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Da cooperação entre Max-Planck-Institut für Limnologie, Arbeitsgruppe Tropenökologie, Plön, Alemanha Oc., e Instituto Nacional de Pesquisas da Amazônia, Manaus – Amazonas, Brasil

Selected bioelements in bark and wood of native tree species from Central-Amazonian inundation forests

by

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Abstract

The chemical differences between tree foliage from várzea- and igapó forests are confirmed by respective analyses of bark and wood. While generally bark presents higher concentrations than wood, bark and wood of trees from the várzea have higher concentrations than those from the igapó forest. Species composition as well as river water chemistry and soil quality account for the differences between várzea and igapó.

Keywords: **Amazon region, bioelements, igapó forest, várzea forest.**

Introduction

A study of foliar bioelements (N, P, K, Ca, Mg and Na) in inundation forest tree species from Central Amazonia (KLINGE et al. 1983) has shown that, on the average, species from várzea forests s e n s u PRANCE (1979, 1980) have a chemically richer foliage than species from the igapó forest. By tropical standards, too, the várzea tree foliage is rich in bioelements, while the igapó tree foliage is very low in them. The foliage bioelement chemistry reflects directly the hydrochemistry of the rivers (várzea forest - Solimões river; igapó forest - Rio Negro).

In the present paper is analyzed how the same trees studied for foliage chemistry compare chemically regarding bark and wood. For chemical analyses see KLINGE et al. (1983).

Results

Mean concentrations of N, P, K, Ca, Mg and Na in bark and wood

Mean element concentrations, in ppm, of the bark and wood samples from two várzea sites (Marchantaria Island and Iranduba locality on the left bank of the Solimões) and from one igapó site (Praia Grande at the right bank of the Rio Negro) are compared to the foliar levels of these elements, in Table 1.

As expected (STARK 1970; GOLLEY et al. 1980a, 1980b; GRUBB & EDWARDS 1982), the bark is generally richer in bioelements than wood, but lower than foliage (Table 2). The bark is particularly richer in calcium than wood, while the concentrations of phosphorus, potassium and sodium in both fractions are very similar. Comparing the bioelement concentrations in foliage and bark, the calcium concentrations in the bark are higher than those in the foliage.

In the study of the foliar bioelements of trees from inundation forests the igapó foliage turned out to be particularly low in calcium and less so in magnesium, phosphorus and potassium (KLINGE et al. 1983). Comparing separately bark and wood bioelement levels of species from the igapó site at Praia Grande to those of tree species from the várzea sites, the former are generally lower in all elements studied. Using the average concentrations of all várzea species, their bark is 1.5 times richer in nitrogen, 4.4 times richer in phosphorus, and twice as rich in potassium than bark of the igapó species. The várzea species present 6 times more Ca, 5 times more Mg and 3 times more sodium in the bark than the igapó species. Similar relations are observed for the wood.

Certain differences of the bioelement levels of bark and wood between both várzea sites are observed. Thus, bark from the Iranduba site is richer in nitrogen, calcium and sodium, and wood from that site is richer in calcium, magnesium and sodium.

Relative composition of bark and wood by alkali-earth and alkali elements

The relative composition of the foliage by calcium, magnesium, potassium and sodium was strikingly similar to the respective composition of the river water (FURCH et al. 1982; KLINGE et al. 1983; FURCH 1984). Thus calcium was dominant with at least 50 % in both the foliage and the river water of várzea sites, while in the igapó site the dominant element was potassium in the foliage and sodium in the water.

Considering the relative composition of bark and wood (Figure 1) it is observed that the dominant element of the bark is calcium as well in the samples from the two várzea sites as in those from the igapó site. The Ca percentage of bark from the várzea sites is however greater (79 % at Iranduba, 67 % at Marchantaria) than in the igapó site (51 %). The dominant element in the wood from both Marchantaria and Praia Grande is potassium, while in the wood from the Iranduba sites the potassium percentage is smaller than the calcium percentage.

In Figure 1, the total concentration of the four elements Ca + Mg + K + Na is also shown. It declines drastically towards the igapó site and is much lower in the wood than in both foliage and bark.

Table 1: Mean concentration of N, P, K, Ca, Mg and Na (in ppm) in foliage, bark and wood of trees from three inundation forest stands in Central Amazonia

	Várzea forests						Igapó forest		
	Marchantaria Island (29 species)			Iranduba (13 species)			Praia Grande (22 species)		
Element	Foliage	Bark	Wood	Foliage	Bark	Wood	Foliage	Bark	Wood
Nitrogen	25582 ± 5183	12612 ± 5639	4636 ± 1677	24908 ± 146	16515 ± 5768	5069 ± 1441	17305 ± 4042	9405 ± 4682	3141 ± 989
Phosphorus	1771 ± 444	793 ± 555	810 ± 456	871 ± 442	624 ± 254	530 ± 440	618 ± 256	162 ± 141	178 ± 142
Potassium	12813 ± 6564	9712 ± 4038	6640 ± 4049	8609 ± 6552	5618 ± 2519	3712 ± 2002	6325 ± 2617	3740 ± 1588	1769 ± 951
Calcium	18357 ± 15558	25873 ± 11751	3480 ± 3853	16314 ± 7729	30334 ± 15144	5582 ± 8978	2506 ± 2041	4560 ± 3510	819 ± 824
Magnesium	3956 ± 1864	3016 ± 1614	1487 ± 910	4029 ± 2447	2024 ± 816	1934 ± 1995	1218 ± 584	515 ± 491	305 ± 231
Sodium	201 ± 345	130 ± 95	121 ± 120	85 ± 53	416 ± 461	558 ± 654	249 ± 441	108 ± 181	89 ± 85

Statistical significance of differences between fractions of stands

+++ $p < 0.001$ ++ $p < 0.01$ + $p < 0.05$ n. s. not significant ($p > 0.05$)

	Foliage : Bark	Foliage : Wood	Bark : Wood	Foliage : Bark	Foliage : Wood	Bark : Wood	Foliage : Bark	Foliage : Wood	Bark : Wood
Nitrogen	+++	+++	+++	+++	+++	+++	+++	+++	+++
Phosphorus	+++	+++	n. s.	n. s.	n. s.	n. s.	+++	+++	n. s.
Potassium	+	+++	++	n. s.	+	+	+++	+++	+++
Calcium	+	+	+++	++	++	+++	+	+++	+++
Magnesium	+	+++	+++	++	+	n. s.	+++	+++	n. s.
Sodium	n. s.	n. s.	n. s.	+	+	n. s.	n. s.	n. s.	n. s.

	Foliage			Bark			Wood		
	Ma : Ir	Ma : PG	Ir : PG	Ma : Ir	Ma : PG	Ir : PG	Ma : Ir	Ma : PG	Ir : PG
Nitrogen	n. s.	++	++	+++	+	+++	n. s.	+++	+++
Phosphorus	+	++	n. s.	n. s.	+++	+++	n. s.	+++	++
Potassium	+	++	n. s.	+++	+++	+	++	+++	++
Calcium	n. s.	++	++	n. s.	+++	+++	n. s.	+++	n. s.
Magnesium	n. s.	++	++	+	+++	+++	n. s.	+++	++
Sodium	+	+	n. s.	+	n. s.	+	+	n. s.	+

Table 2: Ratios of bioelements (Foliage : Bark, Bark : Wood) in three inundation forest stands from Central Amazonia

Element	Marchantaria	Iranduba	Praia Grande
		Foliage : Bark	
Nitrogen	2.0	1.5	1.8
Phosphorus	2.2	1.4	3.8
Potassium	1.3	1.5	1.7
Calcium	0.7	0.5	0.5
Magnesium	1.3	2.0	2.4
Sodium	1.5	0.2	2.3
		Bark : Wood	
	Marchantaria	Iranduba	Praia Grande
Nitrogen	2.7	3.3	3.0
Phosphorus	1.0	1.2	0.9
Potassium	1.5	1.5	2.1
Calcium	7.4	6.4	5.6
Magnesium	2.0	1.0	1.7
Sodium	1.1	0.7	1.2

Bioelement levels in bark and wood of individual species

The concentrations of the six elements studied per individual species are presented in Table 3. The data are arranged in a decreasing order of the respective foliar level of each element (KLINGE et al. 1983). It is observed that the sequence of species differs from element to element. The respective between-species variability of the elemental concentrations is reflected by high standard deviations of both the mean elemental concentrations (Table 1) and the elemental ratios (Table 5).

Very generally, however, species with a very high foliar concentration of one element present often also high elemental concentration in bark and/or wood. Species with extremely low foliar elemental concentrations may also be characterized by low concentrations in bark and/or wood.

By subdividing the total range of the concentration of each foliar sections (classified as 'very low', 'low', 'rich' and 'very rich'), it was possible to classify the species according to their pattern of foliar elemental concentrations and to establish groups of species with a similar pattern (KLINGE et al. 1983). Completing that classification by adding the elemental concentrations of bark and wood, only little is gained, since the levels in bark and wood do not follow closely those in the foliage. To give one example, *Casearia aculeata* JACQ. (Flacourtiaceae) from the várzea forest of the Marchantaria Island is rich in foliar nitrogen, phosphorus, calcium, magnesium and sodium; its bark however is only rich in nitrogen, calcium and sodium, but low in phosphorus and potassium. The wood of this species is rich only in magnesium and sodium, but low in the remaining elements.

Replicates of a species sampled at one site or at different sites presented a high variability of foliar bioelement concentrations, and their chemical variability of bark and wood is also high. The number of replicates is too low to derive a valid generalization regarding the chemical variability between individuals from different sites.

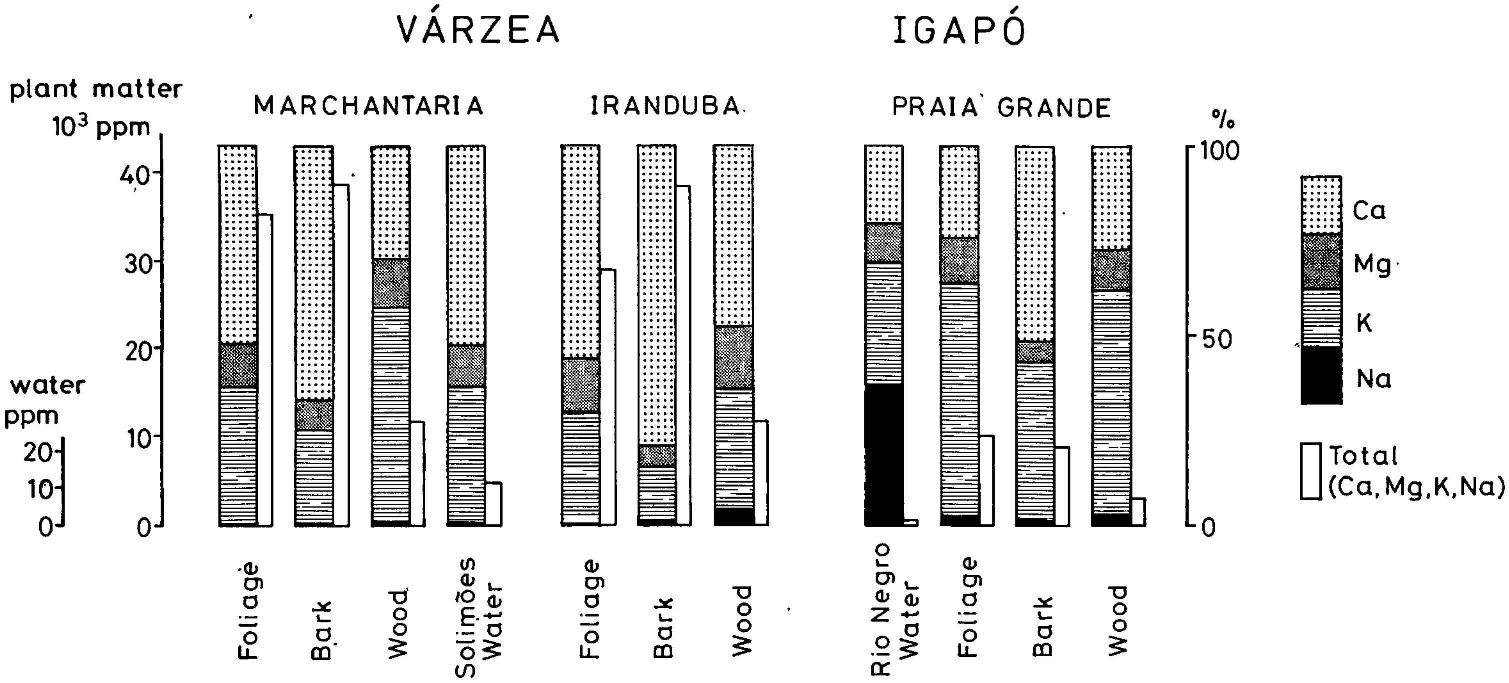

Fig. 1:
Total concentration of alkali- and alkali-earth metals in foliage, bark and wood of three inundation forest and in river water, and the relative contribution of Ca, Mg, K and Na to their sum.

Table 3: Species sampled in three inundation forests and their levels of N, P, K, Ca, Mg and Na (in ppm) in bark and wood

Species	Family	Nitrogen			Phosphorus		
		Species code	Bark	Wood	Species code	Bark	Wood
1. Marchantaria Island							
Inga sp. 2	Leguminosae	M 26	28600	5000	M 23	1850	750
?	Boraginaceae	M 21	17500	9100	M 25	1460	1500
Cecropia latiloba	Moraceae	M 3,32	7450	2550	M 21	2140	960
?	Anacardiaceae	M 25	11250	3300	M 6	660	1500
Pithecellobium multiflorum	Leguminosae	M 11	16900	4300	M 7	110	880
Mimosa sp.	Leguminosae	M 10	9400	5800	M 24	1150	220
Inga strigillosa	Leguminosae	M 29	16100	4300	M 33	1450	1740
Pseudobombax munguba	Bombacaceae	M 23	7100	4600	M 28	860	570
Laetia corymbulosa	Flacourtiaceae	M 1,9,20	9933	3567	M 8	2300	2490
Gustavia augusta	Lecythidaceae	M 28	12900	7800	M 15	900	1060
Pithecellobium inaequale	Leguminosae	M 27	19300	6700	M 4	1170	1200
Alchornea castaneifolia	Euphorbiaceae	M 8	12900	5500	M 1,9,20	307	763
Crataeva benthamii	Capparidaceae	M 2	19300	7700	M 3,32	930	250
Casearia aculeata	Flacourtiaceae	M 15	27200	3800	M 10	100	460
Salix humboldtiana	Salicaceae	M 33	10300	5300	M 2	550	940
Inga sp. 3	Leguminosae	M 31	17100	3800	M 14	670	830
Labatia glomerata	Sapotaceae	M 18,30	13000	5600	M 17	1010	1160
?	?	M 22	10000	3900	M 26	220	550
Ruprechtia tenuiflora	Polygonaceae	M 12	9000	6100	M 18,30	630	760
Crescentia amazonica	Bignoniaceae	M 13	10800	3500	M 11	370	240
Alchornea discolor	Euphorbiaceae	M 4	15500	5800	M 27	670	640
Tabebuia barbata	Bignoniaceae	M 6	11800	5600	M 19	920	790
Mollia sp.	Tiliaceae	M 17	6500	3000	M 16	470	570
Nectandra amazonica	Lauraceae	M 7	8300	3500	M 22	40	400
Genipa sp.	Rubiaceae	M 24	5700	2200	M 13	1010	570
Psidium sp.	Myrtaceae	M 5	7200	4000	M 31	590	610
Trichilia sp.	Meliaceae	M 14	10500	3600	M 5	980	230
Anacampta sp.	Apocynaceae	M 16	15200	3700	M 29	760	780
Rheedia brasiliensis	Guttiferae	M 19	9200	4100	M 12	710	230
2. Iranduba							
Casearia aculeata	Flacourtiaceae	I 8	21200	5400	I 3	280	240
Dulacia candida	Olacaceae	I 3	20000	6500	I 8	580	570
Picramnia spruceana	Simarubaceae	I 7	16500	6100	I 4	1010	630
Swartzia auriculata	Leguminosae	I 1	29500	6200	I 10	300	150
Duguetia quitarensis	Annonaceae	I 4	14300	4200	I 9	1080	1060
Symmeria paniculata	Polygonaceae	I 9	14800	4700	I 6	530	160
Malouetia furfuracea	Apocynaceae	I 6	9200	3000	I 11	360	1180
Vitex cymosa	Verbenaceae	I 10	23600	3000	I 2	910	240
Ruprechtia tenuiflora	Polygonaceae	I 11	13300	8100	I 7	770	360
Unonopsis guatterioides	Annonaceae	I 5	11500	3800	I 12	660	1480
Cassia leiandra	Leguminosae	I 12	17500	4700	I 13	1060	320
Buchenavia sp.	Combretaceae	I 13	10900	5200	I 1	620	130
Talisia sp.	Sapindaceae	I 2	12400	5000	I 5	530	370
3. Praia Grande							
Macrolobium multijugum	Leguminosae	P 20	10400	3400	P 14	280	340
Aldina latifolia	Leguminosae	P 2	17000	4600	P 8	90	280
Parkia discolor	Leguminosae	P 8	8200	3000	P 20	60	190
Swartzia polyphylla	Leguminosae	P 9	18000	3800	P 11	270	110
Sclerolobium hypoleuca	Leguminosae	P 1	18900	2800	P 7	260	110
Swartzia laevicarpa	Leguminosae	P 16	11700	4000	P 13	610	570
Mezilaurus synandra	Lauraceae	P 11	11000	3200	P 9	370	490
Swartzia argentea	Leguminosae	P 17	16900	4500	P 12	240	270
Matayba opaca	Sapindaceae	P 14	7800	1600	P 15	70	240
Blastemanthus grandiflorus	Ochnaceae	P 6	11800	4800	P 16	110	60
Licania apetala	Chrysobalanaceae	P 3	7300	2400	P 1	160	80
Byrsonima chrysophylla	Malpighiaceae	P 13	4600	2000	P 18	230	250
Duroia velutina	Rubiaceae	P 4	6200	2700	P 17	70	190
Buchenavia oxycarpa	Combretaceae	P 19	6900	3000	P 19	10	70
Panopsis rubescens	Proteaceae	P 7	4700	2600	P 21	180	70
Eschweilera coreacea	Lecythidaceae	P 18	8400	4600	P 4	60	110
Sclerolobium odorifera	Leguminosae	P 10	5900	2100	P 2	90	70
Humiria balsamifera	Humiriaceae	P 15	2500	1200	P 3	100	50
Buchenavia ochroprumna	Combretaceae	P 21	8200	3200	P 10	90	50
Franchetella crassifolia wawra	Sapotaceae	P 5	8700	3200	P 5	20	80
Ternstroemia candolleana	Theaceae	P 22	8200	3800	P 6	190	130
Ouratea spruceana	Ochnaceae	P 12	3600	2600	P 22	10	110

Table 3: Continuation

Species	Family	Potassium Species code	Potassium Bark	Potassium Wood	Calcium Species code	Calcium Bark	Calcium Wood
1. Marchantaria Island							
Inga sp.	Leguminosae	M 21	12000	10130	M 2	10260	6030
?	Boraginaceae	M 24	4230	2710	M 15	46870	4170
Cecropia latiloba	Moraceae	M 1,9,20	11103	9660	M 5	45510	3250
?	Anacardiaceae	M 25	9110	5670	M 14	36030	570
Pithecellobium multiflorum	Leguminosae	M 23	7690	4700	M 12	14320	730
Mimosa sp.	Leguminosae	M 15	7690	7140	M 4	37780	3530
Inga strigillosa	Leguminosae	M 10	1570	8350	M 29	37420	1540
Pseudobombax munguba	Bombacaceae	M 3,32	10330	5020	M 26	21620	930
Laetia corymbulosa	Flacourtiaceae	M 13	8670	7660	M 1,9,20	30210	3260
Gustavia augusta	Lecythidaceae	M 19	5890	3090	M 13	38830	2000
Pithecellobium inaequale	Leguminosae	M 6	7170	10570	M 17	23340	3080
Alchornea castaneifolia	Euphorbiaceae	M 33	18180	8080	M 22	14730	2290
Crataeva benthamii	Capparidaceae	M 16	1420	9600	M 25	26090	2650
Casearia aculeata	Flacourtiaceae	M 7	2440	1830	M 6	29210	5390
Salix humboldtiana	Salicaceae	M 8	12350	7870	M 10	2500	7530
Inga sp. 3	Leguminosae	M 11	3870	2440	M 28	25490	3910
Labatia glomerata	Sapotaceae	M 18,30	3720	3750	M 21	25060	5590
?	?	M 17	13860	7490	M 13	16410	3170
Ruprechtia tenuiflora	Polygonaceae	M 2	12130	8780	M 16	3190	1040
Crescentia amazonica	Bignoniaceae	M 28	8740	6580	M 3,32	23645	1575
Alchornea discolor	Euphorbiaceae	M 26	16660	16690	M 19	32860	1660
Tabebuia barbata	Bignoniaceae	M 22	8230	3360	M 18,30	27440	12440
Mollia sp.	Tiliaceae	M 5	11270	6640	M 24	37180	1810
Nectandra amazonica	Lauraceae	M 12	12250	11360	M 27	28660	3840
Genipa sp.	Rubiaceae	M 27	6290	2990	M 7	7260	1600
Psidium sp.	Myrtaceae	M 14	7110	5500	M 8	30110	3020
Trichilia sp.	Meliaceae	M 4	9380	6540	M 23	27480	3640
Anacampta sp.	Apocynaceae	M 29	7590	3510	M 33	29230	3020
Rheedia brasiliensis	Guttiferae	M 31	8130	3320	M 11	13560	1040
2. Iranduba							
Casearia aculeata	Flacourtiaceae	I 3	1810	4580	I 2	33880	5570
Dulacia candida	Olacaceae	I 8	7000	6180	I 8	52370	10120
Picramnia spruceana	Simarubaceae	I 4	8700	1240	I 13	34380	1560
Swartzia auriculata	Leguminosae	I 10	7170	4590	I 3	20070	1660
Duguetia quitarensis	Annonaceae	I 11	8120	8020	I 6	26950	34170
Symmeria paniculata	Polygonaceae	I 9	7840	3350	I 1	26860	2320
Malouetia furfuracea	Apocynaceae	I 7	6330	3300	I 9	58590	690
Vitex cymosa	Verbenaceae	I 13	7530	3480	I 12	27420	2290
Ruprechtia tenuiflora	Polygonaceae	I 5	3900	2340	I 11	13190	1520
Unonopsis guatterioides	Annonaceae	I 6	6222	4360	I 10	32520	5920
Cassia leiandra	Leguminosae	I 1	2070	1090	I 7	16410	3060
Buchenavia sp.	Combretaceae	I 12	4190	4410	I 4	45590	2700
Talisia sp.	Sapindaceae	I 2	2150	1310	I 5	6110	990
3. Praia Grande							
Macrolobium multijugum	Leguminosae	P 22	4230	3080	P 8	4850	260
Aldina latifolia	Leguminosae	P 20	5390	1590	P 9	9560	540
Parkia discolor	Leguminosae	P 6	3690	1500	P 13	5440	1770
Swartzia polyphylla	Leguminosae	P 14	3310	1280	P 20	5570	2150
Sclerolobium hypoleuca	Leguminosae	P 7	4080	1540	P 4	1050	720
Swartzia laevicarpa	Leguminosae	P 17	7520	4330	P 15	2720	770
Mezilaurus synandra	Lauraceae	P 1	4520	2040	P 12	7460	3790
Swartzia argentea	Leguminosae	P 4	4000	1000	P 19	7750	1170
Matayba opaca	Sapindaceae	P 18	3440	2390	P 16	3450	800
Blastemanthus grandiflorus	Ochnaceae	P 16	3540	1540	P 1	7590	500
Licania apetala	Chrysobalanaceae	P 19	2150	1480	P 18	1510	240
Byrsonima chrysophylla	Malpighiaceae	P 8	460	1170	P 21	4010	640
Duroia velutina	Rubiaceae	P 5	4320	1460	P 22	2470	390
Buchenavia oxycarpa	Combretaceae	P 11	1620	780	P 3	1810	290
Panopsis rubescens	Proteaceae	P 13	5400	3290	P 14	5650	550
Eschweilera coreacea	Lecythidaceae	P 21	5310	3310	P 2	5830	860
Sclerolobium odorifera	Leguminosae	P 3	3220	1790	P 17	4670	770
Humiria balsamifera	Humiriaceae	P 9	4650	1270	P 7	1480	250
Buchenavia ochroprumna	Combretaceae	P 2	3810	1450	P 6	3100	590
Franchetella crassifolia wawra	Sapotaceae	P 12	950	900	P 5	2630	570
Ternstroemia candolleana	Theaceae	P 15	990	1080	P 11	810	180
Ouratea spruceana	Ochnaceae	P 10	1550	610	P 10	920	220

Table 3: Continuation

Species	Family	Magnesium Species code	Magnesium Bark	Magnesium Wood	Sodium Species code	Sodium Bark	Sodium Wood
1. Marchantaria Island							
Inga sp. 2	Leguminosae	M 15	3040	2400	M 15	400	600
?	Boraginaceae	M 2	1990	1200	M 31	80	60
Cecropia latiloba	Moraceae	M 14	9510	1770	M 17	130	111
?	Anacardiaceae	M 24	7290	2650	M 12	40	50
Pithecellobium multiflorum	Leguminosae	M 13	2250	650	M 13	190	140
Mimosa sp.	Leguminosae	M 17	5550	1160	M 10	490	150
Inga strigillosa	Leguminosae	M 28	1470	440	M 4	160	80
Pseudobombax munguba	Bombacaceae	M 12	1450	830	M 33	170	150
Laetia corymbulosa	Flacourtiaceae	M 23	3160	1990	M 5	160	110
Gustavia augusta	Lecythidaceae	M 1,9,20	4850	1867	M 2	60	50
Pithecellobium inaequale	Leguminosae	M 25	2790	1380	M 21	220	250
Alchornea castaneifolia	Euphorbiaceae	M 3,32	2790	1380	M 6	240	270
Crataeva benthamii	Capparidaceae	M 5	5790	1350	M 18,30	205	100
Casearia aculeata	Flacourtiaceae	M 21	7360	2310	M 11	60	60
Salix humboldtiana	Salicaceae	M 6	2080	2120	M 25	90	80
Inga sp. 3	Leguminosae	M 16	1350	2450	M 16	150	210
Labatia glomerata	Sapotaceae	M 4	2660	2150	M 24	10	20
?	?	M 18,30	3485	2485	M 1,9,20	63	87
Ruprechtia tenuiflora	Polygonaceae	M 26	1690	440	M 26	50	10
Crescentia amazonica	Bignoniaceae	M 22	2950	1290	M 7	80	140
Alchornea discolor	Euphorbiaceae	M 33	1640	1070	M 22	90	80
Tabebuia barbata	Bignoniaceae	M 10	670	2440	M 8	130	30
Mollia sp.	Tiliaceae	M 19	1650	780	M 27	90	80
Nectandra amazonica	Lauraceae	M 29	2360	620	M 28	50	50
Genipa sp.	Rubiaceae	M 31	2200	570	M 3,32	65	60
Psidium sp.	Myrtaceae	M 7	850	510	M 19	200	200
Trichilia sp.	Meliaceae	M 8	3010	1760	M 29	20	10
Anacampta sp.	Apocynaceae	M 27	1980	620	M 23	10	10
Rheedia brasiliensis	Guttiferae	M 11	690	1450	M 14	190	40
2. Iranduba							
Casearia aculeata	Flacourtiaceae	I 8	2300	2720	I 8	130	110
Dulacia candida	Olacaceae	I 3	2480	5890	I 11	70	80
Picramnia spruceana	Simarubaceae	I 6	2530	4140	I 4	1190	1060
Swartzia auriculata	Leguminosae	I 2	4120	5540	I 7	740	960
Duguetia quitarensis	Annonaceae	I 12	1420	770	I 10	110	170
Symmeria paniculata	Polygonaceae	I 9	2580	1140	I 3	640	1510
Malouetia furfuracea	Apocynaceae	I 10	1470	1570	I 12	50	130
Vitex cymosa	Verbenaceae	I 7	1440	640	I 2	80	70
Ruprechtia tenuiflora	Polygonaceae	I 1	890	360	I 9	40	40
Unonopsis guatterioides	Annonaceae	I 13	2090	390	I 13	120	110
Cassia leiandra	Leguminosae	I 11	1530	740	I 5	740	1460
Buchenavia sp.	Combretaceae	I 4	1830	420	I 1	1340	1390
Talisia sp.	Sapindaceae	I 5	1630	820	I 6	160	1470
3. Praia Grande							
Macrolobium multijugum	Leguminosae	P 3	590	190	P 15	230	180
Aldina latifolia	Leguminosae	P 20	-430	200	P 12	660	300
Parkia discolor	Leguminosae	P 8	440	100	P 11	30	60
Swartzia polyphylla	Leguminosae	P 4	210	320	P 6	120	100
Sclerolobium hypoleuca	Leguminosae	P 14	590	160	P 3	70	190
Swartzia laevicarpa	Leguminosae	P 13	890	500	P 21	120	130
Mezilaurus synandra	Lauraceae	P 1	580	210	P 14	630	190
Swartzia argentea	Leguminosae	P 15	360	220	P 19	80	90
Matayba opaca	Sapindaceae	P 22	520	270	P 20	20	20
Blastemanthus grandiflorus	Ochnaceae	P 19	690	290	P 18	20	10
Licania apetala	Chrysobalanaceae	P 12	340	350	P 17	10	20
Byrsonima chrysophylla	Malpighiaceae	P 2	460	260	P 9	30	10
Duroia velutina	Rubiaceae	P 7	1120	1260	P 22	20	20
Buchenavia oxycarpa	Combretaceae	P 16	460	330	P 4	20	110
Panopsis rubescens	Proteaceae	P 11	410	160	P 10	120	240
Eschweilera coreacea	Lecythidaceae	P 9	340	330	P 13	20	20
Sclerolobium odorifera	Leguminosae	P 6	380	160	P 8	80	90
Humiria balsamifera	Humiriaceae	P 18	290	220	P 1	20	10
Buchenavia ochroprumna	Combretaceae	P 10	2570	340	P 5	30	80
Franchetella crassifolia wawra	Sapotaceae	P 17	510	360	P 7	20	60
Ternstroemia candolleana	Theaceae	P 5	530	250	P 16	10	10
Ouratea spruceana	Ochnaceae	P 21	610	240	P 2	20	10

Comparison of bioelement concentrations in bark and wood from neotropical forests

Comparing the bioelement concentrations of wood and bark from the Central-Amazonian inundation forests to respective data for a few neotropical forests (Table 4), the following sequences of sites are obtained:

	Wood	Bark
Nitrogen	Ma ~ Ir > PG = Ve 1	Ma ~ Ir > PG
Phosphorus	Ma = Ir > PG < Ve 1 > Ve 2	Man. < Ma = Ir > PG < Ve 2
Potassium	Ma > Ir > PG < Ve 1 > Ve 2	Man. < Ma > Ir ~ PG > Ve 2
Calcium	Ma = Ir = PG < Ve 1 > Ve 2	Man. < Ma = Ir > PG > Ve 2
Magnesium	Ma = Ir > PG < Ve 1 > Ve 2	Man. < Ma ~ Ir > PG = Ve 2
Sodium	Ma ~ Ir ~ PG ? Ve 1 ? Ve 2	Man. < Ma ~ Ir ~ PG = Ve 2

The higher levels in bark and wood of the várzea forest samples (Ma, Ir) than those from the igapó forest have already been described above. The floodplain forest in Venezuela (Ve 1) is very similar to the várzea forest of Central Amazonia, while the samples from the forests at Manaus (Man.) and San Carlos de Rio Negro (Ve 2) are more similar to those of the igapó forest (PG). This means that lower concentrations are observed in the Rio Negro basin (Man., Ve 2, PG) where the forests are developed on oxisols (Man, Ve 2) and on alluvial quartz sands (PG). Chemical studies of Central Amazonian freshwaters, soils and vegetation (FURCH & KLINGE 1978; FURCH et al. 1982; FURCH 1984) have shown that the Rio Negro basin is characterized generally by low nutrient levels, specifically calcium, and the present study shows that this is reflected also by the biomass fractions wood and bark. The much higher bioelement levels in the várzea forests (Ma, Ir) and the Venezuelan floodplain forest (Ve 1) correspond to the higher chemical concentrations of their rivers when compared to the Rio Negro, and also to the annual accreation of river sediment load at these sites.

Ratios N/P, K/Ca, Ca/Mg and K/Na

The mean ratios are listed in Table 5. The N/P ratios of the várzea wood is much narrower than the N/P ratios of the bark which resembles the foliar N/P ratios. The N/P ratio of the igapó bark however is drastically wider than the respective ratio of the wood. The K/Ca ratios of bark and wood from the three stands differ relatively little as do the Ca/Mg ratios. The latter are particularly wide in the Iranduba bark. Bark and wood from the Iranduba site have comparatively narrow K/Na ratios.

Table 4: Concentrations of N, P, K, Ca, Mg and Na (in ppm) in wood and bark of selected neotropical forests

Site	N	P	K	Ca	Mg	Na	Source
Wood							
Panama	n. d.	1200	10400	9850	1250	1050	GOLLEY et al. 1975
Venezuela 1 (n = 27)	2787 (1833)	457 (97)	3410 (673)	7420 (813)	563 (66)	n. d.	HASE & FÖLSTER 1982
Venezuela 2 (n = 28)	n. d.	92 (37)	705 (357)	253 (259)	191 (153)	13 (8)	GOLLEY et al. 1980b
Brazil (n = 224)	n. d.	126 (56)	1345 (718)	1780 (1140)	992 (770)	327 (283)	GOLLEY et al. 1980a
Bark							
Venezuela 2	n. d.	197 (66)	2395 (1432)	2214 (1559)	528 (309)	36 (21)	GOLLEY et al. 1980b

Statistical significance of difference between sites

	N	P	K	Ca	Mg	Na
Wood						
Ma : Ir	n. s.	n. s.	++	n. s.	n. s.	+
Ir : PG	+++	++	++	n. s.	++	+
PG : Ve 1	n. s.	+++	+++	+++	+++	
Ve 1 : Ve 2		+++	+++	+++	+++	
Ve 2 : Man.		+++	+++	+++	+++	+++
Bark						
Ma : Ir	+	n. s.	+++	n. s.	+	+
Ir : PG	+++	+++	+	+++	+++	+
PG : Ve 2		+++	++	++	n. s.	n. s.

Ma = Marchantaria, Ir = Iranduba: várzea forest; PG = Praia Grande: igapó forest (KLINGE et al. 1983)

+++ $p < 0.001$
++ $p < 0.01$
+ $p < 0.05$
n. s. $p > 0.05$

Ve 1 floodplain forest, HASE & FÖLSTER 1982
Ve 2 mixed forest at San Carlos de Rio Negro, GOLLEY et al. 1980b
Man. mixed forest at Manaus, GOLLEY et al. 1980a
n. d. = no data

Table 5: N/P, K/Ca, Ca/Mg and K/Na ratios in bark and wood

Sampling site	Bark	Wood
N/P ratio		
Marchantaria	33.9 ± 50.5 a	7.8 ± 4.6 a
Iranduba	32.8 ± 21.6 a	16.0 ± 12.0 b^{x}
Praia Grande	155.3 ± 215.4 bc	28.7 ± 18.0 $c^{xx}d$
K/Ca ratio		
Marchantaria	0.4 ± 0.3 a	3.4 ± 4.2 ab
Iranduba	0.3 ± 0.3 a	1.8 ± 1.7 ac
Praia Grande	1.3 ± 0.9 $b^{xx}c^{xx}$	3.4 ± 2.6 bd
Ca/Mg ratio		
Marchantaria	9.5 ± 5.4 a	2.7 ± 1.9 a
Iranduba	14.9 ± 8.2 bc	3.5 ± 2.5 a
Praia Grande	9.2 ± 9.1 a	3.2 ± 2.8 a
K/Na ratio		
Marchantaria	141.4 ± 164.7 a	153.5 ± 310.3 a
Iranduba	51.5 ± 56.2 b	27.8 ± 33.5 bc
Praia Grande	155.8 ± 137.6 ac	74.6 ± 83.1 a

In each column, figures for a ratio followed by the same letter are not statistically different (t-test, $p > 0.05$). Significance level at $p < 0.01^{x}$, at $p < 0.001^{xx}$

Discussion and Conclusions

GRUBB & EDWARDS (1982) have pointed out that more chemical data are needed from both a variety of tropical forests and replicates of individual species before safe conclusions about the correlations of bioelements in foliage, bark and wood under natural conditions can be drawn. The situation is somewhat different regarding tropical crop trees. As BOLLE-JONES (1957) and MAREL (1960) have shown analysing the much easier sampled *Hevea* bark is as good as analysing leaves for assessing the soil nutrient status, and bark analyses reflect particularly well the effect of P fertilization of rubber trees.

One of the main findings of the present study is the difference in the mean elemental concentrations of bark and wood from three forest sites in the inundation area of Central Amazonia. This is paralleled by differences in the species composition which accounts for high standard deviations of the mean values. The variability of the species composition between the sites also is reflected by differences of the structure and thickness of the bark, and by the range of the specific gravity and density of the wood tissue.

The majority of tree species growing in the várzea is characterized by uncoloured light wood, while those of the igapó site possesses reddish brown, dense and heavy wood. It should also be noted that the wood tissue was not always sampled from transversal bole cuts. Sometimes branches were sampled instead of boles, and in some cases a piece of wood beneath the bark was cut from a big bole.

While the inhomogeneity of the samples, jointly with the species composition, may account for high standard deviations, differences of the chemical quality of the bark, in particular, may be related also to the impact of long flooding. In this period the bark of the várzea sites is in intimate contact with the turbid and chemically rich water of the Solimões. It may well be that such water leaves behind on the bark, specifically if it is not smooth, certain amounts of detritus. If such bark is sampled, the detritus is analyzed jointly with the bark tissue. The bark of the trees growing in the igapó will not be influenced in this way by the river water which is transparent and very poor chemically. However, the bark may be leached during the period of flooding, and this may also occur in the várzea.

We do not have any measure of the impact of these processes and facts on the chemical quality of wood and bark. It is also not assumed that they are reflected by the incongruence of the chemical qualities of foliage, bark and wood. It is probably more correct to relate the differences between these plant fractions with their functions and utilization of chemical elements.

Since results of foliar analyses are generally taken as strong indicators of the soil quality, the differences in the foliage chemistry between species from the várzea and the igapó suggest striking differences in the soil quality in both sites regarding bioelement availability. Bark and wood tissue apparently reflect the soil quality much less than foliage.

The species studied for the chemical quality of their foliage, bark and wood represent only a fraction of the total species pool of the inundation area. Additional species should be analyzed also for additional elements. Chemical analyses of the soil from the sites where species are sampled, should also be included.

Resumen

Diferencias químicas entre el follaje de árboles de bosques inundables amazónicos (várzea, igapó) están comprobadas por resultados de analyses químicos de corteza como tambien de madera. Generalmente, la corteza presenta concentraciones mayores que la madera. Corteza y madera de árboles de la várzea muestran concentraciones mayores que ambas clases de tejidos de árboles del igapó. Tanto la composición por espécies como tambien la química del água de los ríos y la calidad química de los suelos causan la diferencia entre várzea e igapó.

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