IMPACT OF CLIMATIC FLUCTUATIONS ON COMMERCIAL FISHERIES IN THE PARANA RIVER ALONG THE LAST CENTURY

Lic. **Ana Pía Rabuffetti**[1], Dr. **Konrad Górski**[2],
Dr. **Luis Alberto Espínola**[1], Mg. **Elie Abrial**[1], Ing. **Mario Luis Amsler**[1],
Lic. **Aldo Raul Paira**[1].
[1]Instituto Nacional de Limnología (INALI-UNL-CONICET), Ciudad Universitaria "Paraje El Pozo", 3000 Santa Fe, Argentina, Tel/Fax: 54 342 4511645/48.
[2]Departamento de Ecología, Facultad de Ciencias y Centro de Investigación en Biodiversidad y Ambientes Sustentables (CIBAS), Universidad Católica de la Santísima Concepción, Casilla 297, Concepción, Chile.
piarabuffetti@gmail.

ABSTRACT

We analysed the effects of decadal and annual hydrologic fluctuations on freshwater fisheries catches in the Middle Paraná River for a period of six decades from the 1930s to the 1980s. We first analysed changes in the flow regime of the Paraná River for the period between 1930s and 1980s, with focus on the variations of the flood pulse. To build and compare flow typology among years, we used cluster analysis. Principal component analysis (PCA) was used to assess overall similarity of flows among years. The fisheries catch analysed (1935-1983) were obtained along this river corridor. The obtained data consisted of landing reports on monthly/annual catches (total and by species) in ports along the Paraná River. Differences in total catches among decades were tested using a one-way permutational analysis (PERMANOVA). The canonical analysis of the principal coordinates (CAP) was used to assess temporal patterns of similarity in fish catches per decades. To analysed the effects of flow regime variables on the variation of fish commercial catches we used distance-based redundancy analyses (dbRDAs). The climatic fluctuations in this period strongly affected the hydrology of the Middle Paraná River and the characteristics of its flow regime. The magnitude of floods as well as maximum, minimum and mean water levels increased progressively from 1930s until the 1980s concomitantly with increasing frequency and intensity of ENSO events that resulted in differentiation of distinct hydrological periods. The flood pulses were significantly more frequent and of greater magnitudes during the 1970s and 1980s. These large floods resulted in increased commercial fish catches in the 1980s, possibly due to enhanced recruitment. Specifically, large floods increased the commercial fish catches two years later. This effect was stronger for species that use floodplain habitats as areas of reproduction and larval nurseries, such as *Prochilodus lineatus*. We conclude that the natural flow regime of the Paraná River and perhaps other large subtropical rivers must be preserved in order to sustain their productive fisheries.

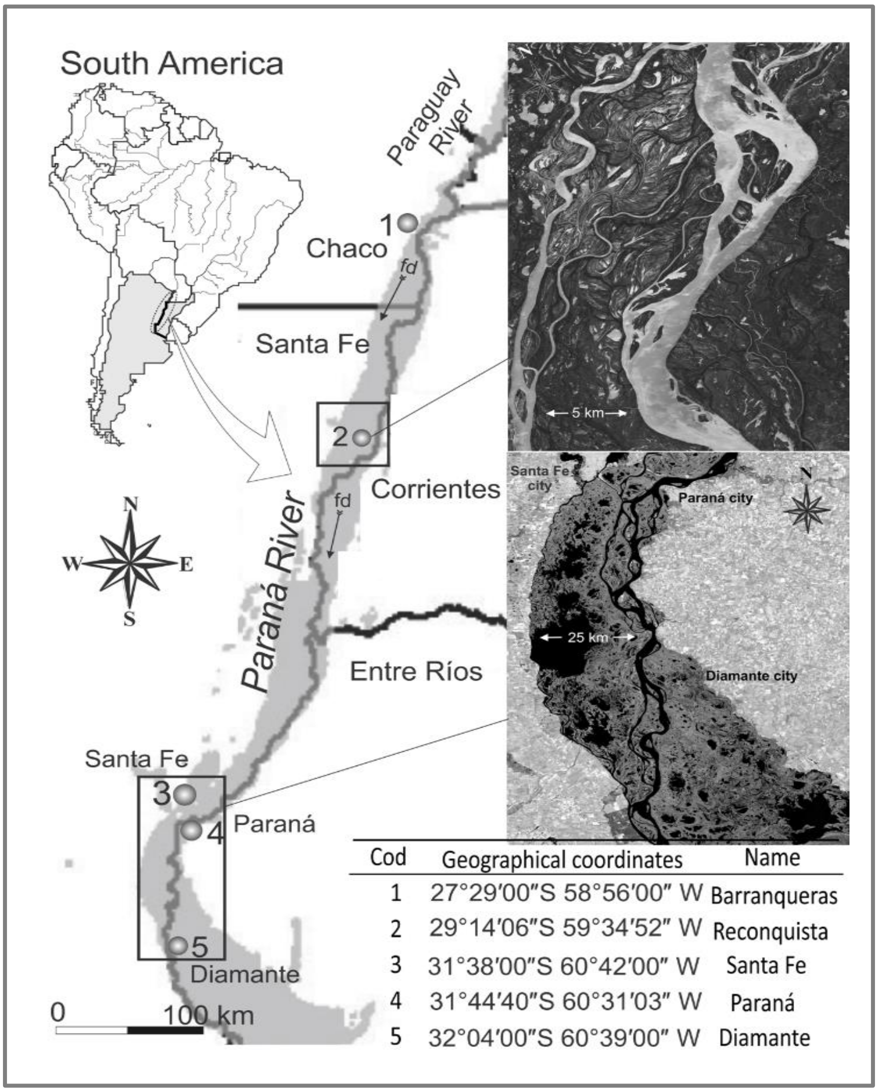
Objective

As climate, hydrology, floods and fish life strategies are directly related, we analysed the effects of decadal and annual hydrologic fluctuations in the past century (from 1930s to 1980s) on the fisheries catch in the middle reach of the Paraná River. We first examined flow regime changes between 1930 and 1980, with focus on the variations of flood pulses attributes. Secondly, we assessed how the commercial fish catches varied in the same time period to discern the effects of hydrologic changes on them.

Methods

Study area

The Paraná River is the ninth river in the world in terms of its mean annual discharge at the mouth (18,000 m^3s^{-1}; Latrubesse, 2008) and its basin is the second largest in South America with an area of 2,800,000 km^2. Our study area extends along the Paraná River and its floodplain from the confluence with its main tributary the Paraguay River to the City of Diamante (Figure 1).



Cod	Geographical coordinates	Name
1	27°29′00″S 58°56′00″ W	Barranqueras
2	29°14′06″S 59°34′52″ W	Reconquista
3	31°38′00″S 60°42′00″ W	Santa Fe
4	31°44′40″S 60°31′03″ W	Paraná
5	32°04′00″S 60°39′00″ W	Diamante

Figure 1. Study area (the Middle Paraná River in Argentina). Numbers indicate ports from which commercial fisheries data were obtained. fd; flow direction.

Hydrologic data and their analyses

Daily water levels were supplied by the Dirección Nacional de Vías Navegables of Argentina and were recorded at the Santa Fe Port gauge (Fig. 1). For the analyses of variables of the hydrological regime within the study area, the height of 4.5 m was selected as overflow level (flood pulses) and the height of 2.3 m was selected as the reference of disconnection level (Paira, 2003). High water level periods that were below bank overflow (3.0 m up to 4.5 m) were referred to as flow pulses (Tockner *et al.,* 2000).

Table I. Hydrological and temperature variables selected to characterize the flow regime. Significant and non co-linear selected variables highlighted in bold.

Group	Code of variable	Description of variable
Flood size and duration	***Hmax***	Maximum water level (m) measured at Santa Fe port
	HmeanFlood	Mean water level at Santa Fe port during flooding
	SupFlood	Duration of the flood for Hmeanflood (flood surface; over the overflowing threshold)
	Duration	Number of days in high waters, flood (> 4.5 m)
Average flow period	***HmeanWetDays***	Water levels below 4.5 m
	Hmean	Annual average water level
	WetDays	Number of days between the overflowing threshold (< 4.5 m) and disconnection threshold (> 2.3 m)
Low-flow period	*Hmin*	Minimum water level measured at Santa Fe port
	HmeanDryDays	Water levels below 2.3 m (dry period)
	DryDays	Number of days below the disconnection threshold (< 2.3 m)
Flood timing	***DateStartFlood***	Date of the start of flooding, julian days
	DateHmax	Date of maximum water level at Santa Fe port
	DateEndFlood	Date of the end of flooding
	Delay	Delay of the flood (number of periods of 15 days between October 1 and the beginning of the flood). Following Oliveira *et al*., 2014
Associate temperatures	***TStartFlood***	Water temperature on the first day of flooding
	TendFlood	Water temperature on the last day of flooding
	TmeanFlood	Mean water temperature during flooding
	TmeanAnual	Annual average temperature

For analyses of the flow regime of the river within the study period (1935-1983), we identified 18 relevant hydrological variables obtained from the daily data records. To build and compare flow typology among years, we used cluster analysis (Ward´s algorithm; Ward, 1963). Subsequently, we used principal component analysis (PCA) and cluster analysis to assess overall similarity of flows among years (using nine selected variables). Seasonal effects were also included in the analysis by considering the daily air temperatures in Santa Fe obtained from the Meteorological National Service of Argentina.

Fisheries data and analyses

Data of commercial fisheries catches in the Middle Paraná River for the study period 1935-1983 were obtained from two sources: Ministerio de Agricultura and Dirección Nacional de Pesca Continental of Argentina.

The differences in total fish catches among decades were tested using a one-way permutational analysis of variance (PERMANOVA). Pair-wise posteriori comparisons were carried out to assess which decades significantly differed. Seven fish species that accounted for approximately 75% of the total of commercial catches in the Middle Paraná River in the analysed period were selected. The canonical analysis of the principal coordinates (CAP; Anderson, 2004) was used to assess temporal patterns of similarity in the structure of fish catches among decades.

Table II. Species of freshwater fish catches registered in the official statistics. Codes used in graphs, common name, family, % of the total catches.

Species	Code	Common name	Family	Abundance in the catch (%)
Pseudoplatystoma sp.	*Pse sp*	Surubí	Pimelodidae	14.32
Luciopimelodus pati	*L pat*	Patí	Pimelodidae	13.83
Colossoma sp.	*Col sp*	Pacú	Characidae	12.44
Pimelodus albicans	*P alb*	Bagre blanco	Pimelodidae	10.07
Prochilodus lineatus	*P lin*	Sábalo	Prochilodontidae	9.65
Salminus brasiliensis	*S bra*	Dorado	Characidae	9.47
Leporinus obtusidens	*L obt*	Boga	Anostomidae	3.76

To analyse the effects of flow regime variables on the variation of fish commercial catches in the Middle Paraná River, we used distance-based redundancy analyses (dbRDAs) (McArdle and Anderson, 2001; Anderson *et al.,* 2008). These analyses were performed using lag periods of 0-6 years, exploring the possible delay in the response of the fish commercial catches to flow regime characteristics, in relation to recruitment. Subsequently, we assessed correlations between fish catches and specific flood variables that were identified as significant explanatory variables.

PERMANOVA, CAP, cluster analysis and dbRDA differences were tested based on the Steinhaus/Bray-Curtis distance matrix (Legendre and Legendre, 2012). The probability values were obtained for predictor variables by 9999 random permutations (Manly, 1997). In all the analysis to eliminate multicollinearity, significant co-linear relationships were identified between flow regime variables (Pearson's $r > 0.6$). Pearson correlations, cluster analysis and PCA were carried out with the R-statistical software (R Development Core Team, 2011). Significance was determined at $\alpha<0.01$ in all analyses.

Results

Flow regime variability

The climate variability during the past century in South America and its impact on the hydrological regimes of some of its major rivers has been studied (Garcia and Vargas, 1998; Giacosa et al., 2000; Barros et al., 2006).

Substantial variations in flow regime among analysed decades were observed (Fig. 2). The average water level at the Santa Fe port gauge varied between 2.82 m (1940s) and 4.23 m (1980s) (Fig. 2A). The maximum water levels registered in each decade were 5.9 m (1930s), 5.83 m (1940s), 6.12 m (1950s), 6.94 m (1960s), 6.36 m (1970s) and 7.35 m (1980s). The floods were larger and more frequent during 1970s and 1980s, with one extraordinary event in 1983, when water levels peaked up to 7.35 m. The 1980s was an exceptionally wet decade with significantly higher rates of flooding, different from all other decades analysed and characterised by flooding every year (1304 flooded days in tota) (Fig. 2A). There was also substantial variation in flow patterns among specific years (Fig. 2B).

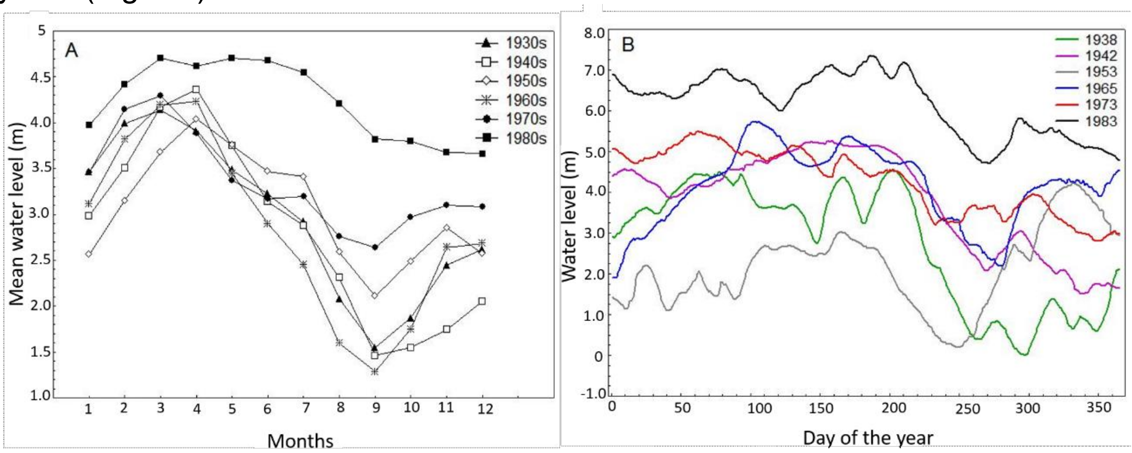


Figure 2. A) Monthly average water level at the Santa Fe port gauge for analysed decades. B) Daily water level for some selected years: 1938, 1942, 1953, 1965, 1973 and 1983.

Cluster analysis of the flow regime of the Middle Paraná River in the study period (1935-1983) resulted in three clearly distinguishable groups (Figure 3). Among 48 years analysed, 31 were characterised by floods (of different magnitude). Group 1 contains of the largest floods with maximum water levels between 5 and 7.35 m and of long durations (40 to 365 days; floods mainly in summer). The entire decade of 1980s belongs to this cluster. Group 2 is composed of flood pulses of low magnitude and a very brief duration (between 7 and 49 days). Group 3 groups years which were characterised by only flow pulses with maximum heights between 3.72 m and 4.27 m.

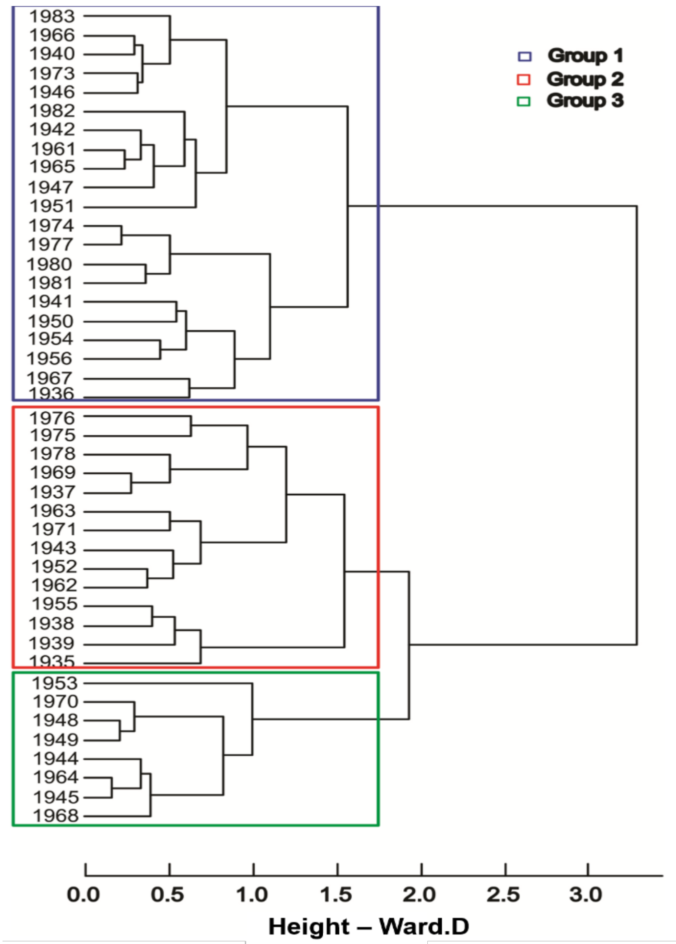


Figure 3. Cluster analysis of flow regime in the study period (1935-1983) using 18 selected hydrological variables.

The PCA using the most significant and non-collinear flow variables resulted in 46% of the total variance explained by Axis 1 and 23% explained by Axis 2. Axis1 was strongly correlated with Hmax, HmeanWetDays, DateStartFlood, TstartFlood, TmeanFlood and SupFlood, i.e., variables that describe the size and duration of the floods and associated temperatures. Axis 2 was correlated with DryDays, WetDays and TmeanAnual, variables that describe the low-flow period (Fig. 4A).

The PCA closely reflected groups obtained in the cluster analysis (Fig. 4B). Group 1 included years with the biggest flood pulses, with maximum water levels between 5.2 m and 7.3 m and of long durations. Group 2 was characterised by years with flood pulses of short duration, with maximum water levels between 4 and 5.9 m, but with flood pulses and predominance of wet days. Group 3 represented only flow pulses, with maximum levels between 3.7 and 4.3 m, and with predominance of dry days.

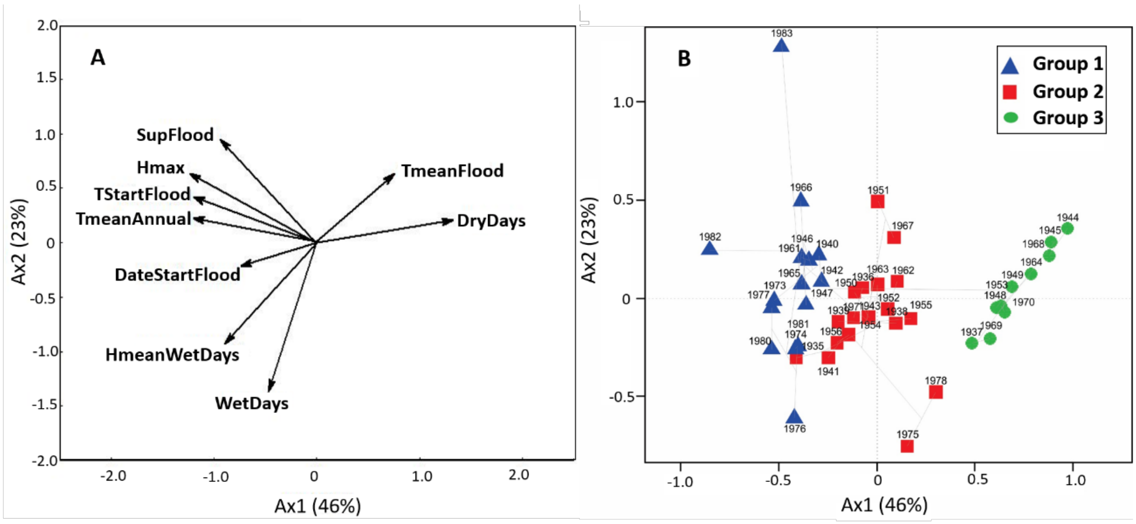


Figure 4. A) Principal component analysis (PCA) of the most significant and non-collinear flow and temperature variables of the years 1935-1983. B) Cluster analysis of individual years; flow regime groups correspond to PCA analysis in A.

Fish catches interdecadal changes

The largest catches of the commercial fish in the Middle Paraná River were obtained in the 1980s followed by the 1940s (Fig. 5). The 1930s is the decade that was characterised by the lowest catches (~300 tons, Fig. 5).

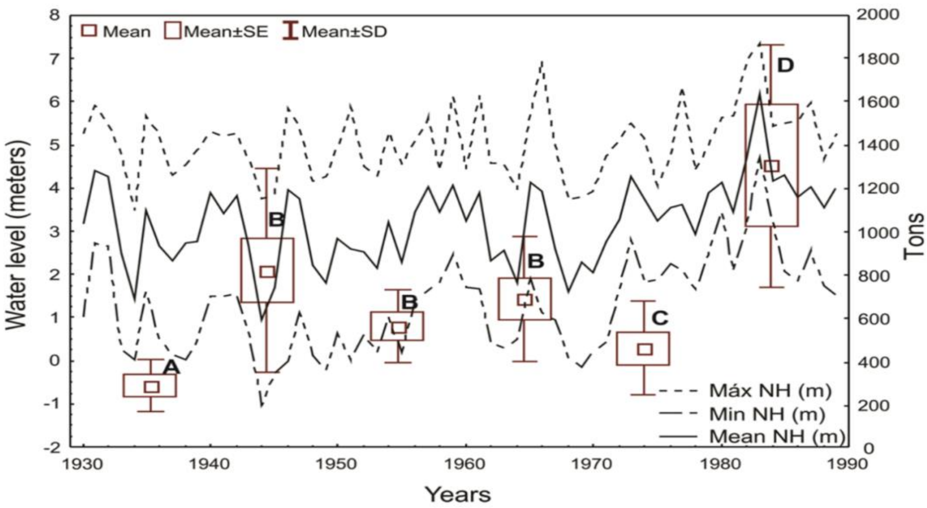


Figure 5. Mean, maximum and minimum (average) annual water levels for the period 1930-1989. Box plot with average of commercial fish catches per decade. Codes A, B, C and D express significant differences among decades along the study period.

The difference in the total catches between decades was statistically significant (PERMANOVA; F=2.965, p<0.01). Observed significant increase in commercial catches was associated with the increase of the minimum, maximum and mean water levels in the river (Santa Fe port gauge) (Fig. 5).
CAP indicated significant temporal differences in the species compositions of catches in the analysed decades (tr(Q_m'HQ_m)=1.469, p<0.001; (Fig. 6). Species composition of the catches gradually changed with the decades (Figure 6A). *Salminus brasiliensis* (dorado) was abundant in the catches from the first two decades. The highest catches of *Colossoma* spp. (pacú) were recorded in the 1940s, diminishing significantly in the 1960s. *Leporinus obtusidens* (boga) and *Prochilodus lineatus* (sábalo) showed a progressive increase in the catches from 1960s onwards and reached the highest catches in the last two decades.

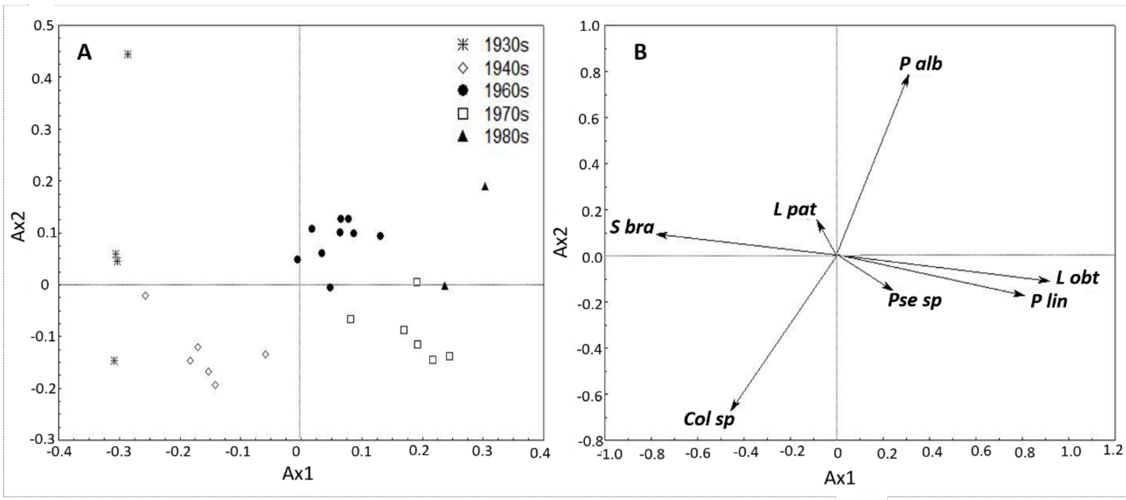


Figure 6. A) CAP of temporal variation of commercial fish species structure on the Middle Paraná River during 1936-1982. B) Commercial fish species catches structured among decades along the study period.

Fish catches interannual changes

The best model (dbRDAs) that explained the structure of commercial fish catches indicated that catches in a particular year were related to flood characteristics occurring two years before (lag 2; Rabuffetti et al. in revision). Axis1 explained 30.6 % of the total variance and was strongly positively correlated with the flood height (HmeanFlood) and negatively with minimum water level (Hmin) (Fig. 7). Variables associated with temperature such as TmeanAnnual and TStartFlood correlated with Axis2 (which explained 11.01 % of the variance) (Fig. 7).

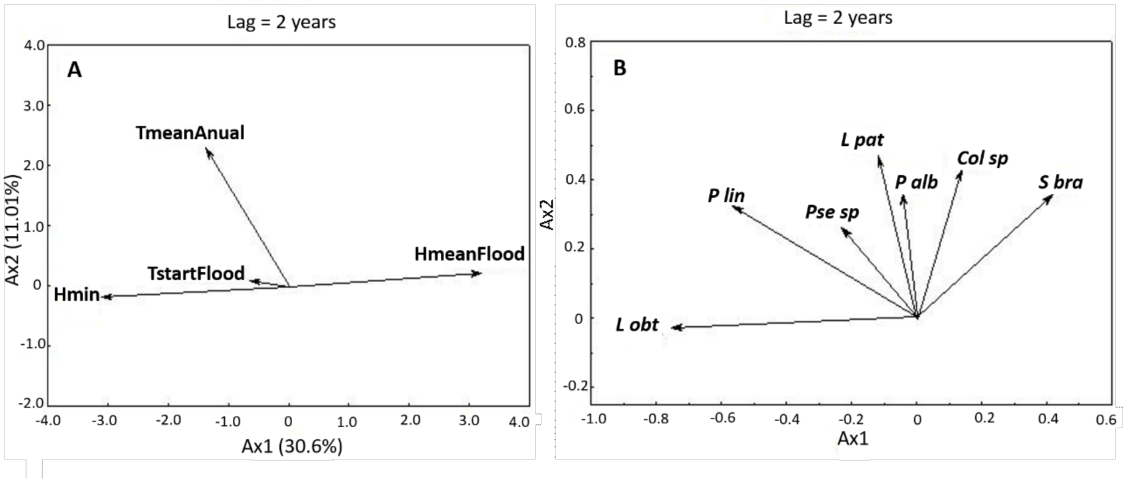


Figure 7. A) db-RDAs of log10-transformed fish catches in the Middle Paraná River from 1936 to 1982 explained by flow regime variables. The analyses were performed with lag 2. B) Plot of commercial fish species catches structured by flow regime variables along the study period.

Concluding remarks

The climatic fluctuations during the 20th century strongly affected the hydrology of the Middle Paraná River and the characteristics of its flow regime. The magnitude of floods, as well as maximum, minimum and mean water levels increased in association with an increment of frequency and intensity of ENSO events. Floods that are a key factor driving recruitment of commercial fish species were significantly more frequent and important in the 1980s. These fluctuations were a direct cause of increased abundance, and commercial catches in the 1980s due to enhanced recruitment of commercially important species. This highlights the positive influence that the duration and magnitude of floods would have on commercial catches of riverine fish in subtropical large floodplain river systems as the Middle Paraná River. Though the effects of other manmade impacts on catches (e.g. overfishing, changes in fishing efforts, etc.) have yet to be investigated, evidences gathered till now support the view of the middle reach as a large, heterogeneous and unimpounded fluvial system where the hydrological regime and water quality remain nearly unchanged. Climate fluctuations would be the main driving force explaining variations of that regime. Thus monitoring of expected changes in climate/hydrology becomes a key task in order to maintain productivity of food resources as the commercial fisheries of this rich ecosystem.

KEY WORDS: climatic fluctuations * historic hydrologic fluctuations * reshwater fisheries * middle Paraná River (Argentina).

References

Anderson MJ. A program for generalised discriminant analysis or canonical correlation analysis on the basis of any distance measure. Department of Statistics, University of Auckland. 2004.

Anderson MJ, Gorley RN, Clarke KR. PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. Plymouth, UK. 2008.

Barros V, Clarke R, Dias PS. Climate Change in the La Plata Basin. Publication of the Inter-American Institute for Global Change Research. CIMA-CONICET-UBA, Argentina. 2006.

García NO, Vargas WM. The temporal climatic variability in the Río de La Plata basin displayed by the river discharges. Climatic Change, 1998; 38:359–79. .

Giacosa R, Paoli C, Cacik P. El río Paraná en su tramo medio (Capítulo 2: 69–103). Centro de Publicaciones, Universidad Nacional del Litoral, Santa Fe, Argentina. 2009.

Latrubesse E. Patterns of an abranching channels: the ultimate end-member adjustment of mega rivers. Geomorphology, 2008; 101:130–145.

Legendre P, Legendre L. Numerical ecology. Amsterdam, Elsevie, 2012; 24:265-335.

Manly BFJ. Randomization, bootstrap and Monte Carlo methods in biology, 2nd. London. 1997.

McArdle BH, Anderson MJ. Fitting multivariate models to community data: A comment on distance-based redundancy analysis. Ecology, 2001; 82:290-297.

Paira AR.Características morfométricas de lagunas de la llanura de inundación del río Paraná Medio. Universidad Nacional del Litoral, Argentina, Tesis de Licenciatura en Cartografía.2003.

R Development Core Team. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Austria. 2011.

Rabuffetti AP, Górski K, Espínola LA, Abrial E, Amsler ML, Paira AR. Long-term hydrologic variability in a large subtropical floodplain river: effects on commercial fisheries. River Research and Applications. 2016. ID: RRA-16-0063.R1

Tockner K, Malard F, Ward JV.. An extension of the flood pulse concept. Hydrological Processes, 2000; 14:2861-83.

Ward JH. Hierarchical grouping to optimize an objective function. Journal of the American Statistical Association, 1963; 58: 236–44.