sedell 1989). Large scale, long-term environmental changes in large river basins are subject to forces that are external to the water and to biological issues. The regulation of the upper Parana for hydroelectricity has been increasing noticeably since the early 1970s. Therefore, we suggest that historic trends in La Plata River Basin development are an adequate framework for a study of the impact of development on water resources and biological communities and to analyse adequate measures to protect riverine fisheries from development activities (Quiros 1990). All over the world fishers try to maximize inputs using less effort. For the La Plata Basin we expect that they are trying to get the best and most valuable fish and that high value large potamodromous fish are their main target. We shall use the large piscivorous fish captured as a tracer to integrate the fishery attributes and, moreover, the environmental quality that sustains this fishery.

The main purpose of this paper is to overview some striking historical events in the La Plata River Basin development and to relate these events to its current environmental and fisheries state. When compared with other subtropical and tropical floodplain fisheries, the Plata Basin is lightly to moderately exploited for fisheries.

## THE PLATA RIVER BASIN

The Plata River Basin (Figure 1) drains large parts of Argentina, Bolivia, Brazil, Paraguay and Uruguay. With an area of 3.2 $10^6$ $km^2$, it is the second drainage system in South America and the fourth largest in the world. The Plata River Basin consists mainly of three sub-basins: the Parana, the Paraguay and the Uruguay river basins (Figure 1). The Parana River flows 4 000 km southwards from its sources in the Precambrian Brazilian Shield to its mouth in the Pampa Plain discharging 20 000 $m^3$ $s^{-1}$ in the Plata River. The Paraguay River extends 2 670 km southwards from its sources in the western hills of the Brazilian Shield at 300 m of altitude to its confluence with the Parana River. The "Pantanal" depression, situated 270 km south from the Paraguay sources, receives water from the Paraguay River itself and from many other tributaries. The Pantanal has a natural regulatory effect on the middle and lower Paraguay River discharge. The Uruguay River flows 1 800 km from its sources in southern Brazil and discharges 5 000 $m^3$ $s^{-1}$ in the Plata River.




■ **Figure 1**. The Plata river basin. MPR, middle Parana River.

Climatic conditions in the basin cover a wide range, with tropical areas at the sources of the Parana and Paraguay Rivers, subtropical in parts of Argentina, Brazil and Paraguay, warm temperate in parts of Argentina and Uruguay and arid areas in the sub-Andean region. With this variety of climates, fertile soils, mineral resources, water resources and the potential offered for hydroelectric energy and navigation, a large proportion of the population of the riparian states has settled within the basin and many national urban and industrial centers are also located there. More than 110 million people inhabit the Plata River Basin. Although differences between national and basin boundaries make statistical comparisons difficult among countries, Tables 1 and 2 are indicative of the importance of the basin in southern South America, both demographically and in economic terms, with reference to gross national product (Barberis 1990). Development is not evenly distributed in the basin. For example, Brasil in the upper basin consumes more than three times electric power than all the other countries in the basin (Table 3).

**Table 1: Total country area and total country population in the basin (from Barberis 1990).**

| Country | % total country area in the basin | % area | % total country population | % total basin population |
|---|---|---|---|---|
| Argentina | 29 | 32 | 68 | 23 |
| Bolivia | 19 | 6 | 22 | 2 |
| Brazil | 17 | 44 | 45 | 68 |
| Paraguay | 100 | 13 | 100 | 4 |
| Uruguay | 80 | 5 | 97 | 3 |

**Table 2: National and basin gross national products (GNP) (modified from Barberis 1990).**

| Country | % national GNP in the basin | % of total GNP in the basin |
|---|---|---|
| Argentina | 70 | 33 |
| Bolivia | 35 | 1 |
| Brazil | 60 | 60 |
| Paraguay | 100 | 3 |
| Uruguay | 95 | 3 |

**Table 3: Energy consumption in the Plata river basin (source World Bank, 1998).**

| | Commercial energy use kg of oil equivalent/10^6 | Electric power consumption kwh/10^6 |
|---|---|---|
| Brazil | 179486 | 305047 |
| Other countries | 76193 | 83433 |

### The International Joint Commission

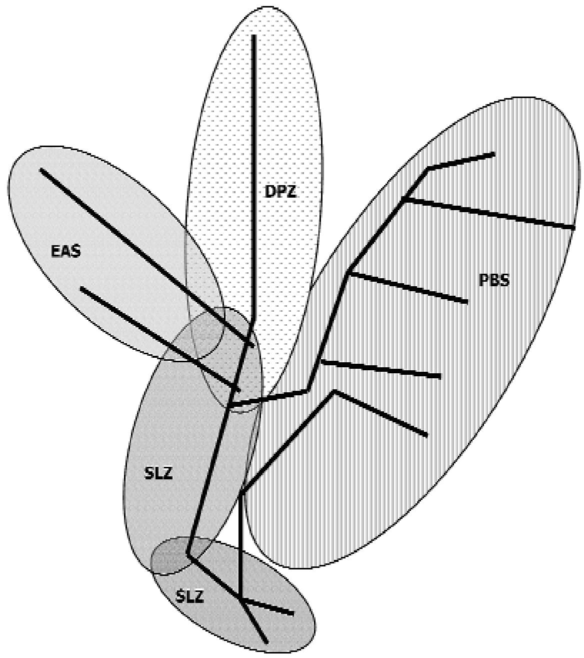
The idea of La Plata River Basin as a unit for development and international co-operation arose towards the 1960s. The Foreign Ministers of the five basin countries met and declared the decision of their Governments "to carry out a joint and integral survey of La Plata Basin, with the view to the realization of a program of multinational, bilateral and national works, useful for the progress of the region". The main areas to be considered, in relation to water resources, are navigation, hydroelectricity, domestic water supply, sanitation, industrial water use and flood control. The Brasilia Treaty of 1969 does not give attention to environmental or fisheries issues (Barberis 1990). The Treaty provides for joint action of the member states, but without interfering with "those projects and enterprises that they decide to carry out in their respective territories".

In practice, the institutional system has not worked well, partly due to the lack of a permanent technical arm. Discussions of the technical groups frequently involve non-technical participants with political bias, resulting in an outcome based on negotiations rather than on scientific and technical grounds. In addition, resolutions of the Conference of Ministers and the Co-ordinating Intergovernmental Committee (CIC) are in the nature of recommendations only and lack any legal force. The competence of the institutional mechanism has been tested and found wanting, in a number of cases (Barberis 1990).

## RIVER BASIN AND FISHERIES DEVELOPMENT

### Sources of floods and nutrients

As with other multicausal complex systems, environmental effects on large river fisheries should be addressed in the multivariate context of riverine ecology. The interaction between hydrology and geomorphology is a good basis to start a wide analysis of the past and present riverine fisheries (Quiros and Cuch 1989). The complex interplay of geomorphology, hydrology and development will determine many of the fisheries characteristics at the basin level. For fisheries analyses, the La Plata River Basin can be subdivided in four main regions (Figure 2):




■ **Figure 2.** Main fishery regions for the Plata basin, as described in text.

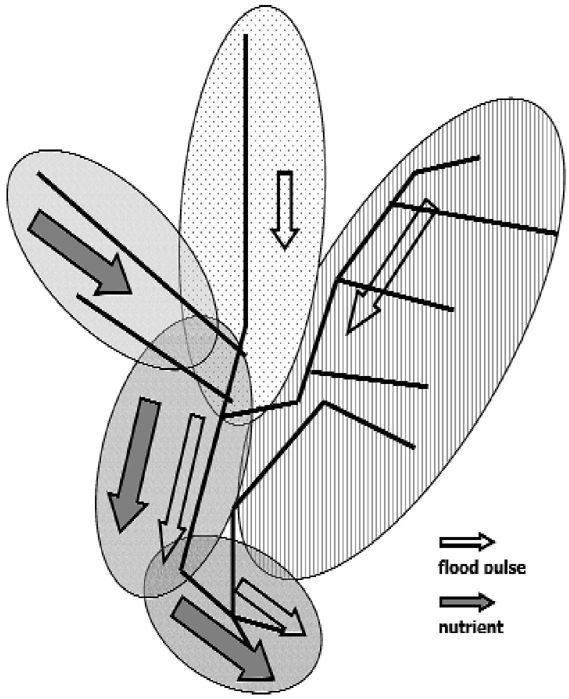
**EAS**: Erosive Andean sub-basins comprising the upper Pilcomayo and upper Bermejo Rivers. Formerly erosive at high sloped headwaters, but presently with highly erosive catchments as a result of mining, deforestation and agricultural activities. Depositional reaches downstream at the Chaco-Pampa Plain. Relatively high nutrient levels. Relatively low water discharges.

**PBS:** Precambrian Brazilian Shield drainages containing the most important upper Parana tributaries and upper and middle Uruguay reaches. Formerly low erosion at headwaters and interspersed with depositional floodplain zones. At present with highly erosive catchments, mainly due to deforestation and agricultural activities. Floodplains highly reduced by dams. Highly influenced by industrial activities. Presently regulated by cascades of reservoirs that retain sediment and nutrients. Relatively low nutrient levels. Highly important water discharges.

**DPZ:** depositional floodplain zones interspersed with Brazilian Shield emergences. Mainly contains the upper and middle Paraguay. Originally low erosive at headwaters but presently lightly erosive catchments by agricultural and mining activities. Comparatively low water discharge and nutrient levels.

**SLZ**: sedimentary middle and lower reaches with massive floodplains at the Chaco-Pampa Plain. Principally consists of the lower Pilcomayo, lower Bermejo, lower Paraguay, middle and lower Parana, lower Uruguay and the Plata River. Industry and annual crops influence at lower reaches. High water discharges and highly depositional at the Parana Delta and the Plata River. Relatively high nutrient levels.

For the middle and lower reaches of the Parana, the origins of the floods and of the sedimentary nutrient loads do not coincide (Figure 3). The spatial difference between the sources of floods and nutrients interacting with the river regulation would have important implications for the riverine dynamics and fisheries for both upper and lower depositional river reaches. As the river with the major discharges in the upper basin, the upper Parana provides the flood pulse to middle and lower river reaches. The Paraguay flows only modulate this pulse (Figure 1). Upper Parana and Paraguay Rivers provide the water for floods in the lower basin (Figure 3). These waters, mainly originating from the heavy rainfall on the Brazilian Precambrian Shield, usually have a relatively lower nutrient content (Maglianesi 1973). The effect of nutrient decrease is amplified by sediment retention in reservoir cascades (Tundisi 1981; Tundisi *et al.* 1991). On the other hand, main sources of nutrients to middle and lower Parana reaches are the headwaters of rivers originating in the Andean ranges (Figures 2 and 3).



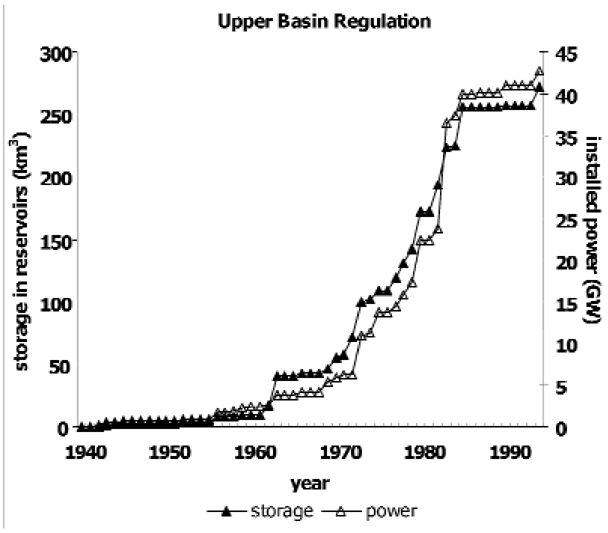

■ **Figure 3.** Main pathways of the flood pulse and the sedimentary transport to the lower basin river reaches.

## Development of the Plata River basin

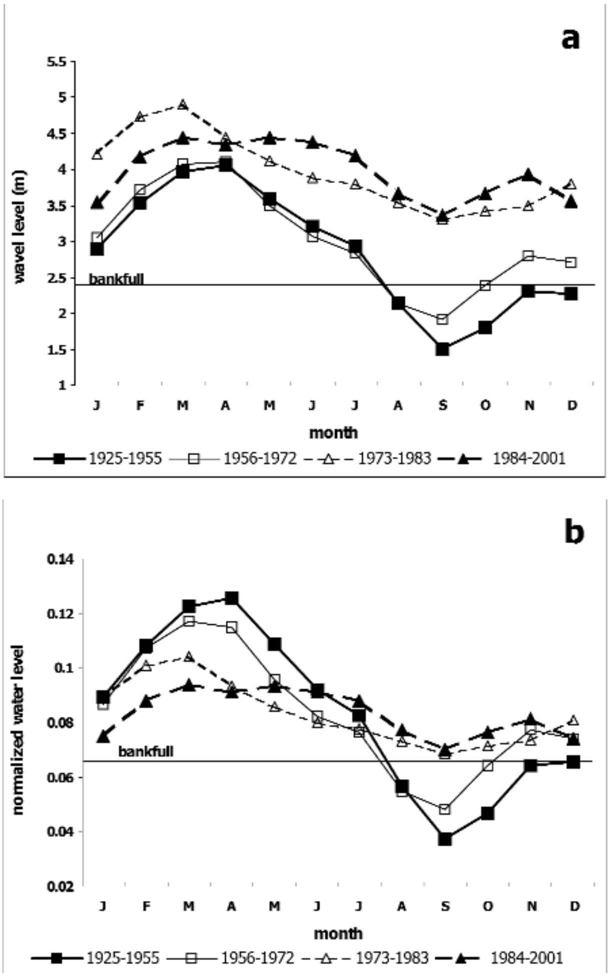
### River regulation

The Parana River runs 5 000 km from its headwaters to its mouth in the Plata River. More than 3 000 km of the upper reaches of the main river and most of its tributaries have been transformed into cascades of reservoirs (Figure 1) (Petrere *et al.* 2002). The upper Plata Basin regulation for hydroelectricity has been increasing noticeably since the early 1970s (Figure 4) (OEA 1985; Quiros 1990) and 70 percent of rivers are now affected by dams (Agostinho *et al.* 2000). Water in reservoirs located in the upper Parana Basin comprises more than 70 percent of the Parana mean annual discharge at its confluence with the Paraguay River (Figure 1) and the upper Parana is the most regulated river in the world (Agostinho *et al*. 2000). Before most of the reservoirs were formed, the middle Parana River showed a regular annual cycle, usually reaching its peak in autumn (March-April) and its minimum flow in late winter (September) (Figure 5a) (Bonetto 1986). However, the natural hydrological regime of the middle and lower Parana reaches has been altered by the operation of upper basin dams (Quiros 1990). These dams have resulted in an increase in minimum water levels in the middle reaches of the Parana and an extended period of floods (Figure 5). Although run-of-the river dams do not have the possibility to control river flow at high waters, downstream control effects are important at low water states. In order to optimize energy production, upstream dams retain water in reservoirs during high and falling water levels to release it during the low water level. These effects are noticeable when round year normalized hydrologic levels were analyzed (Figure 5b). In the middle Parana, water was over the unregulated river bankfull level (2.2 – 2.4 m at Santa Fe Harbor) most of the time during the last 30 years (Figure 5). In the middle and lower Parana Basin the river has lost several of its main characteristics, water cycles are less intense among and within years and water is on the floodplain most of the year (Figure 5). When the differences between maximum and minimum hydrological levels are compared among years for both the unregulated and the regulated river (Table 4), a marked decrease in the amplitude of the flood pulse is evident (Figure 6).

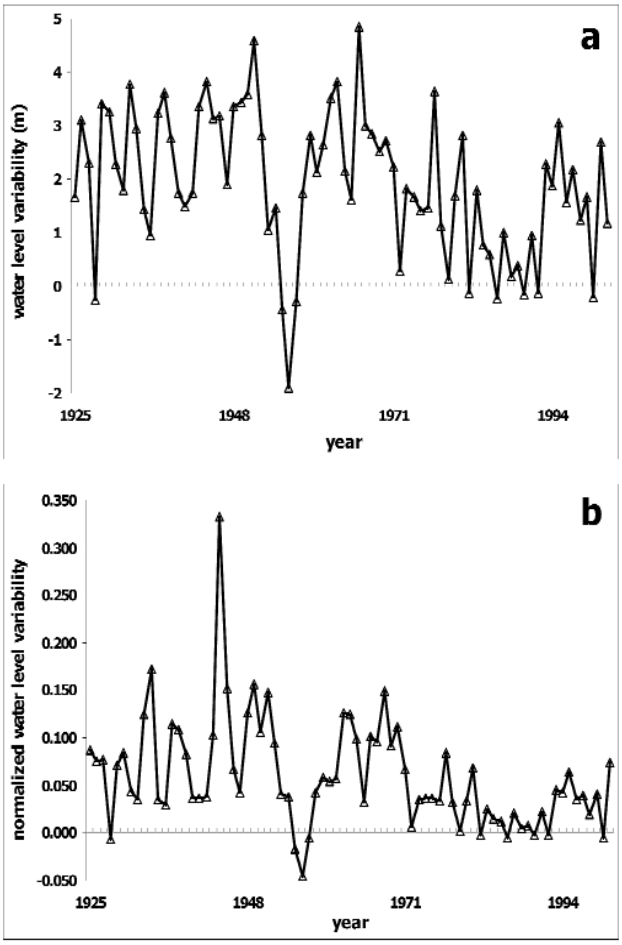
Several dams have been constructed in the Uruguay River Basin and at the headwaters of some tributaries of the Bermejo River and on other small tributaries of the rivers Paraguay and middle Parana. However, the basins of the Paraguay and Uruguay rivers may be considered to be mostly unregulated. This has important consequences for the functioning of the river-floodplain ecosystem. Sediment sources of Andean origin are still available for essential nutrient loading to the lower Paraguay and the middle Parana River (Figure 3).




■ **Figure 4.** The upper Plata basin regulation.




■ **Figure 5**. Water level variation in the middle Parana river (Santa Fe City) for the undeveloped and developed periods. a) actual data; b) round year normalized data




■ **Figure 6.** Water level at the maximum (March) minus water level at the minimum (September) for the middle Parana River (Santa Fe City). a) actual data; b) round year normalized data.

**Table 4: Flood pulse amplitude in the middle Parana river (Santa Fe City) for non-developed and developed river periods.**

| Period | March-September (m) | Relative March-September |
|---|---|---|
| 1925-1945 | 2.45 | 0.087 |
| 1946-1970 | 2.36 | 0.076 |
| 1971-1984 | 1.48 | 0.034 |
| 1985-2002 | 1.12 | 0.024 |

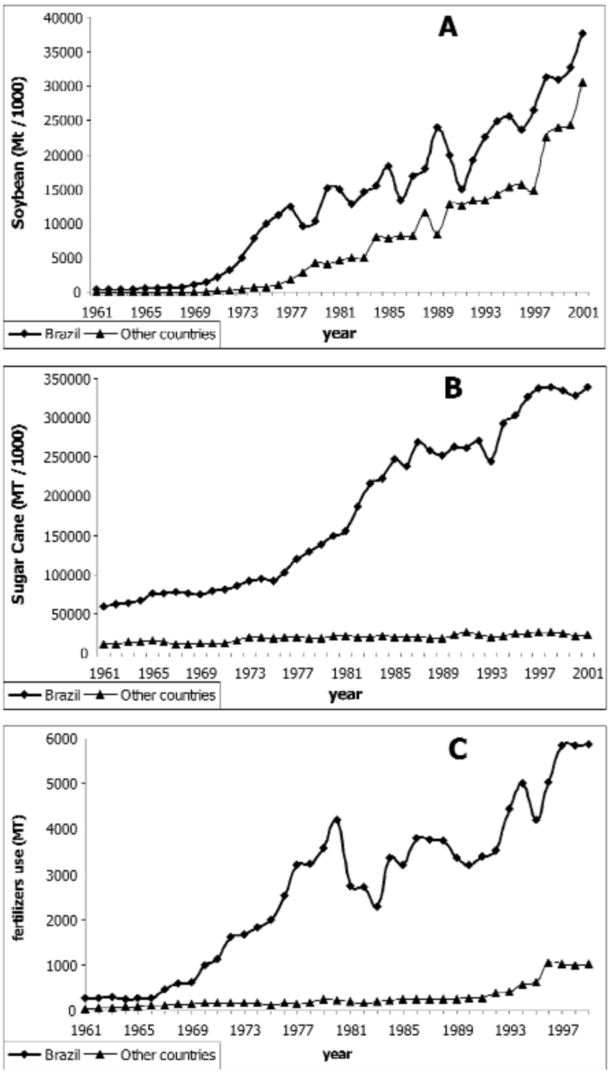
**The basin development**

The level of development among the countries of the Plata Basin development is not even (Table 2). Most of the industry and agriculture of Brazil and Argentina is concentrated in the higher and the lower Parana Basin, respectively. The Paraguay River Basin is mainly agricultural, although mining has become relatively important there as well. The upper Uruguay drainage is agricultural, but industry is also important. Cattle rearing is also significant in both the upper and the lower basins (Quiros 1990).

Development in the Plata Basin has been concomitant with river regulation, mainly in Brazil. Industrial development in the upper basin has been directly related to energy availability and energy consumption in Brazil has been rapidly increasing since 1968 paralleling the increase in energy generated by Brazilian hydroelectric plants (Quiros 1990).

The Plata Basin development is a paradigm for South America. Prior to 1960, the Rio de la Plata River Basin was scarcely developed (see Figure 5). Industrial development in the lower basin started earlier than in the upper basin and had a small increase in the early 1960s. Since the early 1970s industrial and agricultural development has been fast, mainly in the upper basin, responding to the increased availability of electric energy generated by hydroelectric plants (compare Figures 2 and 7). In the upper basin, industry, mining and both agricultural cultivated area and intensity have been increasing from the early 1970s to the present (Figure 7). It can be said that for all the basin countries, most of the fertilizers and other chemicals used by basin countries in agriculture and industry have been used in the Plata Basin.

Information on water quality in the Plata River Basin is scarce, scattered and even contradictory. Suitable international water quality monitoring programs are still to be implemented (CIC 1993). Water quality assessment based on national data is needed. In view of the level of resources that countries can put at the disposal of this activity, the strategies for water




■ **Figure 7.** Some indicators of development for the Plata basin. A. Soybean production (t x 1000); B. Sugar cane production (t x 1000); C. Use of fertilizers (t), for Brazil and the sum of other countries in the basin.

quality assessment will be developed according to minimum levels of monitoring operations mainly in main rivers (CIC 1993). While the most common national requirements are for drinking water of suitable quality, at present each member country has its own water quality standards. The different national water quality guidelines are reflected in different assessments of water quality in the rivers of the basin.

However, some studies in both the upper and the lower basin have confirmed what was expected from trends for some development indicators (macro-pollution variables) showed above (Figures 4 and 7). Developmental activities represent hazards to the health and integrity of fisheries resources (Quiros 1990). Some studies (e.g. Maglianesi 1973; Bonetto 1976; Tundisi 1981; Tundisi *et al.* 1991; Andreoli 1993), both in the upper and the lower basin, have shown different levels of pollution and water quality degradation. Other studies executed by governmental and bilateral agencies in the lower basin have shown significant levels of chloride pesticides in the major rivers and reservoirs. Andreoli (1993) reported the presence of agrotoxic substances in the upper Parana Basin. His research showed that 91 percent of 1 816 water samples contained residues of at least one agrotoxic substance. Agrochemical and industrial toxic concentrations in mussels for two coastal sites in the Rio de La Plata are elevated (IMW 1993). Angelini, Seigneur and Atanasiadis (1992) have reported organochloride pesticides and PCB residues in all sampled fish for the lower Uruguay River and Salto Grande reservoir. Similar results were obtained at the Parana confluence with the Paraguay River and for some lower Parana affluents. As expected, heavy metal levels were usually higher for top predators. However, we cannot assess here the water quality state for the Plata River Basin because water quality data for the basin, as well as water quality reports, are scarce, scattered and often contradictory.

## Plata River basin fisheries

The main fish characteristics of the Parana River were reviewed by Agostinho and Julio (1999), Agostinho *et al.* (2000) and by Bonetto (1986) who separately catalogued the fish faunas of the upper and lower reaches, respectively. Quiros and Cuch (1989); Quiros (1990); Espinach Ros and Delfino (1993); Petrere and Agostinho (1993) and Petrere *et al.* (2002) have all described the status of the fisheries of different parts of the La Plata Basin. Quiros and Cuch (1989) and Fuentes and Quiros (1988) described the structural characteristics of the lower basin fisheries. The fisheries period 1945-1982 for the lower Plata Basin was analyzed with emphasis on dynamic relationships between fish catch and hydrology for the lower basin (Quiros and Cuch 1989) and on fishery development activities in the river basin (Quiros 1990, 1993).

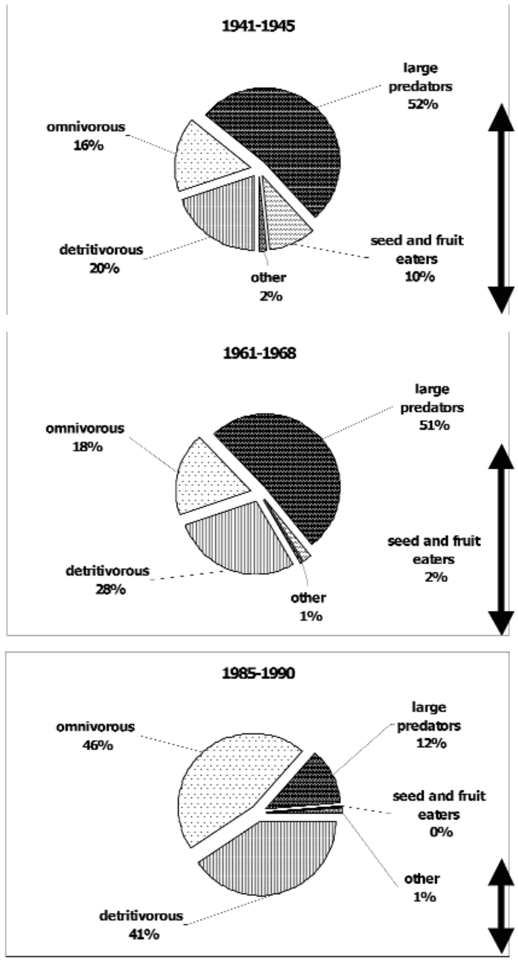
The best historical records for the Plata Basin fisheries are for fish landing sites situated in the lower basin during the 1935-1983 period (Quiros and Cuch 1989; Quiros 1990). For the pre-dam, unregulated river period (1935-1971), fish landings in the lower basin consisted of 6-9-year old fish, mainly large individuals of potamodromous fish (Quiros 1990). It can be assumed that the situation was similar in the other rivers of the undeveloped upper basin during this period. However, for the post-dam (1972-1983) regulated river period, in the middle Parana fish age at landings decreased to 4-6 years old. For this period the estimate of the total catch was 10 000 tonnes $yr^{-1}$. It is estimated that some 60 000 tonnes $yr^{-1}$ of fish, mainly the detritivorous *Prochilodus*, are captured in the middle Parana today.

## Historic fish catches in the lower basin

Fisheries before development were based on large potamodromous fishes (Table 5), mainly siluroids and some characins (Paiva 1984; Petrere 1989; Quiros and Cuch 1989; Petrere and Agostinho 1993). There was a higher proportion of large detritivorous at depositional zones (Bonetto 1986; Quiros and Cuch 1989) and at many river headwaters during seasonal fish migrations (Godoy 1967; Bayley 1973; Payne and Harvey 1989; Smolders, Guerrero Hiza, van der Velde *et al.* 2002). High valued large piscivorous were also captured in the pre-development period (Figures 8a and b). River regulation and basin development have led to some striking changes in fisheries in both the upper and the lower basin. The obligatory migratory fish abundance has sharply decreased in the upper basin and the size of potamodromous fish decreased appreciably in the remnant floodplains in the upper basin (Petrere and Agostinho 1993; Petrere *et al.* 2002). In the middle and lower depositional reaches (Figures 2 and 3), the proportion of the detritivorous *Prochilodus* in fish catches gradually increased when compared with the large piscivorous fish (Figure 8). Several fish species, mainly fruit and seedeaters, disappeared from zones where they were abundant during the predevelopment period. The exotic common carp has become abundant in the lowland depositional rivers but not in fish catches (Quiros 1990).

**Table 5: Main fish species taken by fisheries in the Plata river basin.**

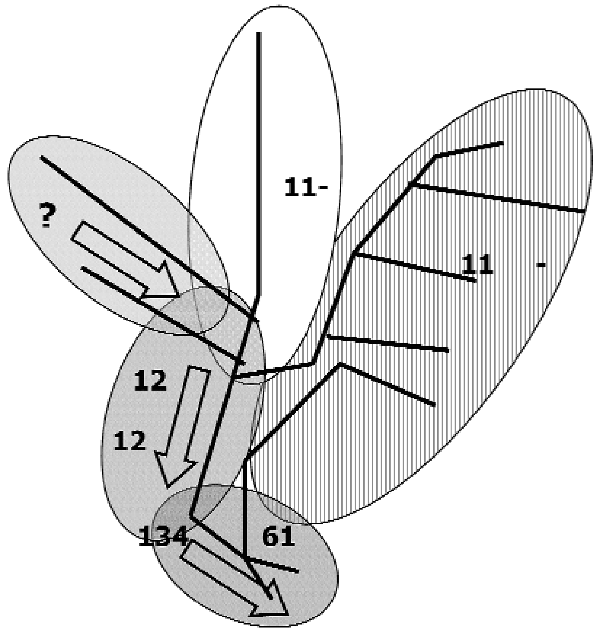
| | |
|---|---|
| Whitefish Species | Blackfish species |
| Large predators | Native species |
| *Pseudoplatystoma corruscans* | *Hoplias malabaricus* |
| *Pseudoplatystoma fasciatum* | *Hypophthalmus edentatus* |
| *Salminus maxillosus* | *Serrasalmus spp.* |
| *Luciopimelodus pati* | *Rhinelepis aspera* |
| *Pinirampus pinirampu* | *Pimelodus maculatus* |
| *Paulicea lutkenii* | *Pimelodus clarias* |
| | *Geophagus brasiliensis* |
| Detritivores | other blackfish |
| *Prochilodus lineatus* | |
| *Prochilodus platensis* | Exotic species |
| | *Cichla monocolus* |
| Omnivores and benthivores | *Plagioscion squamosissimus* |
| *Leporinus spp.* | *Oreochromis spp.* |
| *Leporinus obtusidens* | |
| *Pterodoras granulosus* | |
| other Doradidae | |
| Seed and fruit eaters | |
| *Brycon orbignyanus* | |
| *Piaractus mesopotamicus* | |




■ **Figure 8.** Historical changes in the structure of fish capture from the main channel, lower middle Parana River (Rosario City). Double arrow indicates the relative amplitude for the flood pulse.

## Present fisheries in the Plata River Basin

The complex interplay between geomorphology and hydrology determines many of the biological characteristics of large river-floodplain systems (Quiros and Cuch 1989). Fish abundance in the developed basin, as estimated from the catch per fisher per day (Figure 9), is actually ordered as would be expected from the conceptualisation of a large river-floodplain system as a continuum from its sources to its estuary, interspersed with relatively extensive floodplains where a diminished slope is evident. In this view, fish abundance would be lower at the upper reaches with relatively higher slopes, running on old and hard rocks and poorly developed soils, as compared with the higher fish abundance at the lower, low sloped depositional reaches. This pattern is actually displayed for the La Plata River Basin (Figure 9) despite development. The catch per fisher per day now ranges from 11-30 kg for reservoirs situated in the Brazilian upper basin to more than 110 kg in the lower middle Parana River and more than 300 kg at the Rio de la Plata River (Table 6). Catch rates drop to 8-10 kg of high value fish $fisher^{-1}$ $day^{-1}$ at the Parana-Paraguay confluence and for the Pantanal fishery.



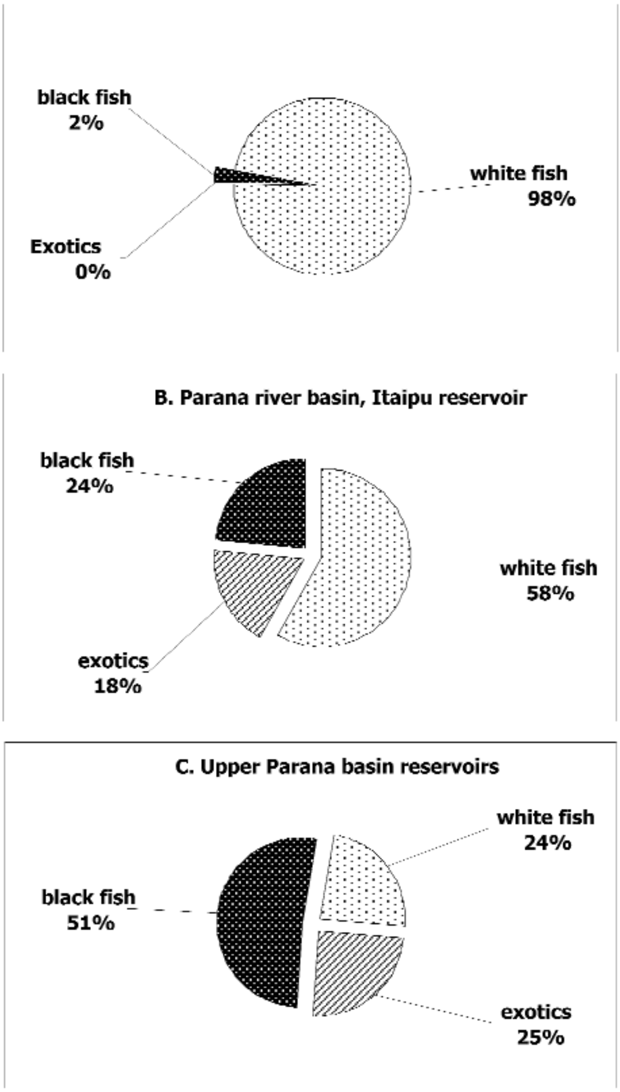

■ **Figure 9.** Catch per unit effort (kg/fisher/day) for fisheries regions as defined in text (from Quiros & Cuch (1989) and Petrere & Agostinho (1993).

However, the fish and the fisheries characteristics for the developed period differ according to the intensity of development and the position of each river reach in the basin. Striking differences in the fish species structure of the catch are noticeable between reservoir and floodplain fisheries (Figure 10) and among floodplain fisheries themselves.

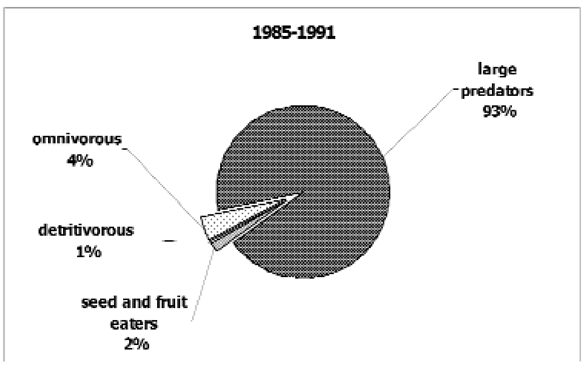
**Table 6: Catch per unit effort in the Parana River below the Itaipu dam for the 1982-1984 period (from Quiros & Cuch (1990) compared with catch per unit effort for Brazilian reservoirs situated in the upper Parana basin (from Petrere & Agostinho (1993) and Petrere *et al.* (2002)). CPUE, catch per unit effort (kg/ fisher/day).**

| Parana river reaches | CPUE | Upper Parana reservoirs | CPUE (a) |
|---|---|---|---|
| Lower upper Parana | 18.3 | Jupia | 24.6 |
| Upper middle Parana | 11.9 | Agua Vermelha | 22.6 |
| Middle middle Parana | 120.9 | Barra Bonita | 27.0 |
| Lower middle Parana | 133.9 | Ibitinga | 10.9 |
| Isolated delta distributary | 12.1 | Promissao | 29.6 |
| Rio de la Plata river | 614.5 | Nova Avanhandava | 15.2 |
| | | Itaipu | 11.8 |

(a), recalculated from original data.




■ **Figure 10.** Actual fish catch composition for the Plata river basin fisheries.

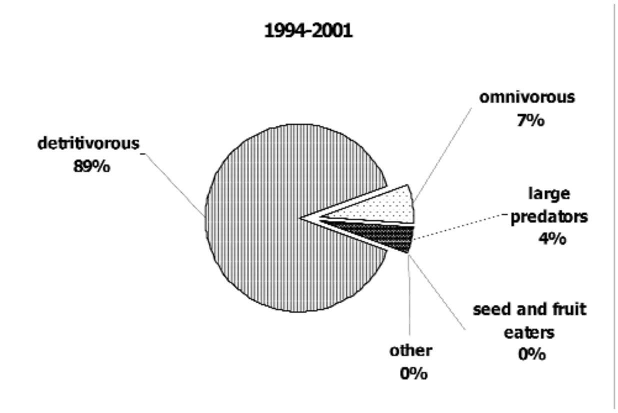



■ **Figure 11.** Structure of the catch at the main channel, upper middle Parana river (Parana-Paraguay confluence) (from Canon Veron 1992a, 1992b).

Fisheries retain several of their original characteristics in unregulated and less developed river reaches, although many changes are still evident (Figure 2, DPZ and EAS zones). For these reaches, large potamodromous fish are still present in the catch and are highly preferred by fishers, but the abundance of large piscivores is lower (Quiros 1990) and fish size at catch is noticeably smaller for most river reaches (Petrere *et al.* 2000; Quiros and Vidal 2000). Small numbers of relatively large piscivorous fish are still captured in river reaches where fisheries are highly regulated for recreation (Canon Veron 1992a, 1992b) (Figure 11). At the Parana-Paraguay confluence mesh size is usually regulated. Such management measures reserve the large piscivores for sport fishers, but they usually also lead to low fish catches with a minor proportion of the smaller omnivorous and detritivorous fishes. As in the Pantanal fisheries (Petrere *et al.* 2002), *Prochilodus* is the predominant species in these depositional river reaches. These fisheries resemble the fishery in an undeveloped river, in spite of their being controlled by very restrictive fishery regulations (Figure 10a). Still, the trophy size and large piscivores abundance have been decreasing during the last two decades at the Parana-Paraguay confluence and at the rest of the Paraguay River reaches (Paiva 1984). Fisheries for detritivorous fish stocks in some river headwaters during cyclic migrations are still important independently of development activities although some negative impact on fish is probable (Payne and Harvey 1989; Smolders *et al.* 2002).

Un-dammed but more regulated and developed lowland rivers (Figure 2, SLZ zones), may be impacted by upstream hydroelectric dams that may create unsuitable habitats for fish that are adapted to normal main channel conditions because they increase river flows during periods that were formerly low waters (Figure 5) or change flows at random (Quiros and Vidal 2000). Migratory whitefish are still the basis for fisheries (Figure 10a). Fishing pressure on the detritivorous *Prochilodus* has increased heavily at the lower depositional reaches during the last decade, as shown by a large increase in fish catches (from 10,000 t $y^{-1}$ to

60,000 tonnes $y^{-1}$) and by the composition of freshwater fish exported to Brazil and other South American and African countries (Figure 12). It should be noted that, when compared with other river reaches, the detritivorous *Prochilodus* is the most abundant fish species at highly depositional zones (Bonetto, Cordiviola de Yuan, Pignalberi *et al.* 1969; Quiros and Baigun 1985). This type of fishery represents a second fishery state corresponding to a developed river with flooplains still present. The concurrent development activities can also impact negatively on fish. Several signs of environmental stress on fish assemblages have been reported for the lower basin (Quiros 1990). Changes in fish species composition in commercial landings in the lower basin have been studied by Fuentes and Quiros (1988). During the last five decades the most noticeable changes were the decrease in landings of the fruit and seed eater species *Piaractus mesopotamicus* (Holmberg), *Brycon orbignyanus* (Val.), the top predators *Paulicea lutkenii* (Steindachner) and *Salminus maxillosus* (Val.), some fish species of marine lineage and an increase in landings of the detritivorous *Prochilodus lineatus* (Holmberg) (formerly *P. platensis*) (Quiros 1990). There was also a noticeable decrease in the frequency of the top predators *Pseudoplatystoma fasciatum* (Eigenmann and Eigenmann) and *Pseudoplatystoma corruscans* (Spix and Agassiz) in landings from the lower middle Parana and Uruguay southwards to the Rio de La Plata (Quiros 1990).




■ **Figure 12.** The structure of the freshwater fish (potamodromous) exportations from the middle and lower Parana River for the 1990-2001 period (source National Authority for Fisheries, Argentina).

For the dammed and highly regulated river reaches (Figure 2, PBS zone), potamodromous fish abundance declined concomitantly with river regulation and development. Hydroelectric dams have created inappropriate habitats for migratory whitefish because they acted as barriers to crucial fish migrations. In river reaches that were transformed into a cascade of reservoirs, potamodromous white fish are absent or their abundance has drastically diminished (Figure 10b and c). The catch of potamodromous fish frequently declines well below 50 percent of the total catch. In reservoirs, fisheries are based mainly in native, floodplain-related low-value black fish and with a sizeable proportion of exotics in the catch (Petrere and Agostinho 1993; Petrere *et al.* 2002) (Table 5). Fisheries in the most recently created reservoirs may represent an intermediate state of fisheries degradation (Figure 10b), especially where open river-floodplain reaches are still present upstream (Delfino and Baigun 1991; Agostinho, Julio and Petrere 1994). However, as was stated recently by Brazilian fishery scientists, the damming of the upper Parana and a high density of human population have contributed to the reduction in fish catches and the disappearance of potamodromous fish species from the upper basin (Petrere *et al.* 2002). Reservoir fisheries in the upper basin represent a third, highly disturbed fishery state.

## DISCUSSION AND CONCLUSIONS

The development of a large river basin is a dynamic process, with any form of development tending to induce both environmental change and further development. Thus, an expansion of hydroelectricity brings with it an increase in industry, agriculture, transport and settlements (Mather 1990). These in turn will result in significant increase in soil erosion, greater withdrawals of water, changes in water quality, reduced fisheries opportunities and probably need for protection of investments against hazards such as flooding. At present, this general statement is of application to Plata River Basin. However, it is difficult to assign causal relationships between river regulation and basin development and the concomitant change in fish assemblages.

The Plata River Basin is a developing river basin and each country member has distinct water related demands and requirements. Equally, each of the countries imposes pressures on the water environment and often on other countries in competition for river resources, including fishery resources. An agreement, which forms the Treaty of the La Plata Basin, was ratified by the five national states and remains in force. The main constraints to unified development and management are political. Sustainable development makes it unrealistic to consider any country in isolation and it is very necessary to be aware of country needs and impositions on basin resources in order to integrate them within the framework of a feasible multi-purpose basin management plan and to adapt this to progressive changes. The Plata Basin is not a heavily populated river basin, with population density of approximately 35 people per square kilometre. Detrimental impact on fisheries, therefore, would be expected to be more related to the industrial and agricultural development using environmentally unfriendly practices, rather than the present population density and fishing pressure. It has been reported that contamination of fish with toxicants commonly used in industry and agriculture has been on the increase during the last decade. There has been also an increase in the number of conflicts among artisanal, commercial and recreational fishers (Quiros 1993).

The Plata River Basin receives its water and nutrients from different sub-basins. This is also valid for a number of other large rivers. Floodwaters may originate on nutrient poor old Precambrian shields, or may arrive from the relatively young alpine ranges and their piedmonts. This will determine their nutrient content and sediment loads. Many fish are very much dependent on floods (Junk, Bayley and Sparks 1989; Bayley 1995) but it is highly probable that fish productivity in sedimentary river reaches may be also highly dependent on nutrient and organic matter loads (Vannote *et al.* 1980; Quiros and Baigun 1985). In order to preserve some of the pristine fish populations of large rivers, some characteristics of the flood pulse should be preserved (Bayley 1991, 1995; Quiros and Vidal 2000). Most river characteristics are lost as a result of damming. As for other large rivers, large potamodromous fish are highly vulnerable to river regulation and changing flows (Quiros and Vidal 1990, among many others). Fish abundance usually decreased in large reservoirs and fish communities change towards smaller non-migratory shorter-lived fish species. This pattern is known also for other reservoirs in the basin (Gomes and Miranda 2001). However, when catch per unit of effort (CPUE) for reservoirs in the upper basin is compared with that of an unregulated river reach in the lower basin, the difference in the total CPUE does not appear to be related to the various levels of development within the basin. The present large catches of detritivorous fish in river reaches with large floodplains can be expected to decline when further development takes place in rivers of Andean origin. To sustain a productive fishery an important part of a high-nutrient sedimentary load should be conserved.

In the lower basin, fish abundance has been historically high in depositional river reaches where floodplains are highly developed and connected (Quiros and Baigun 1985; Quiros and Cuch 1989). Fish abundance increases in river reaches the wider the floodplain as compared with the width of the main channel. However, on such floodplains the monetary value of fish is relatively low due to the high dominance of the detritivorous *Prochilodus* in catches. The opposite is true where the floodplain is narrower. There the mean annual fish abundance is lower but the catch comprises mainly larger, high valued, non-detritivorous potamodromous fish. Fisheries regulations, usually only weakly enforced throughout the basin, are more rigorously applied in the latter reaches.

Riverine fish populations usually change in response to fishing and environmental stress (Welcomme 2001). In the most developed river reaches in the Plata River Basin, potamodromous fish species declined and exotic fish species increased in relation to the total number of species taken by fisheries (Petrere *et al.* 2000). On the other hand, for the less developed reaches large potamodromous fish still dominate the fishery despite the large number of species in the system (Bonetto 1986; Agostinho *et al.* 2000). Many factors may contribute to explain changes in the species composition in fish landings under changing environments.

We have identified three main fishery states for the Plata Basin across broad temporal and spatial scales. A relatively undisturbed state corresponds to the unregulated river, when fishing effort was relatively low to moderate. Here catch is mainly dominated by high value large siluroids and characins. This state is represented by highly regulated recreational fisheries at the Pantanal and the Parana-Paraguay confluence and to a lesser extent by some of the remnant lotic reaches at the upper Parana. A second fishery state corresponds to a developed river, with floodplains disturbed by river regulation and other developmental activities. Here the fisheries are still supported by potamodromous fish but fish size at capture is usually lower. Fishing effort is usually higher, the contribution by weight to the catch of less valuable *Prochilodus* has increased and exotics are usually included in fish captures. The disturbed floodplain fishery state is represented by fisheries of most of the lower basin and at a few unregulated reaches of the upper Parana. Fisheries in riverine reservoirs represent a third, relatively highly disturbed fishery state. The catch of potamodromous fish frequently descends well below 50 percent of the total catch and fish catches are often dominated by blackfish species, less dependent on river flows and with an increasing importance of exotic fish species. Fish size is lower as well as fish value at landing. The Plata Basin fisheries represent almost all of these states at the same time in different parts of the basin.

The fishing effort on the Brazilian territory is usually higher than in other countries of the basin (Petrere and Agostinho 1993; Espinach Ros and Delfino 1993), but the lower Plata River Basin is one of the few sites worldwide that exports freshwater fish from capture fisheries. Riverine fish exports (mainly *Prochilodus*) to other South American and African countries have been increasing during the last decade, but fish quality is more than doubtful.

Many fish species inhabiting large river-floodplain systems have two distinct centers of concentration and fish migrate between the two (Welcomme 1985). Because large potamodromous fish need to migrate relatively long distances by main channels to complete their life cycles, these fish species are highly vulnerable in front of river dams. Despite river regulation, potamodromous fish retain their migration patterns evolved in pristine riverine systems (Quiros and Vidal 2000). Therefore, both untimely changes in flood pulse intensity and changes in flood pulse variability will be expected also to affect adversely potamodromous fish populations in open river reaches situated downstream from regulated river sections. As for other large rivers, periodic fluctuations in the abundance of fish is displayed for non-dammed river reaches especially in relation to past flood events (Quiros and Cuch 1989; Smolders *et al*. 2002).

A modification of discharge pattern is generally detrimental to fish production, which is highly dependent on seasonal inundation of floodplains for breeding and feeding. The regulated nature of the system initially led us to expect negative effects on landings in the lower basin; instead we have found that total fish catch per unit area was almost constant for the 1945-1984 period (Quiros and Cuch 1989). However, industrial “macropollution variables” have had a negative impact on commercial landings for most species (Quiros 1990). On the other hand, moderate enrichment with organic substances in a less variable environment can increase the carrying capacity for detritivorous and bentophagous fish. In conclusion: changes in fish assemblage composition and other signs of environmental stress on fish assemblages appear to be in agreement with a regulated river-floodplain system impacted by toxic substances used in agriculture and industry and lead us to conclude that Plata River Basin fisheries are from lightly to highly affected by development activities, depending principally on development intensity upstream.

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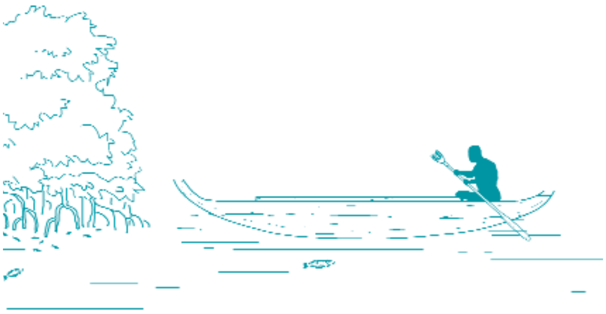

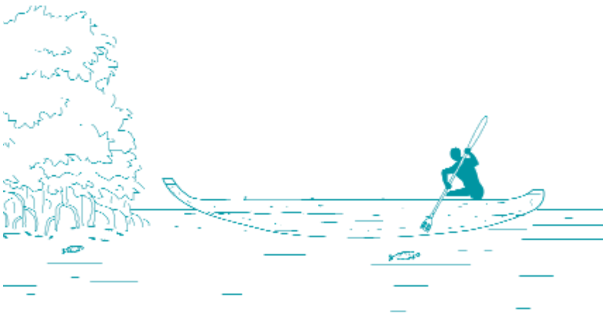

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