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Deposition of sediments during a flood event on seasonally flooded forests of the lower Orinoco River and two of its black-water tributaries, Venezuela

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Abstract. Deposition of suspended sediments and their associated nutrients were estimated during the flood event of 1995 in the seasonally flooded forests of the Mapire and Caura Rivers, two black-water tributaries of lower Orinoco, and on two islands of this white-water river. The deposition spanned a wide range from 0.07 kg m^{-2} in the depositional bar forests of the Mapire River to 73.60 kg m^{-2} on the flooded forests of the Orinoco Island site called Jarizo. This variation is associated with the dynamic nature of sediment mobilization, transport and deposition, as well as with the different geomorphic environments and erosion processes upstream from the study sites. The deposited sediment in all the study areas was highly quartzitic with a relatively high content of kaolinite and goethite. Only in the sediment of the Orinoco Islands was mica (illite) identified in a relatively high proportion. These mineralogical results reflect the intense weathering processes in the catchment areas of the study rivers. The chemical composition of the deposited sediments showed a great variability among the different study areas, which is in part related to the mineral composition of the sediments and their particle size distribution. The highest concentrations of K, Ca and Mg were found on the clay sediments of the Orinoco agricultural island. The total amount of deposited nutrients varied over a wide range, which is influenced by the amount of deposited sediments. In the Jarizo Island site of lower Orinoco were deposited the largest amount of nutrients. In the flooded forests of the Mapire River, the nutrient contribution by the deposited sediments to the nutrient cycling is relatively low in the depositional-bar forests and practically nonexistent in the forests sites on terraces.

Introduction

The biogeochemical cycles in seasonally flooded forests are highly complex. Periodic and drastic natural changes in the regional hydroperiod impose oscillations between aquatic and terrestrial phases on such forested areas. The pulsing of the river discharge is therefore the major driving force responsible for the structure, function and evolutionary history of the biota in these ecosystems (Junk et al. 1989), which assume an intermediate position between open, transporting systems, and closed, accumulative systems (Junk 1997).

Flooded forests contain many complex nutrient pathways, each with different magnitudes and qualities (Brinson et al. 1981). Sediment is one of the major storage compartments of the wetland ecosystem, and its role as a pathway in the nutrient cycling covers essentially the nonbiologically mediated exchanges associated with through-flowing water. Howard-Williams (1985) explains that the most important of these exchanges is that of sedimentation of materials by wetlands under some hydrological conditions, and erosion of materials under other hydrological conditions.

Floodplain forests are important sinks for storing suspended sediment and associated elements mobilized from the upstream catchment (Lowrance et al. 1984; Cooper et al. 1987). High-water periods open the floodplain ecosystem to lateral inflow and outflow of material (Brinson et al. 1981). During these times, flooded forests are frequently inundated by water with variable contents of suspended sediments, and a significant proportion of this material may be deposited, as a consequence of the decreasing water velocities caused by the floodplain vegetation. Walling and He (1996) pointed out that the proportion of deposited sediment may vary between flood events and both within and between different floodplain sites.

Deposition of suspended sediments into the floodplain ecosystem is therefore of great ecological significance, particularly because the fertility of this ecosystem depends largely upon the quality of the deposited material (Junk et al. 1989; Junk & Welcome 1990). Despite the important role attributed to the sediment, very few quantitative data on deposited sediments and associated nutrients are available for tropical floodplain forests. For example, Kalliola et al. (1993) determined the mineral nutrient from recent fluvial sediments in Peruvian Amazonia; Barrios et al. (1994) quantified the amount of sediments and litter inputs in an agricultural plot on an island in the lower Orinoco; Mertes (1994) estimated rates of transport and the fate of water and sediment in a 200 km reach of the Central Amazon River; Chauvel et al. (1996) estimated the sedimentation rates in a Central Amazonian black-water inundation forest; and Irion et al. (1996) summarized the information on sediment transport and deposition for the Central Amazonian floodplain.

The present study was carried out in the floodplain forests of the Mapire and Caura Rivers, two black-water tributaries of lower Orinoco River, and on white-water flooded islands of lower Orinoco. These flooded areas are of particular interest for the local population, because they are used for traditional forest management, fisheries and agriculture. Because suspended sediments are an important nutrient input into these areas, investigation of the deposition of this material is therefore an essential requirement to understand the biogeochemical processes of these wetland ecosystems. The main objectives of the present study were: (i) to quantify the deposition of suspended sediments and associated nutrients during a flood event in the seasonally flooded forests of Mapire and Caura Rivers and on islands of lower Orinoco River, (ii) to determine the mineral composition in the fine fraction of the deposited material in the study areas, and (iii) to examine whether the quantities of sediments and their associated nutrients differ among the different study areas.

Study sites

The Orinoco is the largest river of Venezuela, approximately 2,150 km long draining an area of about 10^6 km^2, the third largest drainage basin in South America (Depetris & Paolini 1991). This river is easily divisible into three main sections: the upper Orinoco, the middle Orinoco and the lower Orinoco. According to Nemeth et al. (1982), the lower Orinoco begins at the confluence with the Apure River (Figure 1). The largest southern tributaries of lower Orinoco are the Caroní and Caura Rivers, which drain the Venezuelan Guayana. The main northern tributaries of lower Orinoco, bringing waters from the Andean foothills and from the plains (Llanos), are generally rich in electrolytes and suspended material (Depetris & Paolini 1991).

The Caura River is 680 km long and drains a large forested watershed (47,000 km^2) in the Guayana Shield, a highly weathered Precambrian terrain (Lewis et al. 1986). The Mapire River is a low-order left tributary of the lower Orinoco, and its basin (283 km^2) occupies a portion of the Pleistocene Mesa Formation, which consists mainly of medium-grained sand, and whose characteristics suggest fluvial channel deposition (Carbón & Schubert 1994). Both the Caura and Mapire Rivers have been classified as black-water rivers because of their brown color and their oligotrophic character in terms of nutrient and primary productivity (Lewis et al. 1986; Vegas-Vilarrúbia 1988; García 1996).

The study sites in the Caura River Basin were located in the flooded forests of the upper Caura (05°10′ N, 64°10′ W), middle Caura (05°56′ N, 64°27′ W) and lower Caura (07°36′ N, 64°55′ W) (Figure 1). The Caura joins the lower Orinoco approximately 20 km upstream from the Mapire River mouth. The study site in the floodplain of the Mapire River was located in the inundation gradient of the lowest reach of this river, near where it joins the Orinoco (7°44′ N, 64°45′ W). In lower Orinoco River the study sites were located in two seasonally flooded islands (7°40–50′ N, 64°3–40′ W) close to the Mapire

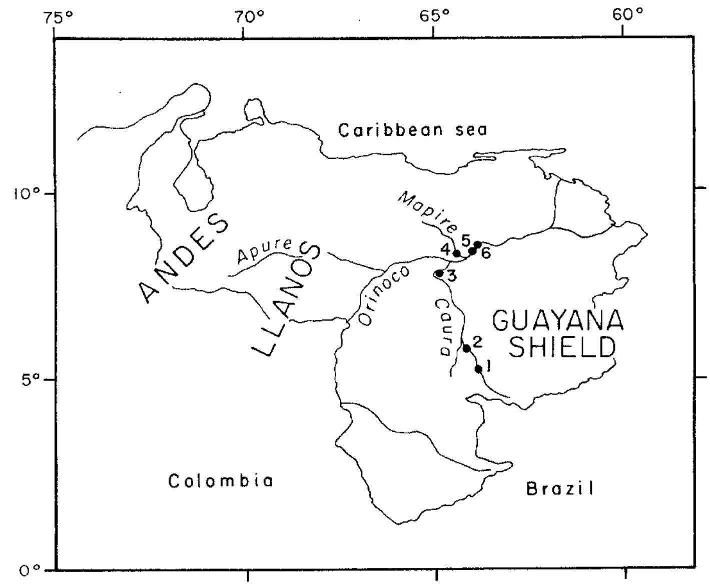

Figure 1. Location of the study areas: 1 = upper Caura, 2 = middle Caura, 3 = lower Caura, 4 = Mapire, 5 = Jarizo Island, 6 = agricultural land.

site; one of the islands is covered by forests dominated by the single species *Coccoloba obtusifolia* (Jarizo) and the other has been cleared and is presently used as agricultural land.

Ewel and Madrid (1968) classified the bioclimate of the Mapire and Orinoco study sites as dry tropical forest. Martínez (1996) has also classified the bioclimate of lower Caura River as dry tropical forest, and the bioclimate of middle and upper Caura as humid tropical rainforest.

The mean annual precipitation in the closest metereological stations to the upper and middle Caura (Entreríos and Ceiato stations) fluctuates between 2,594 and 3,260 mm, with the dry period from December to March and the wet period from April to November (Vargas & Rangel 1996). According to the climatic diagram of Musinacio, the closest metereological station to the study sites located in lower Caura, Mapire and Orinoco Islands, the annual mean precipitation averages 1,333 mm, with the dry season between November and April and the rainy season from May to October (Vegas-Vilarrúbia & Herrera 1993).

During the high water period, the Orinoco River acts as a dam to the Mapire river discharge, resulting in the formation of a standing lake-like waterbody that covers the gallery forest up to the canopy for five to six months (Vegas-Villarrúbia & Herrera 1993). These forests show structural and floristic differences along a gradient from the depositional bar or longer term flooding zone, to the upper terrace, or shorter term flooding zone. The depth of the inundation in this gradient reaches up to 15 m and the most common plant species are typical of the oligotrophic black-water areas of the Amazon floodplain (Rosales 1989). On the other hand, the Orinoco Islands represent alluvial banks that get flooded between June and October.

In the Caura River Basin, the flooded forests are associated with two distinct geomorphic environments: the large floodplain of the lower Caura, and the river channels and floodplains of variable width in those areas of middle and upper Caura where the river is structurally controlled. Rosales (1996) states that these forests get flooded to a depth of 12 m for several months each year, and that their flora represents a mix of species typically found in eutrophic white-water floodplains and those typically found in black-water areas.

The deposited sediments were collected in eight different sites. Along the inundation gradient of the Mapire floodplain, the experiment was carried out in the following areas: (A) depositional bar, or longer term flooding zone, inundated from May to December, (B) lower terrace, or middle flooding zone, inundated between June and November, and (C) upper terrace, or shorter time flooding zone, inundated from July to October. In the lower Caura River (D) the sediments were sampled in the flooded forest growing on the depositional bar, which is flooded from May to October. In the middle (E) and upper Caura (F) the deposited sediments were collected in the depositional bar, inundated from April–May to November–December. In the Orinoco Island (G, H) the sediments were sampled in the depositional bar, that gets flooded between May and October.

Material and methods

Deposition of sediments was estimated during the flood event in year 1995, using sediment traps (Pinay et al. 1995; several authors as reviewed by Walling & He 1997). Sediment quantity in each of the eight study sites was collected using eight smooth sheets of plastic (25×35 cm) randomly placed on the surface of the forest floor. In order to maintain the traps on the soil and to prevent their being washed away during the flood phase, each trap was fixed to the soil by its four corners with 40 cm long metal stakes.

The traps were placed on the forest floor on March 1995, before the beginning of the flood phase. The sediments were removed from each trap just after the end of the flooding period, using a steel frame of $20 \times 28 \times 20$ cm. The collected material was placed in individual envelopes and transported to the laboratory for analysis. The sediments were air dried and passed through a 2 mm soil sieve. Plant litter remnants were removed from the sieved material.

Because the less than 2 mm fraction still contained plant litter remnants, it was subsequently passed through a 0.14 mm soil sieve. The dry weight of both fractions, smaller than 0.14 mm and between 0.14–2 mm, was determined. For each study site, the values obtained of the deposited sediments on the eight sediment traps were averaged and expressed per m^2 of flooded soil.

Samples of the less than 0.14 mm fraction from each sediment trap were kept for chemical and mineralogical analysis. Soil pH was measured in 1M KCl. Sediment texture was determined by the hydrometer method (Day 1965). Total carbon was determined by the Walkley & Black method (Jackson 1976). Total nitrogen was measured following the Kjeldahl method (Jackson 1976). Sediment available phosphorus was extracted with the North Carolina solution (Nelson et al. 1953) and determined colorimetrically (Murphy & Riley 1962). Exchangeable aluminium and exchangeable acidity were extracted with 1M KCl solution and determined by titration with NaOH (McLean 1965). Extractable base cations (K, Mg, Na, and Ca) were determined by atomic-absorption spectrophotometry using 1N ammonium acetate as extracting solution (Thomas 1982). The results were expressed as element concentration and as annual nutrient input to the flooded soil.

The mineral components in the deposited sediments were qualitatively identified in the less than 2 μm fraction using X-ray diffraction analysis, according to the method described by Whittig (1965). During the pretreatment of the analyzed material, the methodology variations proposed by Genrich and Bremner (1972) and Busacca et al. (1984) were considered. Subsequently, the pretreated material was separated following the method of Whittig and Allardiace (1986). Iron oxides were determined in the less than 100 μm fraction taking into account the suggestions of Schwertmann and Taylor (1977). A paired t-test at $P < 0.05$ was used to test for differences among study sites.

Results

Amount of deposited sediments and their particle size distribution

The total amount of sediments (fraction < 2 mm) deposited during the flood event of 1995 in the eight study sites varied over a wide range from 0.07 to 73.60 kg m^{-2} (Table 1). The largest amounts were collected on the Orinoco Island site called Jarizo and the smallest in the flooded forests of the Mapire River. With few exceptions, such as between Mapire lower and upper terrace (t = 1.16; p = 0.26) and between the Mapire depositional bar and the lower Caura (t = 0.79; p = 0.44), there were significant differences in the amount of deposited sediment among all study sites.

Table 1. Amount of deposited sediments and their texture in the studied sites.

Site	Amount of sediment (kg m^{-2})	Particle size (%)			Texture
		Clay	Silt	Sand	
Upper Caura (DB)	25.94 ± 10.72	21	54	25	Silt loam
Middle Caura (DB)	7.19 ± 4.03	26	44	30	Loam
Lower Caura (DB)	1.45 ± 1.08	12	23	65	Sandy loam
Mapire (DB)	2.29 ± 1.51	26	4	70	Sandy clay loam
Mapire (LT)	0.10 ± 0.05	–	–	–	–
Mapire (UT)	0.07 ± 0.03	–	–	–	–
Orinoco agricultural land	5.04 ±1.71	48	34	18	Clay
Orinoco Jarizo Island	73.60 ±15.60	18	67	15	Silt loam

DB = depositional bar
LW = lower terrace
UT = upper terrace

In the Caura River Basin, the deposited sediments decrease downstream significantly from 25.94 kg m^{-2} in the upper Caura to 1.45 kg m^{-2} in the lower Caura ($t = 4.92$; $p = 0.001$). Along the inundation gradient of the Mapire River, the quantities of sediments collected in the upper and lower terrace were practically negligible; the collected quantity in the depositional bar was, however, higher and comparable to those of the lower Caura. Between both Orinoco Island sites, Jarizo and the agricultural land, there were significant differences ($t = 15.53$; $p < 0.0001$) in the amount of deposited sediments, namely 73.6 and 5.0 kg m^{-2} respectively (Table 1).

The collected sediments also showed differences in their textures, particularly with respect to the sand and silt content (Table 1). In Caura River Basin, the sand content in the sediments of the depositional bar increased downstream from 25% to 65%, and the silt content decreased concomitantly from 54 to 23%. The sand content of both Orinoco Island sites was similar, but the clay and silt content showed marked differences. In the Mapire depositional bar, the sand content in the sediment was 70%. Because the amount of sediments deposited on the Mapire lower and upper terrace was negligible, the texture could not be determined.

Table 2. Dominant minerals in the less than 0.002 mm fraction in sediments.

Site	Minerals[1]
Upper Caura	Quartz $\gg$ goethite > kaolinite $\gg$ muscovite > fe ldsparþhematite, mica (illite)
Middle Caura	Quartz $\gg$ kaolinite $\gg$ goethite > muscovite $\cong$ feld spar $\gg$ hematite, mica (illite)
Lower Caura (DB)	Quartz $\gg$ kaolinite > goethite > muscovite $\cong$ feldspa r $\gg$ hematite
Mapire (DB)	Quartz $\gg$ kaolinite $\gg$ goethite $\gg$ hematite
Mapire (LT)	Quartz $\gg$ kaolinite $\gg$ goethite $\gg$ hematite
Mapire (UT)	Quartz $\gg$ kaolinite $\gg$ goethite $\gg$ hematite
Orinoco agricultural land	Quartz $\gg$ kaolinite > goethite $\cong$ mica (illite) > muscovite > feldspar $\gg$ hematite
Orinoco Jarizo Island	Quartz $\gg$ kaolinite > goethite $\cong$ mica (illite) > muscovite > feldspar $\gg$ hematite

[1] Mineral are listed in order of relative peak intensities
DB = depositional bar
LW = lower terrace
UT = upper terrace

Mineral and chemical composition of the deposited sediments

The relative abundance of minerals in the $\leq 2\ \mu$m sediment fraction is given in Table 2. Quartz was present in large amounts at all study sites. With the exception of the upper Caura site, kaolinite and goethite were the second and third respectively most important minerals in the collected sediments. Hematite was also present at all study sites, but in lesser amounts. Mica (illite) was identified only in the sediments of the Orinoco Islands in a proportion relatively similar to that of goethite, and was also present in very small amounts in the upper and middle Caura. Muscovite and feldspar were present in the upper, middle and lower Caura, as well as in the sediments on the Orinoco Islands. In relation to the number of identified minerals, the sediments in the depositional bar of the Mapire River were the poorest and the sediments on the Orinoco Islands and in the upper and lower Caura were the richest.

The element concentration in the deposited sediments is summarized in Table 3 (mean concentration $\pm$ standard deviation). There are marked differences in the chemistry of the sediments among the different study sites. In the sediments of the flooded forests of the Caura River, the C and N concentrations increase downstream significantly from 1.53% C and 0.09% N in the upper Caura to 4.60% C and 0.26% N in the lower Caura (t = 6.47, p <

0.0001 for C; $t = 12.79$, $p < 0.0001$ for N). The element concentration in the sediments of the inundation gradient of Mapire River was determined only in the depositional bar, due to the almost negligible amounts of sediments that were deposited in the terraces. The C and N concentrations in the Mapire depositional bar also showed statistical differences when compared to those of upper Caura ($t = 5.98$, $p < 0.0001$ for C; $t = 3.84$, $p = 0.0018$ for N) and middle Caura ($t = 3.36$, $p = 0.0028$ for C; $t = 2.28$, $p = 0.345$ for N). The lowest concentrations of these elements were found in the sediments of the Orinoco Islands; between both island sites there were also statistical differences in the C and N concentrations ($t = 10.87$ for C and 10.94 for N; $p < 0.0001$). The C/N ratio of the sediments varied from 16.7–18.8 in the Caura River Basin to 11.3–12.2 on the Orinoco Islands. The concentrations of P in the sediments of Caura River decreased downstream significantly from 7.61 μg/g in the upper Caura to 1.73 μg/g in the sediments of lower Caura ($t = 5.45$; $p < 0.0001$). The P concentration in the sediments of the Mapire River was the lowest (1.04 μg/g), and its concentration on the Orinoco Island site Jarizo was high (6.16 μg/g) and comparable to that of the upper Caura (7.61 μg/g) ($t = 1.70$; $p = 0.10$). The base cations increased downstream in Caura River Basin. The highest concentrations of K, Ca and Mg and the highest exchange acidity were found on the sediments of the Orinoco Island used as agricultural land.

The amount of nutrients deposited with the sediments (fraction < 0.14 mm) per hectare of flooded soils is given in Table 4. The total quantity of deposited nutrients during the flood event varied over a wide range, which is influenced both by the amount of deposited sediments (Table 1) and by their nutrient concentration (Table 3). The largest amount of all nutrients were deposited on the Orinoco Island site covered by the tree species Jarizo (*Coccoloba obtusifolia*). The amount of K deposited on the Orinoco Island used as agricultural land was as great as the amount of this element deposited on the Jarizo Island site. The deposited amounts of Ca in the agricultural land and in lower Caura were also relatively large. Apart from the Jarizo Island site, the greatest amounts of C, N and P were deposited in the upper Caura. Table 4 shows also that the sediments contributed very small amounts of base cations and P to the flooded forest in the depositional bar of the Mapire River; in the terraces one would expect the contribution to be even lower, but insufficient sediment mass did not allow for this to be quantified.

Discussion

The amount of sediments deposited during individual flood events will vary according to the magnitude and duration of the event and other characteristics, including the suspended sediment concentrations involved (Walling & He

Table 3. Chemical composition (Mean ± SD) of the deposited sediments in the studied sites.

Site	PH (KCl)	C%	N%	C/N	P(μ/g)	K	Mg	Ca	Al + H	$\sum$
						$cmol_c\ kg^{-1}$				
Upper Caura (DB)	4.2	1.53 ±0.39	0.09 ±0.03	18.5 ±3.9	7.61 ±2.31	0.08 ±0.02	0.36 ±0.15	0.03 ±0.01	0.56 ±0.06	1.03
Middle Caura (DB)	4.0	4.35 ±0.61	0.27 ±0.08	16.7 ±2.7	2.73 ±1.16	0.13 ±0.04	0.55 ±0.09	0.05 ±0.01	1.07 ±0.19	1.80
Lower Caura (DB)	4.1	4.60 ±1.44	0.26 ±0.05	18.8 ±1.8	1.73 ±1.15	0.13 ±0.02	0.40 ±0.20	1.26 ±0.30	0.67 ±0.07	2.46
Mapire (DB)	3.8	3.34 ±0.86	0.21 ±0.09	17.0 ±1.3	1.04 ±0.26	0.19 ±0.10	0.53 ±0.28	0.58 ±0.57	1.64 ±0.23	2.94
Mapire (LT)	3.4	–	–	–	–	–	–	–	–	–
Mapire (UT)	3.6	–	–	–	–	–	–	–	–	–
Agricultural land	3.8	2.1 ±0.41	0.18 ±0.03	11.3 ±1.2	2.02 ±1.00	0.91 ±0.45	0.78 ±0.19	1.97 ±0.33	2.17 ±0.69	5.83
Orinoco Jarizo Island	4.0	0.88 ±0.09	0.07 ±0.02	12.2 ±2.39	6.16 ±1.25	0.07 ±0.01	0.43 ±0.12	1.47 ±0.27	0.43 ±0.12	2.40

$\sum$ = sum (Ca+Mg+K+Al+H)
DB = depositional bar
LW = lower terrace
UT = upper terrace

1997). Accordingly one can only make qualitative statements on the temporal dynamics of the sedimentation process. Between the different study areas, the deposition of suspended sediments during the 1995 flood event varies significantly, not only in the deposited amounts (Table 1) but also in mineral and chemical composition (Tables 2 and 3). This variability is associated with the dynamic nature of sediment mobilization, transport and deposition (He & Walling 1997), as well as with the geological origin of the sediments and the different geomorphic environments and erosion processes upstream from the study sites.

In its lower section, the Orinoco has already received large inflows from rivers that drain the Andes, the Guayana Shield and the Llanos. Owing particularly to the influence of the larger Andean tributaries, the lower Orinoco transports large amounts of suspended sediments (Meade et al. 1990), which will be deposited in an irregular manner, as indicated by our

Table 4. Amount of nutrients (Mean ± SD) deposited with the sediments in the study sites.

Site	Nutrient (kg ha^{-1})					
	C	N	P	K	Mg	Ca
Upper Caura (DB)	2,284.9 ±1,007.8	133.4 ±57.3	1.17 ±0.66	4.69 ±2.19	6.54 ±2.50	0.98 ±0.17
Middle Caura (DB)	2,141.8 ±1,179.1	128.4 ±56.6	0.15 ±0.13	2.37 ±1.21	3.07 ±1.13	0.50 ±0.20
Lower Caura (DB)	545.7 ±171.2	21.27 ±10.04	0.02 ±0.01	0.62 ±0.17	0.57± 0.29	2.98 ±0.71
Mapire (DB)	478.3 ±122.6	29.5 ±12.4	0.02 ±0.00	1.04 ±0.59	0.91 ±0.39	0.96 ±0.42
Mapire (LT)	–	–	–	–	–	–
Mapire (UT)	–	–	–	–	–	–
Agricultural land	451.6 ± 88.1	39.1 ±7.1	0.04 ±0.02	7.63 ±3.74	2.00 ±0.48	8.47 ±1.44
Orinoco Island (Jarizo)	3,279.2 ±1,348.9	271.9 ±59.3	2.10 ±0.47	9.04 ±1.12	18.2 ±5.3	109.4 ±50.5

DB = depositional bar
LW = lower terrace
UT = upper terrace

results in Table 1. The marked difference in the amounts of deposited sediments between the two islands sites, agricultural land and Jarizo (5.0 vs 73.6 kg m^{-2} respectively), can be related to the vegetative cover of these islands and also to local topography. In contrast to the agricultural land, the Jarizo is covered by intricate tree vegetation, which can contribute to more rapid and efficient sedimentation of the suspended material. Dawson (1981) explains that the presence of vegetation in a stream influences the pattern of suspended fine material transport by decreasing water velocities passing through the plants shoots and increasing deposition of material in the vicinity of the plants. The spatial pattern of sedimentation is also dependent on local topography. In places where a large water column remains for a long period with low turbulence, larger amounts of sediments would be deposited. Barrios et al. (1994) report for another agricultural area, on an island near our study site, almost 16 times more sediment deposited during a flood event than at our similar site.

The Mapire River drains an extremely flat region covered by the Pleistocene Mesa Formation, which consists mainly of fluvial sands (Carbón

& Schubert 1994). The very small amount of sediment deposited in the flooded forests of the Mapire River and their sandy texture (Table 1) is then concordant with the lithological and topographical condition of the drainage area of this river.

In the Caura River Basin, as in the other basins of the Guayana Shield, the denudation processes are much slower than in an active mountain belt such as the Andes, and both lithology and basement structure seem to contribute to this slow denudation (Stallard et al. 1990). The amount of deposited sediments collected in the upper Caura was, however, large (Table 1), probably due to the fact that the upper Caura River drains areas with hilly to mountainous topography, where mining activities are occurring. The lower amounts of deposited sediments downstream ranging from 25.9 kg m^{-2} in the upper Caura to 7.2 kg m^{-2} in the middle Caura, and to 1.5 kg m^{-2} in the lower Caura (Table 1) indicate that the sediments is deposited in the small floodplains of the upper and middle Caura and also in the large floodplain of the lower Caura. These results are in agreement with the statement that the lower Orinoco River receives only relatively small inflows of suspended sediments from tributaries that drain the Guayana Shield (Meade et al. 1990).

According to the mineralogical analysis (Table 2), the deposited sediment in all the study areas was highly quartzitic with a relatively high content of kaolinite and goethite. This is related to the intensive weathering processes in the catchment areas of the study rivers. The low number of identified minerals in the sediments deposited by the Mapire River (Table 2) coincides with the results from Vegas-Vilarrubia and Herrera (1993), who identified in the suspended solids of this river only the presence of quartz and kaolinite. These results reflected the mineral poverty of the Pleistocene Mesa Formation.

Stallard et al. (1990) found that the fine sediments in the lower Orinoco are a mixture of sediments from rivers that drain the Andes, Llanos and Guayana Shield. According to our results, the mineral composition of the deposited sediments in the Caura and lower Orinoco (Table 2) was very similar in the number and species of identified minerals. However, the relative abundance of micas in the sediments of lower Orinoco was higher than that in the sediments of Caura River, probably due to the influence of the Andes tributaries in this section of the Orinoco River.

The variability in the chemical composition of the deposited sediments between the different sites (Table 3) could be explained in part by taking into account the mineral composition of the sediments and their particle-size distribution for each study site. However, the marked differences in the C and N concentrations among the sites (0.88–4.60% C and 0.07–0.27% N) showed no relation with the sand or clay content, nor with the relative abundance of minerals in the deposited sediments. These differences remain as yet unexplained, but are possibly due to differences in the inputs of alloctonous flooded forest material.

In relation to the P concentrations in the deposited sediments, Froelich (1988) and Forsberg (1989) pointed out that the capacity of sediments to adsorb and retain phosphate is strongly influenced by their mineral composition. The P concentration associated with the sediment deposited in the upper Caura was higher compared with the other study sites located in the cation – poor and highly leached drainage areas of Caura and Mapire Rivers (Table 3). This difference can be then explained by the fact that the goethite was an important mineral in the sediment of the upper Caura, and according to Parfitt (1989) such iron oxides have a high affinity for phosphate. The Ca, Mg and K concentrations were greatest in the sediment of the agricultural island of the lower Orinoco, whereas the concentration of these elements at the other studied sites were lower and more variable. These differences are strongly associated with the mineral poverty of the drainage area of the Mapire River and, in case of the lower Orinoco, with the relatively high content of minerals in the sediments that this river transports. There is a large difference in the Ca concentration of the sediments of the Mapire and lower Caura (0.58 and 1.26 cmol Kg^{-1} respectively) when compared with the Ca concentration in upper and middle Caura (0.03 and 0.05 cmol Kg^{-1} respectively). This could be associated with the influence of Orinoco River in the lower section of the Mapire River and perhaps also in the lower Caura. Vegas-Vilarrúbia and Herrera (1993) found that the Orinoco waters affected the water chemistry of the Mapire River mouth during the peak flood.

It has been shown (Table 4) that the deposited sediments contribute with large amounts of nutrients to the soils of the Jarizo Island of the lower Orinoco River. The amount of K deposited on the agricultural island was also large, but the amount of P was small and comparable to those deposited in the Mapire and lower Caura. The Mapire River transported very little sediment, which is deposited preferentially on the depositional bar. Therefore, the contribution by sediments to the nutrient cycling is relatively low in the flooded forests of the Mapire River and practically nonexistent in the forests located on the flooded terraces.

Although comparable investigations of deposition of suspended sediments and associated nutrients are very sparse, it can be generally said that the sedimentation rates on tropical floodplains vary over a wide range. Mertes (1994) showed that in a 200 km reach of the Central Amazon River millions of tons of sediments were transferred to and deposited on the floodplain during the 1986 flood. Barrios et al. (1994) reported for an agricultural area on the lower Orinoco a mean quantity of 834 t ha^{-1} of deposited sediments during 1986–1989. The above mentioned results can be considered similar to our results

Table 5. Mean content of basic cations in the deposited sediments of our study sites in comparison to the upper soils (0–10 cm) of seasonally floodplains of Igapó and Várzea. Standard deviations are given in parentheses.

Site	K	Mg	Ca	Reference
	$cmol_c$ kg^{-1}			
White-water floodplain				
Orinoco	0.07 – 0.91 (0.01 – 0.45)	0.43 – 0.78 (0.12 – 0.19)	1.47 – 1.97 (0.27 – 0.33)	This study
Várzea	0.34 (0.13)	2.84 (0.64)	12.5 (3.6)	Furch (1997)
Black-water floodplain				
Caura	0.08 – 0.13 (0.02 – 0.04)	0.36 – 0.55 (0.09 – 0.20)	0.03 – 1.26 (0.01 – 0.30)	This study
Mapire	0.19 (0.10)	0.53 (0.28)	0.58 (0.57)	This study
Igapó	0.18 (0.07)	0.14 (0.04)	0.08 (0.07)	Furch (1997)

of the Jarizo Island on the lower Orinoco (736 t ha^{-1}), but very different to those of the Caura flooded forests (15 to 259 t ha^{-1}), the agricultural land on the lower Orinoco (50 t ha^{-1}) and the Mapire flooded forests ($<$ 1 to 23 ton ha^{-1}).

A comparison between the concentrations of basic cations (Ca, K and Mg) in the deposited sediments of our study sites with the concentrations in the upper 10 cm of the seasonally flooded soils of the Amazon floodplains (Igapó and Várzea, Furch (1997)) is summarized in Table 5. Várzea and Orinoco Islands, as floodplains along white-water rivers, are rich in nutrients when compared with Mapire, Caura and Igapó floodplains, which are located along black-water river. Between Várzea and Orinoco, however, there are enormous differences in Ca and Mg concentrations. In the upper 10 cm of the Várzea soils the values of Ca and Mg are 86% and 79% respectively higher than those of the Orinoco soils. On the other hand, the K concentrations are relatively similar in both Orinoco and Várzea floodplains. The Igapó soils are poorest than those of Mapire and Caura, particularly with respect to the Ca and Mg concentrations.

Finally it is important to emphasize that the rates of sedimentation in the seasonally flooded forests vary from year to year and from site to site. The soils in which these flooded forests grow are in fact the result of superimposed layers of annual sediments. The actual inputs of nutrients and their influence on their cycles is a highly dynamic process reflecting the geochemistry of upstream processes, the alloctonous inputs from the forest itself and the local conditions in which sedimentation occurs. The present results, therefore, provide a basis to the understanding of the sedimentation process in the flooded forests, which is of importance if we want to know the role that these ecosystems play in sequestering and mobilizing nutrients.

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