

## Effects of hydroclimatic anomalies on bacteriological quality of the Middle Paraná River (Santa Fe, Argentina)

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### SUMMARY

Lenitic and lotic aquatic environments were studied in the Middle Paraná River basin, one of the largest rivers of the world (basin: 1,510,000 km<sup>2</sup>, length: 2,570 km). The Paraná River (S 31° 42' 04"; W 60° 29' 39"), during El Niño-Southern Oscillation (ENSO) (1997-1998), registered maximum flows of 29,962 m<sup>3</sup> s<sup>-1</sup> (more than twice the mean flow) and also positive pluvial anomalies (A) (from +120 mm to +161 mm). However, concentrations of *Escherichia coli* remained low, with values similar to the mean ( $p > 0.05$ ) (1.3802 log<sub>10</sub>cfu/100 ml). Only a maximum peak (1.903 log<sub>10</sub>cfu/100 ml), significantly higher than the mean ( $p < 0.0001$ ), was detected during the ascending phase of the flood pulse. During La Niña (September 1999 - March 2000; Q = 11,255 m<sup>3</sup> s<sup>-1</sup>; A = -78 mm to -84 mm), concentrations of *E. coli* were significantly lower than the mean ( $p < 0.0001$ ). During the post-Niña period, with normal flows (Q = 14,900 m<sup>3</sup> s<sup>-1</sup>) but with strong positive pluvial anomalies (A = +118 mm to +377 mm), the fecal indicator density reached maximum values (up to 2.699 log<sub>10</sub>cfu /100 ml,  $p < 0.0001$ ). The multiple regression model used with all the results obtained in the Paraná River showed that variations in concentrations of *E. coli* are mainly explained by pluvial precipitations and hydrometric level ( $p = 0.001$ ). Temporal patterns of concentrations of *E. coli* in a small, secondary course (Q = 101 m<sup>3</sup> s<sup>-1</sup>) followed those of the Paraná River, but concentrations and peaks of *E. coli* produced by exceptional rains showed a higher magnitude (maximum: 3.325 log<sub>10</sub>cfu /100 ml). In the floodplain lakes, away from urban centers, concentrations of *E. coli* were not associated to hydroclimatic anomalies, but directly to vegetable cover: maximum concentrations were always registered during periods that lakes remained covered by floating macrophytes (mainly *Eichhornia crassipes*); on the contrary, minimum concentrations were registered during periods without vegetable cover.

**Key words:** El Niño, Paraná river, *Escherichia coli*, *Eichhornia crassipes*.

### RESUMEN

#### Efecto de anomalías hidroclimáticas sobre la calidad bacteriológica del río Paraná Medio (Santa Fe, Argentina).

Se estudiaron ambientes acuáticos leníticos y lóticos en la cuenca del río Paraná Medio, uno de los ríos más grandes del mundo (cuenca: 1.510.000 km<sup>2</sup>, longitud: 2.570 km). El río Paraná (31° 42' 04"S; 60° 29' 39"W), durante El Niño Oscilación Sur (ENOS) (1997-1998), registró caudales máximos de 29.962 m<sup>3</sup> s<sup>-1</sup> (más del doble del caudal medio) y también anomalías pluviales (A) positivas (desde +120mm a +161mm). Sin embargo, la concentración de *Escherichia coli* se mantuvo baja, con valores similares ( $p > 0,05$ ) a la media (1,3802 log<sub>10</sub> ufc/100ml). Solamente se detectó un pico máximo (1,903 log<sub>10</sub> ufc/100ml) significativamente mayor a la media ( $p < 0,0001$ ) durante la fase ascendente del pulso de la creciente. Durante La Niña (sept. 1999 - marzo 2000; Q = 11.255 m<sup>3</sup> s<sup>-1</sup>; A = -78mm a -84mm), las concentraciones de *E. coli* resultaron inferiores a la media ( $p < 0,0001$ ). Durante el período post-Niña, con caudales normales (Q = 14.900 m<sup>3</sup> s<sup>-1</sup>) pero con fuertes anomalías pluviales positivas (A = +118 mm a +377mm), la densidad del indicador fecal alcanzó valores máximos (hasta 2,699 log<sub>10</sub> ufc /100ml,  $p < 0,0001$ ). La aplicación de un modelo de regresión múltiple al conjunto de los resultados obtenidos en el río Paraná, muestra que las variaciones en la concentración de *E. coli* son principalmente explicadas por las precipitaciones pluviales y el nivel hidrométrico ( $p = 0,001$ ). Los patrones temporales de las concentraciones de *E. coli* en un pequeño cauce secundario (Q = 101 m<sup>3</sup> s<sup>-1</sup>) siguieron a las del río Paraná, pero las concentraciones y los picos de *E. coli* producidos por lluvias excepcionales fueron de mayor magnitud (máximo: 3,325 log<sub>10</sub> ufc /100ml). En las lagunas de la llanura de inundación, lejos de centros urbanos, la concentración de *E. coli* no estuvo asociada con anomalías hidroclimáticas, sino directamente con la cobertura vegetal: las concentraciones máximas se registraron siempre durante los períodos que permanecían cubiertas con macrófitas flotantes (principalmente *Eichhornia crassipes*). Durante los períodos sin cobertura vegetal, por el contrario, se registraron las concentraciones mínimas de *E. coli*.

**Palabras clave:** El Niño, Río Paraná, *Escherichia coli*, *Eichhornia crassipes*

### INTRODUCTION

The cycle of El Niño-Southern Oscillation (ENSO) is an irregular oscillation of the climatic system, which occurs

with a periodicity of approximately 3 to 4 years (28). It consists of a warm phase (El Niño) and a cold phase (La Niña); it is mainly a tropical event, but its impact is global: it affects the pluvial and hydric regime and produces

profound economical and social impacts in extensive areas of the planet (38), including the province of Santa Fe, Argentina (19).

There is evidence that suggests a relationship between hydroclimatic anomalies with diseases and the increase and dispersion of pathogen organisms (5,14, 22, 24, 31, 34, 35). Likewise, anthropogenic alterations (disturbances by which soils and waters are polluted) can intensify the consequences derived from those anomalies (14). Flooding or strong rains can break down barriers between sewage waters (or pollutants deposited on the ground) and waters used for human consumption or recreational activities.

The biological response to the El Niño phenomenon is only known in oceanic and estuarine environments (4, 26). There are no records on the effect of hydroclimatic anomalies on populations of *E. coli* in great fluvial systems.

In the Paraná River basin, the impact of the ENSO was shown in some studies (6-9) and it was unequivocally related to climatic and hydrological anomalies. Depetris and Kempe (7, 8) estimated its effect on the transport of organic and inorganic sediments, carbon dynamics (total, dissolved and particulate carbon) and CO<sub>2</sub> partial pressure pre-ENSO and during the flooding period.

As noticed by Paoli *et al.* (30), the Plata basin is, because of its extension, one of the largest of the world (3,100,000 km<sup>2</sup>). Within this system, the Paraná River basin (1,510,000 km<sup>2</sup>), stands out as the most important river of the hydrographic system of the Plata River due to the magnitude of its mean flow (14,100 m<sup>3</sup> s<sup>-1</sup>), the extension of the tributary area and the length of its course (2,570 km). The overflows of the Paraná River in Argentina depend on contributions produced upstream, outside the Argentinian territory. Inside the territory of Argentina, from the confluence of the Paraná and Paraguay rivers, and after covering a distance of 750 km in a north-south direction up to the city of Rosario, the section is called "Middle Paraná River" (20). Rains produced in the Upper Paraná, Iguazú River and Paraguay River basins directly cause the overflows in the mid and lower sections, while there is a low incidence of contributions of these two sections. Low contributions are due to the precipitation regime, with lower values than in the upper section and with a strong decrease from east to west. The physical characteristics of the mid section contribute to this situation: it is, in its greater proportion, a typically plain area, with a great capacity of superficial storage and low run-off.

About 30% of the Middle Paraná floodplain (approximately 13,000 km<sup>2</sup>) is covered by a wide variety of permanent or temporary lakes. *Eichhornia crassipes* is one of their most abundant floating macrophytes. In the "El Tigre" Lake, for example, its mean biomass (dry weight) is in the range of 8 - 24 t ha<sup>-1</sup> (27). The extreme floodings,

as those produced during the ENSO, can clean those water courses and reaccommodate the communities to their first succesional stages (23), but there are unknown bacteriological aspects associated.

The understanding of the relationships between hydroclimatic factors and bacteriological quality of water can contribute to optimize preventive sanitary strategies. Oriented towards that purpose, the objective of this study was to estimate the effects of hydroclimatic anomalies, produced during 1997 -2000, on the concentration of fecal contamination indicators, in some lenitic and lotic aquatic environments of the Middle Paraná River basin (Santa Fe, Argentina).

## MATERIALS AND METHODS

### Sampling locations

Samples were collected in four aquatic environments: two fluvial environments (Paraná and Correntoso rivers) and two lacustrine ones ("El Tigre" and "Los Matadores" shallow lakes).

In the Paraná River main course, samples were taken from the centre (31° 42' 04"S; 60° 29' 39"W), and the right (31° 41' 58"S; 60° 20' 38"W) and left (31° 42' 18" S; 60°29' 36"W) banks. This cross-section is morphologically stable, quite deep (22 m) and wide (600 m) at average stages. The Paraná river catchment area up to the studied section is 2.04 x 10<sup>6</sup> km<sup>2</sup>, representing 78% of the total drainage surface (2.6 x 10<sup>6</sup> km<sup>2</sup>). The mean annual discharge is 14,100 m<sup>3</sup>/s, so that 88% of total water volume flows through this cross-section (10). The sampling station is free of municipal or industrial important waste waters, which, however, are concentrated in the last 450 km of the course.

The Correntoso River (S 31° 41' 20.5" and W 60° 42' 42.6") is a small secondary course (Q = 101 m<sup>3</sup> s<sup>-1</sup>) of the Middle Paraná floodplain. It begins in the Santa Fe River, 2.5 km downstream of the Santa Fe Port. After going through three islands in a 6 km course, it runs into the Coronda River, another secondary course of the Paraná River (500 m downstream of the mouth of the Salado River). The flow of the Correntoso River is correlated to the flow of the Paraná River (r = 0.999, p < 0.001) and the river overflows when the water level (h) in the Paraná Port exceeds 4.5 m (1).

Los Matadores Lake is located in the Clucellas Island, very close to the Correntoso River. In most of the hydrological cycle it is communicated with the Correntoso River, until h < 2 m. It has a surface area of 32,950 m<sup>2</sup>, a volume = 50,800 m<sup>3</sup>, a mean depth = 1.54 m and a maximum depth= 2.75 m (h = 3.28 m). El Tigre Lake is located in the El Tigre Island, delimited by two arms of the Correntoso River. As the former one, it has aquatic and marshy vegetation. The communication with the Correntoso River stops when h < 3.6 m. The mean volume of the lake is 30,800 m<sup>3</sup> (9,300 to 123,000 m<sup>3</sup>). The water level of the Paraná River, in the Santa Fe Port, explains the variability of the lake water level (r = 0.947, p < 0.01) (17).

### Field and hydroclimatic data

During the samplings, transparency (Secchi disc), pH (B213 Twin, Horiba, reproducibility= ± 0.1 UpH), conductivity, salinity (both with B173 Twin, Horiba, ± 1 %), temperature and dissolved oxygen (D-25, Horiba, reproducibility= ± 0.5%) were measured *in situ*.

According to Rose *et al* (35), extreme precipitation is defined as total monthly precipitation accumulation that far exceed expected total monthly precipitation for station. A Z score is calculated for a specific month from the 100-year average monthly total and then dividing by the corresponding 100-year

standard deviation. Z score = (observed rainfall – 100-year mean) / 100-year standard deviation (33,35).

Meteorological data provided by the INTA EEA Paraná (S 31° 50', W 60° 31') (<http://www.parana.inta.gov.ar>), located in the left margin of the Middle Paraná River and by the CIM (FICH - UNL), Santa Fe (S 31° 38', W 60° 40') (<http://www.fich.unl.edu.ar/cim>), located in the right margin of the same river, were used to analyze the relationships between concentrations of *E. coli* in the Middle Paraná River (center and margins) and pluvial anomalies. At the first station, pluviometric data were available since 1934 and, at the second station, data were available since 1901. Water level data of the Paraná River (period of 100 years) were provided by the CIM (FICH - UNL).

#### Sampling frequency, indicators and bacteriological techniques used

Subsurface samples were collected with sterile glass, Simax like bottles (500 ml), at 15 cm depth and maintained refrigerated and at dark until their analyses (< 5 h). Samples were collected monthly, from November 1997 to December 1998 and again from November 1999 to December 2000.

As an indicator of bacteriological quality, the concentration of *E. coli*, a reasonable indicator of fecal contamination (2), and according to the 21st Agenda (37), an environmental indicator of sustainable development, was used. The indicator is closely linked with several others in the environmental and socioeconomic (health) categories, including biochemical oxygen demand in water bodies, waste water treatment coverage, and percent of population with adequate excreta disposal facilities (37).

The method of enzymatic detection ( $\beta$ -D-Glucuronidase) was used with *Chromocult* (Merck) plates to quantify *E. coli*, according to Emiliani *et al.* (13). Plates were incubated at 44.5 °C  $\pm$  0.2 °C for 24 h in a thermostatic bath. Blue and violet colonies, turning cherry-red when they were covered with indole reagent, were considered *E. coli*.

Previously (11), concentrations of total coliforms and fecal coliforms had been studied under normal hydrological situations in the Paraná River (period February 1978 - May 1979): mean flow = 12,915 m<sup>3</sup> s<sup>-1</sup>; no extraordinary floodings nor extreme pluvial precipitations were registered (11). The same groups were estimated again to compare the results with those obtained in this study. Counts were carried out according to the Standard Methods for the examination of water and wastewater (21), with five tubes per dilution, using Lauryl tryptose broth and EC broth (44.5 °C).

Since there was no data on concentrations of *E. coli* in the Paraná River, concentrations registered during those episodes were compared with the mean concentration of *E. coli* to estimate the impact of anomalous pluvial episodes.

Fecal streptococci (Azide dextrose broth and PSE agar) and *Pseudomonas aeruginosa* (Asparagine broth and Acetamide agar) concentrations were also estimated according to Standard Methods for the examination of water and wastewater (21) to complement the estimation of bacteriological quality during the ENSO.

#### Statistical analysis

GraphPad InStat 3.02 program (GraphPad Software, California) was used for correlations and multiple regression analyses. This program verifies if the contribution of each variable is statistically significant ( $p < 0.05$ ) and also detects problems of multicollinearity (i.e., redundant information). The same program was used for the analysis of differences among means, carrying out parametric or non-parametric tests depending on whether the whole data to be compared corresponded to a normal distribution or not. A statistical software (Graphpad Statmate, San Diego, CA, v. 1.01) provided values of probabilities associated to t and Z tests.

## RESULTS AND DISCUSSION

### Magnitude of hydroclimatic anomalies

Many factors, such as dilution (higher or lower flows), rains, conductivity, sun radiation, temperature, pH, etc., can be involved in processes of higher or lower inactivation of fecal coliforms in natural waters. During the studied period, significant changes in some of the mentioned variables were observed, specially in the hydrometric level and pluvial precipitation.

**Table 1.** The standard normal variable (Z) and significance (p) of pluvial anomalies (A) registered during El Niño (a), La Niña (b) and post-Niña (c) in relation to the pluriannual mean for each month\*.

	A**	Z ***	p
(a) Positive pluvial anomalies in high waters (h= 5.63 m $\pm$ 0.63 m)			
<i>Santa Fe</i> (x)			
December 1997	+83	+1.33	0.092
January 1998	+161	+2.22	0.013
March 1998	+126	+1.51	0.066
<i>Paraná</i> (xx)			
December 1997	+120	+1.69	0.045
January 1998	+110	+1.33	0.092
March 1998	+100	+1.12	0.130
(b) Negative pluvial anomalies in low waters (h= 1.88 m $\pm$ 0.18 m)			
<i>Santa Fe</i> (x)			
October 1999	-84.2	-1.24	0.107
November 1999	-83.6	-1.25	0.106
<i>Paraná</i> (xx)			
October 1999	-77.7	-1.07	0.142
November 1999	-78.3	-1.26	0.104
(c) Positive pluvial anomalies in mid waters (h = 3.24 m $\pm$ 0.36 m)			
<i>Santa Fe</i> (x)			
April 2000	+283	+3.70	0.0001
May 2000	+118	+2.4	0.0082
November 2000	+228	+3.4	0.0003
<i>Paraná</i> (xx)			
April 2000	+377	+5.11	<0.0001
May 2000	+182	+4.14	<0.0001
November 2000	+64	+1.03	0.151

(x) In the CIM Meteorological Station (FICH, UNL), 31° 38' S, 60° 40' W, right margin of the Paraná River.

(xx) In the INTA EEA Paraná Meteorological Station, 31° 50' S, 60° 31' W, left margin.

\*Significance Test of a sample (33).

\*\* A = observed precipitation minus mean precipitation.

\*\*\* Z = A/SD (SD = standard deviation of the mean).

**Table 2.** Comparison between medians\* of some variables during El Niño versus La Niña and post-La Niña.

	Niño	Niña	Post-Niña	p <sub>1</sub> **	p <sub>2</sub> ***
Paraná River (center)					
Oxygen (mg/l)	7.44	8.12	9.21	0.0296	0.0118
Transparency (cm)	39	11	29	0.0034	0.0017
pH (UpH)	7.20	7.60	7.40	0.0006	0.0307
Conductivity (:S/cm)	65	114	86	0.0001	0.0170
Temperature (°C)	23	25	20	0.0391	0.0255
<i>E. coli</i> (log <sub>10</sub> CFU/100 ml)	1.146	0.903	1.433	0.0595	0.2080
Correntoso River					
Oxygen (mg/l)	6.74	7.91	8.97	0.1230	0.0674
Transparency (cm)	36	13	22.5	0.0002	0.0030
pH (UpH)	7.25	7.20	7.40	0.2585	0.1067
Conductivity (:S/cm)	83	132	158	0.0001	0.0002
Temperature (°C)	23	27	19	0.0052	0.1552
<i>E. coli</i> (log <sub>10</sub> CFU/100 ml)	2.000	1.477	2.441	0.0361	0.0088
El Tigre Lake					
Oxygen (mg/l)	6.53	5.04	1.21	0.0857	0.0095
Transparency (cm)	57.5	40	25.5	0.0501	0.0339
pH (UpH)	7.20	6.85	7.05	0.1006	0.5000
Conductivity (:S/cm)	95	200	400	0.0018	0.0095
Temperature (°C)	22.5	27	22.2	0.0381	0.5330
<i>E. coli</i> (log <sub>10</sub> CFU/100 ml)	1.438	1.176	2.456	0.5697	0.0186
Los Matadores Lake					
Oxygen (mg/l)	6.29	4.98	6.82	0.3165	0.1964
Transparency (cm)	58	42	85	0.0296	0.0009
pH (UpH)	7.20	7.20	7.40	0.1170	0.0877
Conductivity (:S/cm)	80	145	270	0.0022	<0.0001
Temperature (°C)	22.5	27	17	0.0090	0.0216
<i>E. coli</i> (log <sub>10</sub> CFU/100 ml)	2.009	1.415	1.398	0.0604	0.0032

\* Mann-Whitney Test (two tales)

\*\*p<sub>1</sub>: p value for El Niño versus La Niña\*\*\*p<sub>2</sub>: p value for El Niño versus post-La Niña

In fact, in the Paraná Port, during October 1997 - June 1998 (Fig. 1), after a prolonged period (179 days) of mid levels (3.41±0.54 m), a period (227 days) with increasing hydrometric levels, from 3.0 m to 6.72 m (which means a flow from 14,000 m<sup>3</sup> s<sup>-1</sup> to, approximately, 30,000 m<sup>3</sup> s<sup>-1</sup>) began. This hydric situation was not only exceptional because of the levels reached but also due to its duration (213 days with higher levels than the alert level: ≥5 m and 58 days with higher levels than the evacuation level: ≥5.5 m). After the mentioned maximum peak, a period of prolonged low water (from 6.72 m to 3.61 m in 101 days) followed and then there was a new peak (5.2 ±0.1 m) of relatively short duration (24 days).

In the Middle Paraná River basin, these positive hydrological anomalies were similar to those registered in 1982 - 1983, but of a lower magnitude and with the particularity of having appeared together with important rains (20). Rains accumulated during December 1997 and

January and March 1998 exceeded the annual means registered during the same months, although with higher or lower statistical significance according to the pluviometric data used (Table 1).

After a period during which hydrometric levels of the Paraná River registered normal values (December 1998 through August 1999,  $\bar{x}$  = 3.60 m ± 0.43 m), a sustained low water began, remaining during six months (September 1999 - March 2000) at below 2.50 m ( $\bar{x}$  = 1.95 m "0.27 m"); at the same time, negative pluvial anomalies were registered (Table 1). The hydroclimatic situation described indicated the beginning of an episode of "La Niña", although of low magnitude (according to the National Oceanic and Atmospheric Administration - www.cpc.ncep.noaa.gov). Coincidentally, differences of pluvial precipitations in relation to historical means were not significant ( $p > 0.05$ ) (Table 1). Nevertheless, medians of some variables were signifi-

**Table 3.** Concentrations of some indicators of bacteriological quality of water during El Niño (November 1997- December 1998).

	TC*	FC*	EC**	FS**	PA*
Rivers					
Paraná (center)					
mean	2.153	1.293	1.187	0.947	0.647
minimum	1.903	1.041	0.740	0.845	< 1
maximum	2.699	1.903	1.903	1.041	1.556
Correntoso					
mean	3.069	2.231	1.975	1.573	0.834
minimum	2.477	1.845	1.699	1.146	< 1
maximum	3.230	3.114	2.544	2.114	2.041
Lakes					
Los Matadores					
mean	3.350	2.194	2.014	1.750	0.434
minimum	3.114	1.230	1.217	1.146	< 1
maximum	3.477	2.699	2.498	2.114	1.699
<i>Los Matadores (Eichhornia crassipes rhizosphere)</i>					
mean	4.608	3.476	3.036	nd	2.462
minimum	3.699	2.602	2.477	nd	2.146
maximum	5.204	4.279	3.556	nd	2.778
El Tigre					
mean	3.164	1.579	1.467	1.033	0.599
minimum	2.699	0.124	0.124	0.602	< 1
maximum	3.342	2.903	2.161	1.431	1.903
<i>El Tigre (E. crassipes rhizosphere)</i>					
mean	4.378	3.455	2.590	2.172	2.466
minimum	2.699	1.700	1.602	2.114	0.301
maximum	6.230	5.690	3.985	2.230	4.146

TC = Total coliforms; FC = Fecal coliforms, EC = *Escherichia coli*; FS = Fecal streptococci, PA= *Pseudomonas aeruginosa*.

nd = non determined

\* Log<sub>10</sub> MPN/100 ml

\*\* Log<sub>10</sub> CFU/100 ml

cantly different ( $p < 0.05$ ) to values registered during “El Niño” (Table 2).

After La Niña, since April 2000 (specially in April, May and November), important positive pluvial deviations were registered (Table 1). During this new rainy period, levels of the Paraná River (h) remained significantly lower ( $p < 0.0001$ ) than those registered during pluvial excesses, which occurred during the previous rainy period ( $h = 3.02 \text{ m} \pm 0.27 \text{ m}$  versus  $h = 5.25 \text{ m} \pm 0.35 \text{ m}$ ).

#### Effects of hydroclimatic anomalies on indicators of fecal contamination in the Paraná and Correntoso rivers

Mean concentration of fecal coliforms (Table 3), obtained during the 1997-1998 period in the Paraná River, was lower than that obtained during February 1978 - March 1979 at the same sampling point (Emiliani, 1980):  $1.293 \text{ log}_{10} \text{ MPN FC}/100 \text{ ml}$  versus  $1.906 \text{ log}_{10} \text{ MPN FC}/$

$100 \text{ ml}$  ( $p < 0.0001$ ). Concentrations of total coliforms were also lower, but the difference was not statistically significant ( $2.153 \text{ log}_{10} \text{ MPN TC}/100 \text{ ml}$  vs.  $2.492 \text{ log}_{10} \text{ MPN TC}/100 \text{ ml}$ ,  $p = 0.2416$ ).

Concentrations of fecal streptococci (Table 3) during the ENSO did not exceed the standards currently used in the European Union (12), nor those of the US-EPA (12) for bathing waters. Neither the concentrations of *P. aeruginosa*, for which concentrations lower than  $100 \text{ cfu}/100 \text{ ml}$  (12) have been recommended.

The concentrations of *E. coli* remained low in the center of the Paraná River and similar ( $p = 0.7250$ ) to those of the right and left margins (Fig. 2). The same figure shows that there were not many variations, with only a peak, in the center as in the margins, in the ascendent branch of the first flooding pulse, coinciding with the extreme local rains (January 1998). Furthermore, during December 1997 and March 1998, also with positive plu-

**Table 4.** Effects of pluvial anomalies on concentrations of *E. coli* ( $\log_{10}$  CFU/100 ml) of the Paraná River (center, right and left margins) in relation to the mean (X).

	<i>E. coli</i>	X	Sx	t*	p
<i>(a) Positive pluvial anomalies in high waters (h = 5.63 m ± 0.63 m):</i>					
Dec-97					
right	1.114	1.348	0.12	-1.92	0.034
center	1.114	1.246	0.09	-1.47	0.077
left	1.114	1.234	0.10	-1.20	0.121
Jan-98					
right	1.903	1.348	0.12	4.53	<0.0001
center	1.903	1.246	0.09	7.3	<0.0001
left	1.903	1.234	0.10	6.64	<0.0001
Mar-98					
right	0.602	1.348	0.12	-6.1	<0.0001
center	1.114	1.246	0.09	-1.47	0.077
left	0.398	1.234	0.10	-7.77	<0.0001
<i>(b) Negative pluvial anomalies in low waters (h = 1.88 m ± 0.18 m):</i>					
Oct-99					
right	0.845	1.348	0.12	-4.12	0.0002
center	0.903	1.246	0.09	-3.80	0.0004
left	1.130	1.234	0.10	-1.04	0.1544
Nov-99					
right	0.301	1.348	0.12	-8.56	<0.0001
center	0.699	1.246	0.09	-6.08	<0.0001
left	0.602	1.234	0.10	-6.29	<0.0001
<i>(c) Positive pluvial anomalies in mid waters (h = 3.24 m ± 0.36 m):</i>					
Apr-00					
right	2.0000	1.348	0.12	5.32	<0.0001
center	1.989	1.246	0.09	8.25	<0.0001
left	2.0934	1.234	0.10	8.54	<0.0001
May-00					
right	1.7924	1.348	0.12	3.63	0.0007
center	1.6232	1.246	0.09	4.19	0.0001
left	2.1875	1.234	0.10	9.47	<0.0001
Nov-00					
right	2.4771	1.348	0.12	9.23	<0.0001
center	2.3384	1.246	0.09	12.1	<0.0001
left	2.6989	1.234	0.10	14.6	<0.0001

\*Significance test of a sample (t-Student distribution);  $t = (EC - X) / Sx$ , where EC: concentration of *E. coli* during the pluvial extreme, X: mean concentration, Sx: standard error of the mean.

vial anomalies, concentrations of *E. coli* were lower than the mean (Table 4).

Minimum concentrations of *E. coli* ( $<1.0 \log_{10}$  cfu/100 ml), in both margins, were detected after the onrush of water in the flood and in coincidence with the two flooding peaks ( $h = 6.72$  m, and  $5.34$  m, April and November 1998, respectively). This decrease of concentrations can indicate the effect of dilution of great water volumes passing through the system. In fluvial systems, the literature

shows that this process of dilution is shared by the total number of bacteria (25) and other aquatic organisms, as macroinvertebrates, phytoplankton and zooplankton (16, 18, 29). On the other hand, if the flooding valley was an important supplier of coliforms, substantial peaks could have been observed during low water, when the valley drains into the river.

Low concentrations of *E. coli* were accentuated, in both margins, during negative pluvial anomalies, which sug-

**Table 5.-** Effects of pluvial anomalies on concentrations of *E. coli* ( $\log_{10}$  cfu/100 ml) of the Correntoso River in relation to the mean (X).

	<i>E. coli</i>	X	Sx	t*	p
<i>(a) Positive pluvial anomalies in high waters (h = 5.63 m ± 0.63 m):</i>					
Dec-97	2.544	2.108	0.091	4.79	< 0.0001
Jan-98	2.176	2.108	0.091	0.75	0.2309
Mar-98	2.000	2.108	0.091	1.19	0.123
<i>(b) Negative pluvial anomalies in low waters (h = 1.88 m ± 0.18 m):</i>					
Oct-99	1.477	2.108	0.091	-7.01	< 0.0001
Nov-99	1.097	2.108	0.091	-11.1	<0.0001
<i>(c) Positive pluvial anomalies in normal waters (h = 3.24 m ± 0.36 m)</i>					
Apr-00	2.992	2.108	0.091	9.71	< 0.0001
May-00	2.467	2.108	0.091	3.99	< 0.0001
Nov-00	3.325	2.108	0.091	13.4	< 0.0001

\*Significance test of a sample (t-Student distribution).  $t = (EC - X) / Sx$ , where EC: concentration of *E. coli* during the pluvial extreme, X: mean concentration, Sx: standard error of the mean.

gests that there are no point sources of contamination near the sampling area.

Fluctuations of concentrations of this indicator in the Paraná River could be due to the higher or lower incidence of non-point sources. As it is known (32), survival of coliforms is variable and depends on physical and biological factors. In general, and particularly for *E. coli*, survival is considered relatively low (36) and, therefore, usually, this bacteria is considered an indicator of recent fecal contamination (15). However, in sectors of non-polluted rivers, *E. coli* is also detected, but always in low concentrations. Thus, for example, concentrations of *E. coli* in non-polluted sectors of the Zambezi River (7 to 70 *E. coli* /100 ml) (15), or of the Ganges River (6 to 68 *E. coli* /100 ml) (3), show the same order of magnitude than those of the Paraná River.

At the end of the drought season, exceptional values in concentrations of *E. coli* were registered (Fig. 2). These concentrations were associated to local pluvial extremes and normal flows. Concentrations varied according to the point of sampling, but almost all of them were statistically significant in relation to the mean (Table 4).

Low concentrations of *E. coli* which were usually registered in the Middle Paraná River can be due to the fact that 95% of the flow is constituted by rains produced upstream (basins of the Upper Paraná, Iguazú and Paraguay rivers; Giacosa *et al.*, 20). These rains reach the Middle Paraná as a flow after passing along 750 km. This distance is covered in one or two weeks, according to the magnitude of the flood and the conditions of the flooding valley (Paoli - INA, pers. comm., 2003). It is probable that, during this period of time, coliforms became affected by environmental factors adverse to their survival or to their

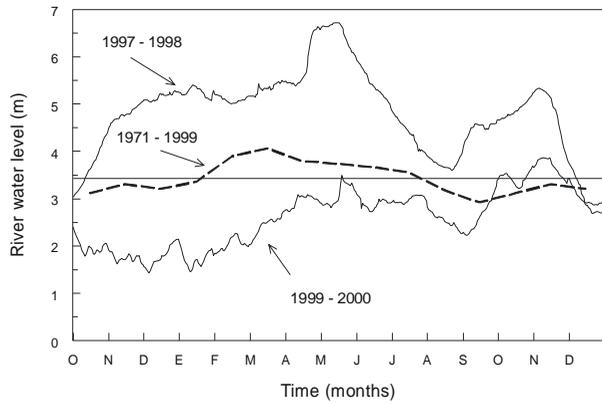
permanence in the water (dispersion and sedimentation). Therefore, maximum concentrations of *E. coli* were expected in the Paraná River, specially in relation to extraordinary local rains and more reduced river flows (Fig. 3). This means a lower dilution capacity and also a lower percentage of mortality (or losses by sedimentation), because of the lower transit time up to the sampling point. Furthermore, during the post-Niña rainy period, the highest concentrations of *E. coli* in the Paraná River were registered in the margins, producing a spatial heterogeneity not observed before (Fig. 2).

The multiple regression lineal model, constituted by the whole group of results, also shows that pluvial precipitations and water level are two factors related with the concentration of *E. coli* ( $R = 0.684$ ;  $p = 0.001$ ). Variables measured in the field (transparency, conductivity, oxygen and temperature) did not give any significant contribution ( $p > 0.05$ ) to the model, or showed collinearity problems.

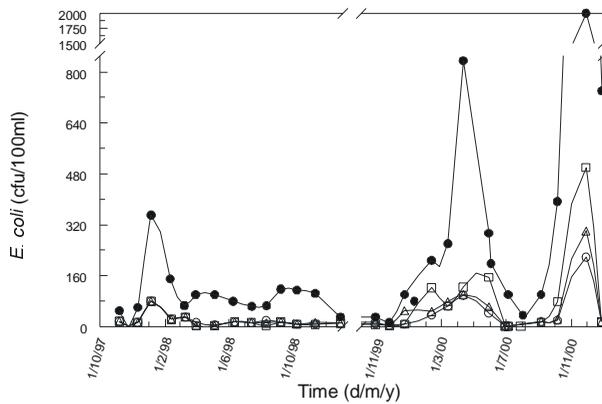
Concentrations of *E. coli* in the secondary course (Correntoso River) showed a pattern of temporal fluctuations similar to those found in the Paraná River (Fig. 2). They differentiated, however, by the higher magnitude of maximum concentrations reached during the episodes of extreme pluvial precipitations (Table 5), specially during the post-Niña period. These higher concentrations, in relation to the Paraná River, can be attributed to the lower capacity of dilution and to being downstream of urban centers (city of Santa Fe).

#### Effects of hydroclimatic anomalies on the fecal contamination indicator in alluvial valley lakes

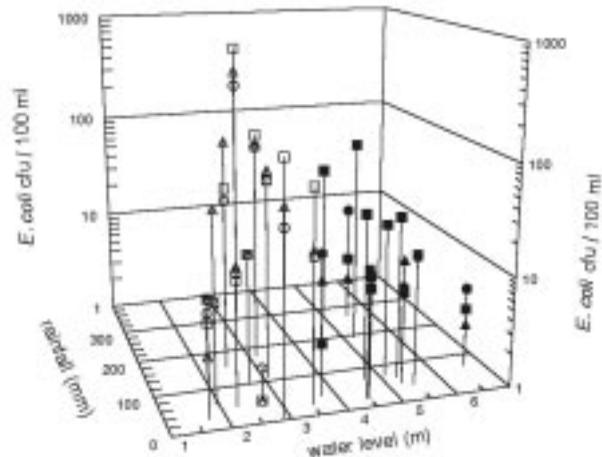
The death of rooted plants that could not grow at the rhythm of the flood (*Paspalum repens*, *Ludwigia peploides*



**Figure 1.** Positive hydrometric anomalies during El Niño (1997-1998) in the Paraná River, compared with negative anomalies (1999-2000) and with an average of 28 years (1971-1999). The horizontal line shows the water level (3.42 m) above which the flooding of the Middle Paraná River floodplain begins.



**Figure 2.** Fluctuations of *E. coli* concentrations in the center (-○-), right margin (-△-) and left margin (-□-) of the Paraná and Correntoso rivers (-●-).



**Figure 3.** Effects of rains on concentrations of *E. coli* in relation to the water level. Black symbols represent results during El Niño in the center (●), right margin (■) and left margin (▲). The same symbols, but in white, represent values during La Niña and post-Niña.

and *Enhydra anagallis*) was verified at the beginning of the flooding process. This episode was associated to minimum dissolved oxygen values (from 1.8 to 0.0 mg/l). It is possible that during decomposition of plants nutrients used by fecal coliforms were freed, which could explain the first peak in concentrations of *E. coli*. On the other hand, the death of aquatic rooted plants left free spaces that favoured the establishment of floating aquatic vegetation (native plants or derived from other aquatic environments).

The effect of El Niño on the permanence of floating aquatic vegetation (specially represented by *Eichhornia crassipes*) was different in the El Tigre Lake than in the Los Matadores Lake. The latter, as opposed to the former, could maintain the cover of macrophytes during the extraordinary flood, both reducing the population during low water.

During low water, concentrations of *E. coli* decreased in both locations, although to a greater extent in the El Tigre Lake (0.124 log<sub>10</sub> cfu/100 ml). High concentrations of *E. coli* in the rhizosphere of *E. crassipes* (Table 3) suggest that the higher or lower cover of floating macrophytes can influence concentrations of *E. coli* in the other water body (without vegetation). The abundance of fecal coliforms in the rhizosphere of aquatic plants is not surprising: they are also found in roots of subtropical terrestrial foraging grasses (39). Possibly, this could be a beneficial association for the macrophyte because of the capacity of fixing N<sub>2</sub> that some species of fecal coliforms have (39). Coliforms, also benefit from a higher provision of nutrients of plant origin and protection of sun radiation in the aquatic environment.

At the end of the drought period, the Los Matadores Lake remained free of vegetation, while the El Tigre Lake was being totally covered by floating macrophytes (until remaining almost inaccessible). As expected, maximum concentrations of *E. coli* were, thus, registered in the El Tigre Lake (2.908 log<sub>10</sub> cfu/100 ml).

The results of this study highlight that bacteriological quality of the Middle Paraná River does not change during negative hydroclimatic anomalies ("La Niña"), nor when extreme rains coincide with extraordinary flows ("El Niño"). The highest deterioration of bacteriological quality of the Middle Paraná River is associated to extreme pluvial episodes that occur during normal flows (post-"La Niña"). The results also allow to conclude that bacteriological quality of alluvial valley lakes of the Middle Paraná River is not directly related to those hydroclimatic events but with the degree of their plant cover.

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