Morphological and hydrological characteristics of the floodplain ponds of the Middle Paraná River (Argentina)

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Abstract

The relationship between the origin and evolution of the ponds and their water regime is stressed.
Direct as well as indirect connections between alluvial channels and floodplain ponds exist. The communication system with the Paraná regime shows four hydrological phases : isolation phase, bankfull rising-water phase, overbanks phase, and bankfull falling-water phase. This lotic-lentic interaction causes an annual mixture between running and «standing» water, and is a primary factor in the evolution and in the physical, chemical and biological behaviour of these waterbodies.

Key words : South America — Paraná River — Floodplains — Alluvial ponds — Hydrology — Freshwater.

Résumé

Caractéristiques morphologiques et hydrologiques des lacs de la plaine d'inondation du Paraná Moyen (Argentine)

La relation entre l'origine et l'évolution de ces lacs et leur comportement hydrologique est discutée.
Dans les cours d'eau et les lagunes on a distingué des connexions directes et indirectes. Le système de communication avec le Paraná, évolue dans ces lacs en quatre phases hydrologiques : phase d'isolement, phase de crue dans le lit mineur, phase de débordement et phase de décrue dans le lit mineur. Ce mélange annuel entre les eaux courantes et les eaux dormantes, constitue le principal facteur de l'évolution et du comportement physique, chimique et biologique de ces plans d'eau.

Mots-clés : Amérique du Sud — Rivière Paraná — Plaines d'inondation — Lacs — Hydrologie — Eaux douces.

Resumen

Características morfológicas e hidrológicas de las lagunas de la llanura aluvial del río Paraná Medio (Argentina)

Se destaca la relación observada entre el origen y evolución de estas lagunas y su comportamiento hidrológico.

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Entre los cauces y las lagunas aluviales se distinguen conexiones directas e indirectas. El sistema de comunicación con el régimen del río Paraná origina, en estas lagunas, cuatro fases hidrológicas : fase de aislamiento, fase de aguas encauzadas en creciente, fase de desborde y fase de aguas encauzadas en bajante. Esta interacción lótica-lenítica, origina la mezcla anual entre las aguas corrientes y las «estancadas», constituyendo el principal factor incidente en la evolución y en el comportamiento físico, químico y biológico de estos cuerpos de agua.

PALABRAS CLAVES : América del Sur — Río Paraná — Llanuras de inundación — Lagunas aluviales — Hidrología — Aguas dulces.

INTRODUCTION

The Paraná River has a length of 3 780 km and drains 2 600 000 km², the second largest catchment of South America. The reach between its confluence with the Paraguay River and Diamante city (Argentina) is known as the Middle Paraná. It is 707 km long (fig. 1). The lateral flood zone of the Middle Paraná River is enlarged downstream from Diamante city (Argentina) giving rise to a deltaic floodplain, with the typical breakdown of the main channel into distributaries producing the classic fan-shaped delta. It is 325 km long, with a maximum width of 65 km and an area of 12 350 km². The mean rate of the delta progradation into the Río de la Plata estuary is about 58 m yr^{-1}. In the Middle Paraná the main channel width varies from broad expanses, over 8 km wide, to 400 m; depths can exceed 40 m and can dwindle to shallows of only a few meters. Current velocity varies from less than 0.2 m s^{-1} in sluggish stretches to more than 2 m s^{-1} at node points. At mid-water stages, the flood-wave velocity exceeds 60 km day^{-1}, with 10 days being the aproximate renewal time of the stretch. The annual average discharge is 16 000 m³ s^{-1}. For the mean suspended sediment concentration, DRAGO and AMSLER (1981) report a value of 276 mg l^{-1}.

Along its middle reach, the Paraná River has built a composite, fringing floodplain (DRAGO, 1973), covering an area of 13 063 km² (width range 6-40 km). About 30% of this is interspersed with different temporary and permanent waterbodies, some of which are as large as 130 km² (laguna Coronda). At the height of the floods, they tend to merge into a continuous sheet of water that covers the whole floodplain. Figure 2 shows (a) the lotic and lentic waterbodies (in black) during mid-waters and (b) the extreme conditions where the whole river valley is flooded. The broken-line marks the boundaries between the alluvial lands and the surrounding non-floodable terra firme. Agricultural practices do not exist in the floodplain and animal husbandry is concentrated mostly on cattle only during low water periods.

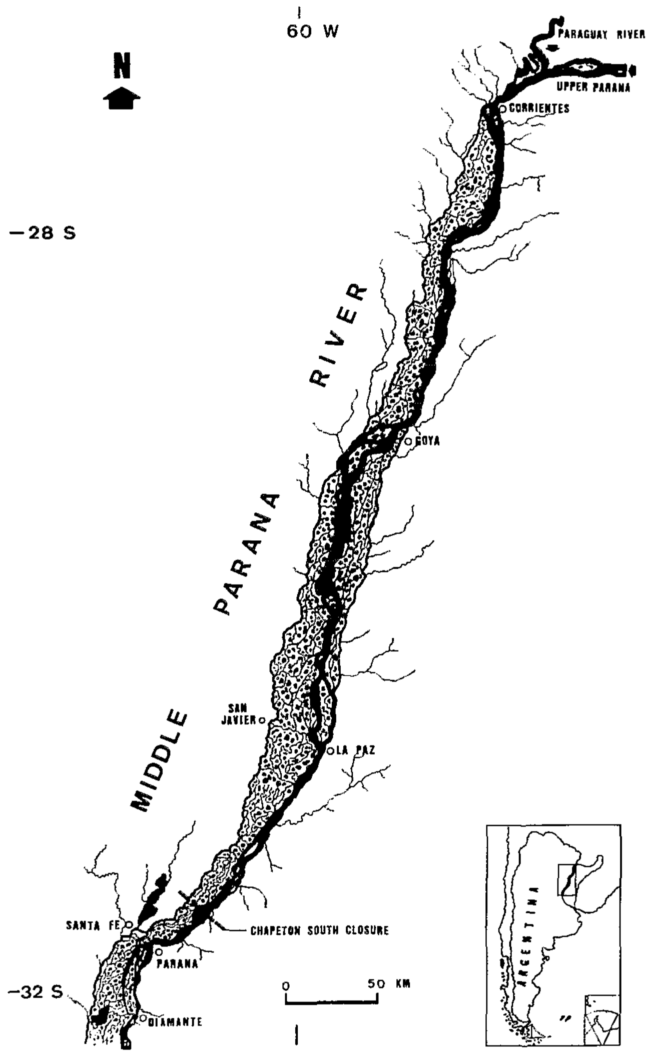

FIG. 1. — The fringing floodplain of the Middle Paraná River between the Paraguay River outlet and Diamante city (Argentina)
La llanura aluvial de borde del río Paraná medio, entre la desembocadura del río Paraguay y la ciudad de Diamante (Argentina)

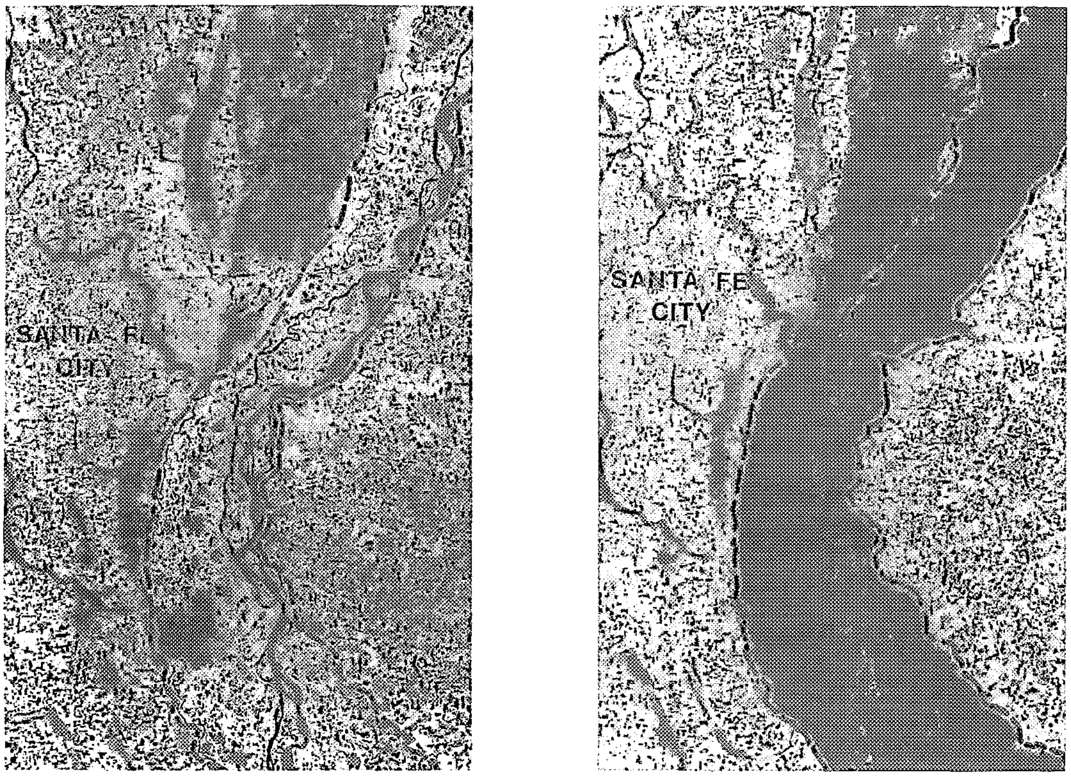

Fig. 2. — Aerial view of the floodplain of the Middle Paraná River near Santa Fe city (Argentina) during (a) mid-water (08-11-81) and (b) high-water (01-10-83); water level difference : 3.16 m. The photos cover an area of about 130 × 95 km. Note the numerous floodplain ponds in (a). (Photos by CNIE Landsat Processing Centre Buenos Aires.)

Vista aérea de la llanura aluvial del río Paraná Medio próxima a la ciudad de Santa Fe (Argentina), durante (a) aguas medias (08-11-81) y (b) aguas altas (01-10-83); la diferencia en el nivel hidrométrico es de 3,16 m. Las fotos cubren un área de aproximadamente 130 × 95 km. Nótese las numerosas lagunas de inundación en (a). (Fotos del Centro de Procesamiento Landsat CNIE Buenos Aires.)

As a consequence of high water discharges, the ponds are periodically engulfed by the Paraná River. However, at low river levels, processes such as the growth and decay of primary producers (mainly macrophytes), and the mixing and resuspension of bottom sediments, govern pond metabolism. According to Junk (1980, 1982, 1983), such waterbodies are intermediate between closed lakes as accumulating systems and rivers as discharging systems; hence, they are not true lakes. For this reason we use the term "pond" for the waterbodies of the Paraná floodplain. They are remarkable, as compared with lakes, by their shallowness and absences of long periods of thermal stratification (Bonetto *et al.*, 1984; Drago and Paira, 1988).

This paper deals with the morphological and hydrological features of the alluvial ponds of the Middle Paraná River floodplain. The relationship between the origin and the water regime of the waterbodies is stressed.

ORIGIN OF THE WATERBODIES

The Middle Paraná, with its high sediment load, has nearly filled up its valley, while forming a very complex floodplain with islands, bars, levees, secondary channels, ponds, and swamps, which are being permanently modified by continuous erosion and sedimentation processes (tabl. I).

According to Drago (1977), in some cross-sections, the floodplain moved eastward at an average rate of 45 m yr^{-1}. The thalweg shiftings are important, reaching 350 m yr^{-1}, and the bar and island migration downstream and laterally can reach mean values of 60 and 35 m yr^{-1}, respectively. The maximum annual average of scour was 3 m yr^{-1}, and the maximum annual average of vertical deposition was 2.6 m yr^{-1}. The maximum rate of bankline buildout was about 22 m yr^{-1}, and the maximum retreat was found to be 90 m yr^{-1}.

Owing to this river and floodplain dynamics, the

TABLE I

Mean general characteristics of a typical floodplain section of the Middle Paraná River at mid-water level
Características generales, en aguas medias, de una típica sección de la llanura aluvial del río Paraná medio

Number of ponds by km^2	-	3
% of area covered by ponds	-	18
Mean shoreline development	-	1.6
Number of swamps by km^2	-	2
% of area covered by swamps	-	16.6
Mean shoreline development	-	1.3
Number of channels by km^2	-	2
% of area covered by channels	-	6
Drainage density (km/km^2)	-	2.2

thousands of floodplain ponds in the Middle Paraná vary considerably in shape and size. The ponds range in shape from dendritic to circular, with lengths from less than 100 m to more than 10 km. They are shallow, rarely exceeding 5 m depth at mid-water stage, and with regular bottom topography.

The evolution of these waterbodies is related to geomorphological, hydrological, and biological (e.g., palustrine and aquatic vegetation) factors. Taking into account the processes responsible for building, excavation, and damming (DRAGO, 1976), we can classify the Paraná floodplain waterbodies according to the following main types:

Obstruction ponds, formed by sediment deposition at the ends of abandoned, well-defined secondary channel stretches. They vary in their shapes from slightly to strongly curved, elongated, and narrow troughs. They are extremely common in the Paraná floodplain, due to the meander migration of the anabranches (e.g., oxbow and meander scroll ponds).

Levee ponds, troughs entirely surrounded by levees, originated by the downstream evolution of channel bars and islands. Each bar or island will be converted into a basin as soon as deposition closes the open ends, which then remains as a central cavity that will form the new pond. Levee ponds may be also formed in the islands and bars of an internal delta, building up when a tributary flows into the ponds (fig. 3). They are triangular in shape. These kinds of waterbodies can be observed in the Lower Paraguay River (DRAGO, 1975) and in the Amazon, Niger and Zaire Rivers (WELCOMME, 1985), where the channel islands form levees with depression ponds at their centre.

Lateral expansion ponds, similar in origin to the preceding types, but owing to breaking of levees, the water drowned adjacent lowlands. They present a very particular basin shape, with the former channel connected to a lateral trough.

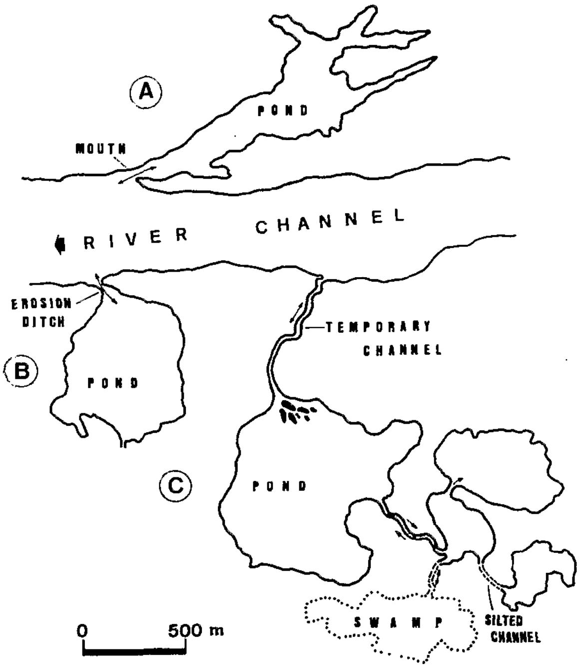

FIG. 3. — Direct connection degrees during mid-water stage through (A) mouth, (B) an erosion ditch, (C) a temporary channel with reversible flow. Note in (C) the internal delta built up in the largest pond and the other waterbodies with indirect connection with the main channel. (Los Mellados Island, Santa Fe, Argentina.)
Grados de conexión directa durante aguas medias a través de (A) boca, (B) cárcava de erosión, (C) cauce temporario con flujo bidireccional Nótese en (C) el delta interno construido en la laguna de mayor superficie y los otros cuerpos de agua de conexión indirecta con el cauce principal. (Isla Los Mellados, Santa Fe, Argentina.)

Inter-bar ponds, formed when a large channel stretch is dammed at its ends by fluvial bars or islands. Their surfaces are great and dentritic.

Overflow ponds, lying in smooth depressions originate from uneven aggradation or degradation during floods. They have irregular shapes and are situated near the main channels.

Annexation ponds, formed by a fusion of two or more waterbodies. Their shapes vary between subrectangular-elongated and dendritic.

Swamps, lying in old pond troughs, filled up by the river sediments and organic materials. They are the final stage in the evolution of the Paraná floodplain ponds and may be associated with other waterbo-

TABLE II

Number of waterbodies and drainage density for different floodplain areas
A : near the main channel ; B : away from the main channel
Número de cuerpos de agua y densidad de drenaje en diferentes áreas de la llanura aluvial
A : próxima al cauce principal; B : alejada del cauce principal

	A	B
Number of ponds by km^2	0.12	2.63
Number of swamps by km^2	0.75	3.65
Number of channels by km^2	1.02	2.51
Drainage density (km/km^2)	0.95	3.40

TABLE III

Annual periods of isolation and connection for two Paraná floodplain ponds separated by 7 km (time in days)
Períodos anuales de aislamiento y conexión en dos lagunas de inundación separadas por 7 km (tiempo en dias)

	1975	1976	1977
Los Matadores pond			
Isolated	19	0	17
Connected	346	366	348
El Negro pond			
Isolated	354	243	224
Connected	111	123	141

dies. They support dense growth of aquatic macrophytes, covering up to 100% of their surface.

CONNECTION DEGREES BETWEEN LOTIC AND LENTIC ENVIRONMENTS

The floodplain geomorphology and the origin and evolution of its waterbodies will determine the connection degrees between running and "standing" waters. Generally, the communication systems between alluvial ponds and rivers become more complex with increasing distance from the main channel (tabl. II).

The shallow waterbodies are filled annually during periods of rising flood by the river water. During falling stages, the surplus pond water flows back into the river. At low stages, large portions of the ponds become dry. At high stage the floodplain becomes inundated and the ponds may lose their identity. Thus, the floodplain ponds are strongly influenced by the seasonal fluctuations of the Paraná level, and they expand and contract according to the annual flood cycle. Some permanent waterbodies may be in communication with the main river or its anabranches during a great part of the year (tabl. III).

During mean water stage, two kinds of connection between rivers and ponds can be distinguished (DRAGO, 1981 ; fig. 3) :

1) *Direct connection*, communication through a mouth, ditch, or a short channel only. The river water fluctuations are quickly reflected in the ponds, and the communication channel has a reversible flow.

2) *Indirect connection*, communication through channels of greater lenght, with intermediate pond and/or swamp basins. The pond waterlevel shows more irregular oscillations due to a greater isolation from the main channel.

These different connection degrees are reflected in the diverse hydrological behaviour of the waterbodies and in the quality of water they will receive from the Paraná River and its anabranches. Some physicochemical characteristics of the river water show strong changes during its displacement across the floodplain (fig. 4).

WATER REGIME OF THE FLOODPLAIN PONDS

In spite of its lenght, the Paraná River presents a similar flood regime along the upper and middle reaches. Important tributaries, such as the Iguazú and Paraguay Rivers, do not alter its flood patterns significantly (fig. 5). The water level fluctuations range is about 3-6 m in the middle reach (Paraná city, Argentina), with a highwater period during the first six months of the year (flood peaks in March-April) and low waters in the rest of the year (minimum stages in September). The proportion of the floodplain which remains permanently under water is generally as difficult to establish as is the total area submerged at the peak of the floods. Nevertheless, the data obtained from a satellitary image of the Middle Paraná floodplain, give an area of 18 000 km^2 at peak flood, larger than the 14 350 km^2 calculated for the Paraná deltaic plain (area at low water : 12 350 km^2), and 2 500 km^2 for the Lower Paraguay fringing floodplain (area at low water : 1 954 km^2). The floodplains of the Lower Paraguay and the delta of the Paraná are immediately up — and downstream of the Middle Paraná floodplain.

The degree of connection between the rivers and

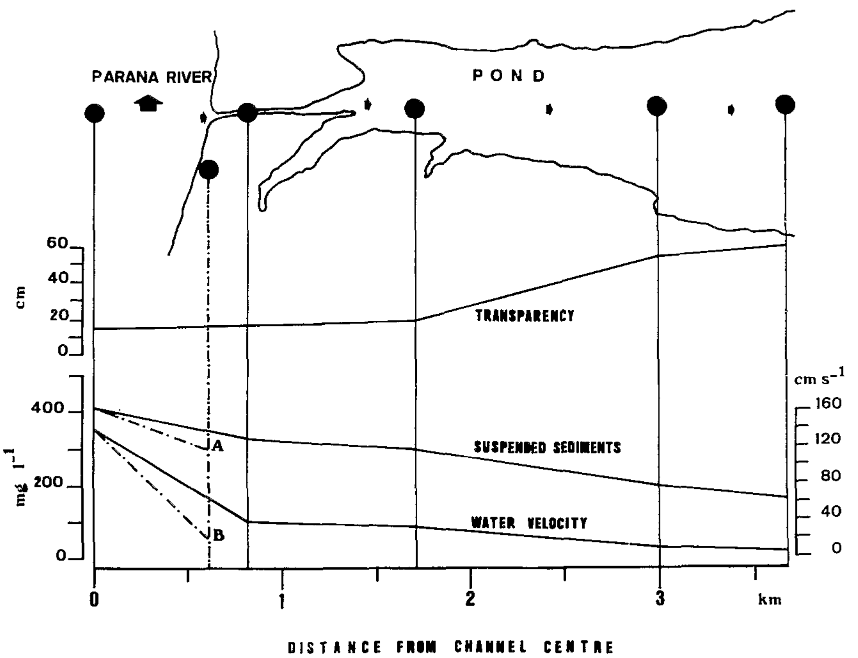

FIG. 4. — Changes in transparency (Secchi disc), suspended sediment concentration, and current velocity during the start of the overbanks phase (24-03-77). A and B : data measured on the flooded levee. Note the direct connection degree between the Paraná River main channel and the La Cuarentena pond

Cambios en la transparencia (disco de Secchi), concentración de sedimentos suspendidos y velocidad de corriente, durante el comienzo de la fase de desborde (24-03-77). A y B : datos medidos sobre el albardón inundado. Obsérvese el grado de conexión directa entre el cauce principal del río Paraná y la laguna La Cuarentena

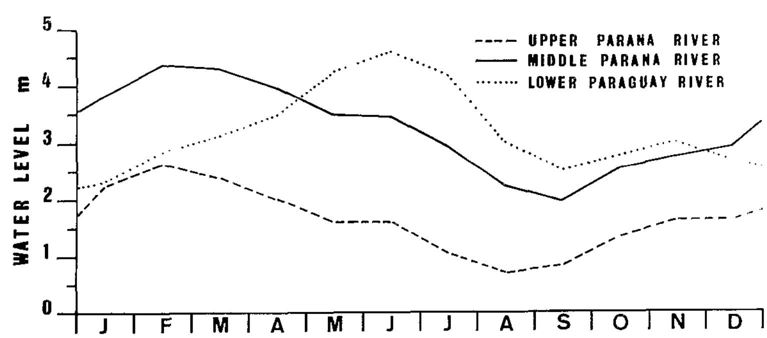

FIG. 5. — Water level of the Upper Paraná River (at Posadas city, Argentina) and Middle Paraná River (at Corrientes city, Argentina), downstream from outlets of Iguazú and Paraguay Rivers, respectively. Note that the water level regime of the Lower Paraguay River (at Formosa city, Argentina) does not alter the behaviour of the Middle Paraná River at Corrientes city. The mean annual discharges of the Paraná and Paraguay Rivers at the confluence are 13684 $m^3 s^{-1}$ and 4186 $m^3 s^{-1}$ respectively

Limnigramas del rio Alto Paraná (en Posadas, Argentina) y en el Paraná medio (en Corrientes, Argentina), aguas abajo de la desembocadura de los ríos Iguazú y Paraguay, respectivamente. Nótese que el régimen del río Paraguay inferior (en Formosa, Argentina), no altera el comportamiento del río Paraná medio en la ciudad de Corrientes. Los caudales medios anuales de los rios Paraná y Paraguay en la confluencia son de 13684 $m^3 s^{-1}$ y 4186 $m^3 s^{-1}$, respectivamente

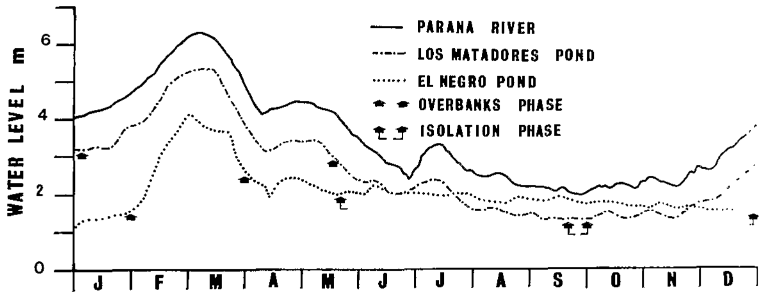

FIG. 6. — Hydrological phases in two floodplain ponds of the Middle Paraná River during an annual cycle (1977). Note the different periods for the overbanks phase (January-May) and for the isolation phase (May-December) for both ponds, separated by 7 km. Los Matadores pond presents a direct communication with the river and El Negro pond an indirect connection. The arrows are indicating the different periods of overbanks and isolation phases for both ponds

Fases hidrológicas, durante un ciclo anual (1977), en dos lagunas de inundación del río Paraná medio. Nótese los diferentes períodos de la fase de inundación (enero-mayo) y de la fase de aislamiento (mayo-deciembre) en las dos lagunas, separadas por una distancia de 7 km. La laguna Los Matadores, tiene una conexión directa con el río y la laguna El Negro, una conexión indirecta. Las flechas indican los diferentes períodos de las fases de inundación y de aislamiento para ambas lagunas

the floodplain ponds, together with the yearly waterlevel fluctuations of the Paraná River, generate four hydrological phases in these alluvial ponds. The intensity of mixing between running and "standing" waters will be dependent on these phases, as described in the following paragraphs :

1) *Isolation phase*, there is no communication between rivers and ponds, because the running waters are confined within the main channel and its side-arms. Usually, the means of connection (mouth, erosion ditch, or channel) dry up completely. If this phase is very prolonged, the shallowest waterbodies may dry up wholly, producing mass fish mortalities. Furthermore, conditions in the ponds may be influenced by meteorological factors such as air temperature, wind, and rainfall. For example, in the case of El Negro pond daily rains ranged between 51 and 94 mm recorded during 1975-77, giving rise to an average increment of 16 mg l^{-1} in the suspended sediment concentrations.

2) *Bankfull rising-water phase*, the river waters flow into the floodplain ponds without overspilling the levees and other higher flats. The annual supplies of allochthonous material to the ponds begins with this phase.

3) *Overbanks phase*, further rises above the bankfull level result in overspill onto the plain. The floodwater spreads over the levees, flats, and waterbodies, and the ponds lose their lentic identity and attain their maximum depths. Organic and inorganic materials of the floodplain flats become suspended and are carried into the ponds. The mixing between running and "standing" waters reaches its maximum during this phase. The basin morphology and the proximity of some ponds to the main watercourses promote the temporary acquisition by them, completely or partially, of some lotic characteristics (e.g., current velocities over 0.9 m s^{-1}).

4) *Bankfull falling-water phase*, further decline in stage below the overbanks level originates a flow from the ponds to the rivers. The running waters will again be confined progressively to the channel banklines, and the waterbodies will return to their lentic conditions.

The streamflow fluctuations and the communication systems between lotic and lentic environments will determine the duration and the time of the year of each phase. Clearly, the stage limits will not be the same for waterbodies with different origins and connection degrees (tabl. III). Hence, for the same river level it is possible to find isolated and connected ponds. Furthermore, the persistence of a specific gauge height will determine the duration of the corresponding phase. Usually, in the Middle Paraná River the pond isolation periods are detected between July and December, while the flooding periods are between January and June. However, particularly low or highwater peaks can deflect this regime pattern. Data obtained by DRAGO (1980) emphasize the importance of hydrological relationships between streams and ponds in the Paraná floodplain. Figure 6 shows the different annual stage regimes of two shallow waterbodies 7 km apart; one of them which was isolated about 61% of the year and the other only 5%.

CONCLUSION

Data concerning the morphology and water regime of floodplain ponds in general, and those of the Paraná alluvial ponds in particular, are scarce, and hence our knowledge of such aquatic habitats is limited. However, the available information enable an outline of the main morphological and hydrological features of the Paraná floodplain waterbodies to be given.

According to genetic and evolutive processes, the alluvial ponds of the Middle Paraná River can be classified into the following seven general types : 1) obstruction ponds, 2) levee ponds, 3) lateral expansion ponds, 4) inter-bar ponds, 5) overflow ponds, 6) annexation ponds, and 7) swamps. The water regime of these lentic bodies is affected principally by the Paraná River stages and is conditioned by the degrees of communication between channels and troughs. The two connection types, direct and indirect, are determined by the origin and evolution of the waterbodies, which reflect in turn the floodplain dynamics.

Four hydrological phases can be distinguished for this river-pond system : isolation phase, bankfull rising-water phase, overbanks phase, and bankfull falling-water phase. This lotic-lentic relationship allows an annual mixture between running and "standing" waters and an exchange of biotic and abiotic materials. This has a very strong influence on the ponds, on the river, and on the whole Paraná floodplain.

In this fringing wetland, the following major terrestrial and aquatic features can be distinguished during mid-water stages : levees, flats, splays, bars, islands, main channel, anabranches, isolated ponds, communicating ponds, and swamps.

The Middle Paraná Dam Project (Chapetón South Closure, fig. 1), will form a man-made lake over 300 km long, which will cover ca. 50% of the floodplain surface. This reservoir will affect the water-level fluctuations and sediment load of the water and will change the ecological conditions of the Middle Paraná River valley. Therefore, additional and intensive studies of the aquatic habitats are needed in order to specify floodplain areas for protection.

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