Aquatic Botany, 47 (1994) 213–223

0304-3770/94/$07.00

Quantitative importance of particulate matter retention by the roots of *Eichhornia crassipes* in the Paraná floodplain

Alicia Poi de Neiff*,[a], Juan J. Neiff[a], Oscar Orfeo[a], Richard Carignan[b]
[a]*Centro de Ecología Aplicada del Litoral (CECOAL), Casilla de Correo 291, 3400 Corrientes, Argentina*
[b]*Université du Québec, INRS–Eau C.P. 7500, Ste-Foy, Que. G1V 4C7, Canada*

(Accepted 16 November 1993)

Abstract

The amounts of organic and inorganic particulate matter retained by the roots of the floating macrophyte *Eichhornia crassipes* (Mart.) Solms were followed for 17 months at two sites in the floodplain of the Paraná river. The average particulate matter burden associated with the roots was 925 g m^{-2} in a lake located near (0.3 km) the main river channel, and 511 g m^{-2} in the lake located farther (2 km) from the river. At low water, floating meadows in the distal lake retained more coarse particulate organic matter than those of the proximal lake. At high waters, inorganic sediment retention by the roots was much higher (1326 g m^{-2}) in the proximal lake than in the distal lake (179 g m^{-2}). Illite was the most abundant clay mineral associated with the roots and was supplied by the Paraguay–Bermejo rivers. Organic and inorganic sediment retention by the roots of *E. crassipes* floating meadows may represent a significant fraction of the annual nutrient demand by the meadows.

Introduction

Although several authors have mentioned the possible importance of sediment retention by submerged or floating macrophytes (Sculthorpe, 1967; Howard-Williams and Lenton, 1975; Haslam, 1978; Mulholland, 1981; Carignan, 1985; Esteves, 1988; Junk et al., 1989), relatively few quantitative data can be found on this subject. In the Amazon, Junk (1970) found that sediment retention by *Paspalum* floating meadows can amount to more than ten times the dry weight of the roots.

In the Paraná floodplain, *Eichhornia crassipes* (Mart.) Solms is one of the most abundant aquatic macrophytes. In the numerous water bodies where this plant is abundant, monthly average biomass ranges from 8.6 to 24 t ha^{-1} dry weight, with more than 35% as root tissue (Neiff and Poi de Neiff, 1984).

*Corresponding author.
SSDI 0304-3770(93)00367-H

Biomass increases from October to March, and declines to about 50% of its annual maximum from April to September.

Lakes in the floodplain can be flooded one to three times per year. During throughflow periods, floating macrophytes are retained in the lakes by fringing forests. During rising water, the roots of *E. crassipes* act like filters and trap riverborne particulate matter as well as particulate organic matter produced in the floodplain.

The capture of organic and inorganic particles by the root system of *E. crassipes* may represent a significant component of the nutrient budgets of the floating meadows and of the lakes. In this report we provide the first estimates of particulate organic and inorganic matter retention by the roots of *E. crassipes* in the Paraná floodplain. Spatial and temporal differences in the accumulation of materials in two lakes are highlighted in relation to changing water levels. Particle size and mineralogy of the inorganic fraction are used as indicators of the origin of the retained sediments.

Site description

The Lower Paraná is a fringing floodplain river with a 10 km wide alluvial valley at Corrientes. Its mean discharge is 16 000 m^3 s^{-1}, but can reach 60 000–70 000 m^3 s^{-1} in extraordinary floods such as that of 1983.

The Upper Paraná and Lower Paraguay rivers merge near Corrientes to form the Lower Paraná river (Neiff, 1990). Most of the suspended load carried by the Lower Paraná originates from the Bermejo river, which supplies approximately 10^8 t $year^{-1}$ to the Lower Paraguay and Lower Paraná (Drago and Amsler, 1988; Orfeo, 1992). The suspended load of the Upper Paraná is mainly composed of chlorite and kaolinite, whereas that of the Paraguay and Bermejo is characterized by larger amounts of illite and montmorillonite (Bonetto and Orfeo, 1984).

The study was conducted in lakes San Nicolás (Site A) and Esperanza (Site B) located in the right margin of the Paraná river (Fig. 1), opposite to the city of Corrientes (Argentina). San Nicolás lake (27°27′S; 58°55′W) is small (200 m × 2000 m), shallow (0.40–2 m) and hydrologically connected to the Paraná river one to three times per year, when the level of the river exceeds the 5.0 m mark at Puerto Corrientes. In this lake, *E. crassipes* forms cohesive mats which may cover up to 80% of the surface at the end of a prolonged low water period. The root systems of *E. crassipes* fill up the volume between the surface and the bottom only at low water.

Esperanza lake (27°30′S; 58°55′W) is located on Barranqueras Island in the main course of the Paraná river. The lake, 25 ha in area, is dendritic and bounded by 50 m wide, 6.0 m high alluvial levées occupied by a gallery forest. The river communicates with the lake by a narrow channel when the water level at Puerto Corrientes exceeds 4 m. Its depth fluctuates from 0.6 to 2.5 m

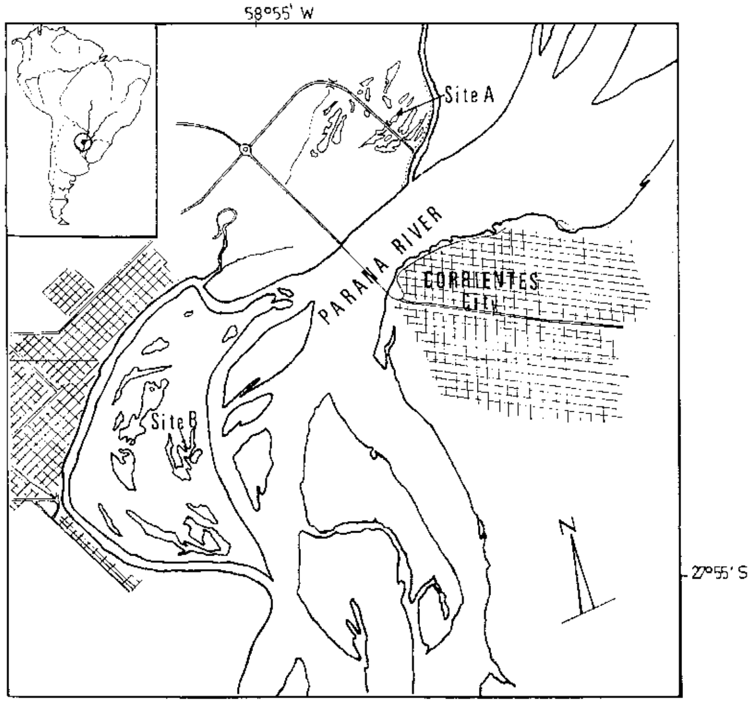

Fig. 1. Map of the Paraná river floodplain showing San Nicolás lake (Site A) and Esperanza lake (Site B) in Barranqueras island.

in relation to the hydrological regime of the river. The coverage of the lake by *E. crassipes* is less than 40%. During low and high water there is a free water layer between the roots and the sediments.

Materials and methods

The interior of the floating meadows was accessed by poling a small canoe through the mats.

Materials retained by the roots of *E. crassipes* were sampled in the two lakes on six occasions between November 1988 and March 1990, during low and high water phases (Fig. 2). On these occasions, vertical profiles of temperature, oxygen concentration and conductivity were recorded at 20 cm distances through the floating meadows, from the water surface.

Three replicate root samples were taken from monospecific stands by enclosing root clusters and surrounding water in plastic bags. Each root was agitated in three to five successive water baths until clear rinses were obtained. The resulting suspensions were passed through a 1 mm screen to remove the coarse particulate organic matter fraction (CPOM). This fraction was mainly

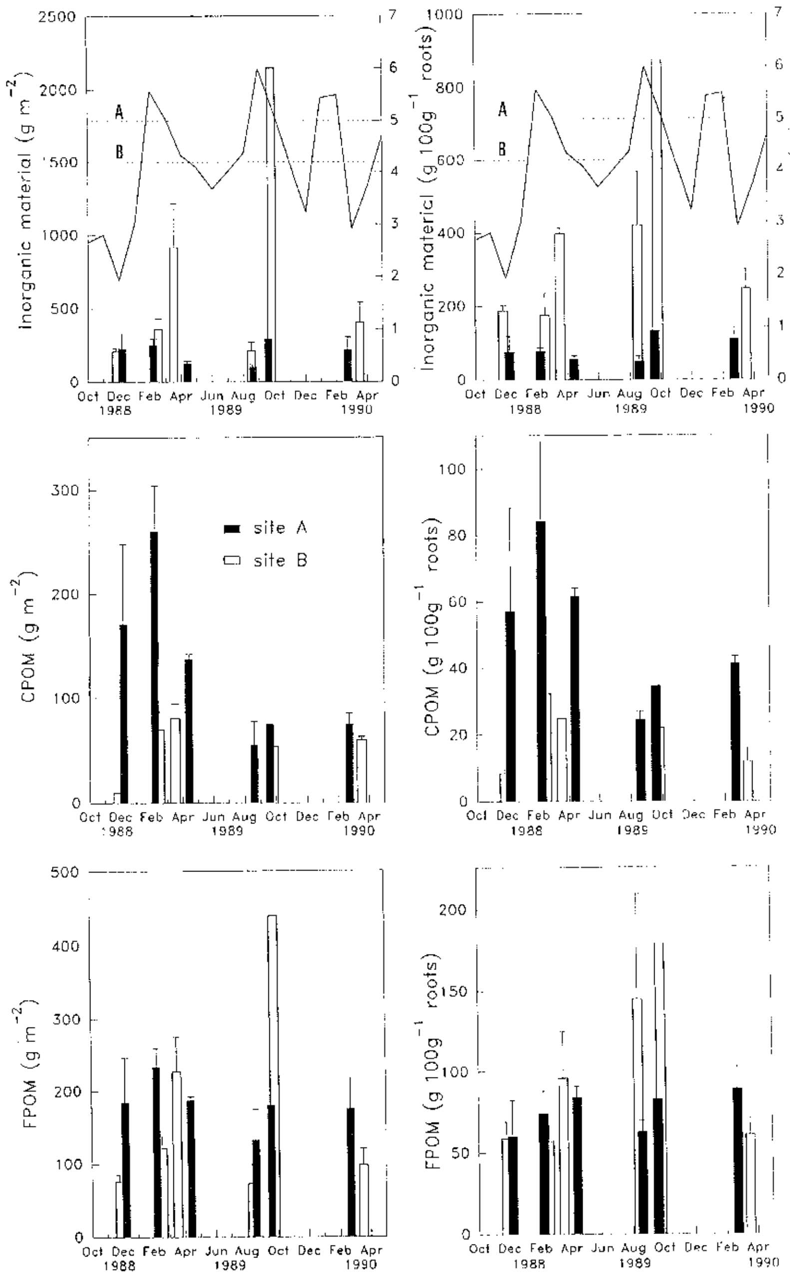

Fig. 2. Dry weight of inorganic material (IM), coarse particulate organic matter (CPOM) and fine particulate organic matter (FPOM) on Sites A and B. The values were expressed in g m^{-2} (on the left) and g per 100 g root dry weight (on the right). Vertical bars represent standard deviation. The mean monthly water levels of Paraná river at Puerto Corrientes between 1988 and 1990 are indicated in the top diagrams. Dotted lines indicate the flood level at Sites A and B.

composed of more or less decomposed roots and leaves of *E. crassipes*. Macroinvertebrates were separated manually from the detritus. The fine fraction (< 1 mm) was sedimented in glass containers using aluminium disulphate as a flocculant. The cleaned roots were dried at 105°C for 96 h. The attached material was dried to constant weight (96 h, 60°C) and weighed. Subsamples were ashed (6 h, 550°C) in a muffle furnace to determine the ash-free dry weight of the fine particulate organic matter fraction (FPOM). The dry weight of the CPOM, FPOM and inorganic matter (IM) was expressed in g m^{-2} and g per 100 g of root dry weight.

To determine the size distribution and mineralogical composition of inorganic particles, FPOM subsamples were oxidized using H_2O_2 and dried at 60°C (Carver, 1971). The residual inorganic material was then washed with distilled water through a 62 μm stainless steel sieve in order to retain sand grains. Finer material (silt and clay) that had passed through the sieve was analysed by the pipette method using sodium hexametaphosphate as dispersant. X-ray diffraction analyses of the clay fraction (< 4 μm) were carried out by the Centro de Investigaciones Geológicas (CIG–CONICET, La Plata, Argentina).

Results

The water level of the Paraná river at Puerto Corrientes fluctuated between 2 and 6 m during the study period (Fig. 2). Low water phases occurred from November 1988 through February 1989 and from April through August 1989. Sites A and B were flooded in late February and September 1989, and late January 1990. From September 1989 the Paraná river rose frequently and periods of isolation from the main channel were short.

There was significantly more root dry weight per m^2 at Site A (Table 1) than at Site B (ANOVA, $P<0.01$). The average dry biomass of roots in plants growing near the river was 170 g m^{-2} and 243 g m^{-2} in those growing distant from the main channel. At Site B the root clusters were considerably compact, whereas they reached a length of 80 cm at Site A at low water. Such morphological differences between roots of floating macrophytes growing in flowing waters compared with isolated waters have been reported by others (Engle and Melack, 1989) and have been attributed to differences in nutrient supply (Junk, 1970).

According to the average particulate matter retention (g m^{-2}) and average root biomass shown in Table 1, 1 m^2 of *E. crassipes* floating meadow accumulates 511 g at the more distant lake (Site A) and 925 g of total particulate matter in the lake located nearest to the Paraná river (Site B). The inorganic fraction amounts to 200 g m^{-2} at Site A and 707 g m^{-2} at Site B. These averages should be considered as approximative since root biomass can be quite variable within floating meadows.

Table 1
Root dry weight of *E. crassipes* and attached materials (inorganic+organic)

	Root dry weight ($g\ m^{-2}$)		Total retained particulate matter				IM/OM		
			g per 100 g root		$g\ m^{-2}$				
	A	B	A	B	A	B	A	B	
1988									
November	287.3	115.8	192.8	255.1	579.5	295.1	0.64	2.7	LW
December	±23.1	±6.1	±95.4	±1.8	±238.5	±16.1			
1989									
February	320.9	213.2	236.4	265.2	742.9	548.9	0.49	1.9	LW
	±42.8	±30	±40.1	±54	±46.6	±37.1			
March	223.4	242.3	201.7	517.6	449.2	1223.3	0.38	3.3	HW
April	±12.5	±26	±13.5	±196.2	±6.4	±360			
August	217.4	52.0	137.6	564.8	284.5	283.4	0.57	2.8	LW
	±83.8	±4.9	±19	±212	±85.9	±82.4			
September	217.9	245.6	251.3	1075.7	543.4	2642.0	1.13	4.3	HW
	±23.4	±32.1	±37.1	±325	±37.9	±420.2			
1990									
February	194.9	158.4	240.1	319.9	468.1	560.9	0.84	3.3	LW
March	±21.4	±22	±46.7	±83	±126.7	±158			
$\bar{X}$	243.6	171.2	209.9	499.7	511.2	925.6			

A, San Nicolás lake; B, Esperanza lake; IM, inorganic mattter; OM, organic matter; LW, low water; HW, high water.

Retention at low water

No significant differences (ANOVA, $P<0.01$) in total (Table 1) and inorganic material (Fig. 2) retention by roots were observed between both sites during low water periods. The roots of *E. crassipes* retained an average of 201 $g\ m^{-2}$ of inorganic sediments at Site A and 295 $g\ m^{-2}$ at Site B. CPOM retention was significantly higher (ANOVA, $P<0.01$) in the lake more distant from the main channel (Site A) than at Site B. FPOM was also significantly higher at Site A when expressed as $g\ m^{-2}$ (Fig. 2). However, the values were not significantly different when expressed on a g per 100 g of roots basis.

Retention at high waters

At Site B, the roots retained a maximum of 1075 g per 100 g, or 2642 $g\ m^{-2}$ of total particulate matter in September 1989 (Table 1). One sample was lost in this month before the ash-free dry weight was measured. The standard deviation for IM, CPOM and FPOM is not illustrated in Fig. 2. However, we assume these values may be acceptable because of the standard deviation of total particulate matter (<15% in September; Table 1).

During rising waters there was more IM associated with the roots at Site B compared with Site A (Fig. 2). Roots of plants growing near the main river channel had significantly less CPOM than those of plants located about 2 km from the Paraná river. FPOM retention was higher at Site B and the IM/OM ratio was higher at Site B.

Note that material retention was higher during the September 1989 flood (6 m) than during the March 1989 flood (5 m). The water levels shown in Fig. 2 are average monthly levels. Maximum levels recorded during these floods were 6.95 m in September and 5.99 m in March.

Mineralogy

At the start of the rising water period, the texture of the IM at Site B consisted of roughly equal proportions of silt and clay, with small amounts of sand (<2%). However, samples taken immediately after flow peaks showed a clear dominance of the clay fraction (nearly 85%) (Table 2). Site A showed larger proportions of sand and silt than Site B.

Table 3 shows the mineralogy of the clay fraction. Samples from Site B showed an almost invariable compositon with illite being the dominant (near 70%) mineral followed by chlorite (20%) and kaolinite (5–20%). Smectite was detectable in only one sample (5%). At Site A, illite was also dominant (mean 62%), followed by chlorite (15%), kaolinite (15%) and smectite (10%). Interlayer chlorite/smectite and chlorite/kaolinite represented about 20% of the clay content at Site A.

Limnological conditions

Vertical profiles of temperature taken in San Nicolás (Site A) and Esper anza (Site B) lakes, which extended 1 m below the surface, showed ephem

Table 2
Textural composition of inorganic materials gathered on *E. crassipes* roots

Sampling date	Site	Fractions abundance (% in weight)		
		Sand (2.0–0.062 mm)	Silt (0.062–0.004 mm)	Clay (<0.004 mm)
7 December 1988	A	11.65	47.82	40.53
6 February 1989	A	5.07	52.32	42.61
12 April 1989	A	13.58	59.35	29.07
28 August 1989	A	24.32	0.38	75.30
23 February 1990	A	9.01	1.27	89.72
17 February 1989	B	1.98	43.11	54.91
15 March 1989	B	0.43	15.13	84.44
14 March 1990	B	0.12	15.49	84.39

Table 3
Mineralogical composition of the day fraction (< 4 μm) retained by *E. crassipes* roots

Sampling date	Site	Clay mineral abundance (% in weight)			
		Illite	Chlorite	Kaolinite	Smectite
7 December 1988	A	60	20	10	10
6 February 1989	A	60	15	15	10
12 April 1989	A	50	30	–	Interlayer chlorite/smectite = 20
28 August 1989	A	80	Interlayer chlorite/kaolinite = 20		
23 February 1990	A	60	Interlayer chlorite/kaolinite = 20 Interlayer chlorite/smectite = 20		
17 February 1989	B	60	20	20	–
15 March 1989	B	70	20	10	–
14 March 1990	B	70	20	5	5

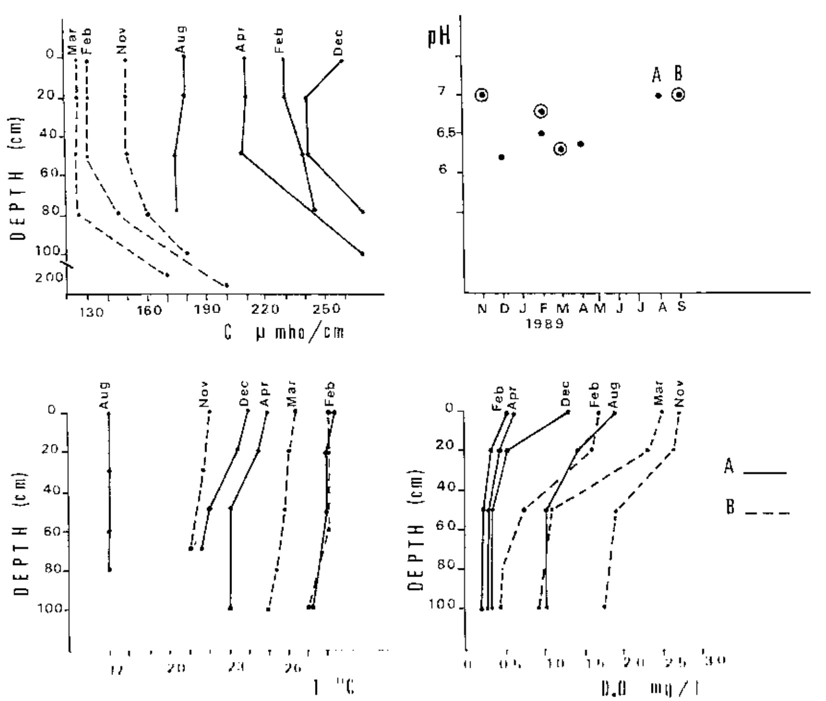

Fig. 3. Vertical profiles of conductivity (C), temperature (T) and dissolved oxygen (DO), and pH variation at water surface. The measurements were taken at 10:00 h in each month.

eral stratification which implies a frequent mixing of the water column. In the floating meadow complete circulation may occur once or twice a week (Carignan and Neiff, 1992).

Conductivity has orthograde profiles with lower values at Site B than at Site A (Fig.3). Vertical profiles of dissolved oxygen concentration are clinograde and show a more pronounced depletion at Site A. Low dissolved oxygen concentrations are presumably attributable to intense heterotrophic activity within the submerged part of the floating meadows. The pH varied between 6.2 and 7.0 (Fig. 3).

Discussion

Our results indicate that floating meadows play a double role as particulate matter traps. They retain both coarse and fine particulate organic materials produced within the meadows, and they retain inorganic sediments that are either supplied by the river during floods, or resuspended during low water periods. The relative importance of the inorganic and organic matter retained is probably attributable to the location of the water bodies within the floodplain and to differences in water quality.

The importance of lake location within the floodplain arises from the fact that, during normal floods (6–6.5 m), turbid river water does not penetrate very far into the floodplain, even if most of the 10 km wide floodplain becomes flooded. During such floods, the entering river water loses most of its suspended load (up to 1200 mg l^{-1}; Bonetto and Orfeo, 1984) within the first 100 m off the main river channel. It is only during exceptional floods (> 7.5 m) that turbid waters penetrate several kilometres into the floodplain (Carignan and Neiff, 1992). Thus, the floating meadows of ponds located several kilometres from the main channel, such as San Nicolás, are not expected to trap much inorganic sediment. On the other hand, the floating meadows of Esperanza lake trapped seven times as much inorganic material as San Nicolás lake during rising waters. Esperanza lake is located on an island, 300 m from the main channel, and receives turbid river water directly. The data of this lake are comparable with those reported by Junk (1970) in the Amazon for *Paspalum* meadows growing in flowing waters.

More CPOM was found during low and high waters in the lake located far from the river. This may be attributable to the major development of the root systems and to the lower oxygen concentrations and lower pH observed in this site (Fig. 3). Decomposition of *E. crassipes* leaves is slow (decay coefficient = 0.002 per day) in these conditions with accumulation of CPOM (Poi de Neiff and Neiff, 1988).

Retention by the roots and mineralization of locally produced CPOM ensures an efficient within-meadow recycling of nutrients. Carignan and Neiff (1992) have estimated that litter decay contributes about 20% of the nitrogen requirement of such meadows. In addition, the large amount of inorganic sediments retained by the meadows during floods (up to 1030 g m^{-2}) represents a significant fraction of the annual phosphorus requirement by the floating meadows. This increment is calculated here as the difference between inorganic sediment found associated with the roots immediately after (1327 g m^{-2}) and before (295 g m^{-2}) floods. R. Carignan and P. Vaithiyanathan (unpublished data) have found that sediments from the Lower Paraguay contain about 15 μmol g^{-1} of calcium-bound phosphorus which is rapidly transformed into dissolved orthophosphate when submitted to the acidic conditions prevalent in the floodplain during isolation phases. Thus, floating meadows that are proximal to the river can capture as much as 15.5 μmol m^{-2} of available phosphorus during floods. The total phosphorus content of *E. crassipes* at our study site varies from 0.15 to 0.4% (Carignan et al., 1993), and seasonal biomass increments are in the order of 1 kg m^{-2}. This means that the seasonal phosphorus demand by meadows is in the order of 50–130 μmol m^{-2}. Therefore, the capture of inorganic available phosphorus during floods may represent 12–31% of the seasonal phosphorus requirement by the floating medows. It should be noted that we did not observe any significant loss of floating meadows to the river channel during the flood pulses described in this study.

Floodplain wetlands covered by *E. crassipes* accumulate and transfer organic and inorganic materials within the flood valley, especially during high water. Thus, any organic or inorganic nutrients captured by the meadows during normal floods represent net increments for the lakes. Significant plant loss to the river or surrounding forest only occurs during exceptional floods (> 7.5 m). Extreme floods partially clean these water bodies and rearrange the communities to earlier successional stages (Junk et al., 1989; Neiff, 1990).

Textural differences of inorganic materials at Site B followed the hydrological fluctuations of the Paraná river within the floodplain. A higher proportion of sand appeared in the peaks. The clay mineral associations were roughly similar in both ponds, but smectites appeared in a higher proportion at Site B as a distinctive feature. Kaolinite and smectites on plant roots were probably supplied by the Paraguay and Upper Paraná rivers, which drain the tropical Brazilian shields and extensive areas covered by basalts and lateritic soils (Depetris and Griffin, 1968; Bonetto and Orfeo, 1984). Illite was supplied by the Paraguay–Bermejo river system, which drains the arid environments of the Andean mountains.

Acknowledgements

We feel greatly indebted to the Centro de Investigaciones Geológicas (CIG–CONICET, La Plata) for doing the X-ray diffraction analyses. We are grateful to Dr Robert W. Wetzel for reviewing the manuscript.

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