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CHARACTERIZATION AND UTILIZATION OF VÁRZEA AND TERRA FIRME FORESTS IN THE AMAZON ESTUARY

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*ABSTRACT - The várzea and terra firme forests of the Ilhas de Abaetetuba, in the Amazon estuary, were compared as to their utilization, forest structure, biomass, and tree-ring characteristics. Várzea forests are inundated twice daily throughout the year. These forests have been altered heavily by human activities, especially through the management/cultivation of açaí palm (*Euterpe oleracea *Mart.). Both the number of trees and the number of tree species are limited due to human management and frequent inundations. Terra firme forests are also composed of secondary forests, but human impacts have been less and possess more tree species with a higher wood density than the várzea counterparts because latewoods are formed during the dry season. Without human intervention, the forest biomass of the várzea exceeds that of the terra firme. However, it is reduced to less than one-third when strongly disturbed. It was also found that the wood density was closely related to the brightness contrast between early and latewoods, and in general, the várzea species with a low wood density had a small brightness contrast.*

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KEY WORDS: Amazon estuary, Várzea forest, Terra firme forest, Açaí palm (*Euterpe oleracea* Mart.), Tree-ring.

RESUMO - As características sobre manejo, estrutura florestal, biomassa, e anéis de crescimento foram comparadas nas matas da várzea e terra firme da região das Ilhas de Abaetetuba, estuário amazônico. As matas de várzea são inundadas duas vezes ao dia, durante todo o ano. Estas matas foram alteradas profundamente pelas ações humanas. A alteração mais recente está ocorrendo pelo manejo/cultivo da palmeira açaí (Euterpe oleracea *Mart.*). *Aqui, o número de árvores e o número de espécies são restritas por causa das condições ecológicas e intervenção humana. As matas de terra firme são também compostas de matas secundárias, mas o impacto humano tem sido restrito e contém um número maior de espécies de árvores com madeiras de alta densidade que a várzea. A longa estação seca é responsável pela maior ocorrência de madeiras densas. Sem a intervenção humana, a biomassa da mata da várzea supera a da terra firme. Constatamos que a densidade de madeira está relacionada ao contraste de brilho entre a madeira nova (earlywood) e madeira madura (latewood). Em geral, as espécies de várzea com madeiras de baixa densidade demonstra um contraste de brilho reduzido.*

PALAVRAS-CHAVE: Estuário Amazônico, floresta de várzea, floresta de terra-firme, palmeira de açaí (*Euterpe oleracea* Mart.), Anéis de crescimento.

INTRODUCTION

About 3% of forests in Amazonia are called várzea forests (Goulding 1993). The tidal flooded forest lines the low-lying terrain around the mouth of the Amazon, and is inundated twice a day when the fresh water is pushed back with the incoming tide. In contrast, forests standing 7-8m above the floodlands are not influenced by the tidal activity. These terra firme forests are usually found in the interior of the islands.

Most people live along the numerous channels that drain the estuary, since transportation and communication are effected mostly through waterways. The recent growth of Belém's population, now surpassing 1.5 million, and the expansion of its economic influence are changing the way local people manage their resources. Exploitation of forest products is accelerating, and cash crops such as açaí palm (*Euterpe oleracea* Mart.) are mass produced to increase income (Brabo 1979; Anderson 1990). Following repeated cycles of clearing and regrowth, current vegetation is made up mostly of secondary forests. Although the area under açaí cultivation is still limited, there is an urgent need to examine the forest biomass so that appropriate management practices and policies can be established (SUDAM/PNUD 1994; Fearnside *et al.* 1990). The purpose of this study is to compare the várzea and terra firme forests in the Amazon estuary under different management patterns and moisture conditions.

RESEARCH AREA

The study area is located to the southwest of Bélem (Figure 1). The Ilhas de Abaetetuba (shaded area) are formed by olocene sediments transported by Rio Pará, that drains the southern estuary of the Amazon, and by Rio Tocantins, that originates on the Brazilian Highlands.

The width of the várzea forest, found along the drainage channels, varies between 100-3,500m. The area is inundated twice a day throughout the year. The diurnal tidal changes along the Rio Maracapucu Mirí, near Abaetetuba, is shown in Figure 2. Twice a month, during the spring tides, fresh water covers the forest floor to a depth of 30cm or more for a period of up to three hours. However, the seasonal changes in water level are not as large as in the middle Amazon, where it reaches 7 to 13m (Sioli 1984). The range decreases in its lower course. The seasonal difference between March and September is about 2m at Abaetetuba.

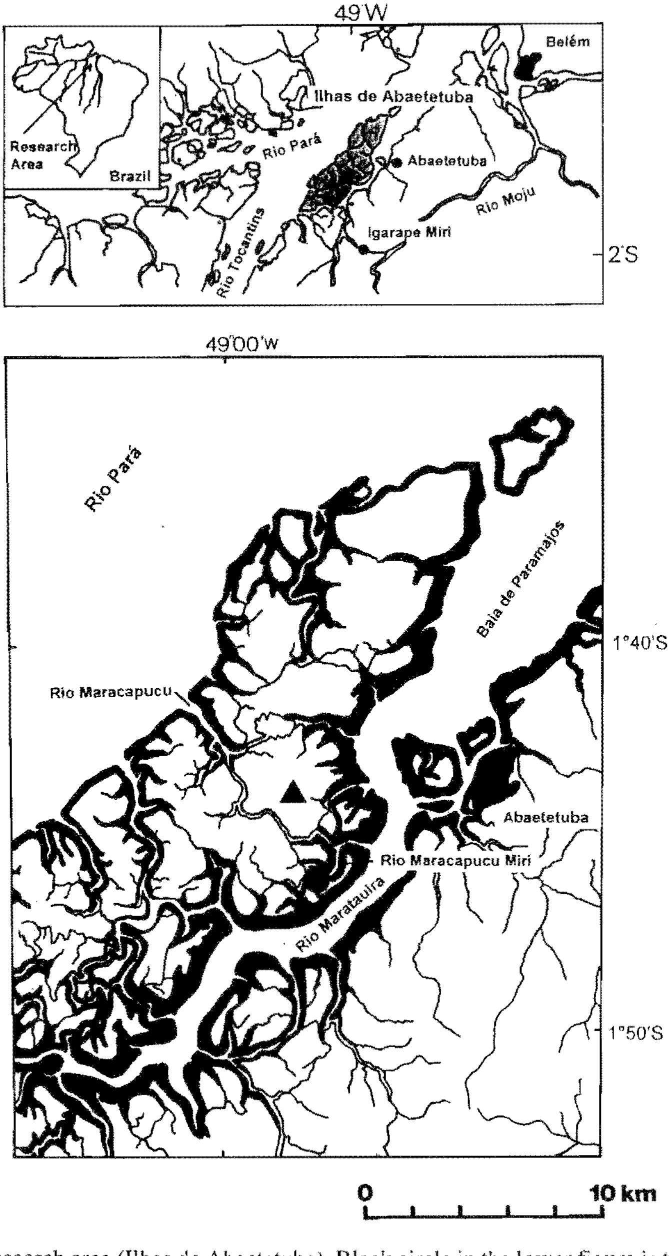


Figure 1 - Research area (Ilhas de Abaetetuba). Black circle in the lower figure is the location of várzea quadrats, and black triangle is the location of terra firme quadrats. The várzea is shown as a black shade.

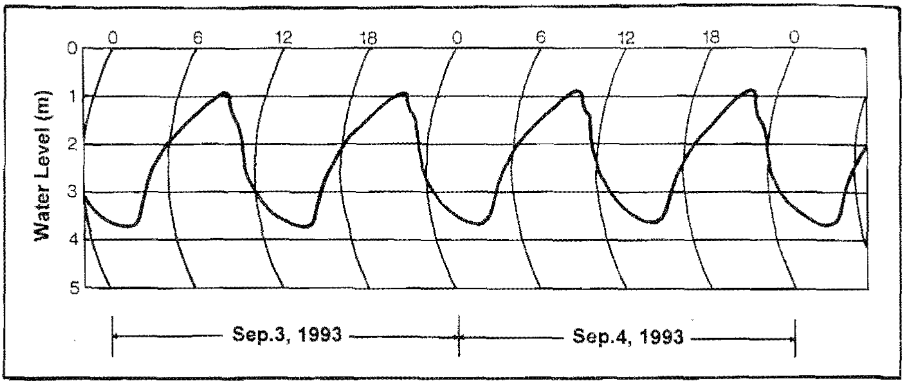


Figure 2 - Diurnal fluctuation of water depth at Rio Maracapucu Mirí during Sep.3 to 4, 1993.

The area from eastern Pará to the Guianas is one of the rainiest regions of Latin America. Annual precipitation averages 2,400mm in Belém, and it exceeds 3,500mm in some places (Nimer 1972). However, there is a major variation between the wet and dry seasons. This influences the annual tree ring formation in the terra firme forest that adjoins the várzea forest (SUDAM/DRN 1981). In várzeas, on the other hand, trees are not influenced by seasonal changes in rainfall. The species and structures are different from those of terra firme forest (Ayres 1993).

STUDY METHODS

Fieldwork was carried out in the várzea and terra firme forests of the Ilhas de Abaetetuba during 1993 and 1994. Four várzea quadrats were established along the Rio Maracapucu Mirí, and another four quadrats were demarcated in a terra firme forest along the Rio Maracapucu, about four kilometers away from the várzea quadrats (Figure 1). The size of each quadrat was 400m². In selecting the sites for várzea quadrats, consideration was given to include açaí under different treatments.

The number of trees in each species was counted, and the tree height and diameter at breast height (DBH) of all the trees whose DBH was larger than 5cm were measured in each of the three várzea (VZ1 to VZ3), and terra firme (TF1 to TF3) quadrats. Stem disks at a height of 1.0m were collected from the remaining quadrats (VZ4 and TF4). Disks for stem analysis were collected from 7 species by felling the main stem and cutting at intervals of 1.0 to 2.0m. They were polished on both sides using a sandpaper (#40 and #100) attached to a grinder. The ring widths of major and minor axes were measured by a measurescope (Nikon, MM22) within an accuracy of 0.001mm, and the average was taken as the ring width for each year. The wood density of 11 várzea and 13 terra firme species was measured with an electronic densimeter (Mirage Trading, EW120SG), after drying the disks at a temperature of 90°C for 72 hours in a drying oven (Yamato, DV400).

In order to evaluate the tree-ring characterisitcs in two forests with different water conditions, the reflected brightness spectrum of the surface of tree disks was measured. A photograph was taken through a microscope, where a CCD camera (Tokyo Electronic Industry, CS5510) was mounted. The image was printed by a color video printer (Mitsubishi, SCT-CP1000), after processing with an image analysis software (NEXUS, Qube9000). The reflected brightness of radial direction in each tree-ring was measured, and the brightness was divided into 256 stages from 0 to 255 in each of the three components; R, G and B.

RESULTS AND DISCUSSION

Forest Characteristics

The açaí palm is widely cultivated/managed in várzea forests. Although the açaí agroforest is commonly located around the dwellings along rivers, its area is limited (0.5-3.0ha). Açaí commonly occurs in association with other trees, which are either planted or occur naturally. The palm is raised by protecting the naturally regenerating ones or by planting the seedlings. Açaí is a multi-stemmed palm. For maximum production, each clump is pruned to have no more than 4-6 mature stems (10-15m in height), aged 3-10 years. After reaching peak production, old trunks are removed to promote the growth of juveniles. The palm hearts (*palmito*) and the fruit are harvested for sale (Pollak *et al.* 1995). Palm hearts are processed for export and the fruit is marketed in the region. The açaí fruit juice, called vinho do açaí, obtained by macerating and sieving the mesocarp, constitutes one of the main components of the diet of the regional population. As such, it has become the most important cash crop in the Amazon estuary.

In the açaí agroforests, therefore, most competing species or branches are removed. The human impact can be estimated by counting the number of açaí clumps. For example, quadrat VZ1 shows a limited impact since the number of clumps is only 11 in an area of $400m^2$, whereas VZ2 with 42 clumps indicates a medium impact, and VZ3 with 83 clumps exhibits a strong impact. Other tree population in each of those quadrats numbered 87 in VZ1, 55 in VZ2, and 38 in VZ3, respectively.

Terra firme forests are used mainly as sites for manioc (*Manihot utilissima*) swiddens. The tubers, processed into manioc flour, are destined mainly for domestic use (Moran 1995). The number of trees felled and area cleared are small, in contrast to the várzea forests, since manioc is not cultivated by every family and the crop is produced only to meet household needs. Since ecological conditions are not favorable, açaí is not raised in the terra firme.

Tree age was counted from the stem disks of 41 trees at VZ4 (total number of trees = 56), and from the disks of 55 trees at TF4 (total number of trees = 80). Since the relationship between tree age and radius had a large correlation coefficient in each quadrat, tree age was estimated in the other quadrats, and the trees were sorted by tree age classes. On the average, the percentage of trees older than 30 years was 3.3% on the várzea and 5.6% on terra firme quadrats. It is believed that the trees in these quadrats are about the same age.

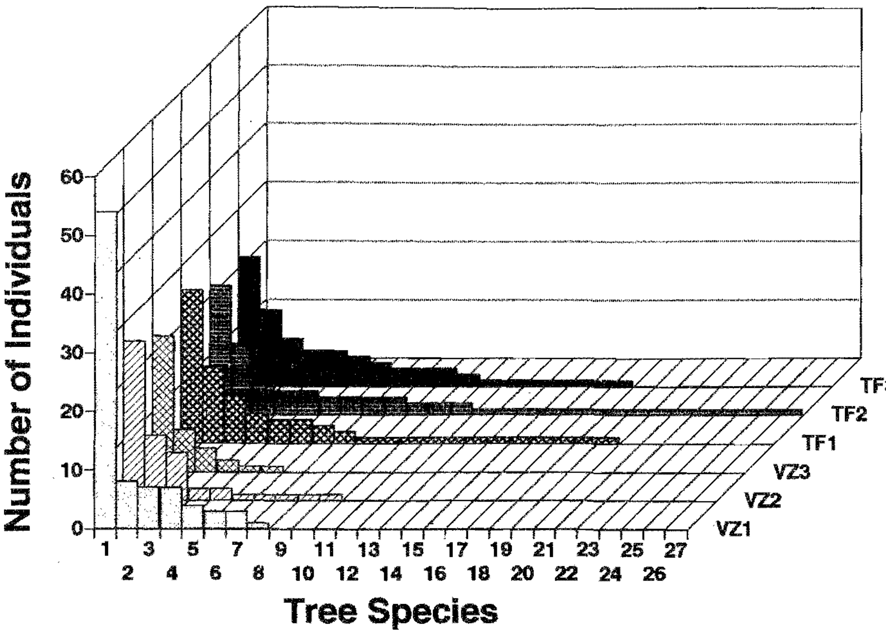
Forest Structure

In the várzea quadrats, the number of tree species are less than 10/400m², and about one half is composed by a single tree species (*Pterocarpus amazonicus*), while in the terra firme quadrats, the number of tree species is larger, i.e., 27 species in TF2, and the population is dispersed into several species (Figure 3). This suggests that the high water table, poor drainage, and frequent floods in the várzea severely limit the number of species (Anderson 1988). Further, there is an inverse relationship between the number of açaí and other trees. As management increases, açaí population increases, while other trees decline in number.

The counterpart of açaí palm in the terra firme forests is inajá (*Maximiliana maripa*), a palm which reaches less than 20m in height. Trees are taller than those in the várzea forests, and the canopy reaches 30m. Figure 4 offers a comparison of tree population in each height class in 6 quadrats. There is no tree taller than 25m in the várzea, and they seem to appear uniformly in each height class. In the terra firme, however, trees can be divided into two classes: those less than 10m and those above 10m. The result shows that the differences in human impacts affect the number of shrubs and juvenile trees near the forest floor.

Forest Biomass

Disks for stem analysis were collected from 4 várzea and 3 terra firme trees. They are (1) *Pachira acuatica*, (2) *Vatairea guianensis*, (3) *Pterocarpus amazonicus*, (4) *Virola surinamensis* (várzea tree species),



VZ1: 1 *Pterocarpus amazonicus*, 2 *Pachira acuatica*, 3 *Vatairea guianensis*, 4 *Virola surinamensis*, 5 *Avicennia nitida*, 6 *Mangifera indica*, 7 *Margaritaria nobilis*, 8 *Caryocar villosum* VZ2: 1 *Pterocarpus amazonicus*, 2 *Pachira acuatica*, 3 *Vatairea guianensis*, 4 *Mangifera indica*, 5 *Symphonia gloulifera*, 6 *Avicennia nitida*, 7 *Duroia macrophylla*, 8 *Virola surinamensis*, 9 *Margaritaria nobilis*, 10 *Zygia sp.* VZ3: 1 *Pterocarpus amazonicus*, 2 *Hevea brasiliensis*, 3 *Virola surinamensis*, 4 *Pachira acuatica*, 5 *Pentaclethra macroloba*, 6 *Margaritaria nobilis* TF1: 1 *Vochysia vismiaefolia*, 2 *Goupia glabra*, 3 *Gustavia augusta*, 4 *Triplaris surinamensis*, 5 *Eschweilera amazonica*, 6 *Tapirira guianensis*, 7 *Emmotum tagifolium*, 8 *Manilkara amazonica*, 9 *Acacia polyphyla*, 10 *Apeiba burchelli*, 11 *Aspidosperma eteatum*, 12 *Duguettia cauliflora*, 13 *Duroia macrophylla*, 14 *Iryanthera sagotiana*, 15 *Sagotia racemosa*, 16 *Sterculia speciosa*, 17 *Sterculia elata*, 18 *Buchenauia sp.*, 19 *Undefined* (Jeneira), 20 *Erisma uncinatum* TF2: 1 *Hymenaea intermedia*, 2 *Vochysia vismiaefolia*, 3 *Triplaris surinamensis*, 4 *Gustavia augusta*, 5 *Platonia insignis*, 6 *Eschweilera amazonica*, 7 *Manilkara amazonica*, 8 *Clidemia hirta*, 9 *Poragueiba guianensis*, 10 *Ormosia coutinhoi*, 11 *Swartzia racemosa*, 12 *Erisma uncinatum*, 13 *Acacia polyphyila*, 14 *Pachira acuatica*, 15 *Didymopanax morototoni*, 16 *Duguettia cauliflora*, 17 *Duroia macrophylla*, 18 *Goupia glabra*, 19 *Guarea kunthiana*, 20 *Mora paraensis*, 21 *Simaruba amara*, 22 *Sterculia pilosa*, 23 *Tapirira guianensis*, 24 *Tovomita cephalostigma*, 25 *Vouacapoua americana*, 26 *Sterculia elata*, 27 *Buchenauia sp.* TF3: 1 *Eschweilera amazonica*, 2 *Vochysia vismiaefolia*, 3 *Myrcia falax*, 4 *Duguettia cauliflora*, 5 *Undefined* (Cama), 6 *Triplaris surinamensis*, 7 *Hymenaea intermedia*, 8 *Humiria balsamitera*, 9 *Pachira acuatica*, 10 *Gustavia augusta*, 11 *Duguettia tlagelaris*, 12 *Britoa acida*, 13 *Guarea kunthiana*, 14 *Iryanthera sagotiana*, 15 *Pipthecellobium decandrum*, 16 *Simaruba amara*, 17 *Undefined* (Azulzinho), 18 *Clidemia hirta*

Figure 3 - Number of individuals of each tree species in várzea and terra firme quadrats.

(5) *Goupia glabra*, (6) *Triplaris surinamensis* and (7) *Vochysia vismiaefolia* (terra firme tree species). All of them are representative tree species from each forest. Figure 5 is a vertical section of *P. acuatica*, a várzea tree, and of *T. surinamensis*, a terra firme tree. The vertical axis represents the height in which the disks were collected, and the horizontal one is the location of tree-ring boundaries (dotted lines: estimated tree-ring boundaries). The basal portion of *P. acuatica* is wider, and the stem shows a long slope, while *T. surinamensis* has a more vertical growth to that of a thickening one. It is believed that the várzea species support the biomass by broadening the basal growth, since they grow mostly on a clay surface where inundation is frequent.

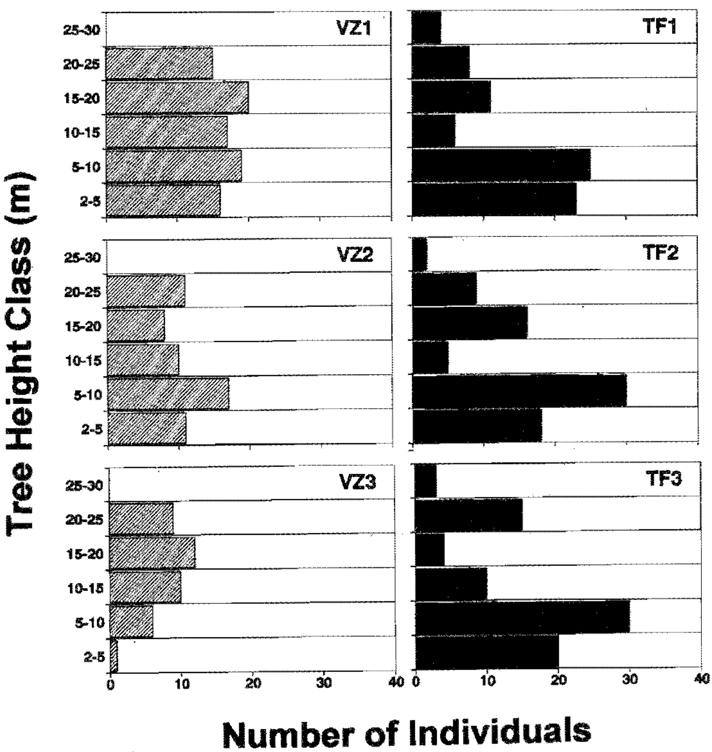


Figure 4 - Number of trees in each height class in three várzea and three terra firme quadrats.

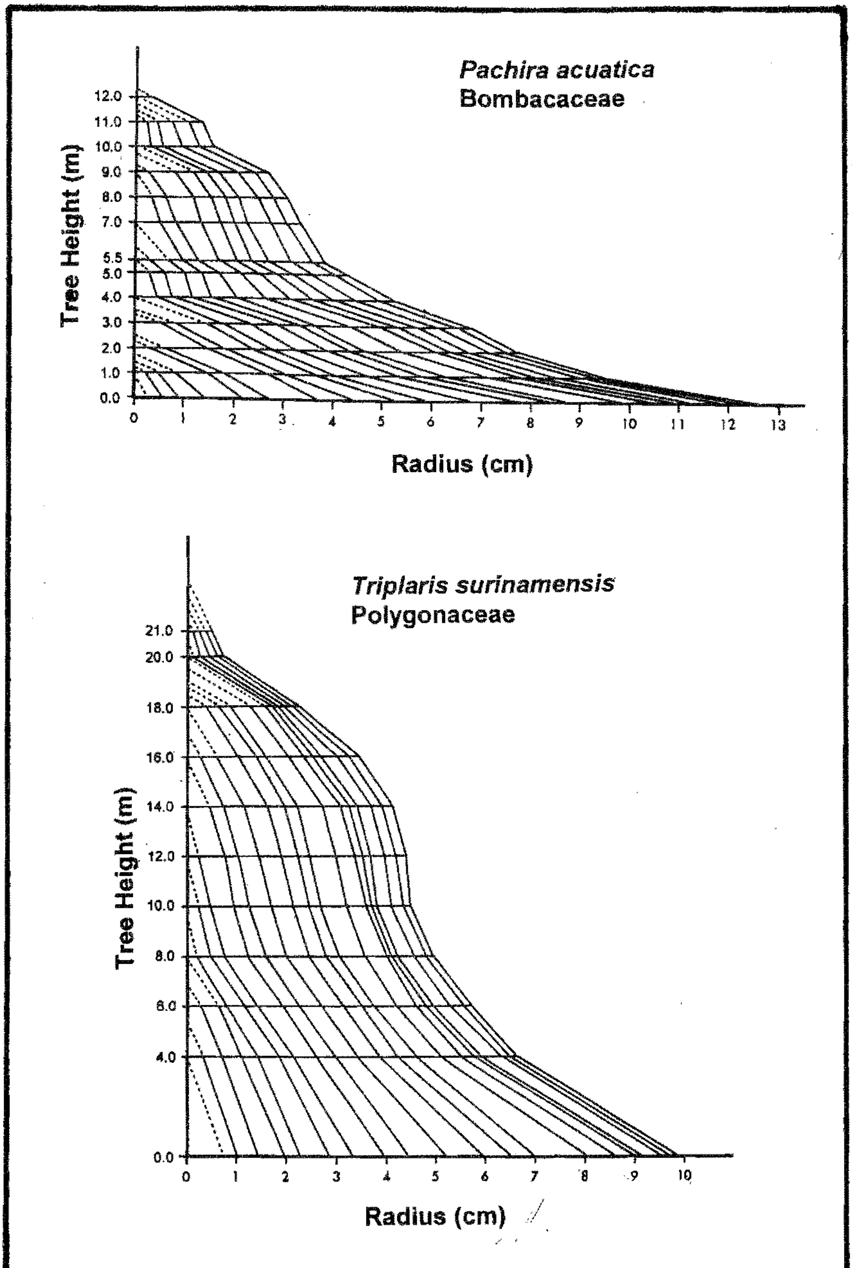


Figure 5 - Vertical section of *Pachira acuatica* (upper) and *Triplaris surinamensis* (lower).

The stem volume was calculated from tree-ring width data of each disk by using the integration formula of solid revolution. Then, the annual wood volume was added to understand the growth rate (Figure 6). In the várzea, wood volume of *P. acuatica* predominates, and the volume of the other three species is about half. It is not possible to directly compare the volume because tree ages are different. However, the growth rate of *P. amazonicus* is apparently larger. Rodrigues (1989) describes that this species grows faster and becomes the canopy layer in várzea forests, while the other species, such as, *P. acuatica* and *V. surinamensis* are found in the intermediate layer. Therefore, it is believed that *P.amazonicus* continues growing but the growth of the other species will reach the limit. These species were ranked as the top four in the number of individuals (*P. amazonicus*: 104/1200m², *P. acuatica*: 21/1200m², *V. guianensis*: 15/1200m², *V. surinamensis*: 12/1200m²). Similar results are found for the terra firme species. *T. surinamensis*, a canopy species, has a high growth rate and exceeds the other two species. *V. vismiaefolia* is also one of the canopy species and has the largest population (51/1200m²). The wood growth is still small because it is a 15 year-old trees. However, its growth rate is comparable to *T. surinamensis*.

Next, the forest biomass was compared in the 6 quadrats. Referring to Higuchi *et al.* (1994), the following equations were used to estimate the biomass: (1) $\ln(FW) = -2.4768 + 2.2301\ln(D) + 0.6518\ln(H)$ ($5 =< D < 20$cm), (2) $\ln(FW) = -3.8102 + 1.4631\ln(D) + 1.8190\ln(H)$ ($D >= 20$cm). Here, FW: fresh weight, ln: natural log, D: DBH, H: tree height. The FW of each quadrat was calculated by substituting DBH and height data of all the individuals in the quadrat. Then, the FW was converted to dry weight from the description of Higuchi *et al.* that the dry weight represented about 60.4% of FW.

The result is shown in Figure 7. The difference among three terra firme quadrats is small, while the biomass in várzea quadrats varies widely from 20.43t/400m² at VZ1 to 6.01t/400m² at VZ3. It is thought that this was brought about by the different degrees of human intervention related to the cultivation of açaí palm. The várzea which is strongly disturbed has a small dry weight, while the várzea with small human impact has a larger dry weight than that of terra firme. However, the biomass of palms is excluded in this estimate. If the palm biomass is included, the total biomass of disturbed quadrats such as VZ2 and VZ3 will be close to VZ1.

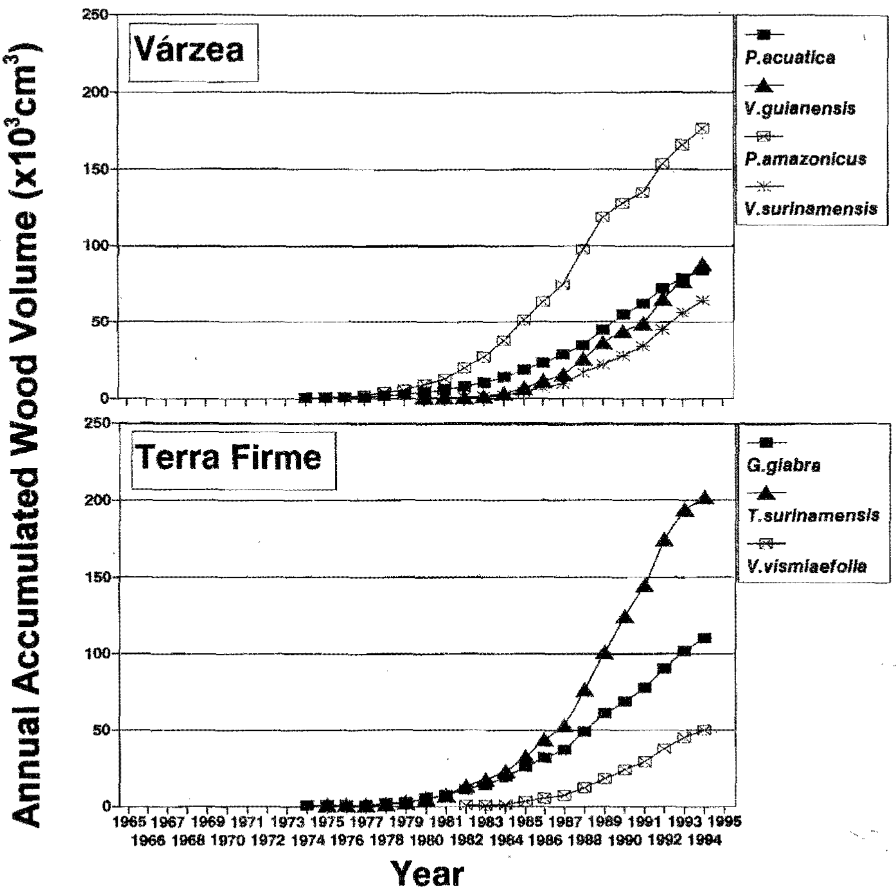


Figure 6 - Accumulated stem wood volume of four várzea species (upper) and three terra firme species (lower).

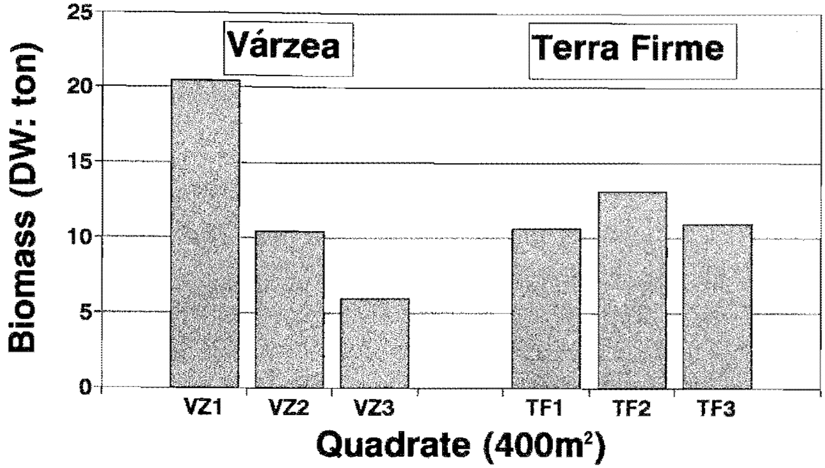


Figure 7 - Comparison of forest biomass (dry weight; ton) among three várzea and three terra firme quadrats.

Tree-ring Characteristics

A comparative study of tree-ring characterisitcs, as they appeared in the reflected brightness spectrum in early and latewood boundaries, was carried out to better understand the above difference.

Figure 8 shows an example of reflected brightness in a radial direction within a tree-ring of representative tree species in each forest type, i.e., *Pterocarpus amazonicus* for the várzea, and *Triplaris surinamensis* for the terra firme. Along the vertical axis, brightness varies from stage 255 (brightest color) to stage 0 (darkest color). In the case of *P. amazonicus*, the latewood width is narrow (about 10%), and the decrease in brightness is small in all three components (R, G, B). In the brightness curve of *T. surinamensis*, the latewood width is larger (latewood ratio: 40%), and all three components decrease in value compared to those of the earlywood.

Although várzea forest trees are subject to a limited water stress, the counterparts in the terra firme forest slow down the cambial activity during the dry season and the latewood is characterized by a small

small proportion of tracheal element. Early and latewood boundaries are formed here, and the boundaries appear in the brightness contrast. This difference appeared in the wood density as well. The mean wood density of 11 várzea species was 0.61g/cm³, while that of 13 terra firme species was 0.70g/cm³.

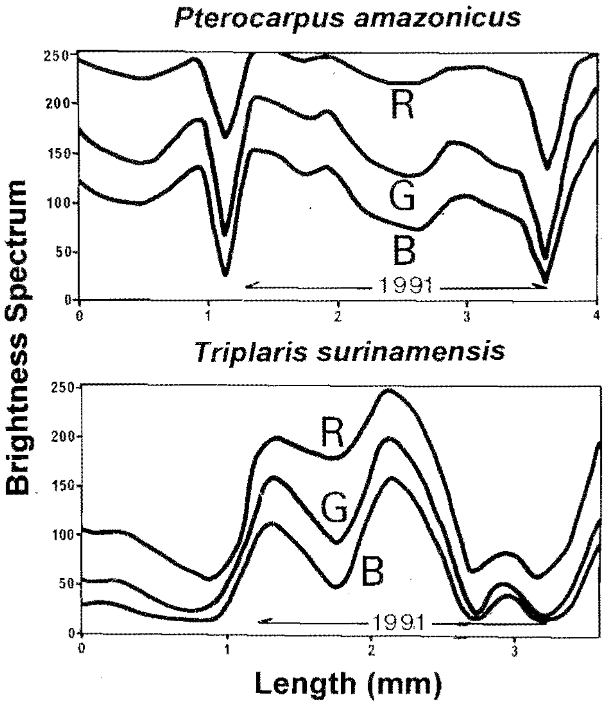


Figure 8 - Reflected brightness spectrum within a tree-ring of várzea species (*Pterocarpus amazonicus*, upper) and terra firme species (*Triplaris surinamensis*, lower).

Next, the brightness index (BI) of trees was compared. Peak brightness (PB) and bottom brightness (BB) were calculated by averaging three components. Then, the BI was calculated from the equation: BI = (PB - BB)/PB. The difference was divided by PB to non-dimensionalize the absolute value of color stage. The BI was calculated in 11 várzea tree species at VZ4, and 13 terra firme tree species at TF4. After measuring the brightness curves of at least 20 tree rings for one species, the average was defined as the BI peculiar to that species. Figure 9 shows the relationship between the BI and wood density. It is found that tree species with a large BI has a high wood density, while those with a small BI has a low wood density. The latter relationship is particularly marked in várzea forests, where species like *P. amazonicus* and *P. acuatica*, have a density less than 0.40g/cm³. Obviously, there are exceptions. For example, várzea species like, *Pentaclethra macroloba*, *Guarea kunthiana*, *Genipa americana*, *Duroia macrophylla*, *Margaritaria nobilis*, and *Mora paraensis* show high values in both BI and wood density, with values comparable to those of terra firme species. According to Rodrigues (1989), the reddish colored wood of *P. macroloba*, *G. kunthiana*, *G. americana*, and *M. nobilis* are resistant to insects and thus are employed in the local cabinetry and furniture industries. The same author also notes the slow growth rate of foregoing species. Trees with red color are common on the terra firme, and their growth is likewise slow, but an adequate explanation does not exist for their presence on the várzea. The presence of these anomalous species on the várzea cannot be adequately explained in terms of a highly aquatic environment alone. Further studies are needed from different angles.

Early and latewoods can be easily distinguished in the tree rings of terra firme species, e.g., *T. surinamensis* with a wood density of 0.79g/cm³. Analogous to tree rings of conifers, where earlywood is whitish and latewood brownish, tropical uplands' counterparts can be separated by color shades. The densities, on the other hand, varies between 0.60 and 0.88g/cm³. Tree rings of várzea species are difficult to distinguish on the basis of color shades alone. No obvious tree-ring color differences exist. This fact implies that density differences between early and latewoods are small, and most species have a low density. Consequently, it is possible to argue that the wood quality of most várzea species is not suitable for construction and firewood.

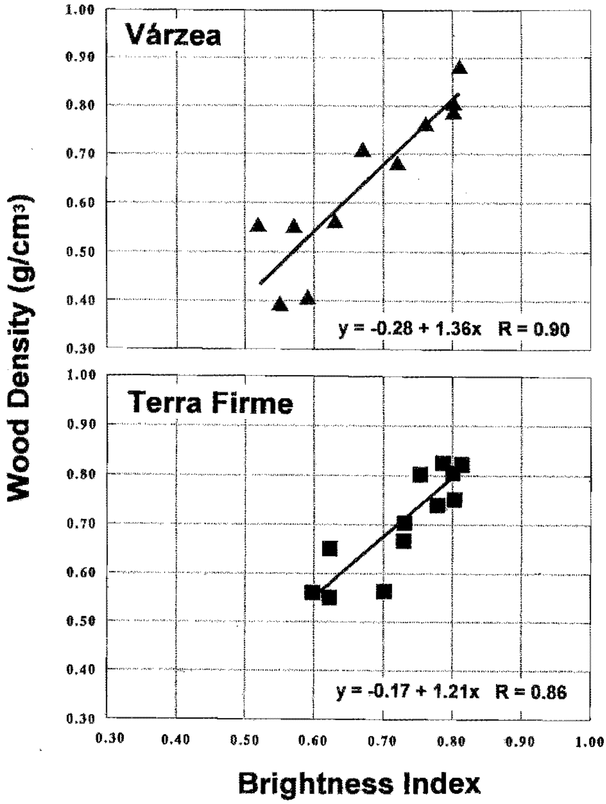


Figure 9 - Relationship between brightness index and wood density of 11 várzea (upper) and 13 terra firme species (lower).

CONCLUSIONS

The forest structure, biomass, and tree-ring characteristics of várzea and terra firme forests were compared in this study. The following results were found:

(1) The Amazon estuary is one of the rainiest regions of Latin America, yet there is a dry season between August to December, when a 300mm water deficit develops on an annual basis. Therefore, unlike the frequently inundated várzea forests, the terra firme forests are influenced by the seasonal moisture deficit.

(2) In várzea forests, açaí palms are frequently managed. In such areas the number of trees and species are limited. Likewise, tree height differences are small. On the terra firme, the forests are divided into two height classes and the canopy layer is taller than that of the várzea forest. In areas under limited human impact, the variations in aboveground biomass between várzea and terra firme quadrats are negligible. This results from the fact that although the várzea forest has a low average tree height and a low wood density, the growth rates of várzea species are as large as those of terra firme. However, once the forest is managed for açaí cultivation, the biomass is reduced to less than one third.

(3) Terra firme species have a large brightness contrast between early and latewood boundaries. This is related to the high wood density caused by the dry season moisture deficiency. Várzea forest species have a low wood density, since the water stress is limited by the frequent tidal inundations.

An adequate amount of nutrients is transported from upriver portions and deposited on the várzea, especially during the rainy season spring tides (Souza 1990). The process is different on the terra firme forests characterized by an ordinal process of litter decomposition through micro organisms. This suggests, among other variables, a necessity to place greater emphasis on root depth and soil nutrient dynamics, as well as hydrochemistry, for a better understanding of forest growth.

Várzea forest management practices have changed drastically after the 1970s, as a result of the collapse of traditional agriculture (Hiraoka 1995). Currently, the major source of income production for most of the inhabitants is the açaí palm, while for others is the manufacture of ceramic products like tile and bricks. In the former case, açaí is managed through thinning of forests, while in the latter, firewood is obtained by felling the várzea forest. Várzea forests are limited in area and species, but they are subject to continued cutting, despite their limited energy output, since they are found along rivers where access and transport are facilitated. This study points to a need of a future research where the focus would be on wood consumption by the local inhabitants. In combination with the biomass data obtained in the present study, an assessment of consumption and forest biomass production can be made.

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