THE PARANA RIVER BASIN DEVELOPMENT AND THE CHANGES IN THE LOWER BASIN FISHERIES

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Fish production and fish yield in rivers are related to both the spatial and the temporal structural characteristics of the drainage system. In comparative river studies, fish yield has been shown to be related to drainage basin characteristics and to the extent of floodplain for systems with a low degree of modification (Welcomme, 1976, 1979). On the other hand, in individual river systems, fish yield has been shown to be related to the strength of the flood pulse (Junk *et al.*, 1989) in the years previous to the fish capture, affecting the prerecruitment life stages of the fisheries target stocks (Krykhtin, 1975; Holcik and Bastl, 1977; Welcomme, 1986, 1989; Novoa, 1989; Quirós and Cuch, 1989; see also Welcomme *et al.*, 1989, for a review). 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). However, those effects on total fish production and fish yield are more controversial, and differences of opinions exist as to the relative importance of river regulation and lower water-quality as opposed to natural environmental factors.

The main purpose of this paper is to test the effects of the La Plata basin development and the upper Parana river regulation on both the fish yield and the species composition of the fish harvest in the lower basin.

The main limnological characteristics of the lower La Plata basin were overviewed by Quirós and Cuch (1989). Earlier reviews are in Bonetto *et al.* (1969b) and Bonetto (1975). The main characteristics of the fish fauna of the lower Parana basin were reviewed by Bonetto (1986). 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 Baigun, 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 (Bonetto *et al.*, 1969a, 1970; Oldani and Oliveros, 1984; Quirós and Cuch, 1989; among others). Moreover, towards the river mouth in the La Plata river (Quirós and Cuch, 1989) both the catch per unit effort and the proportion of *Prochilodus* sp. in the catch increase with the relative size of the floodplain with respect to the main channel.

The River System

The La Plata basin consists mainly of three sub-basins: the Parana, the Paraguay, and the Uruguay river basins (Fig. 1). With an area of $3.1\ 10^6$ km^2, it is the second drainage system in South America and the fourth largest in the world. The Parana river flows 4000 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 La Plata river. The Uruguay river flows 1800 km from its sources in southern Brazil and discharges 5,000 m^3.s^{-1} in the La Plata river. The Paragua 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 "Gran Pantanal" depression, situated 270 km south from the Paraguay sources, receives water from

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the Paraguay river itself and from many other tributaries. The Pantanal has a natural regulatory and buffer effect on the lower Paraguay river discharge.

The headwaters situated north of the basin belong to the tropical summer rainfall zone. Southward the climate becomes warm temperate without a dry season. However, the complexity of the system and of its various water sources makes the discharges into the La Plata river completely out of phase with minimum and maximum discharges in spring for the Parana and the Uruguay rivers, respectively. From its confluence with the Paraguay river, the Parana river changes its geomorphological and physiographical characteristics to form the middle Parana river with its massive floodplain that widens downstream and covers more than 20,000 km² (Bonetto *et al.*, 1969b). South of Rosario City⁽¹³⁾ (Fig. 1) the lower Parana divides its flow in several distributaries forming a delta of more that 10,000 km².

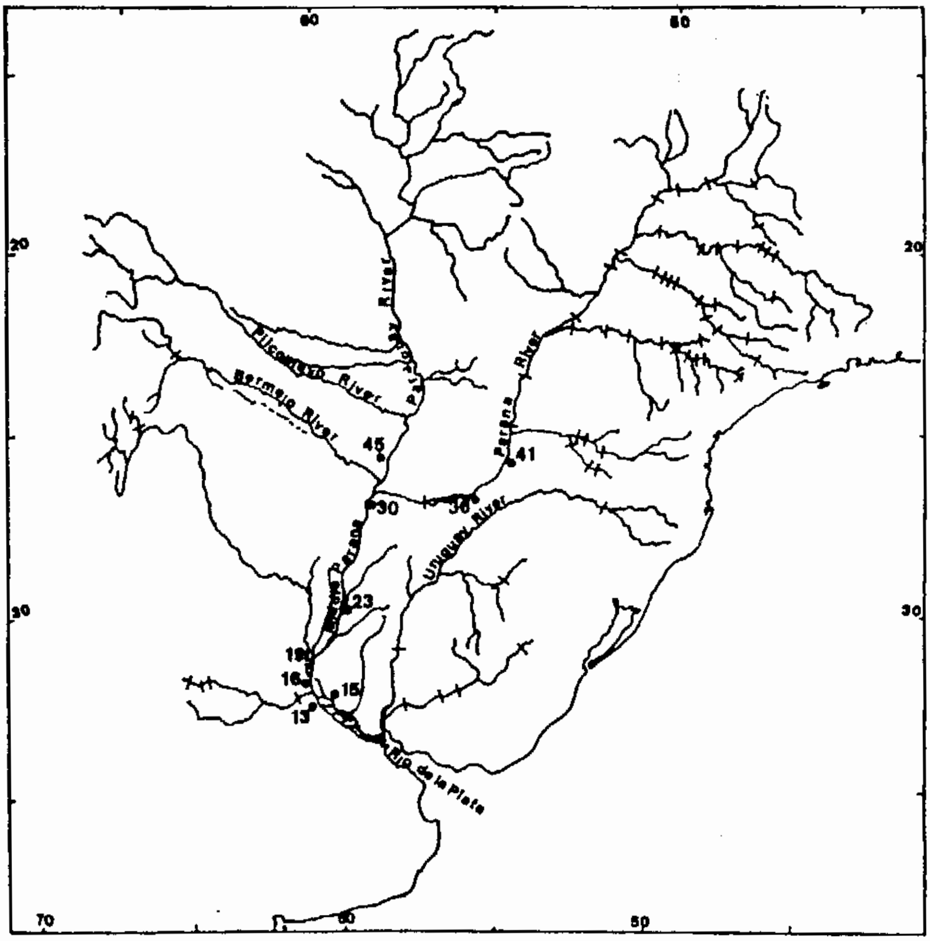

Fig. 1. The lower La Plata River Basin. Numbers indicate fish landing sites. Rosario (13), Victoria (15), Puerto Gaboto (16), Santa Fe (19), La Paz (23), Corrientes (30), Posadas (36), El Dorado (41), Formosa (45).

With an area of 3.1 10^6 km² the La Plata basin has a population of more than 80 million people. Brasil, in the higher catchment, accounts for more than 60% of the population, while Argentina accounts for a 25% in the lower basin. Most of the Brazilian industry is established in the higher basin of the Parana river. Agriculture is also important. On the other hand most of the Argentinian industry is established in the lower basin south of Puerto Gaboto ⁽¹⁶⁾ (Fig. 1). 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 Parana basin is currently highly regulated (OEA, 1985). Water in reservoirs located in the upper Parana 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. Several signs of stress on fish are listed in Table I, though their importance at the system wide level cannot be evaluated at the present. That is the reason why more site specific stresses on fish like poor habitat, due to low dissolved oxygen, water releases by turbiness, or the high fish mortalities in spillways, and hour to hour downstream flow modifications for the Itaipu dam, have not been included in Table I.

Data Sources and Methods

Landing data were collected from published and unpublished sources from the Dirección Nacional de Pesca Continental (Santa Fe 1548, Piso 7, 1060 Buenos Aires). Fish data time series for the 1957-1960 period was completed using data on industrial fisheries for the 1952-1956 and 1961-1965 periods provided by the Instituto Nacional de Estadísticas y Censos (Hipólito Irigoyen 250, Piso 12, 1407 Buenos Aires). *Prochilodus* catch time series for the 1970-1973 period was reconstructed using averages of industrial fisheries for the 1966-1969 and 1974-1977 periods. River discharges and hydrologic levels were collected from published sources and unpublished files from the Dirección Nacional de Construcciones Portuarias y Vías Navegables (Av. España 2221, Costanera Sur, Buenos Aires). Mean monthly air temperature data were collected from hand-written sources from the Servicio Meteorológico Nacional (25 de Mayo 658, 1002 Buenos Aires). Information on flooded areas at different flood return periods was provided by the Instituto Forestal Nacional (Av. Pueyrredón 2445, 1110 Buenos Aires) and information on hydrologic levels at several landing sites for different flood return periods was provided by the Instituto Nacional de Ciencias y Técnicas Hídricas (Lima 763, 1073 Buenos Aires). Landsat imagery south of Santa Fe City for high and low water in the middle Parana system (February 1-2, 1985 and October 8-10, 1981, respectively) was provided by the Comisión Nacional de Investigaciones Espaciales Av. Dorrego 4010, 1425 Buenos Aires). Those data were used to develop curves relating hydrologic level with flooded area for several landing sites (Cuch and Quirós, unpubl. data). The relationship (FA-2,000) = 280.74 exp (0.51 HLSF was used here, FA, flooded area (km^2), including the main channel, for the middle Parana river and the delta up to the La Plata river, and the Argentinian borders in the upper Parana and Paraguay rivers; HLSF, hydrologic level (m) for the Parana river at Santa Fe City; maximum HLSF = 6.3 m for the equation presented here. Data on river regulation and constructed dams were collected from OEA (1985). Data concerning macropollution variables (e.g. human population. industrial development) were provided by the Instituto Nacional de Estadísticas y Censos. Those variables represent aggregate variables that act as surrogates for direct pollutional loadings (Summers *et al.*, 1985).

TABLE I

SIGNS OF ENVIRONMENTAL STRESS ON FISH ASSEMBLAGES IN THE LOWER LA PLATA BASIN

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 Parana river south of Puerto Gaboto (16), and also from the catches in the La Plata and Uruguay rivers.	Fuentes and Quirós (1988) Quirós (pers. obs.)
— 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 Parana.	Fuentes and Quirós (1988)
— the commercial catches of the pelagic top predator *Salminus maxillosus* have been decreasing since the late forties in all the lower basin, though its commercial catch has been highly restricted.	Fuentes and Quirós (1988)
— populations of most of the migratory fish species are severely diminished in the middle and upper Uruguay river.	Roa (pers. 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 *et al.* (pers. comm.)
— 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 Parana.	Candia (pers. comm.) Vidal (pers. comm.)
— maximum size of the big *Pseudoplatystoma* sp. at catch has been decreasing for the last three decades in the lower middle Parana.	Vidal (pers. comm.)
— increase of the conflictive situations between recreational and commercial fishermen at the confluence of the Parana and Paraguay rivers, though total fish effort seems not to have increased.	Quirós (pers. obs.)

The 1945-1980 period in the history of the lower La Plata basin fisheries was analyzed here. Unfortunately there is no information on catch per unit effort available for most of the period (Quirós and Cuch, 1989), therefore, only catch and catch per flooded area are used here. Hydrographic, climatic and pollution conditions during spawning and prerecruitment periods would be expected to have the greatest influence on year class strength. Therefore, the mean annual average for the minimum monthly hydrologic level at Rosario (13) (HLMIRi, m) or the annual mean hydrologic level at Santa Fe (HLMSFi, m), the mean air temperature for the September-March period at Junin City (TEMPi, C), the installed power at hydroelectric stations (HP, MW), the storage capacity in reservoirs (RVOL, hm^3), and the installed production capacity for the petrochemical industry in the lower basin (PCHI, tm), were identified as candidate explanatory variables for fish catch. Subindices in variable names indicate time lag. The change of net materials from cotton to nylon in Argentina was initiated in 1957. To take account of the change in the gear catchability, a variable (GEAR) which takes values of 1, 2 and 3 for the periods 1945-1956, 1957-1962, and 1963-1983 respectively, was included in the analyses. The catch in any given year would also be dependent on contributions from all past fishable age groups (parental stocks). However, past catches were expressly not included as explanatory variables for two reasons. The first is related to statistical reasons like high autocorrelation between lagged catches (see for example Walters, 1985), and the second is that availability of space, habitat conditions, and food within the floodplain appear to be substantially more important than parental stock size in determining fishable stocks in large floodplain rivers (Welcomme and Hagborg, 1977).

My intention here is to analyze fish catches with the objective of partitioning their variability to individual explanatory variables based on ecological principles and not just to obtain good empirical representations of response variables (Rose *et al.*, 1986). For that reason, exploratory multiple regression of time series and not Box-Jenkins models were used here. Fish response variables considered are listed in Table II. Two or more fish species are sometimes grouped together in the commercial catch records. Therefore, a single variable in the analysis may represent a "species" group (Table II). Total catch (TC, tm) in the summatory of the individual "species" catches. In those cases where catch per unit flooded area (CPUA, kg ha^{-1} is used, it will be expressly specified.

Multiple regression of time series for each catch and catch per unit flooded area variable was conducted using step-wise standard regression techniques (Draper and Smith, 1981), and terms for interactions between variables were not included. RVOL, HP, and PCHI were log transformed previously. Model building was conducted in order to explain maximum variability in catch but also trying to include the fewer variables with the lower collinearity among them.

River Basin Development and Fish Harvest Changes

The installed capacity of hydroelectricity generating plants (Fig. 2a) and the volume of water in reservoirs (Fig. 2b) in the upper Parana basin have been increasing since the early fifties but a sharp increase is noticed from 1970-1972 up to the present. Before most of the reservoirs were built, the middle Parana river showed a regular annual cycle, usually reaching its peak in March or April and its minimum flow in September (Fig. 3a). The upper basin dams have produced an increase of the water levels downstream and a delay in the timing of floods (Fig. 3a). 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. Compared to the 1925-1971 period, the mean monthly water level in September for the 1972-1989 period for the middle Parana river has increased in more than 1.8 m leading to inundation all over the year (Fig. 3b). However, these differences may have been magnified because the 1972-1989 period was a relatively wet period with mean annual river discharges above the average for all the 1925-1989 period (Table III).

The industrial development in the upper basin was directly related to energy availability, and energy consumption time series in Brazil has a sharp increase since the 1968-1970 period resembling the increase in energy generated by hydroelectric plants (Fig. 2a). In the lower basin the industrial development was earlier than in the upper basin. For example, the Argentinian petrochemical industry has been developing since the early sixties (Fig. 4). The waste discharges of the petrochemical industry are usually considered as highly harmful for fishes.

The mean monthly minimum water level at Rosario(13) and mean annual air temperature at Junín are presented in Figures 5a and 5b. It is expected that their cyclic behavior explains some of the fish catch variability. The total fish catch and the total catch minus that of *Prochilodus* in the lower Parana basin for the 1945-1983 period are presented in Figures 6a and 6b. The total catch and the catch for each of the most important fish "species" for the 1945-1983 period have been shown to be more related to the quantity of water remaining in the system during the low water season (Quirós and Cuch, 1989), although the mean monthly minimum water level has increased since 1972 due to river regulation (Fig. 5a). There are both cyclic behavior and trend in the minimum water level time series. Therefore, significant positive correlations between its trend and the monotonic trends in the regulated water volume variable (Fig. 2b) and any other macropollution variable should be expected.

The mean CPUA for the period of study and for the 1945-1962 and 1963-1980 periods are presented in Table IV. Both TC and CPUA had increased in the 1945-1983 period. For the migratory species, the most noticeable catch increase was for *Prochilodous* and the most noticeable decrease was for *Salminus maxillosus*.

The change of the fish "species" composition in the commercial landings for the lower Parana basin has been studied by Fuentes and Quirós (1988). Data for more than 30 landing sites in 6 time periods (210 different spatial and temporal "sites") have been used. The most noticeable changes were the decrease in the frequencies of *Colossoma mitrei, Paulicea lutkenii, Brycon* sp., and *Salminus maxillosus* (PCA3, Fig. 7), and the increase in the frequency of *Prochilodus* sp. (PCA1, Fig. 7) for all the system, and the decrease in the frequency of *Pseudoplatystoma* sp. for landings situated from the lower middle Parana southwards to the La Plata river (both PCA1 and PCA3, Fig. 7).

TABLE II

FISH TAXA IN COMMERCIAL LANDINGS FOR THE LOWER PARANA BASIN, AND VARIABLE NAMES USED IN THE ANALYSES

fish taxa	*variable*
Prochilodus sp.	SAB
Pseudoplatystoma fasciatum	
Pseudoplatystoma coruscans	SUR
Salminus maxillosus	DOR
Luciopimelodus pati	
Megalonema platanum	PATI
Brycon orbignyanus	
Brycon sp.	PIRA
Colossoma mitrei	PACU
Paulicea lutkenii	
Pseudopimelodus zungaro	MANG
Basilichthys bonariensis	PEJ
Oxydoras kneri	
Pterodoras granulosus	
Rhinodoras d'orbignyi	ARM
Lycengraulis olidus	ANCH
Parapimelodus valenciennensi	BGTO
Leporinus spp.	BOGA
Pimelodus clarias	BAMAR
Ageneiosus spp.	
Sorubim lima	MAND
Pimelodus albicans	MONCH
Hoplias malabaricus	TAR

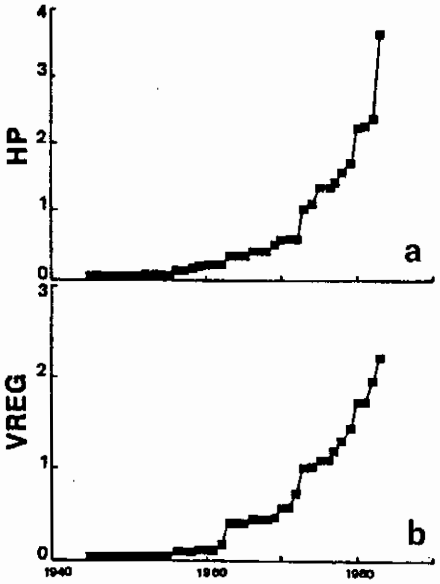

Fig. 2. a, installed power at hydroelectric stations (HP, MW. 10—4), b, storage capacity in reservoirs (RVOL, hm^3. 10^{-6}), for the upper Parana basin.

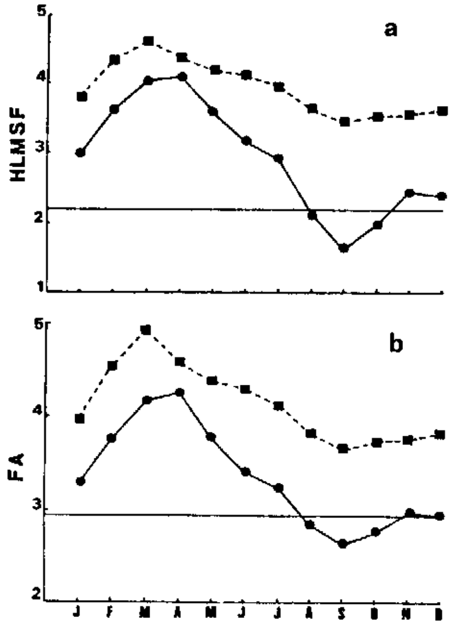

Fig. 3. a. mean monthly water level at Santa Fe (HLMSF, m); b. mean monthly flooded area including the main channel (FA, km^2. .10^{-3}) for the lower Parana basin. The bankfull water level for Santa Fe (HLMSF = 2.20 m, Drago [1986]) and the corresponding flooded area are indicated. (———), 1925-1971 period (- - - - -), 1972-1989 period.

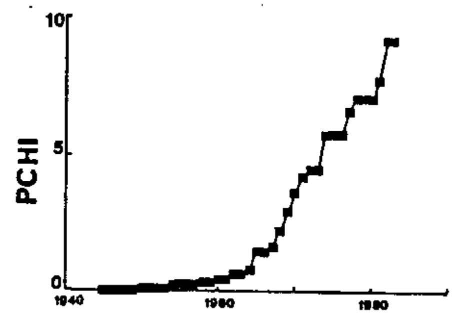

Fig. 4. Installed production capacity for the Argentinian petrochemical industry (PCHI, tm. yr^{-1}. 10^{-6}).

Partition of the Fish Harvest Variability

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 fisheries were born (Quirós and Cuch, 1989) (Fig. 8). An unexpected result here was the inverse relationship between the fish catches and the mean annual air temperature in the spring-summer period for the one or two years immediately after the fish taken by the fishery were born (Fig. 9).

Multiple regression models for the variation of both catch and CPUA in the period 1945-1985 included hydrologic, climatic, river regulation, and macropollution variables. Only some examples are presented here (Quirós, data files) (Table V). Reservoir storage capacity (RVOL) had a positive effect on catch and CPUA in all developed models. As expected, PCHI was negatively related to TC and the catches for individual "species" after river regulation effects (RVOL) have been accounted for. However, PCHI and RVOL are highly and directly correlated ($r = 0.90$, $P < 0.0001$). Similarly to direct lagged correlations, the lagged hydrologic levels (HLMSFi or HLMIRi) and the lagged air temperatures (TEMPi) were respectively usually positively and negatively related to the fish catches, after regulation and river regulation effects had been accounted for. However, hydrologic and temperature time series were negatively related for the 1945-1980 period. *Prochilodus* catches an exception being positively related to lagged TEMP after accounting for hydrologic effects (Table V). Models for CPUA were qualitatively similar to those for catch, but they 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. Total explained variability for catch was higher for the period 1945-1980 when the 1981-1983 period, with uncommon high catches of *Prochilodus* for processing and exportation, was excluded from the analysis. However, the analysis of both the 1945-1980 and 1945-1983 periods gave qualitatively similar results.

The models developed for individual "species" catches are also well adjusted to the empirical trends. For example, Figure 10 shows the "best" model fit obtained for the CPUA of *Salminus maxillosus* in the lower Parana basin ($R^2 = 0.82$). Pollution effects explained half of catch variability (49%) but hydrologic and temperature effects were also important.

Coinciding with historical trends in river regulation (Fig. 2) and pollution (Fig. 4), only the models for the period 1963-1980 included river regulation terms. Similar results were obtained for pollution effects, but those effects were also noted for the first analyzed 18 year period (Table V).

General Conclusions

The lower Parana river system has been affected by the development of the upper basin (industry, agriculture, mining, river regulation), but it is also affected by the development of the

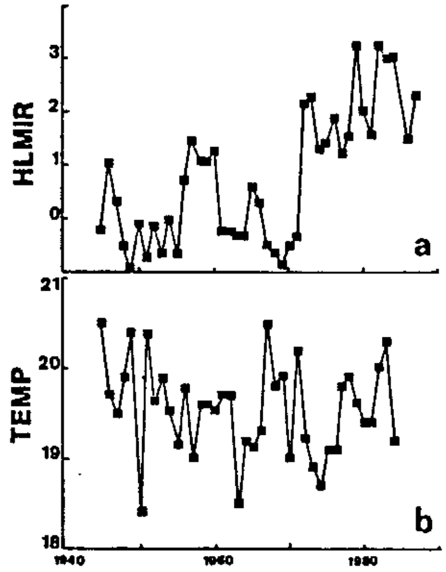

Fig. 5. a. annual average for the mean monthly minimum water level at Rosario (HLMIR, m); b. mean air temperature for the September-March period (TEMP, °C).

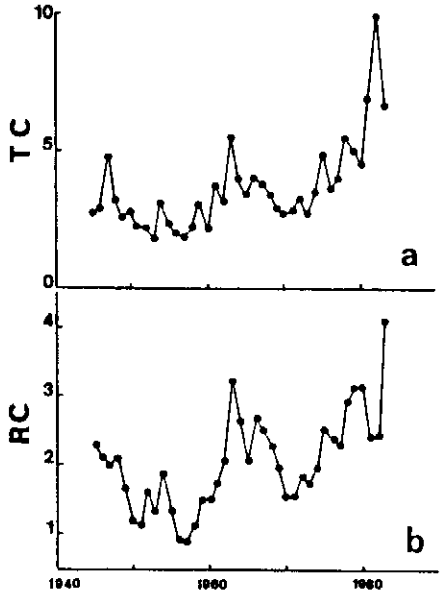

Fig. 6. a. total catch (TC, tm. yr^{-1}.10^{-3}), and b. total catch minus that of *Prochilodus* (RC, tm. yr^{-1}.10^{-3}), for the 1945-1983 period.

TABLE III

MEAN HYDROLOGIC LEVEL AT SANTA FE CITY (HLSF, m) AND MEAN FLOODED AREA, NOT INCLUDING THE MAIN CHANNEL (FA, km²). STD, STANDARD DEVIATION

	1925 - 1989	*1925 - 1971*	*1972 - 1989*
HLSF	3.19 (STD = 1.39)	2.90 (STD = 1.41)	3.94 (STD = 1.73)
minimum	—0.87	—0.87	1.86
maximum	7.09	6.50	7.09
FA	1,430 (STD = 571)	1,235 (STD = 576)	2,095 (STD = 475)

TABLE IV

MEAN CATCH OF FISH PER UNIT OF FLOODED AREA (CPUA, kg ha^{-1}). IN THE LOWER PARANA BASIN. CPUATC, TOTAL CATCH; CPUAR, TOTAL CATCH MINUS THAT OF *Prochilodus;* CPUASAB, *Prochilodus* sp., CPUASUR, *Pseudoplatystomas* sp.; CPUADOR, *Salminus maxillosus;* CPUAPAT, *Luciopimelodus pati*

	1945 - 1980	*1945-1962*	*1963-1980*	*1981 - 1983*
CPUATC	9.8 (4.8-19.8)	8.4 (4.8-15.6)	11.3 (6.6-19.8)	14.4 (12.8-16.8)
CPUAR	5.9 (2.4-11.7)	4.9 (2.4-7.6)	4.4 (2.4-8.1)	5.8 (3.1-8.3)
CPUASAB	3.9 (1.2-9.1)	3.4 (1.2-9.1)	6.9 (3.9-11.7)	8.7 (5.4-11.0)
CPUASUR	2.0 (0.5-4.9)	1.3 (0.5-2.6)	2.7 (1.4-4.9)	1.6 (0.5-2.7)
CPUADOR	0.5 (0.01-1.3)	0.7 (0.3-1.3)	0.3 (0.01-1.0)	0.3 (0.1-0.6)
CPUAPAT	1.1 (0.3-2.0)	0.7 (0.3-1.2)	1.4 (0.8-2.0)	0.9 (0.7-1.1)

lower basin itself (industry, agriculture). Modern Brazilian industry was developed in direct relation to hydroelectric energy availability, and its trend was supposed to resemble the trend in installed power capacity (HP). As well as PCHI, HP is highly and positively correlated with RVOL. However, in most of the cases, HP either had a negative effect on catch variation after accounting for river regulation or was not significant to improve catch explained variability. More specific effects, like those from waste products of the mining industry of the upper basin, cannot be evaluated at the present time.

In order to do an exploratory analysis of available data (Quirós and Cuch, 1989) the commerical landings have been supposed to be a measure of stock abundance in the lower La Plata basin for the period 1945-1980. However commercial landing may or may not be a measure of stock abundance depending upon the degree to which fishing effort affects landings. In multiple regression models for landings of SUR and PATI, the change of net materials (GEAR) was an important variable to explain catch residual variability in some developed models. The decrease in the time lag for hydrologic variable effects for the last analyzed period (1963-1980) may also indicate an increased effort, but time lag decrease could also be the result of other external stresses on fish.

The cyclic relationships between fish catch and lagged hydrologic regime have been previously reported for other river systems (Krykhtin, 1975; Holcik and Bastl, 1977; Novoa, 1989; Welcomme, 1979, 1986, 1989) and also for the lower La Plata basin (Quirós and Cuch, 1989). The time lag for the hydrologic variables significant in explaining fish catch variability usually correspond to the age of the age classes taken by the fishery (Quirós and Cuch, 1989). An unexpected result here was the inverse relationship between fish catch and the mean air temperature for the spring-summer season lagged one or two years less than the significant lagged hydrologic variables. Those results suggest a negative effect of high temperature for the first one or two years of life. *Prochilodus* was an exception for both hydrologic and temperature effects. *Prochilodus* catches appear to be more directly related to the amount of water in the floodplain in the years inmediately preceding the catch. Those catches showed positive relationships with lagged temperatures. As was suggested before, *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 (Bonetto *et al.*, 1969a; Bonetto *et al.*, 1970b; Cordiviola de Yuan and Pignalberi, 1981; Quirós,

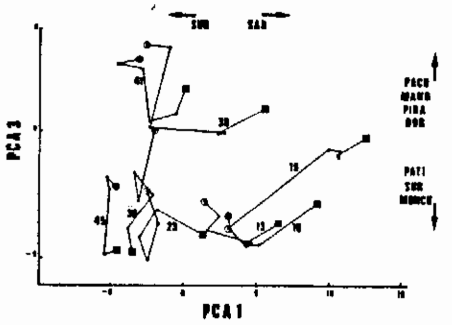

Fig. 7. Fish "species" change for the 1941-1984 period in the lower Parana basin (modified from Fuentes and Quirós [1988]. Rosario (13), Victoria (15), Puerto Gaboto (16), La Paz (23), Corrientes (30), Posadas (36), El Dorado (41), Formosa (45). (●), 1941-1945 period; (■), 1982-1984 period.

unpubl. data). Thus, in differentiating the detritivorous *Prochilodus* from other predatory or omnivory migratory fishes (Bonetto, 1975), there is a reason to believe that the former is best suited to floodplain aquatic environments than the migratory fish. The *Prochilodus* dependence on the years immediately preceding the catch may be related to the high mortalities of fish in drying floodplain pools and lagoons at the low water season in dry years (Bonetto, 1975). Adults of the genera *Pseudoplatystoma*, *Salminus*, and *Luciopimelodus* are rarely present in very shallow non-flowing floodplain environments in summer. For those fish, it can be speculated that the inverse dependence in water temperature, one or two years after the fish were born, may be related to increasing mortalities in floodplain environments for preadults in warm years (e.g. higher water temperatures and lower dissolved oxygen concentrations). This relationship should further be investigated given that it may change the more standard view translating individual fish growth dependence on temperature directly into fish community production for floodplain rivers. Unfortunately, the observed relationships may also simply be a methodological artifact showing spurious results due to highly correlated time series.

For all developed catch models, every significant relationship to river regulation and pollution were positive and negative, respectively. The latter relationship was expected although it is certainly not causal evidence of negative pollution effects. In the particular case of *Salminus maxillosus*, macropollution variables explain much of the declining trend in its catches, in despite

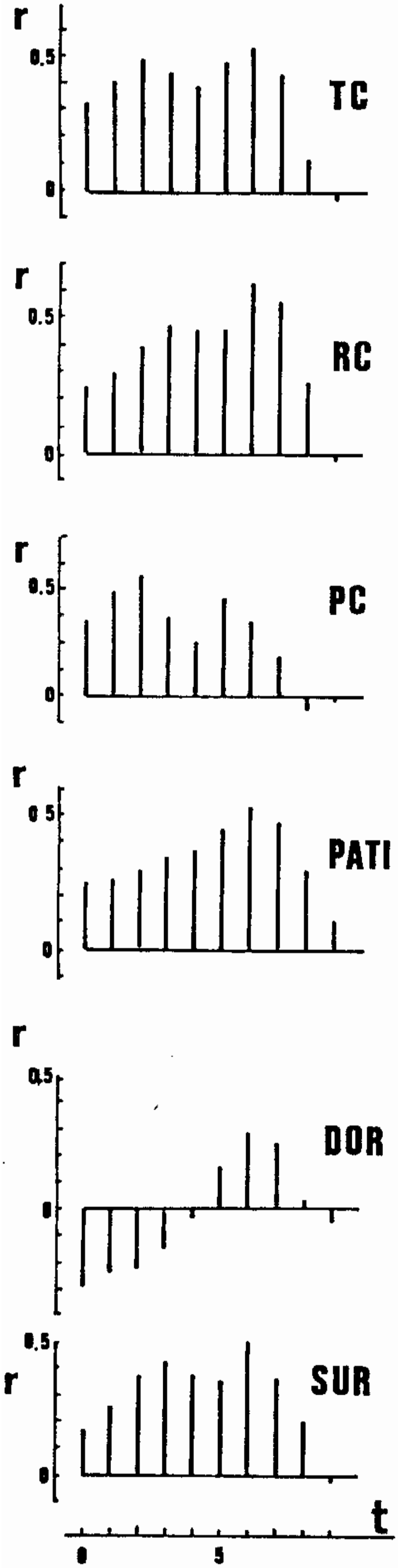

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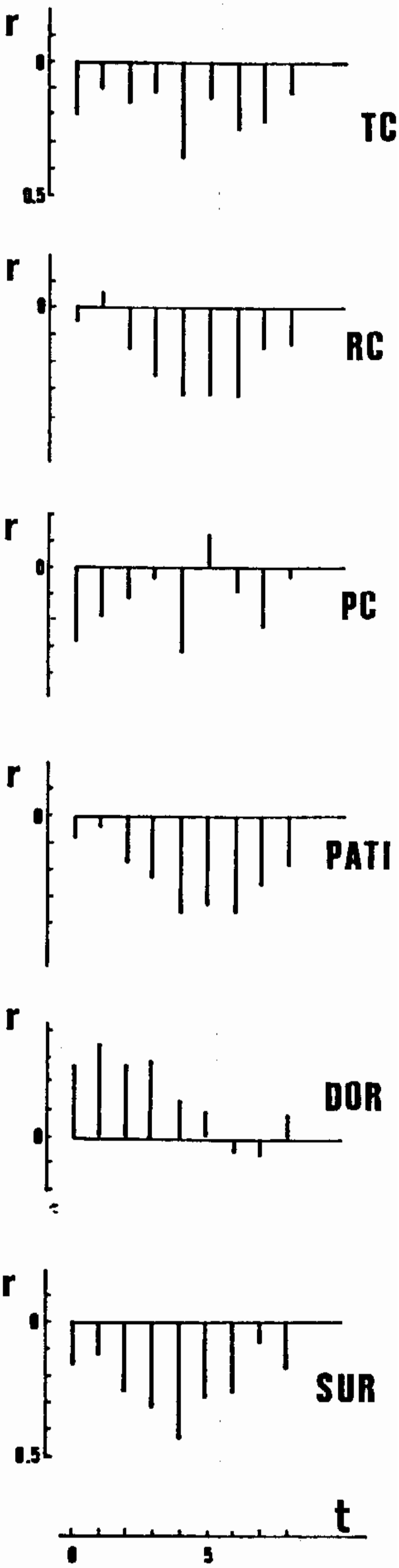
Fig. 8. Time lagged correlations between the fish catch time series in the lower Parana basin and the annual average for the mean monthly minimum water level at Rosario (HLMIR, m) time series lagged 0-9 yr. r, correlation coefficient; t, time lag. TC, total catch; RC, total catch minus that of *Prochilodus;* PC, *Prochilodus* catch; PATIC, *Luciopimelodus* catch; DORC, *Salminus maxillosus* catch; SURC, *Pseudoplatystoma* catch.

→

Fig. 9. Time lagged correlations between the fish catch time series in the lower Parana basin and the mean air temperature for the September-March period (TEMP) time series lagged 0-8 yr. r, correlation coefficient; t, time lag. TC, total catch; RC, total catch minus that of *Prochilodus;* PC, *Prochilodus* catch; PATIC, *Luciopimelodus* catch; DORC, *Salminus maxillosus* catch; SURC, *Pseudoplatystoma* catch.



of controls on *Salminus* fishing (banned periods, restrict fish harvest, size limits, closed seasons, gear restrictions) from the early sixties up to the present (Fuentes and Quirós, 1988). Positive effects of the upper Parana river regulation on fish catches in the lower river may simply indicate a high quantity of suitable habitat for fish in the middle Parana floodplain, but the positive effects were also noted on catch per unit flooded area. It may be indicating a relation to other untested variables. Bonetto *et al.* (1989) suggested that the increasing upper Parana regulation has a negative effect on fish production in the lower basin. The obtained results do not support that contention. The nutrient (phosphorus and nitrogen) and the total suspended matter inputs from the upper Parana to the lower river, have not increased between 1973 and 1986, in despite of the increase in consumption of fertilizers and the increase of human population in the upper basin. A trapping mechanism in the upper reservoirs has been hypothesized (Pedrozo and Bonetto, 1989). The Bermejo river, through the lower Paraguay river, supplies more than six times of suspended sediments than the upper Parana to the middle Parana river (Drago and Amsler, 1988). Phosphorus content, related mainly to clay fractions, and total organic matter concentration in surface waters, ranged from 3 to 5 times higher for the lower Paraguay than for the upper Parana (Maglianesi, 1973; Pedrozo and Bonetto, 1989). It could be expected that the differences increase for deep waters. Almost the same nutrient input, related to particulate matter, and the increasing water levels in the main channel-floodplain system, conducting to lower mean water velocities, might produce a higher nutrient retention in the system. It may be a plausible mechanism to explain positive effects of upper river regulation on catch per unit flooded area in the lower river. Those findings may also contribute to explain why the regulation of the upper Parana river has not negatively influenced the fish harvest in the middle Parana, and also to predict which will be the effects on fish production in the lower basin when the upper Bermejo is regulated. However, there is no conclusive evidence to support the obtained results. They may or may not be also due to simple coincidence of increasing trends in the fishery, and in the river regulation and the industry development.

In the last few decades changes in fish assemblages may be as-

TABLE V

EFFECTS OF HYDROLOGY, CLIMATE, RIVER REGULATION, AND MACROPOLLUTION ON COMMERCIAL LANDINGS IN THE LOWER PARANA BASIN

variable	*period*		
	1945 - 1980 (n=36)	*1945 - 1962 (n=18)*	*1963 - 1980 (n=18)*
		— RC —	
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 (—)
$\hat{R}^2$	0.812	0.936	0.824
RMSE	299.34	142.03	267.22
F (overall)	17.22	20.95	11.25
P <	0.001	0.001	0.001
		— PC —	
HLMSF	15.7 (+) (i= —2)	56.4 (+) (i= —1)	46.3 (+) (i= —2, —3)
	43.7 (+) (i= —5)	20.8 (+) (i= —6)	31.5 (+) (i= —5, —6)
TEMPi	11.3 (+) (i= —4)	—	13.1 (+) (i= —4)
RVOL	30.5 (+)	—	—
PCHI	16.5 (—)	47.0 (—)	—
$\hat{R}^2$	0.453	0.725	0.822
RMSE	449.81	355.50	240.82
F (overall)	4.63	10.57	11.05
P <	0.003	0.001	0.001
		— TC —	
HLMSFi	5.5 (+) (i= —3)	—	25.7 (+) (i= —2, —3)
	11.6 (+) (i= —5, —6)	84.3 (+) (i= —6, —8)	21.9 (+) (i= —5, —6)
TEMPi	8.0 (—) (i= —4)	15.7 (—) (i= —4)	—
RVOL	37.1 (+)	—	8.7 (+)
PCHI	25.5 (—)	—	7.4 (—)
$\hat{R}^2$	0.725	0.683	0.918
RMSE	601.63	511.27	321.66
F (overall)	11.85	8.60	20.66
P <	0.001	0.001	0.001

Percent of catch variability explained by indicated variables in multiple regression models. HLMSF, annual mean water level at Santa Fe (m); HLMIR, annual average for the minimum monthly mean water level at Rosario (m); TEMP, mean air temperature for the September-March period at Junin (C); RVOL, storage capacity in upper basin reservoirs ((hm^3); PCHI, installed production capacity for Argentinian petrochemical industry ($tm.yr^{-1} .10^{-3}$). Both variables VREG and PCHI loge transformed. i, indicates time lag for lagged variables. The determination coefficient ($\hat{R}^2$) and the root mean square error (RMSE) for regression models are included. PC, *Prochilodus* catch tm (yr^{-1}). RC, total catch minus that of *Prochiodus* (tm. yr^{-1}).

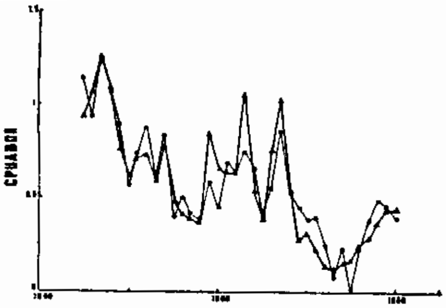


Fig. 10. Comparison of observed values (Δ) of the *Salminus maxillosus* catch (tm. yr−1) and those predicted (●) from the "best" obtained multiple regression model (R 2 = 0.82).

sumed for the lower La Plata basin. The *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 in the lower reaches, and the sharp decrease in the landings for *Salminus maxillosus* (Fuentes and Quirós, 1988) are in agreement with a regulated river-floodplain system impacted from toxic substances used in agriculture and industry.

The difficulties in determining cause and effect relationship in river ecosystems has been emphasized in order to propose a holistic approach to the management of fish communities in large rivers (Petts *et al.*, 1989). It was proposed by Quirós (1989) to solve conflicts between commercial and recreation fishermen at the Parana and Paraguay river confluence focusing in the upper basin influence. On large rivers, important changes in river geomorphology, physiography, and ecology may occur imperceptibly over decades or centuries (Kellerhals and Church, 1989; Petts *et al.*, 1989). As was stated before, the study of the ordering of events in time and of the differences in processes related to the internal system structuration (e.g. upper on lower reaches effects, main channel-floodplain interactions, reservoir discontinuities) will help to understand some broad responses of the system. The lower reaches of the Parana river have been transformed more intensively for the last few decades. The middle reaches and the upper basin of other major tributaries will be similarly transformed for the next decades. The present results may be no more than a glance over the half way state of the riverine system in its transforming way between the pristine and the full developed system states.

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