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Particulate organic carbon and nitrogen in the Orinoco river (Venezuela)

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Abstract. Total suspended solids (TSS), particulate organic carbon (POC) and particulate nitrogen (PN) were measured over a two year period, 1983–1985, in the Orinoco River at Ciudad Bolívar, 450 km from its mouth. Additionally, samples of the main stem at other localities and main tributaries were included in the present study.

The suspended sediment concentrations showed a peculiar pattern of temporal variations: two maxima (May–June and November) and two minima (March–April and August–September).

The POC and PN concentrations fluctuated with the water discharge, and higher values were observed during the rising limb than during the falling limb of the hydrograph. As dry weight percent of solids, the values ranged between 0.84 and 9.06% for organic carbon and between 0.08 and 1.45% for total nitrogen. The carbon-nitrogen ratio in the sediment averaged 9.1. The major contribution of organic carbon and nitrogen in particulate form to the Orinoco main stem comes from the left margin tributaries, which have their headwater in the mountainous regions of the Andes.

Introduction

The studies on major rivers of the world have been intensified during the last fifteen years, especially those related to quantifying the transport of organic carbon for the purpose of constructing an accurate global carbon budget. In 1981, SCOPE started an ambitious research program entitled: 'Transport of carbon and minerals in major world rivers' whose coordinator was Prof. Dr. Egon T. Degens at the SCOPE/UNEP International Carbon Unit-University of Hamburg. The objective of the project was to assess riverine discharge of water, dissolved and particulate organic matter, as well as nutrients and minerals to the world oceans on local, regional and global scales. Many of the results of this work were published in the book 'Biogeochemistry of Major World Rivers' (Degens et al. 1991).

Available estimates of transport rates of riverine carbon vary from 0.2 to 1.0×10^{15} g C yr^{-1} (Kempe 1988; Meybeck 1982; Richey et al. 1980; Schlesinger & Melack 1981) and for riverine nitrogen from 14 to 35×10^{12} g N yr^{-1} (Ittekkot et al. 1983; Ittekkot & Zhang 1989; Meybeck 1982).

In a comprehensive review, Meybeck (1982) found that particulate organic carbon averages 1 weight % of the suspended sediments with a range from 2 to 4 wt% for most rivers. Particulate nitrogen varies between 0.1 and 1.3 wt%.

The Orinoco is one of the rivers for which data on carbon and nitrogen transport including seasonal variations are notoriously lacking (Schlesinger & Melack 1981). The present paper deals with the concentrations of particulate organic carbon (POC) and particulate nitrogen (PN) in the Orinoco River at Ciudad Bolívar during the years 1983–1985 (seasonal variations), and in the Orinoco River main channel ($\approx$1,600 km) with its major tributaries (spatial variations).

Site description

The Orinoco is the largest river in Venezuela (2,150 km long), being surpassed only by the Amazon and the Zaire rivers. It drains an area of about one million square kilometers between Venezuela and Colombia and has an average yearly discharge of 36,000 $m^3\ s^{-1}$. The Orinoco basin can be divided into the three following regions (MARN 1993; Vila 1960):

1. Upper Orinoco in the Amazon region. The river traverses the vast peneplains in the Casiquiare. This waterway connects the Orinoco and Amazon rivers systems via the Rio Negro. In this region, the river lacks major waterfalls, but rapids are common downriver as far as the confluence with the Meta river. The main tributaries of this region are Padamo, Ocamo, Atabapo, Ventuari, Guaviare and Vichada.
2. Middle Orinoco. Having passed the rapids of Atures and Maipures, near Puerto Ayacucho, the Orinoco slows down, reflecting the gentle slope of the terrain. During the 490 km between Caicara del Orinoco and Ciudad Bolívar its slope is only 6 cm/km. The middle Orinoco region is subdivided into four subregions: the Southern Orinoco, the Western, Central, and Eastern Plain.
   - 2a. Southern Orinoco. This subregion corresponds to those tributaries that drain the Guayana Shield and is dominated by blackwater rivers such as the Caroní and Caura. In this subregion there are a number of waterfalls, such as Churún-Merú or Angel Falls, 979 m.a.s.l., and Marevari Falls, 700 m.a.s.l. The Guri hydroelectric dam (10.000 MW) was built at the Necuima waterfalls on the Caroní and has resulted in an artificial lake which covers an area of 4.250 km^2 and has a total volume of 135 km^3. Other rivers of this subregion are the Parguaza, Suapure, Aro and Cuchivero.
   - 2b. Western Plains. The left margin subregion drains the western Plains. Its tributaries originate in the Andes where they cut deep, narrow valleys and carry clear waters until they meet the Plains. There, due

to the flat topography and the seasonal rainfall, they become typically turbid (whitewaters) with undefined channels. The main examples are: Meta, Apure, and Arauca.

2c. Central and Eastern Plains. The rivers of these subregions drain the Central and Eastern Plains. Many of these tributaries originate in the Coastal Range Mountains. They are generally highly seasonal and of low discharge. The main tributaries are: Guárico, Manapire, Guariquito, Mapire, Zuata, Pao and Caris.

3. Lower Orinoco or Delta. These lowlands are crossed by many rivers and branches (caños) of the Orinoco. The main channels are the Boca Grande, Mánamo and Macareo. Other rivers that are important tributaries are the Morichal Largo, El Tigre, and Uracoa from the Eastern Plains.

The annual hydrograph of the Orinoco shows a distinct seasonal cycle in its middle and lower reaches (Fig. 1a). Normally the rising period begins in April/May, and the river reaches its maximal stage in middle August. The extreme discharges measured at Musinacio were 2,980 and 86,000 $m^3 s^{-1}$, i.e., they differ by a factor of 25 (Pérez-Hernández 1985).

Materials and methods

For the study of the seasonal variations, the Orinoco river was monitored during May 1983–March 1985 at Ciudad Bolívar under the suspension bridge at Angostura, ca. 450 km from the river mouth. Surface samples were collected directly in 2.5 L plastic bottles at three localities across the river. Deep samples were taken with a Van Dorn bottle. During October 1984 the main channel of the Orinoco and the mouths of its major tributaries were sampled to measure spatial variations. Additionally the main stream of the Apure river at several localities was sampled in June and October 1986.

Suspended matter obtained by filtration of water samples through precombusted (500 °C) glass fiber filters (Schleicher & Schuell, No. 6 vg) was analyzed for organic carbon and nitrogen using a Carlo Erba Elemental Analyser, Model 1104 and NA1500.

Results and discussion

Seasonal variations

Maximum concentrations occur in May through June as water discharge begins to increase (Fig. 1b). Concentrations then decrease to low values during the time of maximal water discharge (August–September) before increasing

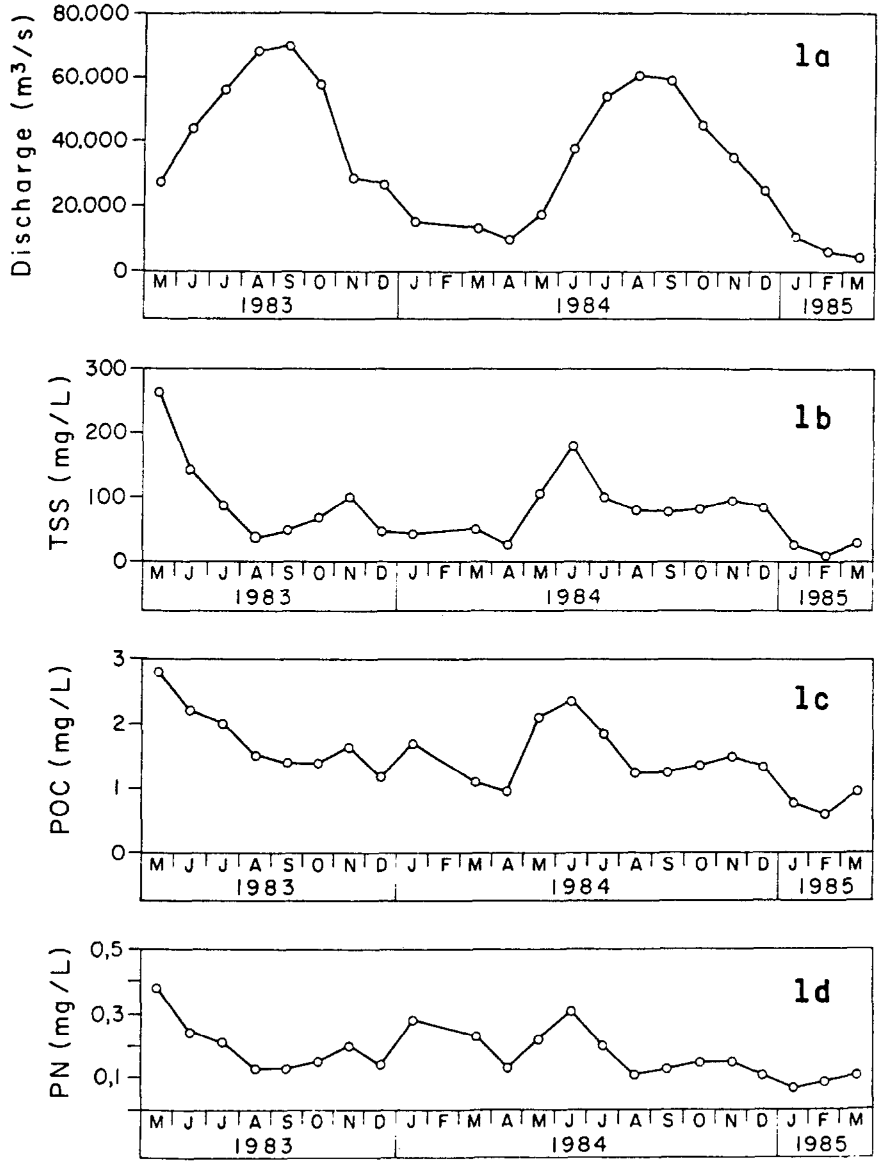

Fig. 1. Seasonal variations in water discharge, total suspended solids (TSS) particulate organic carbon (POC) and particulate nitrogen (PN) in the Orinoco River at Ciudad Bolívar, May 1983–March 1985.

slightly again as discharge decreases. Concentrations during the low water stage (January to April) are generally low.

The highest concentration of suspended matter precedes the discharge peak by two or three months. Such a pattern is typical for other major rivers such as the Amazon (Schmidt 1972; Meade et al. 1985), Mississippi (Robbins 1977) and Paraná (Cascante et al. 1985). This seasonal pattern in the concentration of suspended matter can be explained by the following mechanism. As water discharge increases, an increase in mechanical erosion can be expected, which causes resuspension of fine material that was deposited during the interval of declining discharges of the previous years (Lewis & Saunders 1989).

When the discharge reaches its maximum, there is a decrease in concentration of suspended solids due to a depletion of the easily resuspended fine material in the channel, and the waters enter into the floodplain, where storage of a substantial amount of particulate material can occur through sedimentation (Meade et al. 1983). Another reason for this decrease in sediment concentration during peak flow is probably the occurrence of back water in the mouths of some major sediment-contributing tributaries (Meade et al. 1990).

During the falling water stage a slight increase in the concentration of suspended matter was observed. This probably reflects the separation of the river from the floodplain, which eliminates the sedimentation losses of the floodplain, as well as the return of some portion of stored materials to the channel (Meade et al. 1983). Another possibility is bank-erosion, when the river banks are exposed during the falling stage of the river.

Particulate organic carbon concentrations (POC) (Fig. 1c) closely follow the variations in suspended sediments, with the highest concentration during the rising water period (May–June) with typical values ranging from 2.1 to 2.8 mg/L and the lowest concentration (0.6 to 1.0 mg L^{-1}) during the low water periods (January to April). Particulate organic nitrogen (PN) (Fig. 1d) showed the same pattern as the POC. During the ascending limb of the hydrograph the greatest concentrations, which range from 0.22 to 0.38 mg L^{-1} were observed.

Particulate organic carbon (POC) contents as a percentage of suspended solids are in the range of 0.8–9.1%; with an average of 2.4%, which is very close to that reported by Ittekkot (1988) for the rivers of the world in the 50–150 mg/L TSS range. The lowest value of POC corresponds to the rising stage in May–June, while the highest occurs during the periods of low sediment concentration (January–March and August–September) (Paolini & Ittekkot 1990).

An inverse relation was found between POC (%) and suspended solids (Fig. 2), that fits a logarithmic model with a correlation coefficient of −0.842. A similar pattern has been observed for other large rivers such as the Yangtze

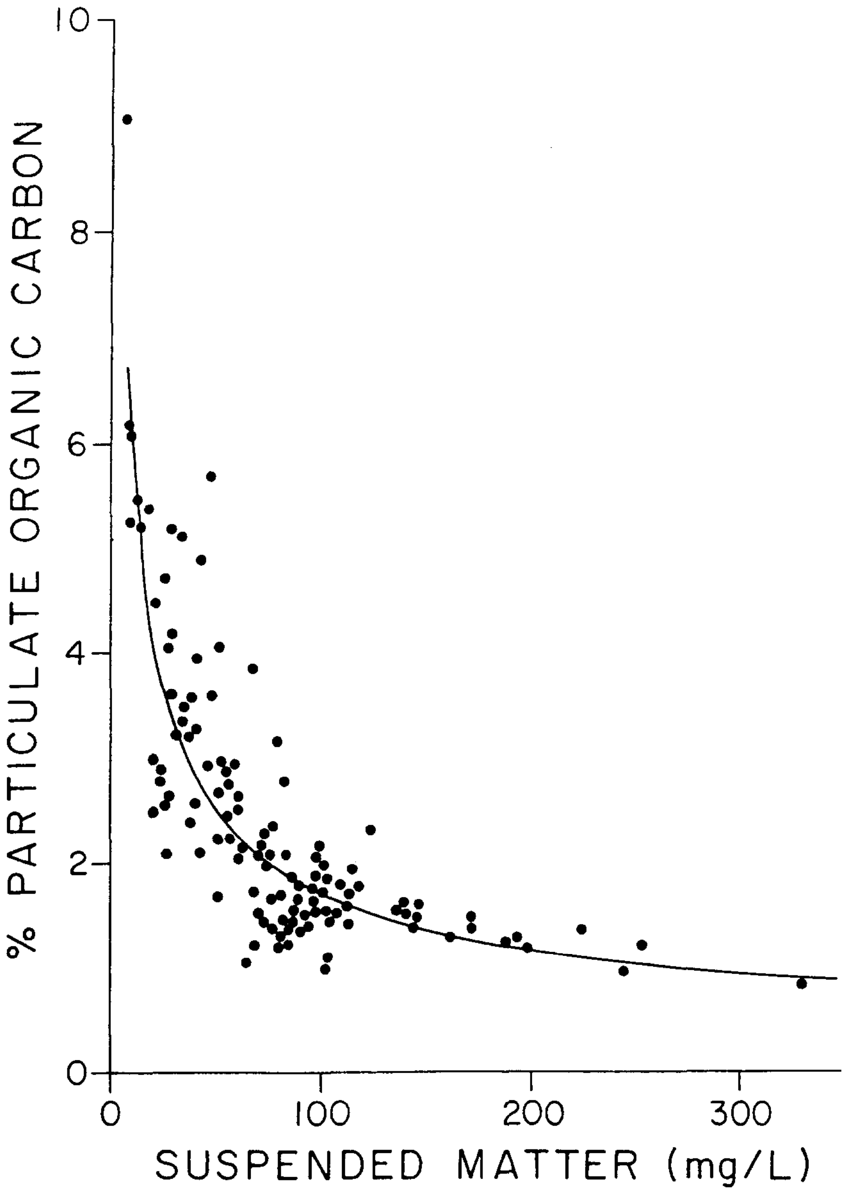

Fig. 2. Relationship between POC (in % of suspended matter) and concentrations of suspended matter in the Orinoco River at Ciudad Bolívar.

(Milliman et al. 1984), Gambia (Lo 1984), Caroní, (Paolini 1986) and the Orinoco (Paolini et al. 1987).

Meybeck (1982) explains the above mentioned trend by two processes. First, terrestrial plant debris is diluted by minerals and clays, especially when erosion rates are great. Second, planktonic organic carbon is diluted by mineral sources from land. Further, at high suspended matter concentrations, the penetration of light is reduced thereby decreasing primary production and thus the autochthonous POC concentration in the rivers (Thurman 1985).

The percentage of nitrogen in the suspended matter ranges from 0.09 to 1.45% with a mean value of 0.30%. The highest values were observed during the months of high primary production at low water stage (Lewis 1988). The %N in the sediments has a similar trend to that of the %C (Fig. 3). The correlation coefficient for a logarithmic relationship was −0.781.

The atomic ratio C/N is a very useful parameter in trying to establish the sources of the transported materials by the rivers; it varies from low values (C/N = 5–7) for plankton dominated systems to high values (≈150) in systems dominated by terrestrial detritus. For surface soils and for the top layer of lake and marine sediments, the C/N ratio falls within well-defined limits, usually about 10 to 12 (Stevenson 1982). For trunk wood and leaves from local plants and whole tissues from macrophytes of the Amazon watershed, this ratio is 210, 28 and 46, respectively (Hedges et al. 1986). Recently Ittekkot & Zhang (1989) have found that the C/N ratio for transported sediments by large rivers varies between 8.1 and 12.9 and is independent of the climatic differences encountered in the drainage basins of the rivers.

For the Orinoco River at Ciudad Bolívar, the C/N ratio has an average of 9.1 and shows seasonal variations. Low ratios in February–March coincided with high primary production in the river (Lewis 1988). Higher ratios were associated with rising and high water stages, when input of terrestrial material and resuspended sediments from the riverbed can be expected. This figure is quite similar to that reported for fine (<63μm) particulate matter in the Amazon (11.1; Hedges et al. 1986) and for suspended matter in the Paraná (8.4; Depetris & Cascante 1985).

The POC transport for the Orinoco at Ciudad Bolívar was 1.93×10^6 t yr^{-1} and 1.43×10^6 t yr^{-1} during the years 1983–84 and 1984–85, respectively, and PN transport was 209×10^3 t yr^{-1} and 155×10^3 t yr^{-1} for the same years. These figures represent approximately 1% and 0.6% of the global transport for POC and PN, respectively.

Spatial variation

In Table 1 the analytical results for %C, %N, POC, PN and C/N values for the suspended sediment at the main stem of the Orinoco river and some of its major tributaries are summarized, including samples from the Delta region

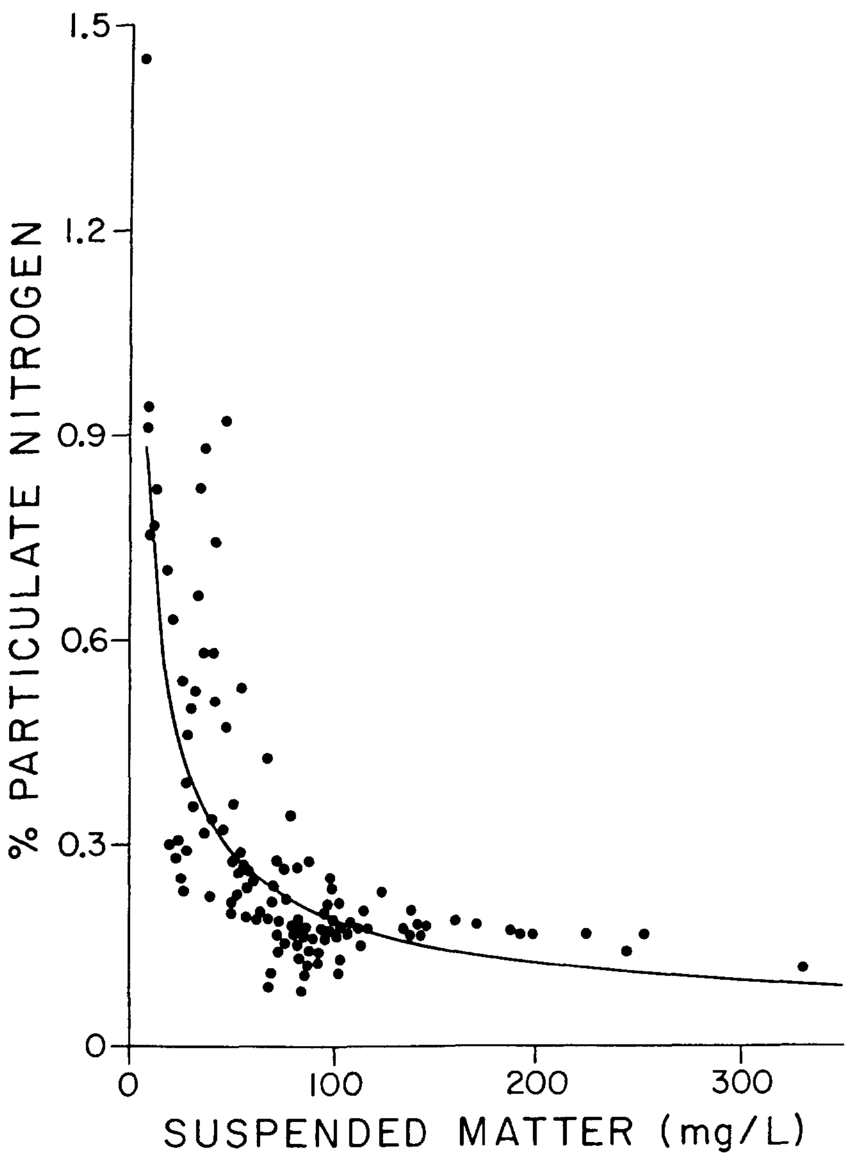

Fig. 3. Relationship between PN (in % of suspended matter) and concentrations of suspended matter in the Orinoco River at Ciudad Bolívar.

(Caño Mánamo and Macareo) and floodplain lakes of the lower reach of the Orinoco.

There are clear differences among the tributaries of the Orinoco river (Table 1). The Guayana rivers have an extremely high content of %C and

Table 1. Averages and standard deviations of carbon, nitrogen, particulate organic carbon, particulate nitrogen and C/N ratio for suspended sediments in the Orinoco river. (n = number of samples averages). Also included are samples at Ciudad Bolívar for the Orinoco river and at Parque Cachamay and Paso de Caruachi for the Caroní river.

Sample	%C	%N	POC(μg/L)	PN(μg/L)	C/N	n
Main stem	3.4 ± 2.2	0.33 ± 0.22	2,211 ± 1,392	244 ± 216	10.5 ± 2.4	19
Guayana rivers	14.8 ± 8.9	1.79 ± 1.28	947 ± 625	108 ± 81	9.9 ± 4.2	51
Andean rivers	2.1 ± 1.2	0.29 ± 0.19	2,952 ± 1,449	399 ± 187	7.4 ± 1.2	36
Plain rivers	7.4 ± 5.9	1.36 ± 1.18	890 ± 416	141 ± 118	7.7 ± 3.7	23
Caño Manamo	11.0 ± 6.1	1.58 ± 0.94	2,371 ± 598	341 ± 93	7.1 ± 1.3	14
Caño Macareo	2.4 ± 0.4	0.36 ± 0.06	2,378 ± 464	353 ± 80	6.8 ± 0.5	6
Lakes	10.0 ± 4.4	2.03 ± 1.52	3,766 ± 2,704	725 ± 598	5.8 ± 2.3	17
Ciudad Bolívar	2.4 ± 1.4	0.30 ± 0.23	1,504 ± 592	174 ± 81	9.1 ± 2.2	120
Caroní river	9.4 ± 5.8	0.97 ± 0.53	497 ± 277	54 ± 32	9.7 ± 2.5	39

%N, as is expected for blackwaters rivers. (Gordeev et al. 1992; Hedges et al. 1986; Paolini 1986). The high content of carbon and nitrogen in the suspended matter of the floodplain lakes is related to high phytoplankton densities during the isolation phase (Hamilton & Lewis 1987) when the samples were taken. This is also reflected by the low C/N ratio. The Plain rivers took an intermediate place between the Guayana and Andean tributaries. These rivers drain low or flat relief, land being dominated by savanna or grassland vegetation and the soil being rich in quartz.

In the main stem, the contents and concentration correspond to a mixture of materials originating in the Andes and Guayana Shield and those introduced from the adjacent floodplain. The concentration of POC and PN for the Orinoco main stem and some of its tributaries are summarized in Fig. 4. Contributions of POC and PN to the Orinoco main stem is small for the tributaries draining the Guayana Shield and some tributaries located in the Plains such as the Vichada, Inírida, Cinaruco, Mapire, Zuata, etc. (Paolini 1991).

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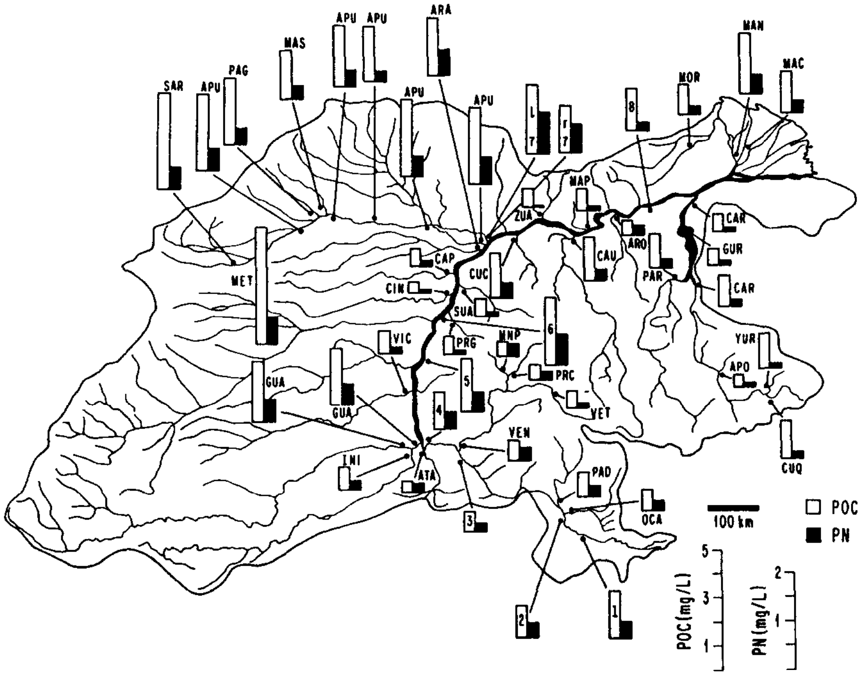

Fig. 4. Concentrations of POC and PN along the Orinoco main stem and its major tributaries. Sample locations in the main stem: 1. at Platanal; 2. at Ocamo; 3. upstream the confluence with River Ventuari; 4. upstream the confluence with river Guaviare; 5. at Isla Ceiba or Bachaquito; 6. at Parguaza; 7. at Curiquima (l = left; r = right) and 8. at Ciudad Bolívar. Major tributaries: a) right bank: OCA = Ocamo; PAD = Padamo; VEN, VET = Ventuari; PRC = Parucito; ATA = Atabapo; MNP = Manapiare; PRG = Paragua; CAR = Caroní; GUR = Guri Lake; APO = Aponwao; YUR = Yuruaní; CUQ = Cuquenan. b) left bank: GUA = Guaviare upstream River Inírida and below River Inírida; INI = Inírida; VIC = Vichada; MET = Meta; CIN = Cinaruco; CAP = Capanaparo: APU = Apure mouth and at several localities; PAG = Pagüey; MAS = Masparro; ZUA = Zuata; MAP = Mapire; MOR = Morichal Largo; MAN = Caño Mánamo; MAC = Caño Macareo.

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