Inland fisheries under constraints by other uses of land and water resources in Argentina

ABSTRACT

Argentinean silverside is the most important fish in the very shallow lakes ("lagunas") of the Pampa plain. Patagonian silverside is common to most Patagonian lakes except for those in Tierra del Fuego. Both species of the Atherinidae family develop extensively in eutrophic lakes. Salmonoid biomass, most abundant in southern glacial lakes, is inversely related to water quality (transparency, low cost of treatment, aesthetic appeal) and mean annual air temperature. Fish yield of all these species declined from 1938 to 1973 in the shallow lakes and reservoirs of the Pampa plain, apparently as a consequence of increasing human population, gross regional product and industry development.

The La Plata basin is formed by three great sub-basins: those of Paraná, Paraguay and Uruguay rivers. Most of the Brazilian industry and an important portion of the intensively cultivated land is located in the higher Paraná basin. The Paraguay basin is mainly developed for agricultural use, although mining is currently an important activity there. The upper Uruguay drainage basin was developed for intensive agricultural use; industry however, is also important. Although dams have been constructed in the three sub-basins, only the upper Paraná basin is highly regulated. On the other hand most of the Argentinean industry is established near the Paraná river mouth. In the lower Paraná basin extensive agriculture and cattle raising activities are also important. Human induced stresses on the fish assemblages of the lower La Plata basin have been increasing in the last three decades.

Despite to the lack of conclusive evidence for determining cause and effect relationships, the detritivorous fish Prochilodus increase in the commercial landings, the decrease in abundance of the fruit and seed eater species and of the fish species of marine lineage, and the sharp decrease in the landings of the top predator *Salminus maxillosus* in the La Plata river are in agreement with the increase of toxic substances used in agriculture and industry impacting the upstream regulated river-floodplain system.

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FIGURE 1a
Argentina, showing some of the lakes and reservoirs studied

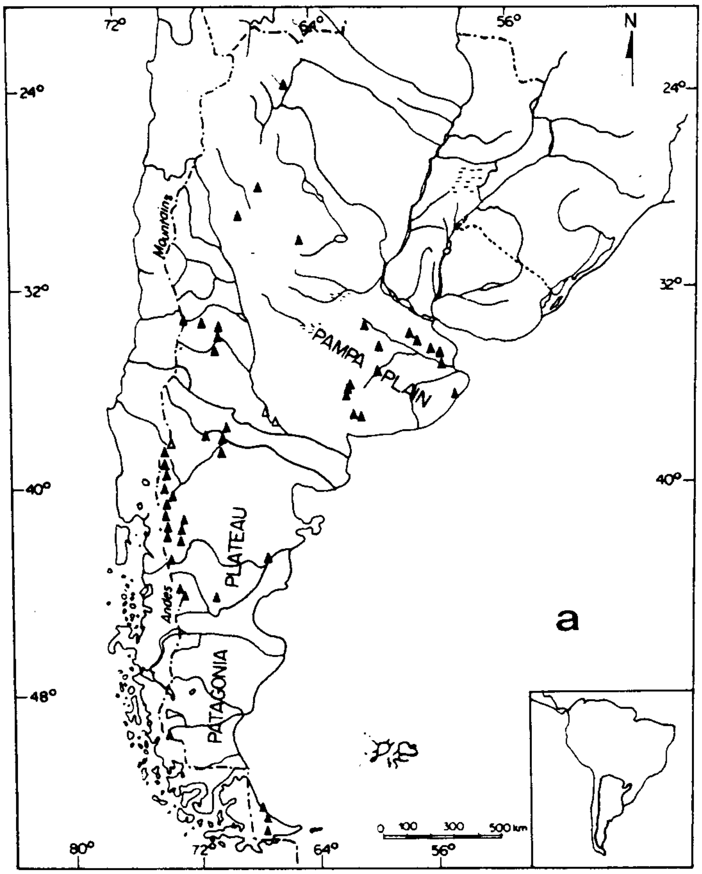
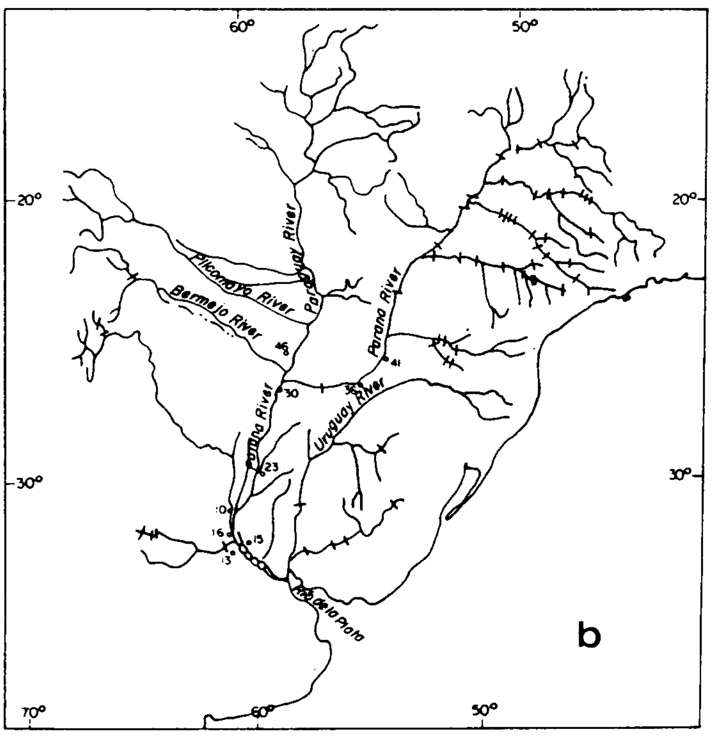


FIGURE 1b
La Plata River Basin



With the advent of industrialization and increasing populations, the increase of water requirements for industry, agriculture, and other human activities and the discharge of their wastes, have direct and indirect undesirable effects on fish and fisheries. However, those effects on fish production and fish yield are more controversial, and differences of opinions exist as to the relative importance of water regulations and lower water quality as opposed to natural environmental factors. The intention here is to present some case studies of development effects on fish and fisheries in the southern part of Latin America.

RELATIONSHIPS BETWEEN LAKE WATER QUALITY, FISH ABUNDANCE AND FISH ASSEMBLAGE COMPOSITION IN LAKES AND RESERVOIRS

The Lake and Reservoir System

One hundred and ten lakes and reservoirs in Argentina (Figure 1a) were surveyed for water quality (Quirós 1990c) and fish (Quirós 1990b) in mid-summer from 1984 to 1987. The sites are located between 25 and 55°S latitude throughout the central-western and northwestern arid regions of Argentina, the Pampa Plain, the Patagonian Plateau, the Patagonian Andes, and Tierra del Fuego. A wide range of climatic, morphometric, edaphic, and land and water use characteristics were sampled. Patagonian and Tierra del Fuego Andes lakes are typically ultraoligotrophic or oligotrophic. Most of the central-western and northwestern reservoirs and Patagonian Plateau lakes ranged from mesotrophic to eutrophic. Lake trophy of the Pampa Plain lakes ranged from eutrophic to hypereutrophic. Most of the fish species of the central and northern reservoirs have been introduced from outside Argentina or from other river basins in Argentina. A majority of glacial Andes lakes have been successfully colonized by salmonids. The Pampa Plain lakes are practically the only Argentinean lakes with a relatively high fish community diversity and most of the fish species there are native to the Pampa Plain (Quirós 1990b).

Relationship Between Lake Water Quality and Relative Fish Biomass

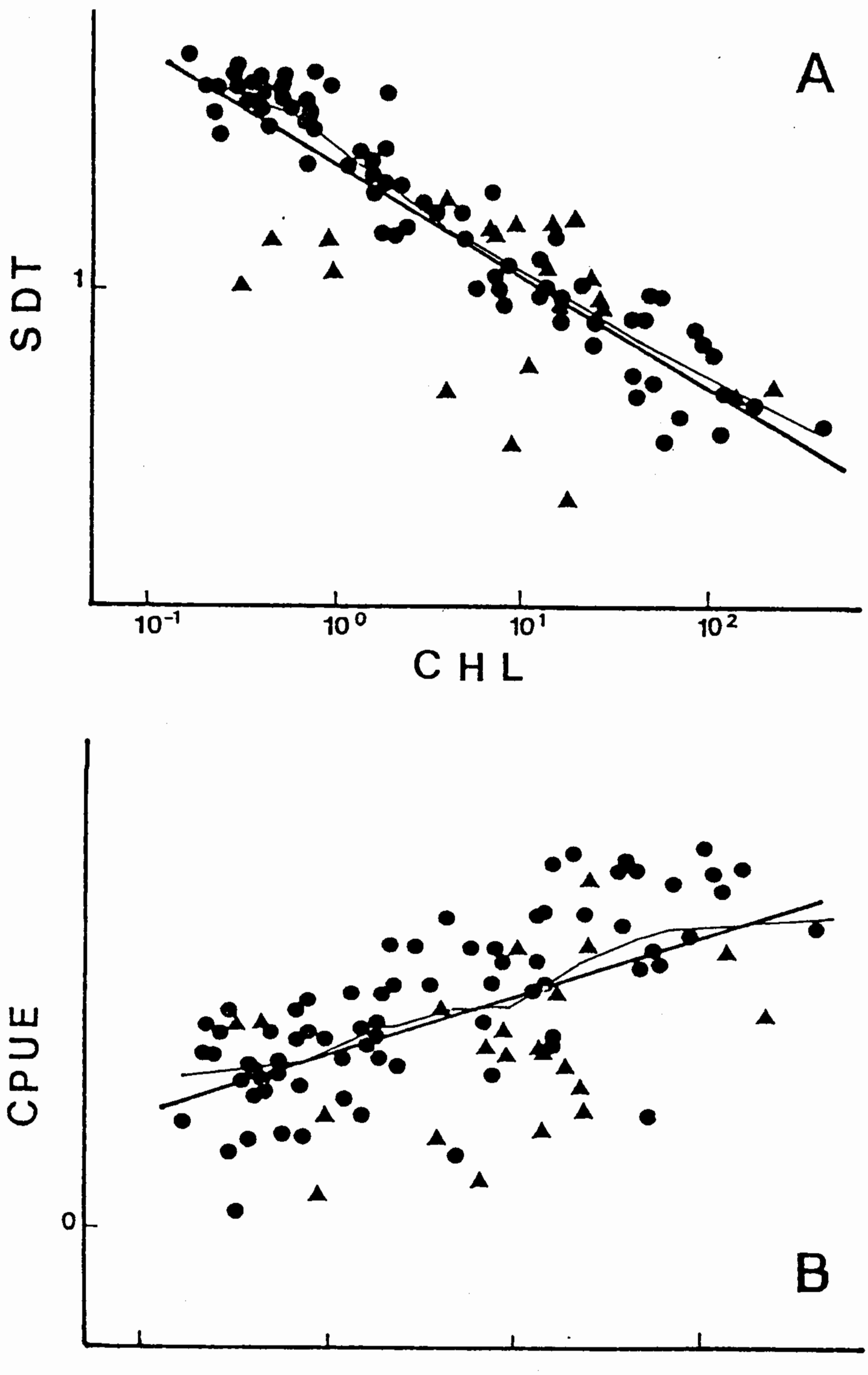
Necessarily, maximum fish biomass and maximum fishery yield results from high biological productivity and high plankton biomass (Jones and Hoyer 1982; Wagner and Oglesby 1984; Quirós 1990b, among others), while high water quality, high water transparency, low treatment costs, and the greatest aesthetic appeal are usually associated with low plankton biomass (Olem and Flock 1990). As expected, that was the pattern for Argentinean lakes and reservoirs (Quirós 1991). The better the lake water quality, the poorer the total fish biomass.

After data screening for lakes known to be subject to extensive human influence were excluded (Quirós 1990b), chlorophyll concentration explained 77% and 37% of Secchi disk transparency and relative fish biomass respectively (Figures 2a and b). After lakes and reservoirs with limnological anomalies or unsuitable conditions for fish were removed (Quirós 1990b), chlorophyll explained 92% and 55% of water transparency (Figure 2a) and fish biomass (Figure 2b) respectively. Silt-laden low transparency water and low dissolved oxygen concentration at the sediment-water interface resulted in lower fish biomass than predicted for least impacted lakes and reservoirs (Figure 2b).

The decrease in the slope of the relationship between fish biomass and chlorophyll for lakes with high chlorophyll concentration may be related with the positive effects of fertilizers and the negative effects of pesticides used in agriculture on fish abundance respectively.

FIGURE 2

Relationship between: (A) Secchi disk transparency (SDT, m) and mid-summer chlorophyll (CHL, mg.m^3); (B) fish biomass (CPUE, kg/night per standard gillnets) and mid-summer chlorophyll (CHL, mg.m^3). ( ) lakes and reservoirs with bottom dissolved oxygen less than 2.0 mg.L^{-1} or high inorganic turbidity



Relationships Between Water Quality and Fish Assemblage Composition

In Argentinean freshwaters, the Argentinean silverside (*Basilichthys bonariensis*) is common to most lakes and reservoirs in the Pampa Plain and central-western and northwestern arid regions. *Basilichthys microlepidotus* (Patagonian silverside) is common to most Patagonian lakes except for those in Tierra del Fuego. Both species of the *Atherinidae* family are most abundant in eutrophic lakes (Figure 3a) and have been reported as zooplanktivorous and microbenthophagous fish.

Most of the glacial lakes in Patagonia and Tierra del Fuego had been successfully colonized by introduced salmonids. Fish of the *Salmonidae* family are most abundant in southern glacial lakes, and salmonoid biomass was inversely related to water quality and mean annual air temperature.

In conclusion, along a trophic-status continuum ranging from oligotrophic (nutrient-rich, low algal biomass, good water quality) through eutrophic (nutrient-rich, high algal biomass, poor water quality) there is a continuum of fish yield, and also a smooth change in fish assemblage structure (Figures 3a and b).

FISH YIELD CHANGES IN THE PAMPA PLAIN VERY SHALLOW LAKES

The system

Lakes in the Pampa Plain are shallow and very shallow eutrophic and hypertrophic lakes ("lagunas") and mean depth ranged from 0.7 to 5.2 m (Quirós 1988). Argentinean silverside is the most important fish in both the commercial catches and in the recreational fishery. For four of the most important lake fisheries, maximum silverside yield ranged between 30 and 190 $kg.ha^{-1}$ yr^{-1} in the 1938-1979 period. The fish community composition was related to the amount of open water and vegetated areas and wetlands, and to the total organic matter in the water (Quirós 1990b).

Chascomús Lake Fishery

Good water quality in lakes is essential in maintaining recreation and fisheries and in the provision of municipal drinking water. These uses are clearly in conflict with the degradation of water induced by agricultural use and by industrial and municipal waste disposal practices. For Chascomús lake catchment in the Pampa Plain, the increase in human population in urban and rural areas, and the related agricultural and industrial development leaded to lower Chascomús lake water-quality conditions and have been producing marked changes in fish community composition and silverside fish yield (Figure 4). Extended fish mortalities were common in the sixties.

To analyse the decline in the fishery, development variables (total population and total urban population for Chascomús county and city respectively, gross national product, number of industries and manpower at work in industries, etc.) were used as surrogates for direct pollutional loadings. All those variables have almost the same trend. Furthermore, the Chascomús City does not have municipal waste disposal plant. No much progress has been made particularly with respect to the controllable point source discharges of waste, and to the

FIGURE 3

Relationship between: (A) biomass of atherinids (CPUEA, kg/night per standard gillnets) and mid-summer chlorophyll (CHL, mg.m^3). (B) biomass of salmonoids (kg/night per standard gillnets) and mid-summer chlorophyll (CHL, mg.m^3)

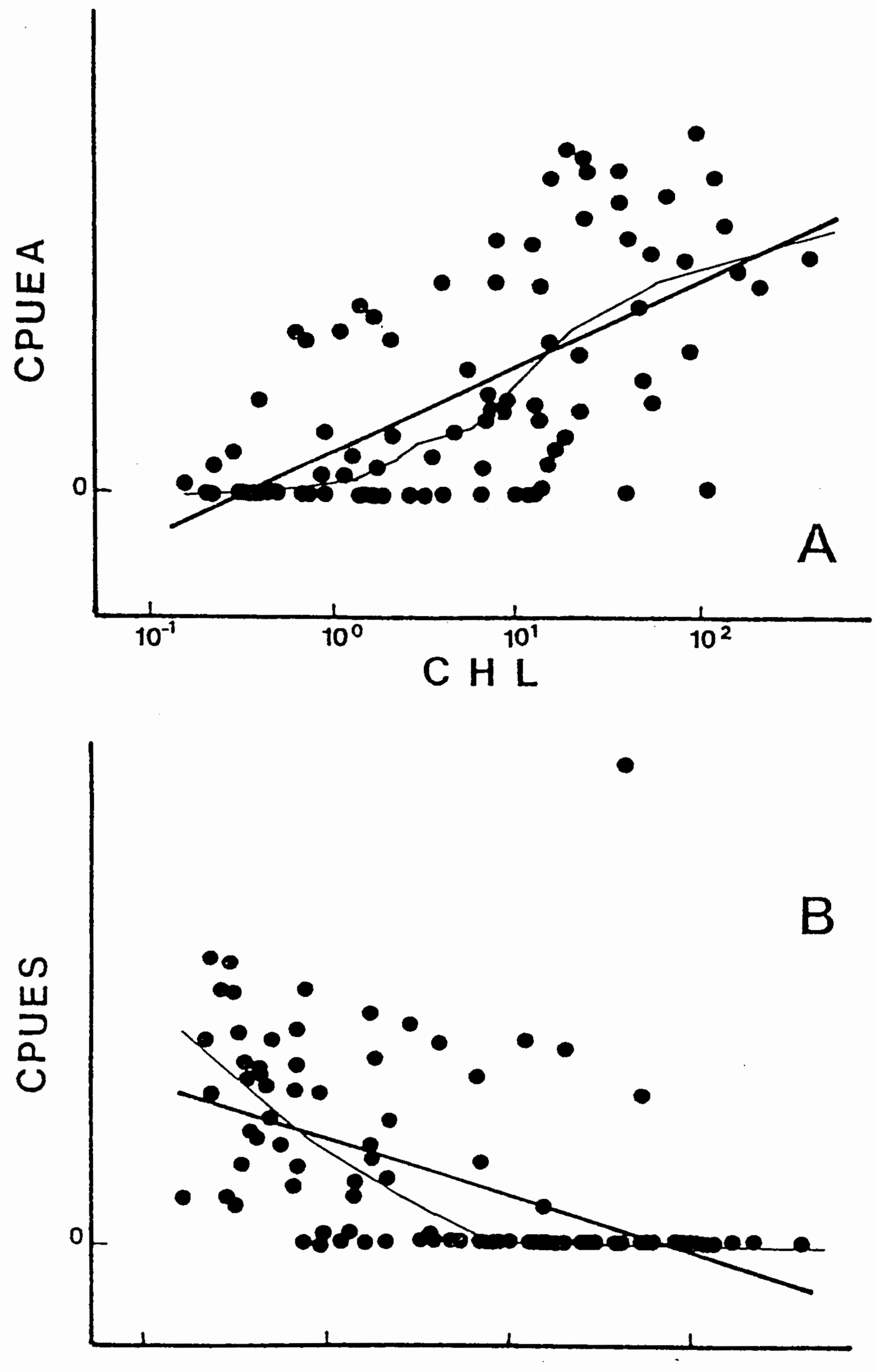


FIGURE 4
Chascomús Lake. Argentinean silverside catch (mt/yr) for the 1938-1973 period

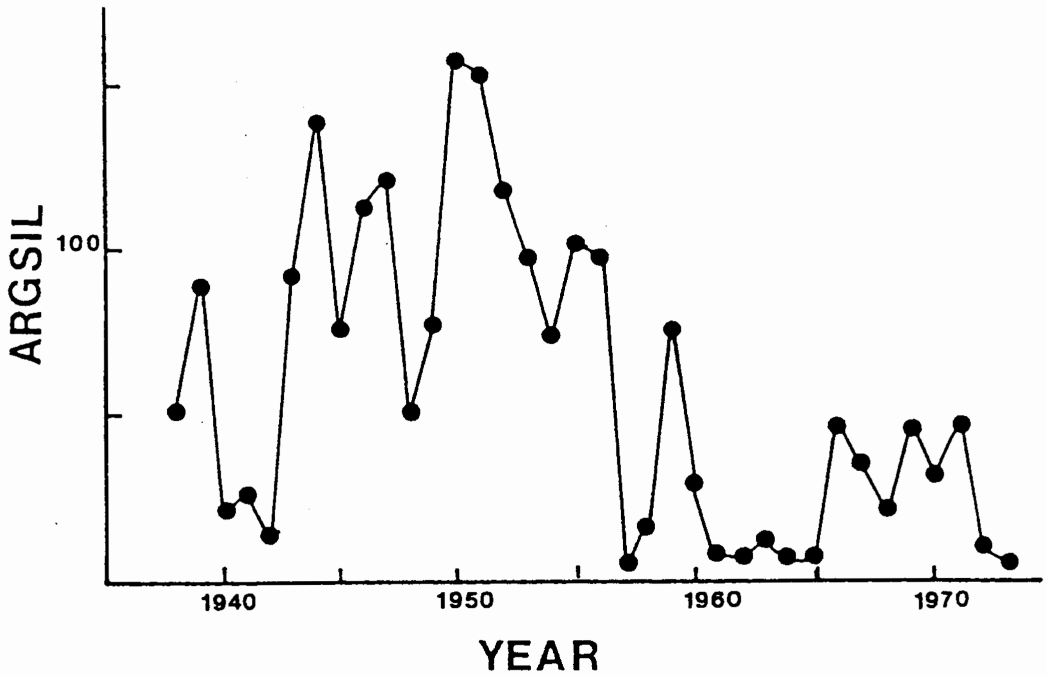
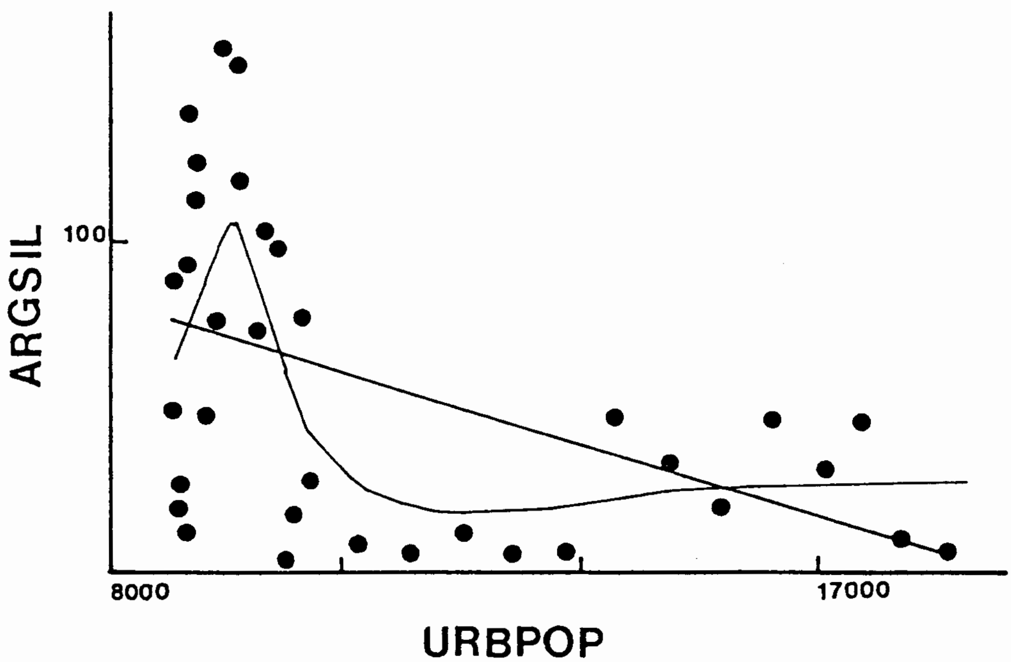


FIGURE 5
Relationship between Argentinean silverside catch (mt/yr) and urban population for Chascomús City



more pervasive impacts of diffuse sources of pollution within the watershed. The development of the Chascomús catchment, including the Chascomús city, conducted to the decline and close of the commercial silverside fishery (Figure 5) in 1974. Fish yield declined from 88 kg.ha^{-1} yr^{-1} for the period 1938-1956 to 24 kg.ha^{-1} yr^{-1} for the period 1957-1973.

LA PLATA RIVER BASIN DEVELOPMENT AND FISH HARVEST CHANGES

The River System

The La Plata basin (Figure 1b) consists mainly of three sub-basins: the Paraná, the Paraguay, and the Uruguay river basins. The Paraná river flows 4000 km southward from its sources in the Precambrian Brazilian Shield to its mouth in the Pampa Plain discharging 20 000 m^3/s in the La Plata river. The Uruguay river flows 1800 km from it sources in southern Brazil and discharges 5000 m^3/s in the La Plata river. The Paraguay river extends 2670 km southward from its sources in the western hill of the Brazilian Shield at 300 m of altitude to its confluence with the Paraná river.

With an area of 3.1 x 10^6 km^2 the La Plata basin has a population of more than 80 million people. Most of the Brazilian industry is established in the higher basin of the Paraná river. Agriculture is also important. On the other hand most of the Argentinean industry is established in the lower basin near the Paraná river mouth.

Argentina and Brazil are the most important component countries in the La Plata basin. Brazil, in the higher catchment, accounts for more than 60% of the population, while Argentina accounts for more than 25% in the lower basin. Most of the arable land and most of Brazil's industry are in the higher basin of the Paraná River. On the other hand most of the Argentinean arable land and most of its industry are in the lower basin near the Paraná river mouth. The Paraguay basin was mainly developed for agricultural use, although mining is currently an important activity there. The upper Uruguay drainage basin was developed for intensive agricultural use, industry however, is also important. Although dams have been constructed in the three sub-basins, only the upper Paraná basin is highly regulated (OEA 1985). Water in reservoirs located in the upper Paraná basin comprises more than 60% of the mean annual discharge at its confluence with the Paraguay river (OEA 1985). In the lower basin extensive agriculture and cattle raising activities are also important. Human induced stresses on the fish assemblages of the lower La Plata basin have been increasing in the last three decades.

The main limnological characteristics of the lower La Plata basin were overviewed by Quirós and Cuch (1989). The structural characteristics of the lower basin fisheries were previously described by Quirós and Cuch (1989) and Fuentes and Quirós (1988). Total fish biomass was suggested to be spatially related to total organic matter both in the water column and in bottom sediments in depositional zones (Quirós and Baigún 1985; Quirós and Cuch 1989). The detritivorous fish species of the genus *Prochilodus* are the most important fishes in both the commercial catches and in experimental fish studies (Quirós 1990a). *Prochilodus* appears to be more related to the floodplain than the other migratory fish species (Quirós and Cuch 1989). The proportion of *Prochilodus* in floodplain lagoons and backwaters is very high and it is practically the only migratory species present there, with the exception of some preadults of other migratory species.

Development and Fish Changes

The installed capacity of hydroelectricity generating plants (Figure 6a) and the volume of water in reservoirs (Figure 6b) in the upper Paraná basin have been increasing since the early fifties but a sharp increase is noticed from 1970-1972 up to present. The upper basin dams have produced an increase in the water levels and a delay in the timing of floods downstream in the lower basin (Quirós 1990a). Although dams at high water do not have the possibility to control the river, at low water downstream control effects are important. The water management in the upper dams, conducted to maximize power generation, retains water in reservoirs during falling waters to release it during low waters. Water is over the middle Paraná river floodplain most of the year (Quirós 1990a).

The industrial and agricultural development in the upper basin was directly related to energy availability, and energy consumption in Brazil has a sharp increase since the 1968-1970 period resembling the increase in energy generated by hydroelectric plants (Figure 6a). In the lower basin the industrial development was earlier than in the upper basin. For example, the Argentinean petrochemical industry has been developing since the early sixties (Figure 7). The agriculture in the upper basin is most intensive than in the lower basin, but its development was more steady and later than in the lower basin.

Several signs of stress on fish are listed in Table 1, though their importance at the watershed system wide level cannot be evaluated at the present. More site specific stresses on fish like poor habitat due to low dissolved oxygen, or the high fish mortalities in dam structures like turbines or spillways, and hour to hour downstream flow modifications for dams, have not been included here.

River regulation practices changing the hydrological and geomorphological dynamism of the natural system, and the related industrial development leading to lower water-quality conditions might produce marked changes in fish communities (Petts *et al.* 1989). Hydrographic, climatic, and pollution conditions during spawning and prerecruitment periods would be expected to have the greatest influence on year class strength (Krykhtin 1975; Holcik and Bastl 1977; Welcomme 1986; 1989; Novoa 1989; Quirós and Cuch 1989). The 1945-1980 period in the history of lower La Plata basin fisheries was analysed for development caused changes (Figure 8). As surrogates for direct pollutional loadings (Summers *et al.* 1985) macropollution variables (e.g. human population, gross national products, industrial and agricultural development indicators) were used (Quirós 1990a).

The fish catches in the lower La Plata basin have been shown to be dependent on flooding intensity and on the amount of water remaining in the system during the low water season in the years in which the age classes taken by the fishery were born (Quirós and Cuch 1989). The time lag for the hydrologic variables significant in explaining fish catch variability usually correspond to the age or the age of the age classes taken by the fishery. An inverse relationship between the fish catches and the mean air temperature for the one or two years immediately after the fish taken by the fishery were born, has been also shown (Quirós 1990a). Those results suggest a negative effect of high temperature for the first or two years of life.

As expected, multiple regression models for the variation of both catch and catch per unit flooded area included hydrologic, climatic, river regulation, technological change in the

FIGURE 6
(a) Installed power at hydroelectric stations (HP, MW.10^{-4}(b) Storage capacity in reservoirs (RVOL, hm^3 10^{-5}) for the upper Paraná basin (from Quirós 1990a)

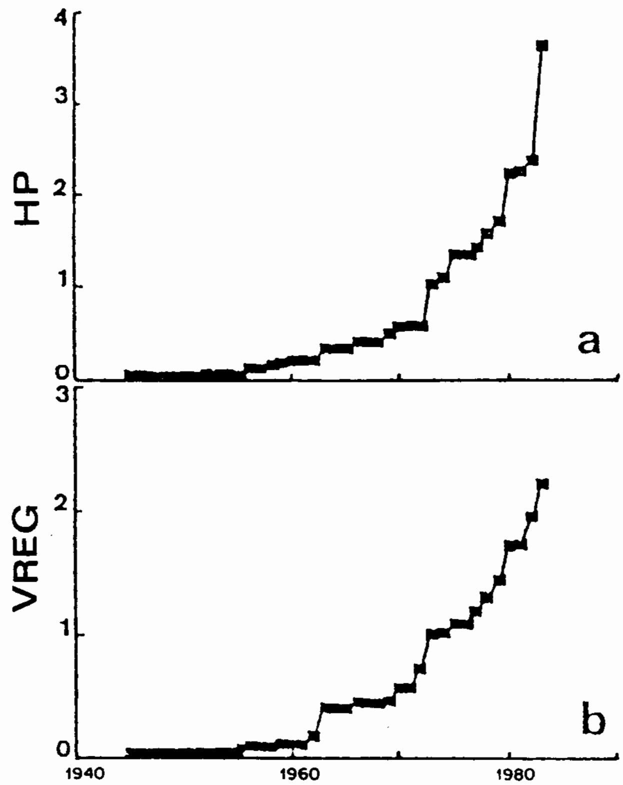


FIGURE 7
Installed production capacity for the Argentinean petro-chemical industry (PCHI, $mt.yr^{-1}$ 1 10^{-6}) (from Quirós 1990a)

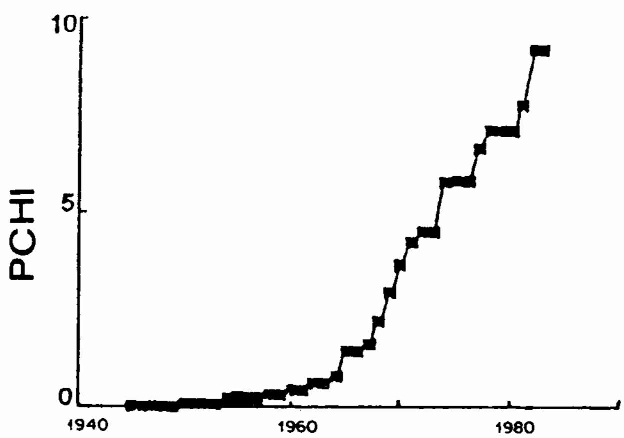
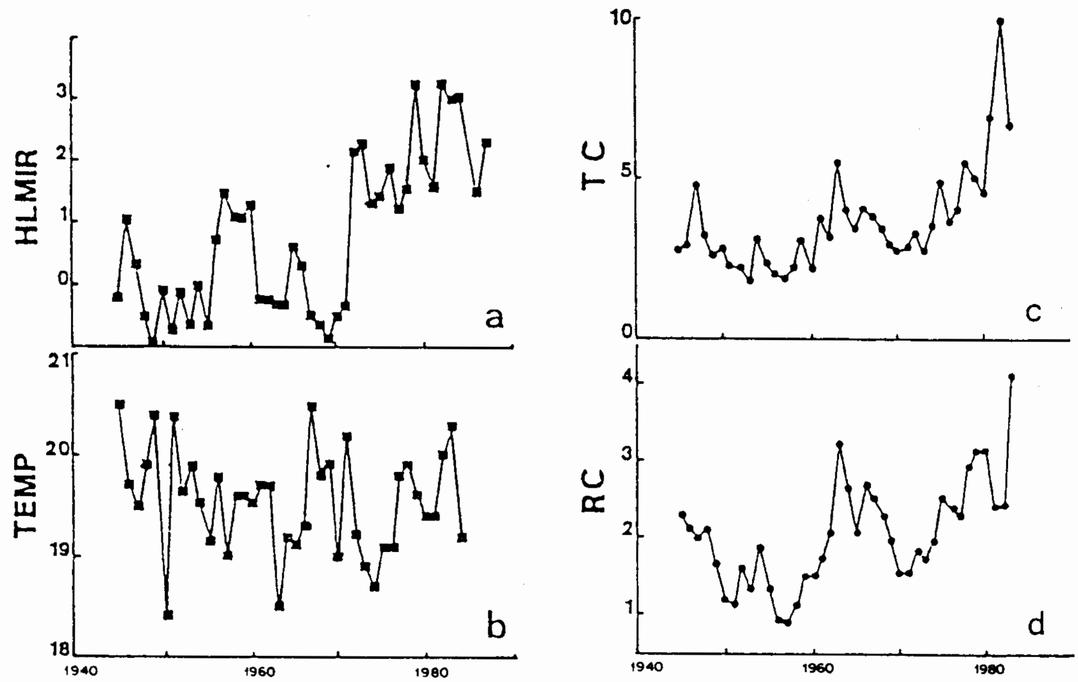


TABLE 1
Signs of environmental stress of fish assemblages in the lower La Plata Basin (from Quirós 1990a)

Symptom of stress	Source
Fruit and seed eater species of the genera *Colossoma* and *Brycon* and the big catfish *Paulicea lutkenii* have practically disappeared from the commercial catch in the lower Paraná River, and also from the catches in the La Plata and Uruguay rivers	Fuentes and Quirós (1988); Quirós (personal observation)
Fish species of marine lineage of the genera *Basilichthys* and *Lycengraulis*, usually moving upstream from the estuary in winter, have practically disappeared from the commercial catches in the middle Paraná	Fuentes and Quirós (1984)
The commercial catches of the pelagic top predator *Salminus maxillosus* have been decreasing since the late 1940s in all the lower basin, though its commercial catch has been highly restricted	Fuentes and Quirós (1984)
Populations of most of the migratory fish species are severely diminished in the middle and upper Uruguay river	Roa (personal comm.) Oldani (pers. comm.) Quirós (pers. obs.)
Relatively high levels of agricultural pesticides and heavy metals were detected on fish tissues	Moreno (pers. comm.); Angellini (pers. comm.)
Periodic massive fish mortalities were reported in the lower Paraná delta and the La Plata river	
Low water oxygen levels and massive fish mortalities were detected in the lower Paraguay river, and discharges of high organic matter content effluents from the agricultural industry have increased in the upper basin	Espinach Ros (pers. comm.); Ferraz de Lima (1987)
The exotic *Cyprinus carpio* was the most important species in biomass in the experimental catches in the La Plata river, and its catch has been increasing in the middle Paraná	Candia (pers. comm.); Vidal (pers. comm.)
Maximum size at catch of the big catfish of the genera *Pseudoplatystoma* has been decreasing for the last three decades in the lower middle Paraná	Vidal (pers. comm.)
The conflicting situations between recreational and commercial fishermen have been increasing, and the trophy size of *Salminus* has been decreasing at the confluence of the Paraná and Paraguay rivers, though total fish effort seems not to have increased	Quirós (pers. obs.)

fishery, and macropollution variables (Quirós 1990a). Reservoir storage capacity had a positive effect on catch in all developed models, after hydrologic and climatic effect have been accounted for. As expected, macro-pollution variables, as installed production capacity for the Argentinean petrochemical industry, were negatively related to total catch and the catches for individual "species" after hydrologic, climatic, and river regulation effects have been accounted for (Table 2). The later relationship was expected although it is certainly not causal evidence of negative pollution effects. The river regulation and the industrial development in the lower basin are highly related ($r=0.90$, $P < 0.0001$) though out of phase. Net positive effects of river regulation on total fish abundance in spite of river catchment development were discussed elsewhere (Quirós 1990a).

FIGURE 8
(a) Annual average for the mean monthly minimum water level at Rosario City (HLMIR, m); (b) mean annual air temperature for the September-March period (TEMP, °C); (c) total catch (TC, mt. yr^{-1} 10^{-3}); and (d) total catch minus that of *Prochilodus* (RC, mt. yr^{-1} 10^{-3}, for the 1945-1983 period (from Quirós 1990a)



Models for catch per unit flooded area usually included a negative hydrologic term accounting for "same year" effects; years with more water in the floodplain also had lower catches per unit flooded area, all else being equal. The models developed for individual species catches are also well adjusted to the empirical trends. For example, Figure 9 shows the "best" model fit obtained for the catch per flooded area of *Salminus maxillosus* (Figure 9a, r^2 = 0.81) and *Luciopimelodus pati* (Figure 9b, r^2 = 0.82) respectively. Pollution effects explained 36% of catch variability for the former and 19% for the later fish species. Coinciding with historical trends in river regulation (Figures 6a and b) and pollution (Figure 7), only the models for the period 1963-1980 included river regulation terms (Quirós 1990a). Similar results were showed for pollution effects, but those were noted for the period 1945-1962 (Table 2).

In the last few decades changes in fish assemblages (Figure 10) may be assumed for the lower La Plata basin.

FIGURE 9
Comparison of observed values (●) of: (a) *Salminus maxillosus* catch (mt. yr^{-1}) and (b) *Luciopimelodus pari* (mt. yr^{-1}) and those predicted (▲) from the "best" obtained multiple regression models (modified from Quirós 1990a)

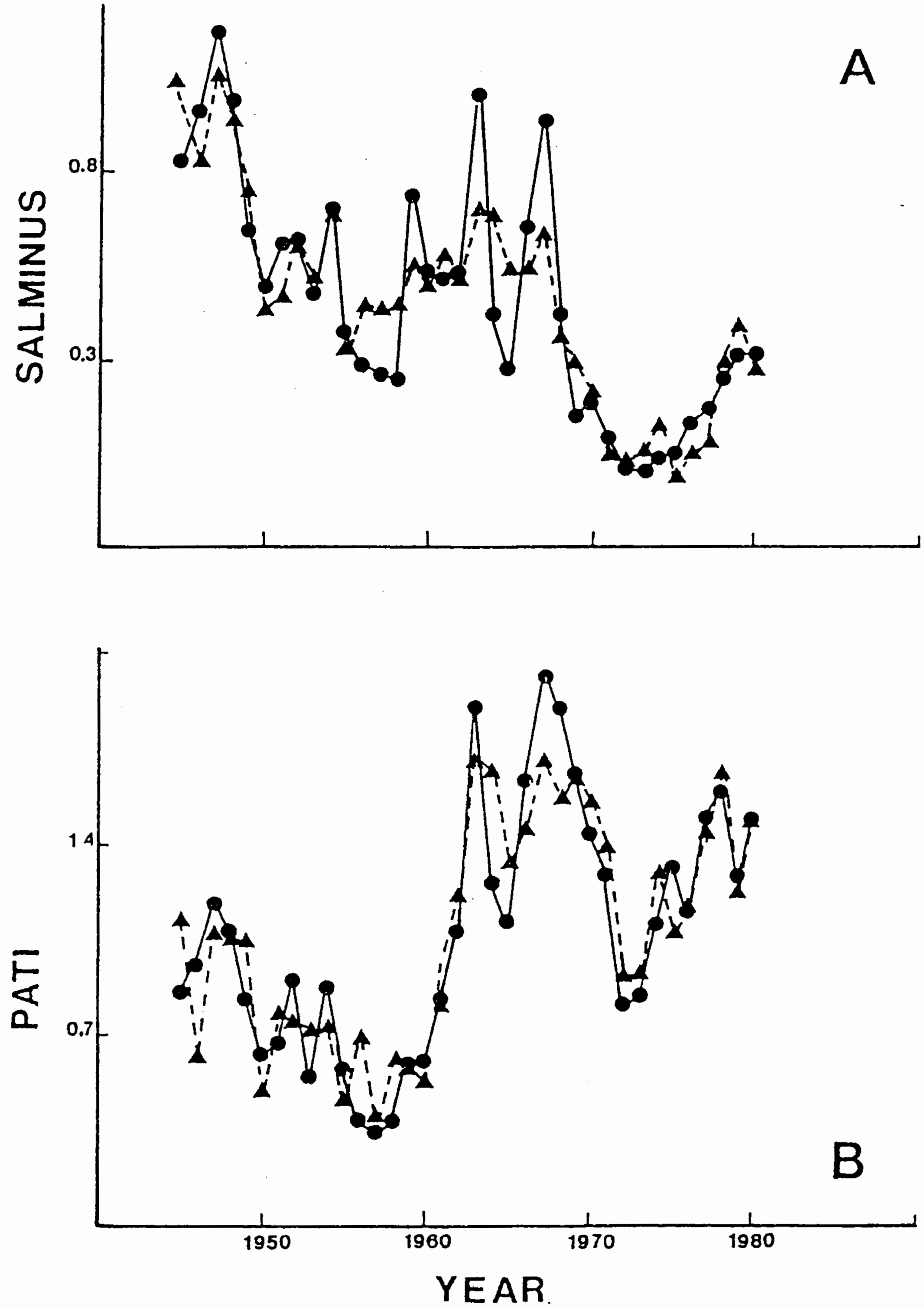


TABLE 2

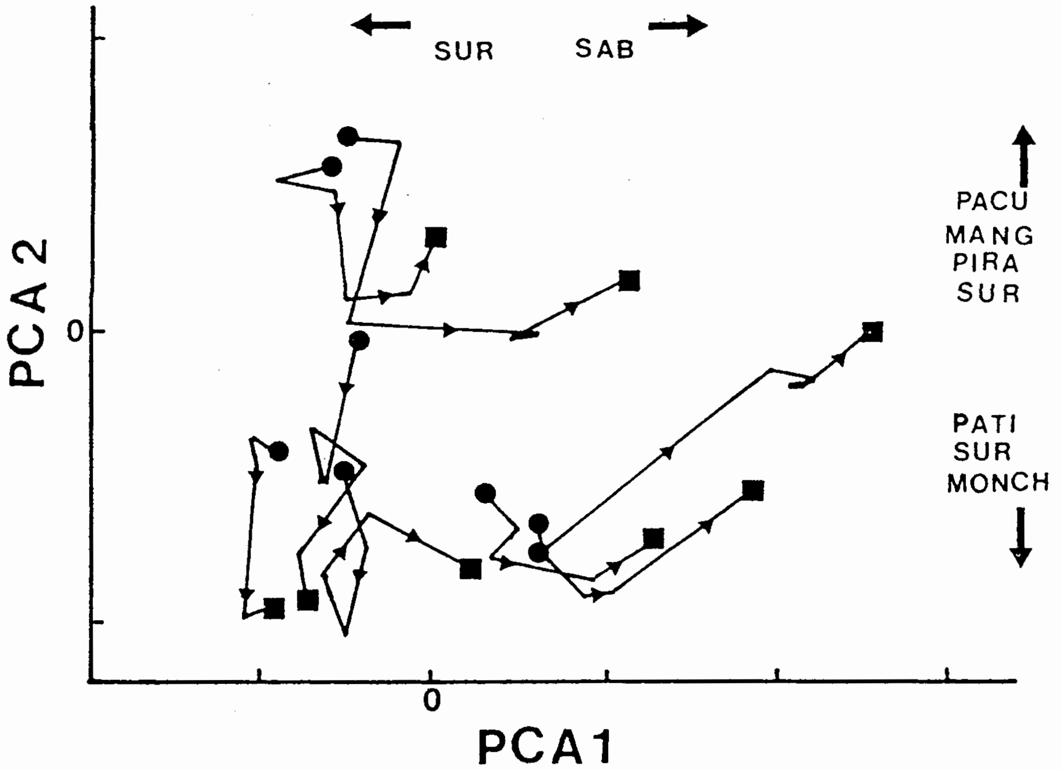
Effects of hydrology, climate, river regulation and macropollution on commercial landings in the lower Paraná basin. Percent of catch variability explained by indicated variables in multiple regression models. Mean catch of fish per unit of flooded area (CPUA, $kg.ha^{-1}$). HLMSFi, annual mean water level (m); HLMIRi, annual average for the minimum monthly mean water level (m); TEMPi, mean air temperature for the spring-summer period (°C); RVOL, storage capacity in upper basin reservoirs (hm^3); PCHI, installed production capacity for Argentinean petrochemical industry (tm. yr^{-1}. 10^{-3}). Both variables RVOL and PCHI were log transformed. The determination coefficient (r^2) and the root mean square error (RMSE) for regression models are included.

Variable	Period		
	1945-1980 (n=36)	1945-1962 (n=18)	1963-1980 (n=18)
	total catch minus that of *Prochilodus*		
HLMIRi	21.8 (+) (i=-4, -6, -7)	57.9 (+) (i=-4, -6, -7, -8)	5.8 (+) (i=-6)
TEMPi	7.5 (-) (i=-4, -5)	31.8 (-) (i=-4, -5)	9.8 (-) (i=-4, -5)
RVOL	16.1 (+)	-	36.8 (+)
PCHI	10.5 (-)	10.3 (-)	36.8 (-)
r^2	0.81	0.94	0.82
RMSE	299.34	142.03	267.22
F (overall)	17.22	20.95	11.25
P <	0.001	0.001	0.001
	Prochilodus catch		
H' MISFi	15.7 (+) (i=-2) 43.7 (i=-5)	56.4 (+) (i=-1) 20.8 (i=-6)	46.3 (+) (i=-2, -3) 31.5 (i=-5, -6)
TEMPi	11.3 (+) (i=-4)	- -	13.1 (+) (i=-4)
RVOL	30.5 (+)	-	-
PCHI	16.5 (-)	47.0 (-)	-
r^2	0.45	0.73	0.82
RMSE	449.81	355.50	240.82
F (overall)	4.63	10.67	11.05
P <	0.003	0.001	0.001

The difficulties in determining cause and effect relationship in river ecosystems has been emphasized previously (Petts *et al.* 1989).

There is not conclusive evidence to support the results presented here. They may or may not be also due to simple coincidence of increasing trends in the fishery, and in the river regulation and industry and agriculture development. However, the detritivorous fish *Prochilodus* increase in the commercial landings, the decrease in abundance of the fruit and seed eater species and of fish species of marine lineage, and the sharp decrease in the landings of the top predator *Salminus maxillosus* (Fuentes and Quirós 1988) are in agreement with a regulated river-floodplain system impacted from toxic substances used in agriculture and industry.

FIGURE 10
Fish "species" change for the 1941-1984 period in the lower Paraná basin (●), 1941-1945 period (◆), 1982-1984 period (modified from Fuentes and Quirós 1988)



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