THE GEOPHYSIOLOGY OF AMAZONIA

VEGETATION AND CLIMATE INTERACTIONS

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Chapter 13

Element Cycling in the Amazon Basin: A Riverine Perspective

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The Amazon River basin has a vast central plain bordered by highlands and a drainage network including different-sized tributaries that provide inputs to the main channel and its extensive floodplain.

The water of the Amazon and its tributaries carries dissolved and suspended chemical materials, both organic and inorganic in composition. These materials are washed by runoff into the river from the land, are formed by chemical transformations within the river, or originate in exchanges with the atmosphere. The material from land may be biological debris or mineral nutrients lost from the land vegetation.

Heavy rainfall, of which about 50% is recycled via evapotranspiration (Salati et al., 1978), mobilizes sediments and leaches nutrients from the lithologically and topographically distinct subdrainages of the Amazon (Gibbs, 1972; Stallard and Edmond, 1983). These elements, the majority of which is Andean derived, provide the critical nutrients needed for primary production of phytoplankton and the extensive vegetation in the floodplain along the river (Schmidt, 1973; Sioli, 1975; Fisher and Parsley, 1979).

Thus, sufficiently detailed sampling and chemical analyses of the composition of the water from the Amazon and its tributaries, if properly interpreted, should provide considerable information on overall ecological properties of the land–river system and, if continued over time, show how these properties change with land use change.

ELEMENT CYCLING: THE MICRO- AND LARGE-SCALE APPROACHES

The most common approach to the study of element cycling is to consider nutrient cycling for an individual process or site. On a slightly larger scale, such studies have been integrated to provide a view of cycling in "small watersheds" (Bormann and Likens, 1967). Examples of this approach include the Hubbard-Brook forest of the northeastern United States, the Coweeta watershed of the southeastern United States, and the Reserva Ducke watershed near Manaus, Brazil. The other extreme is represented by the study of the global patterns of such elements as carbon and nitrogen.

Microscale studies have shown the Amazon region to be a dense rain forest growing on highly leached, impoverished soils, with most of the nutrients contained in the vegetation. Plant growth is maintained through rapid and efficient recycling of dead plant materials (Klinge, 1976; Herrera et al., 1978; Jordan, 1982).

ELEMENT CYCLING: A MESOSCALE RIVERINE PERSPECTIVE

The sheer size of the Amazon (over 6×10^6 km^2) and its diversity make it difficult to extrapolate from any site-specific study. Global-scale analyses do not provide information at fine enough resolution to describe unique regional details. To obtain such details, we must apply a regional-scale approach that incorporates the spatial and temporal variability of the basin with sufficient resolution to be "useful," while coupling to changes in driving functions (climate) and ultimately to changes in global cycles. This approach should be done efficiently because of the considerable logistic problems inherent in any large-scale study of the Amazon.

These requirements are fulfilled by study of the water and material fluxes from their input as precipitation in the respective subdrainages to the output of the river system to the ocean. Rivers act as integrators of basinwide properties: Their loads are a composite of organic and inorganic materials representing a spectrum of sizes and chemical characteristics. Richey (1983) outlined a conceptual model of the biogeochemistry of river basins, which considers the river as a series of linked reaches, with each homogeneous reach receiving inputs from its catchment and exchanging materials with its floodplain. From discrete river samples integration information is obtained on the source of that material, which could be differentiated back to a description of the source properties.

The potential of this approach can be demonstrated with results from the CAMREX (Carbon in the AMazon River EXperiment) project—a cooperative research program between the University of Washington (Seattle, USA), the Instituto Nacional de Pesquisas da Amazônia (Manaus, Brazil), and the Centro de Energia Nuclear na Agricultura (Piracicaba, Brazil). Eight sampling cruises were conducted at different stages of the hydrograph from Santo Antônio do Içá to Obidos (Fig. 1). The spatial resolution was approximately 100 km over a 1750-km stretch of river, with time scales on the order of weeks. This work has been reported in a series of papers (Meade et al., 1985; Richey et al., 1986; Devol et al., in press; Hedges et al., in

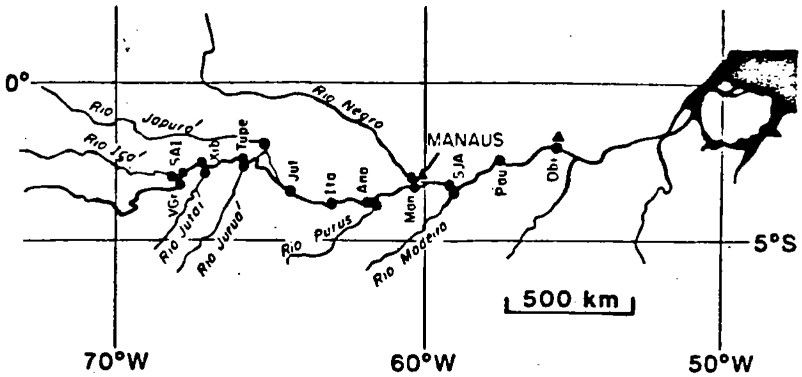

FIGURE 1. CAMREX station locations. VGR = Vargem Grande, SAI = Santo Antônio do Içà, Xib = Xibeco, Tup = Tupe, Jut = Jutica, Ita = Itapeua, Ano = Anori, Man = Manacapuru, SJA = São José do Amatari, Pau = Paura, and Obi = Obidos. Points on tributaries indicate tributary sampling stations.

press). Briefly, a series of parameters varies systematically over space and time; these distributions have been analyzed to deduce some of the key processes operating within the river itself. The tributaries are assumed to provide discrete inputs to the main channel.

Outflow from a tributary represents the sum of the biogeochemistry of its drainage, as transformed during its residence in the river. The concentration of major ions in the tributaries and subsequently in the mainstem is strongly influenced by the weathering regimes in the respective catchments. Superimposed on these patterns are the effects of nutrient cycling by the vegetation. If the Amazon had a homogeneous distribution of primary production and nutrient cycling, the tributaries draining the different subbasins would exhibit similar patterns of carbon and nutrient fluxes. We would expect to see low levels of the limiting nutrient, for example, nitrogen, in the draining waters, with little annual variance in flux.

To compare drainage basins of different sizes, we have computed the area-normalized flux of water and nitrate for the different tributaries (Fig. 2). Water discharge at Vargem Grande (representing primarily the Andean drainage) ranged between 0.0002 and 0.0006 m^3 ha^{-1} s^{-1}, which was comparable to that of the Rios Japurá, Içá and Jutaí (although the timing varied). Unit discharge was slightly lower in the Rio Purus and even lower in the Rios Juruá and Madeira. The Rio Negro had the greatest temporal variation in discharge, from 0.0001 to 0.0009 m^3 ha^{-1} s^{-1}.

The patterns of nitrate flux in the tributaries were more variable than was the discharge. At Vargem Grande, nitrate followed the discharge hydrograph, even showing increasing concentrations on the ascending limb, with a maximum flux of 0.009 mmol ha^{-1} s^{-1}. Less accentuated patterns were seen for the Rios Japurá and Madeira; the Rio Juruá apparently was diluted

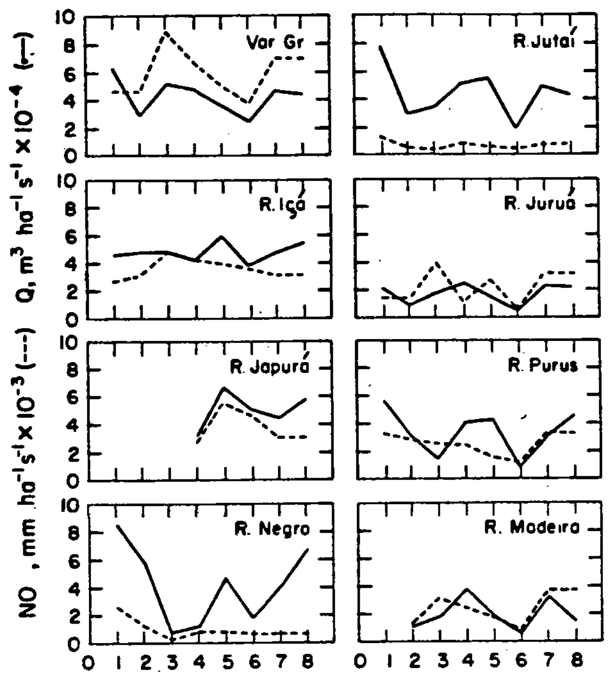

FIGURE 2. Comparison of tributary fluxes of water (Q) and NO_3 per unit of drainage basin. Vargem Grande (Var Gr) can be considered as the "Andean" tributary.

at high water. Fluxes in these rivers were generally less than 0.005 mmol ha^{-1} s^{-1}. More damped patterns were characteristic of the Rios Içá. Jutaí. Purus, and Negro, with particularly low fluxes of less than 0.002 mmol ha^{-1} s^{-1} in the Jutaí and Negro.

The chemical composition of their organic matter provides another perspective on the tributaries. The CAMREX project analyzed water samples for a series of tracers that are uniquely characteristic of the different possible origins of the organic material carried by the river (Hedges et al., 1986). The ratio of the stable carbon isotopes ^{13}C to ^{12}C (that is, δ ^{13}C, which is 1000 times the ratio of ^{13}C to ^{12}C divided by the standard PDB ratio minus one) versus lambda (the total carbon-normalized phenols produced by lignin oxidation; Ertel et al., 1984) indicates the composition of the material in transport (Fig. 3). The outstanding characteristics of particulate carbon in the Amazon itself are its nearly uniform composition and relative concentrations, with material larger than 0.063 mm mostly composed of undegraded leaf (80%) and wood (20%) remains and with material smaller than 0.063 mm mostly refractory, soil-derived substances. However, the tributaries exhibit a much wider variability. Therefore, the organic matter at Vargem Grande is mixed with tributary material of varying compositions that is generally

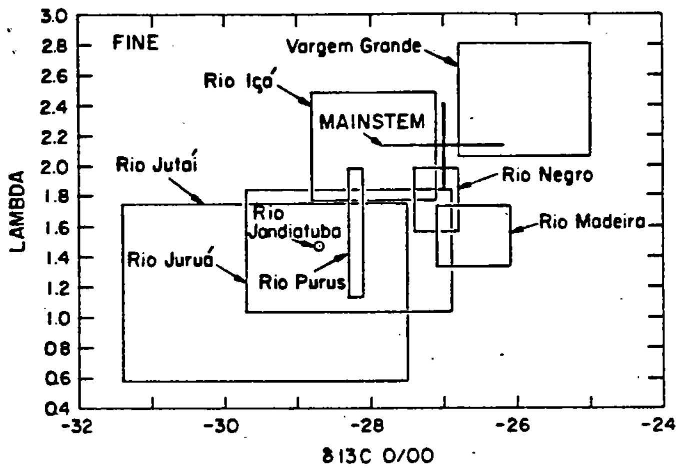

FIGURE 3. Plot of lambda (total mg lignin-derived phenols per 100 mg organic carbon) versus $\delta^{13}C$ for Amazon mainstem (+) and tributary fine suspended sediments. Rectangles represent mean ±1 standard deviation.

isotopically lighter, with lower lambda, modifying the Amazon composition downstream.

Examination of area- and discharge-normalized nitrate flux and the indices of organic composition indicate several properties of importance: (1) Tributary chemistry is considerably more variable and dynamic than would be expected if the "uniform production and tight nutrient-cycling" hypotheses were entirely true. (2) The variability clearly occurs on a systematic and analytically tractable basis. Our mesoscale biogeochemical approach holds considerable promise for elucidating some of the overall properties of water, sediment, and chemical fluxes through the system, as necessary to assess the potential consequences of land use change in Amazonia.

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