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Phytosociology of the remaining xerophytic woodland associated to an environmental gradient at the banks of the São Francisco river - Petrolina, Pernambuco, Brazil[1]

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ABSTRACT – (Phytosociology of the remaining xerophytic woodland associated to an environmental gradient at the banks of the São Francisco river - Petrolina, Pernambuco, Brazil). Floristic and phytosociological surveys were carried out for 12 months in the Embrapa-SPSB, Petrolina, Pernambuco, Brazil. A transect was laid on starting at the river bank extending for 790 m away from the river and divided into 140 10 × 10 m contiguous plots. In each plot, all standing plants, alive or dead, with stem diameter at soil level ≥ 3 cm and total height ≥ 1 m were sampled. Along this transect, an elevation range of 9.40 m was registered and five topographical environments were identified: riverside (MR), dike (D), floodable depression (DI), boundary terrace (TL) - all of them belonging to the fluvial terrace with Fluvic Neosol and Haplic Cambisol both silty textured eutrophic soils - and the inlander tableland (TS), with medium sandy-textured Red-Yellow Argisols. Fourty-eight species/morphospecies, distributed into 39 genera and 21 families, were identified. Four phytogeoenvironments (MR, D + TL, DI + TL, and TS) were registered based on environmental variations and floristic similarities among plots using cluster analyses. The MR environment showed the largest total density, total basal area, maximum and medium heights and maximum diameter. Moreover, it had 8.1% of plants with heights above 8 m against 0.6% for D + TL, 0.2% for DI + TL, and 0% for TS. The species with the largest importance value were *Inga vera* subsp. *affinis* (DC.) T.D. Pennington in MR, *Mimosa bimucronata* Kunth in D + TL and DI + TL and *M. tenuiflora* (Willd.) Poir. in TS.

Key words - phytosociology, São Francisco river, semi arid, soil, woody vegetation

RESUMO – (Fitossociologia de um remanescente de caatinga, associado a um gradiente ambiental à margem do rio São Francisco, Petrolina, Pernambuco, Brasil). Foi realizado, durante um período de 12 meses, um levantamento florístico e fitossociológico do componente arbustivo-arbóreo, em área da Embrapa-SPSB, em Petrolina-PE. A partir da margem do rio, foi aberto um transecto, com o comprimento de 790 m, onde foram instaladas 140 parcelas contíguas de 10 × 10 m, para amostragem de todos os indivíduos vivos ou mortos ainda em pé, que tivessem o diâmetro do caule ao nível do solo ≥ 3 cm e altura total ≥ 1 m. Ao longo do transecto foi registrado um desnível de 9,4 m e identificados cinco ambientes topográficos: margem do rio (MR), dique (D), depressão inundável (DI), terraço limite (TL), todos pertencentes ao terraço fluvial, com Neossolos Flúvicos e Cambissolos Háplicos, ambos eutróficos e com textura siltosa, e o tabuleiro sertanejo (TS) com solo do tipo Argissolo Vermelho-Amarelo textura arenosa média. Foram encontradas 48 espécies/morfoespécies, distribuídas em 39 gêneros e 21 famílias. Quatro fitogeoambientes foram registrados: MR, D + TL, DI + TL e TS, com base nos aspectos morfopedológicos e na similaridade florística entre as parcelas, calculada por meio da análise de agrupamento, e identificados os diferentes conjuntos florísticos ligados ao terraço fluvial e ao tabuleiro sertanejo. A MR destacou-se dos demais ambientes pela maior densidade total, área basal total, alturas máxima e média e diâmetro máximo, além de apresentar 8,1% dos indivíduos com altura superior a 8 m, contra 0,6% do D + TL, 0,2% do DI + TL e 0% do TS. As espécies com maior valor de importância (VI) foram: *Inga vera* subsp. *affinis* (DC.) T.D. Pennington na MR, *Mimosa bimucronata* Kunth no D + TL e DI + TL e *M. tenuiflora* (Willd.) Poir. no TS.

Palavras-chave - fitossociologia, rio São Francisco, semi-árido, solo, vegetação lenhosa

Introduction

Caatinga is a typical denomination of the Brazilian semi-arid vegetation. The word is of indigenous origin (caa = forest; tinga = white, open). It is composed of xerophilous, deciduous trees and thorny bushes, as well as succulent plants and seasonal bushes (Andrade-Lima 1981). In all its physiognomical variation, the caatinga is a vegetation of tropical steppe. From hot semi-arid climates, directly linked to climatic and pedological

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overall regional conditions (Ab'Saber 1990). For Egler (1951), the caatinga involves a large number of plant associations with different physiognomies and floristic complexes, being a very heterogeneous vegetation, with a wide physiognomic variation from a place to another, within the same region, and throughout the different seasons.

Considering the relationships between the caatinga vegetation and abiotic factors, several authors, studying the plant associations of caatingas, found that the physiognomic differences are associated with physical factors, with climate playing a chief role (Ab'Saber 1970, Reis 1976).

Andrade-Lima (1981) stated that the vegetation types found in the caatingas result from climate-soil interactions, with a high number of combinations that, once there is no complete information on soils, topography and climate, it is very difficult to classify caatinga communities at a phytosociological level. Kuhlmann (1974) emphasized that the caatinga shows multiple landscapes resulting from the variation in drought period length, soil depth, degradation from human activities, etc.

Based on the climate-soil-vegetation interaction, Andrade-Lima (1981) defined seven physiognomic types of caatinga: 1) tall forest caatinga; 2) median forest caatinga; 3) low forest caatinga; 4) open arboreous caatinga; 5) shrubby caatinga; 6) open shrubby caatinga and 7) forest fringe caatinga.

Fringe forest caatingas, especially those at the São Francisco river margins, have been showing a strong degradation due to agricultural endeavors, thus increasing erosion on its riverbanks and silting (Vasconcelos Sobrinho 1949, Duque 1973). Travelling from Bom Jesus da Lapa to Juazeiro, Bahia, Luetzelburg (1923) related that the São Francisco riverbanks' vegetation included carnaúba palm, Cactaceae (*Cereus*), Mimosaceae, Euphorbiaceae and crawling Bromeliaceae. He also noted the extensive extraction of carnauba wax (*Copernicia cerifera* (Arruda) Mart.), a typical plant of the Northeast perennial rivers. Kuhlmann (1951) noted that the vegetation on the banks of that river were virtually nonexistent due to prospecting and land clearings for planting; he asserted the need for reforestation. Moreover, Rabelo *et al.* (1990) cited that dam construction aggravated the problems of loss vegetation cover on the São Francisco riverbanks.

Despite their relevant role to sustain biodiversity, forests located on the riverbanks have been suffering deforestation in several parts of Brazil. According to van den Berg & Oliveira Filho (2000), these forests are fragile systems which occur at valley bottoms, corresponding to the most fertile soils of a basin, which are, therefore, highly vulnerable to destruction for agricultural purposes. These forests are most important in the trophic chains of water bodies as they furnish leaves, flowers, fruits and seeds as well as shelter and feeding grounds for birds and mammals; another function is to serve as a venue for genetic interchange among populations (Mantovani *et al.* 1989, Marinho Filho & Reis 1989).

Due to the importance of the vegetation of the São Francisco river banks, a study was carried out aiming at describing the floristic and phytosociological variations occurring along a presumed environmental gradient associated to topography and soils extending between the fluvial terrace and the tableland in Petrolina, Pernambuco State, Brazil.

Material and methods

The study area is a squared 64-hectare-fragment on the São Francisco riverbank, with sidelength of 800 m, within a property belonging to the Brazilian Agricultural Research Corporation (Embrapa) – Basic Seed Production Services (SPSB), a government research agency, in the Municipality of Petrolina, Pernambuco State. Coordinates are 9°02' S and 40°14' W (figure 1) at an altitude of 337 m (Condepe 1988).

In geomorphologic terms, the area occupies the São Francisco peripheric depression, from the fluvial terrace to the inlander tableland. The fluvial terrace was formed by alluvial deposits from valley slopes (Guerra 1975, Leinz & Leonardos 1971) and is composed of sedimentary deposits of clay, sand and/or silt of fluvial origin that formed stratified alluvium layers, from the Holocene, Quaternary (Jacomine *et al.* 1973, Brasil 1983).

The tableland occurs right after the fluvial terrace, with a pediplain surface, formed by a sedimentary covering (pediment) of a clay/sandy nature, from the Tertiary period, which covered the pre-Cambrian crystalline base. Its surface varies from flat to slightly wavy (Jacomine *et al.* 1973, Brasil 1983, Cavalcanti *et al.* 1998, Embrapa 1998).

The climate is semi arid and warm. Summer rains occur between January and April with an average annual rainfall of 570 mm. Average annual temperature is 26.3 °C with barometric pressure standing at 61.7% (Teixeira 1998). According to Köppens's classification, the climate is of the BSwh' type (Jacomine *et al.* 1973).

The vegetation within the area, especially on the São Francisco fluvial terrace, was classified by Andrade-Lima (1981) as fringe "forest caatinga", whereas the area located further away was found to be bush-arboreal.

A transect was opened (figure 2) to trace the topographic ground profile using a surveyor's level. The transect was divided into plots for soil identification, being the location of each plot (figure 3) defined by the topography, following heights of 5 m, 7 m and 9.40 m. In this initial step of the work, soil samples were taken, labelled and classified according to Camargo *et al*. (1988) and Santos *et al*. (1989).

In order to know the soil transitions along the transect, three borings were made in each odd plot of figure 2, for later composition of one soil sample at the depths of 0 to 20 cm and 20 to 40 cm, according to Batista & Couto (1992a, b).

Chemical and physical analyses of soil types and borings were performed by Embrapa Soil, Water and Vegetable Tissue Laboratory from Petrolina, Pernambuco, according to standardized universal methods described in the Soil analyses methods manual adopted by Embrapa (Oliveira 1979). The analysed soil parameters were the following: 1) chemical analysis – organic matter; pH; electrical conductivity; available phosphorus; exchangeable potassium, calcium, magnesium, sodium and aluminum; potential acidity; total bases; cation exchange capacity; base saturation, and 2) texture analysis – sand, silt, clay, true and apparent density and moisture at 1/3 and 15 atm.

Five topographic environments were identified along the transect (figure 3) leading from the São Francisco riverbanks to the higher lands according to topographic situation and types of soil. The first four environments are located on the São Francisco river fluvial terrace. The fifth

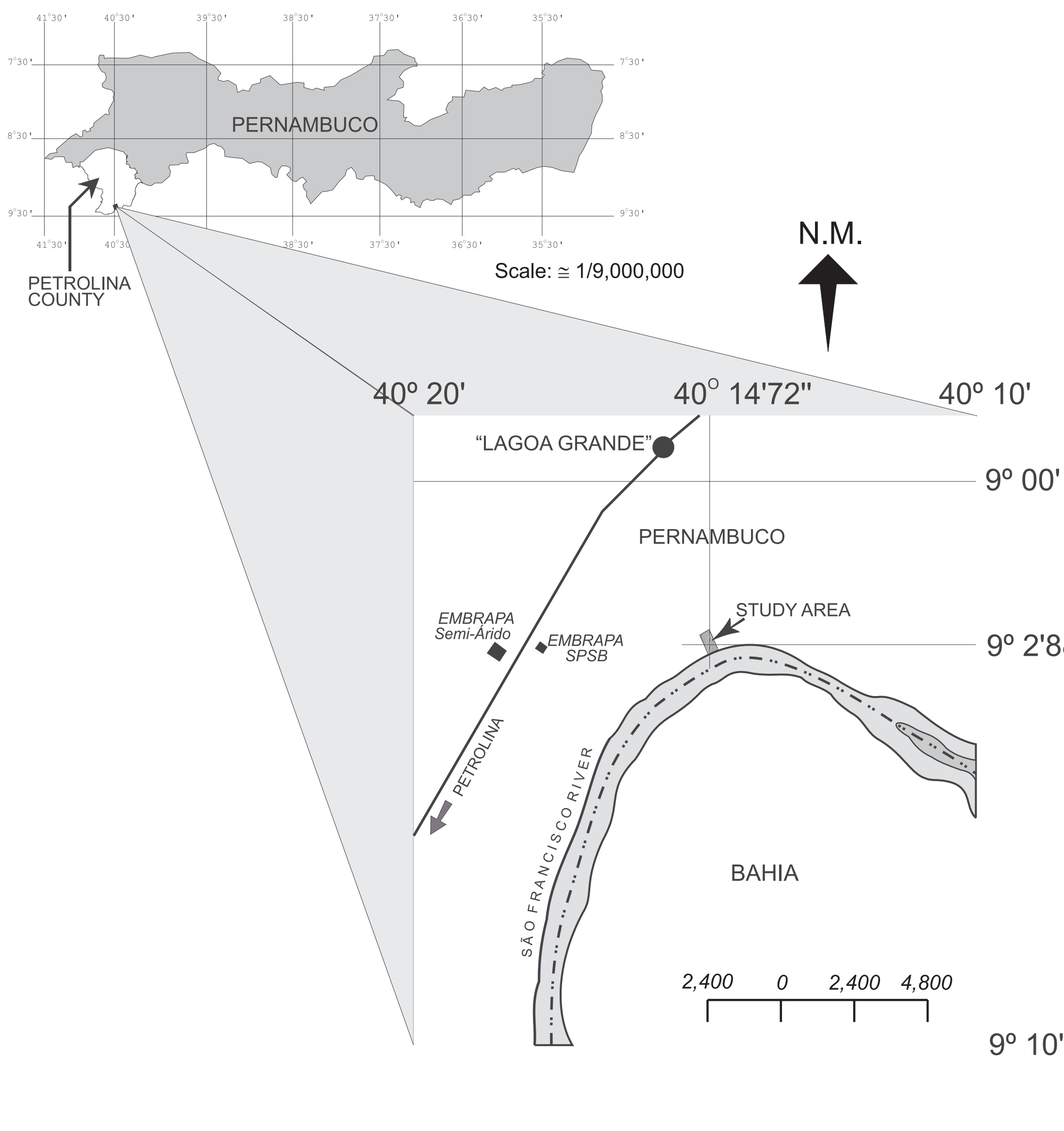

Figure 1. Study area in a caatinga remaining by the São Francisco river margin. Embrapa-SPSB, Petrolina, Pernambuco.

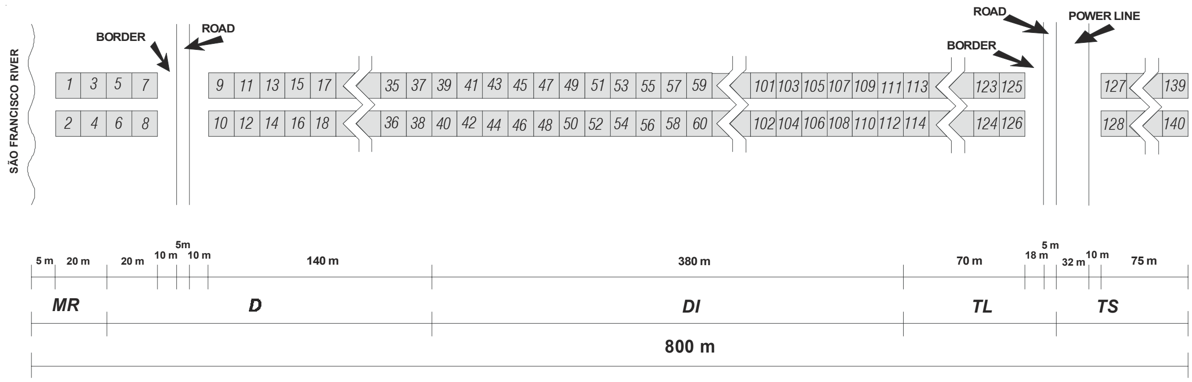

Figure 2. Horizontal projection of the transect and the 140 plots on a caatinga remaining area at the São francisco river margin. Embrapa-SPSB, Petrolina, Pernambuco.

environment is located in higher lands, specifically related to the inlander tableland. Height variation of the profile was found to be at 9.40 m.

The soil classes found in the five topographic environments were the following: 1) at the riverside (MR), the soils are Fluvic Neosol euthropic class silty, endo-sodic phase fringe forest plain relief; 2) at the dike (D), the soil is euthropic Haplic Cambisol class silty/average texture endo-sodic phase plain relief caatinga hyperxerophytic meadow; 3) the floodable depression (DI) is a gley euthropic Haplic Cambisol class saline-sodic silty texture phase plain relief caatinga hyperxerophytic meadow; 4) the boundary terrace (TL) is an euthrophic Fluvic Neosol class endo-solid-saline medium texture phase plain relief caatinga hyperxerophytic meadow; and 5) the inlander tableland (TS) soils are of the medium/sandy Argisol Red-Yellow euthrophic plinthic texture phase plain relief caatinga hyperxerophytic.

In the topographic environments MR, D, DI, TL and TS, 4, 34, 74, 14 and 14 plots, respectively, were delimited.

Botanic sample materials collected from the study area were analysed according to standard methods (Mori *et al.* 1989). The classification system of Cronquist (1981) was adopted for Magnoliophyta.

For quantitative vegetation sampling, 140 contiguous plots measuring 10 × 10 m were established along the transect. A minimum distance of 10 m from all local roads was kept in order to prevent a border effect. Height and diameter of all plants, alive or dead, but still standing, the stem of which stood at ≥ 3 cm at soil level and had a total height ≥ 1 m, were measured (Rodal *et al.* 1992). Numbered PVC labels were placed on all stems. Diameter and height measurements were obtained with dendrometer and aluminum tubes, respectively.

Floristic similarities in the plots were calculated using a presence/absence matrix, the plots being the variables and the presence/absence of sampled species being the attributes. A group analysis was performed using Sørensen's similarity coefficient (Kent & Coker 1995) and the unweighted pair-groups method using arithmetic averages (UPGMA) by the Fitopac software package, version 2.0 (Shepherd 1995).

The environments D + part of TL and DI + part of TL were grouped taking into consideration the drainage

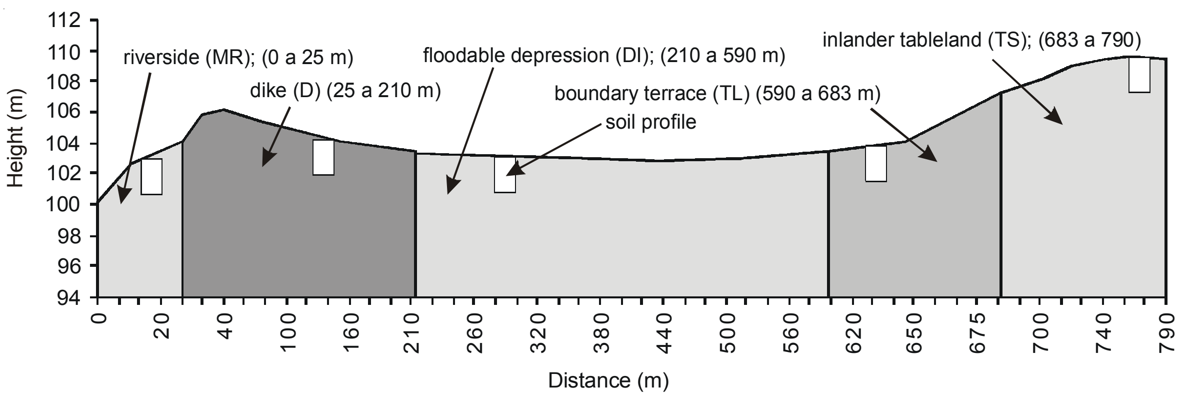

Figure 3. Scheme of topography and the distribution of five topographic environments and soil profiles on a caatinga remaining area at the São Francisco river margin. Embrapa-SPSB, Petrolina, Pernambuco.

conditions and mainly the analysis of floristic similarity. In each of the new groups (D + part of TL and DI + part of TL) there were 43 and 79 plots, respectively.

In the physiognomy characterization (Martins 1990) of each environment along the transect, density and total dominance were calculated (Rodal *et al.* 1992), as well as the distribution of the number of individuals by classes of diameters (3 cm) and height (1 m) in fixed intervals. For the sprouting individuals, the average diameter was calculated using an arithmetic mean to obtain the diameter class distribution.

An abundance analysis of sampled populations in each environment was performed based on density, relative frequency and dominance, importance value per species (Martins 1991) and on Shannon's diversity index (Magurran 1988), using the Fitopac software package, version 2.0 (Shepherd 1995).

Results and Discussion

Topography and soil – The first part of the fluvial terrace, on the riverside (MR), begins after the fluvial or flooding plane (Lima 1989) and shows a 4 meter level difference. The soils are marked by the presence of leaf litter and offer good draining conditions as well as low sodium content (7% to 11% sodium saturation) and salinity (0.6 to 0.9 dS m^{-1} electrical conductivity) in the last two layers of the lower profile.

The dike (D), also called marginal dike or fringe (Guerra 1975), occupies the second part of the fluvial terrace between the riverbank and the "floodable depression" and shows differences in level in relation to the river of 4 to 6 m. Drainage in these soils is more restricted and soil sodium content stands at 13.5% to 14% saturation and salinity at 0.1 to 1.4 dS m^{-1} electrical conductivity in the last two layers of the lower profile.

The floodable depression (DI) is located in the central area occupying a lower or basin-like part of the fluvial terrace between the dike and the final limits of the terrace with level difference of 3.5 m. In these soils, it was found the typical hydromorphic process due to iron reduction in an anaerobic environment, giving them a gray color and solid-compact appearance. Sodium content (22% to 23% of saturation) and salinity (6.2 to 6.5 dS m^{-1} electrical conductivity) were found in the last two layers of the soil profile.

Following the floodable depression comes the boundary terrace (TL) located on the last part of the fluvial terrace, bordering the high lands of the inlander highlands with level difference of 3.5 to 7 m. The soils show stratified layers and high levels of sodium (34% to 49% sodium saturation), as well as salinity (4.0 to 6.6 dS m^{-1} electrical conductivity) in the last two layers of the lower profile.

The soils from the four environments on the fluvial terrace are very deep, as found by Duque (1973) in his studies of the São Francisco river marginal soils in a stretch of the Sertão area of Pernambuco.

Finally, there is the inlander tableland (TS) or tableland (Guerra 1975), a plain surface in the first part of the high lands occurring right after the fluvial terrace of the São Francisco river and occupying a plateau with level difference of 9.4 m in relation to MR. The soils have good to moderate drainage conditions and are very deep. They show a texture gradient (clay loss at the upper part of the sub-surface part) which characterizes the B texture following the plinthite formation process where iron oxide segregation occurs resulting from soil wetting and drying. Sodium content (4.5% to 8% of saturation) and salinity (0.4 to 2.0 dS m^{-1} electrical conductivity) were found in the last two layers of the soil profile.

Table 1 shows mean values for the physical and chemical variables of the plots and soil profiles. There is a tendency towards a finer granulometry from MR to DI and a coarser granulometry towards TS where drainage conditions are less restricted than in other fluvial terrace environments.

Generally, calcium was found in high amounts with highest concentration (9.15 $cmol_c$ kg^{-1} soil) in DI and lowest (1.28 $cmol_c$ kg^{-1} soil) in TS (table 1). Duque (1973) noted that, among all elements, calcium is found in the highest proportion in the marginal soils of the São Francisco river. Found magnesium amounts are considered high (4.84 $cmol_c$ kg^{-1} soil), especially in DI (table 1).

Table 1 shows amounts of sodium, aluminum and organic matter. The highest sodium concentration was found in DI (0.64 $cmol_c$ kg^{-1} soil). Generally, aluminum showed the lowest concentration, with highest amount in MR (0.42 $cmol_c$ kg^{-1} soil) whereas D and TS had the lowest amounts (0.08 and 0.11 $cmol_c$ kg^{-1} soil). Organic matter was found in the highest amounts in MR (1.66%) with the amounts falling towards TS (0.48%).

Flora and topography – In the floristic survey, which included trees, bushes and climbing plants, 48 species/morphospecies were identified, being distributed among 39 genera and 21 families (table 2). From these 48 species/morphospecies, 91.7% were identified at the specific level and 8.3% were identified at the generic level.

Table 1. Mean values and standard deviation of the physical and chemical variables obtained from soil samples at 0-40 cm depth, on a caatinga reminiscent area at the São Francisco river margin. Embrapa-SPSB, Petrolina, Pernambuco.

Variables	Topographic environments				
	Riverside (MR) ± sD	Dike (D) ± sD	Floodable depression (DI) ± sD	Boundary terrace (TL) ± sD	Inlander tableland (TS) ± sD
Sand (%)	33.50 ± 9.89	23.73 ± 7.84	7.73 ± 3.94	61.38 ± 20.70	82.16 ± 0.29
Silt (%)	43.25 ± 2.47	51.92 ± 3.17	50.33 ± 4.39	15.88 ± 5.28	12.67 ± 2.30
Clay (%)	23.25 ± 7.42	24.38 ± 6.39	42.06 ± 3.58	22.75 ± 15.76	5.16 ± 2.02
Calcium ($cmol_c kg^{-1}$)	5.20 ± 0.49	5.62 ± 1.48	9.15 ± 1.40	3.95 ± 2.54	1.28 ± 0.36
Magnesium ($cmol_c kg^{-1}$)	1.48 ± 0.53	2.35 ± 0.55	4.84 ± 0.80	1.90 ± 1.22	0.56 ± 0.02
Sodium ($cmol_c kg^{-1}$)	0.14 ± 0.00	0.08 ± 0.06	0.64 ± 0.29	0.08 ± 0.06	0.01 ± 0.00
Aluminum ($cmol_c kg^{-1}$)	0.42 ± 0.52	0.08 ± 0.04	0.16 ± 0.10	0.20 ± 0.06	0.11 ± 0.04
Organic matter ($dag kg^{-1}$)	1.66 ± 0.19	1.16 ± 0.43	1.04 ± 0.18	0.99 ± 0.22	0.48 ± 0.16

The families with the largest amount of species were Euphorbiaceae, with eight species, followed by Caesalpiniaceae and Mimosaceae (seven species each) and Bignoniaceae, Boraginaceae and Cactaceae (three species each). It is important to note that Euphorbiaceae, Caesalpiniaceae and Mimosaceae were also the most important families in all xerophytic woodland surveys of the Brazilian semi-arid (Albuquerque *et al*. 1982, Fonseca 1991, Rodal 1992, Alcoforado Filho 1993, Oliveira *et al*. 1997, Ferraz *et al*. 1998), the only change being in position.

As can be seen on table 2, no species was present in all five topographic environments. Despite the fact that *Mimosa arenosa* and *Capparis cynophallophora* are listed in DI, their individuals were found in peripheral plots of this environment. Out of all 48 species/morphospecies found, 28 (58.3%) occurred in only one environment. This suggests that each habitat is specific. Sørensen's similarity index used in the five topographic environments shows that DI and TS are the most distinct without any species in common, whereas most similarities, 25% and 14%, occurred among D and TL and DI and TL, respectively. These results show a greater similarity among three fluvial terrace topographic environments (D, DI and TL) and this could be justified by the presence of more similar abiotic conditions due to the water availability associated to a finer texture. This is the opposite of what occurs in the tableland area (TS), where water availability is lower and texture is coarser. Apparently, these environmental differences would justify the presence of a more specific floristic set in TS.

Taking into consideration the floristic variations along the five topographic environments, a group analysis was conducted to differentiate them from the floristic point of view.

Figure 4 shows the dendrogram obtained from presence/absence data of the 39 species/morphospecies in the 140 plots, according to Sørensen's similarity. The figure shows that the presence/absence of species as well as its greater/lesser plot frequency are partly related to topographic situations.

The analysis of the dendrogram, which presented a correlation coefficient of 0.83, shows that in the first level of similarity (7%) two groups can be defined: Group I is formed solely by TS plots with several exclusive species such as *Aspidosperma pyrifolium*, *Caesalpinia microphylla*, *Cnidoscolus phyllacanthus, Commiphora leptophloeos, Croton sonderianus, Erythroxylum pungens, Jatropha ribifolia, Pilosocereus gounellei, Sapium scleratum, Schinopsis brasiliensis* var. *brasiliensis, Spondias tuberosa* and *Tabebuia spongiosa*, all of them typical of other TS areas in Northeastern Brazil (Andrade-Lima 1957, 1970, Nóbrega 1991, Rodal 1992, Araújo *et al*. 1998).

Group II is composed of the remaining plots and can be further subdivided into several other groups, according to increasing levels of similarities. At the 11% level, occurs Group III formed only by a plot from D, whereas Group IV is composed of remaining plots and can be further subdivided into Groups V and VI.

Group V, at the 17% level, is formed by 75% of MR plots. Exclusive to this environment are *Inga vera* subps. *affinis, Gaya aurea, Mimosa pigra* and *Paullinia pinnata*, with the first listed as the most abundant, as confirmed by observations made by Tigre (1974), Braga (1976), Rocha (1984), Andrade-Lima (1989). Group VI

Table 2. List of families and species sampled inside (A) and outside (B) the plots, following the inclusion criteria, their growth habits and topographic environment on caatinga reminiscent at the São Francisco river margin. MR: riverside; D: dike; DI: floodable depression; TL: boundary terrace; TS: inlander tableland. Embrapa-SPSB, Petrolina, Pernambuco.

Family/Species	Local name	Habit	A	B	Topographic environment				
					MR	D	DI	TL	TS
ANACARDIACEAE									
Schinopsis brasiliensis Engl. var. *brasiliensis*	baraúna	tree	-						x
Spondias tuberosa Arruda	umbuzeiro	tree	-						x
APOCYNACEAE									
Aspidosperma pyrifolium Mart.	pereiro	tree	-						x
BIGNONIACEAE									
Tabebuia spongiosa Rizzini	sete-cascas	tree	-						x
Melloa quadrivalvis (Jacq.) A.H. Gentry	-	bush		-		x			
Arrabidaea sp.	-	bush		-		x			
BORAGINACEAE									
Cordia verbenacea A. DC.	moleque duro	bush	-			x		x	
Cordia globosa (Jacq.) Kunth	moleque duro	bush		-		x			
Tournefortia rubicunda Salzm. ex DC.	pau cachimbo	bush	-			x			
BURSERACEAE									
Commiphora leptophloeos (Mart.) J.B. Gillett	umburana-de-cambão	tree	-						x
CACTACEAE									
Cereus jamacaru DC.	mandacaru	tree		-		x			
Harrisia adscendens (Guerke) Britton & Rose	bugi	bush	-			x			x
Pilosocereus gounellei (F.A.C. Weber) Byles & G.D. Rowley subsp. *gounellei*	xique-xique	bush	-					x	x
CAESALPINIACEAE									
Bauhinia pentandra (Bong.) Vogel ex Steud.	unha de cabra	bush		-		x			
Caesalpinia ferrea Mart. ex Tul.	pau-ferro	tree	-			x			
Caesalpinia microphylla Mart.	catingueira-rasteira	bush	-						x
Hymenaea courbaril L.	jatobá	tree		-		x			
Poeppigia procera C. Presl	muquém	tree	-			x		x	
Senna spectabilis (DC.) H.S. Irwin & Barneby var. *excelsa* (Schrad.) H.S. Irwin & Barneby	canafístula	bush	-			x			x
Senna macranthera (Collad.) H.S. Irwin & Barneby	são joão	bush	-						x
CAPPARACEAE									
Capparis cynophallophora L.	feijão-brabo	bush	-			x		x	x
CONVOLVULACEAE									
Ipomoea carnea Jacq. subsp. *fistulosa* Mart. ex Choisy	canudo	bush	-				x		
CUCURBITACEAE									
Wilbrandia sp.	batata de teiú	climbing plant	-			x			x
ERYTROXYLACEAE									
Erythroxylum pungens O.E. Schultz	rompe-gibão	bush	-						x
EUPHORBIACEAE									
Cnidoscolus phyllacanthus (Muell. Arg.) Pax & K. Hoffm.	faveleira	tree	-						x
Croton campestris A. St.-Hil.	velame	bush	-		x	x		x	x
Croton conduplicatus Kunth	quebra-faca	bush	-						x
Croton sonderianus Muell. Arg.	marmeleiro	bush	-						x
Jatropha mutabilis (Pohl) Baill.	pinhão	bush	-					x	x
Jatropha ribifolia (Pohl) Baill.	pinhão	bush	-					x	x
Phyllanthus cf. *chacoensis* Morong	piranheira	tree	-		x	x			
Sapium scleratum Ridley	burra leiteira	tree	-						x

continue

continuation

Family/Species	Local name	Habit	A	B	Topographic environment				
					MR	D	DI	TL	TS
MALVACEAE									
Gaya aurea A. St.-Hil.	-	bush	-		x				
MIMOSACEAE									
Acacia farnesiana (L.) Willd.	coronha	tree	-			x	x	x	
Inga vera subsp. *affinis* (DC.) T.D. Pennington	ingá	tree	-		x				
Mimosa arenosa (Willd.) Poir.	jurema vermelha	tree	-			x		x	
Mimosa bimucronata Kunth	alagadiço	tree	-		x	x	x	x	
Mimosa pigra L.	calumbi	bush	-		x				
Mimosa tenuiflora (Willd.) Poir.	jurema preta	tree	-			x		x	x
Pithecellobium parviflorum Pittier	arapiraca	tree	-			x			x
PALMAE									
Copernicia cerifera (Arruda) Mart.	carnaubeira	tree		-		x			
PAPILIONACEAE									
Geoffroea spinosa Jacq.	marizeiro	tree	-		x	x	x	x	
RHAMNACEAE									
Zizyphus joazeiro Mart.	juazeiro	tree	-		x	x			x
SAPINDACEAE									
Cardiospermum halicacabum L.	chumbinho	climbing plant	-			x		x	
Paullinia pinnata L.	-	climbing plant	-		x				
SOLANACEAE									
Lycium cf. *martii* Sendtn.	-	tree		-		x			
STERCULIACEAE									
Byttneria filipes Mart. ex K. Schum.	-	bush		-			x		
ULMACEAE									
Celtis membranacea Miq.	juaí	tree	-		x	x			
Total					10	27	5	13	23

is composed of remaining plots and can be further subdivided into Groups VII and VIII.

At the 22% level, Group VII is made up of 4.16% of DI plots dominated by *Ipomoea carnea* subsp. *fistulosa*, a species which, according to Andrade-Lima (1957), although widely seen in all xerophytic woodland in the state of Pernambuco, is also characteristic of this São Francisco region, thanks to its abundant population. The remaining plots form Group VIII and can be further subdivided into Groups IX and X.

At the 30% level, Group IX is made up of one MR plot and three D plots. Apparently, the separation of a MR plot and its link to the three D plots, located on the higher dike elevations, is due to the absence of *Inga vera* subsp. *affinis*. A larger number of species per plot is found in this group. Group X can be further subdivided into Groups XI and XII.

Figure 4 shows that at the 40% similarity level, some plots from D, DI and TL were very close. Mueller-Dumbois & Ellenberg (1974) recognized that, from this level on, plots or surveys can be considered as being from the same vegetal community, a fact that can be applied to this study.

The 122 plots in the D, DI and TL topographic environments were regrouped into two phytogeoenvironments, D + TL and DI + TL, taking into consideration the following aspects: drainage conditions and, mainly, floristic similarity obtained by dendrogram analysis due to the highest numbers of individuals from *Mimosa arenosa* and *Mimosa tenuiflora* in D and TL plots, and *Mimosa bimucronata* and *Geoffroea spinosa* in DI and TL plots. Therefore, instead of five topographic environments (MR, D, DI, TL and TS), we have four phytogeoenvironments: riverside (MR); dike + part of boundary terrace (D + TL); floodable depression + part of boundary terrace (DI + TL) and inlander tableland (TS). Upon studying natural vegetation on the banks of the Passa

Cinco river, in Ipeúna, São Paulo, Bertani *et al.* (2001) identified three types of vegetation with their own floristic and structural characteristics.

The union of part of the TL plots, located near TS, with plots from the intermediate part of D is due to the high frequency of *Mimosa arenosa* and *Poeppigia procera* in both. It should be expected that all D plots had the same floristic and physiognomy composition; however, that was not the case.

On the other hand, the bigger similarity among parts of TL and DI plots (TL plots closer to DI) is due to the fact that species such as *Mimosa bimucronata* and *Geoffroea spinosa* are found in both; they can also be found in remaining fluvial terrace environments (MR and D). Bigarella *et al*. (1975), Braga (1976) and Andrade-Lima (1989) noted that *Geoffroea spinosa* is frequently found in floodable meadows and riverbanks in almost all xerophytic woodland areas in Northeastern Brazil. Barbosa *et al.* (1989), in his phytosociological studies, noted the presence of *Mimosa bimucronata* in fringe forest stretches of Mogi-Guaçu, São Paulo. Thus, annual floods, from MR to TL, created floodable habitats favorable to *Geoffroea spinosa* and *Mimosa bimucronata*.

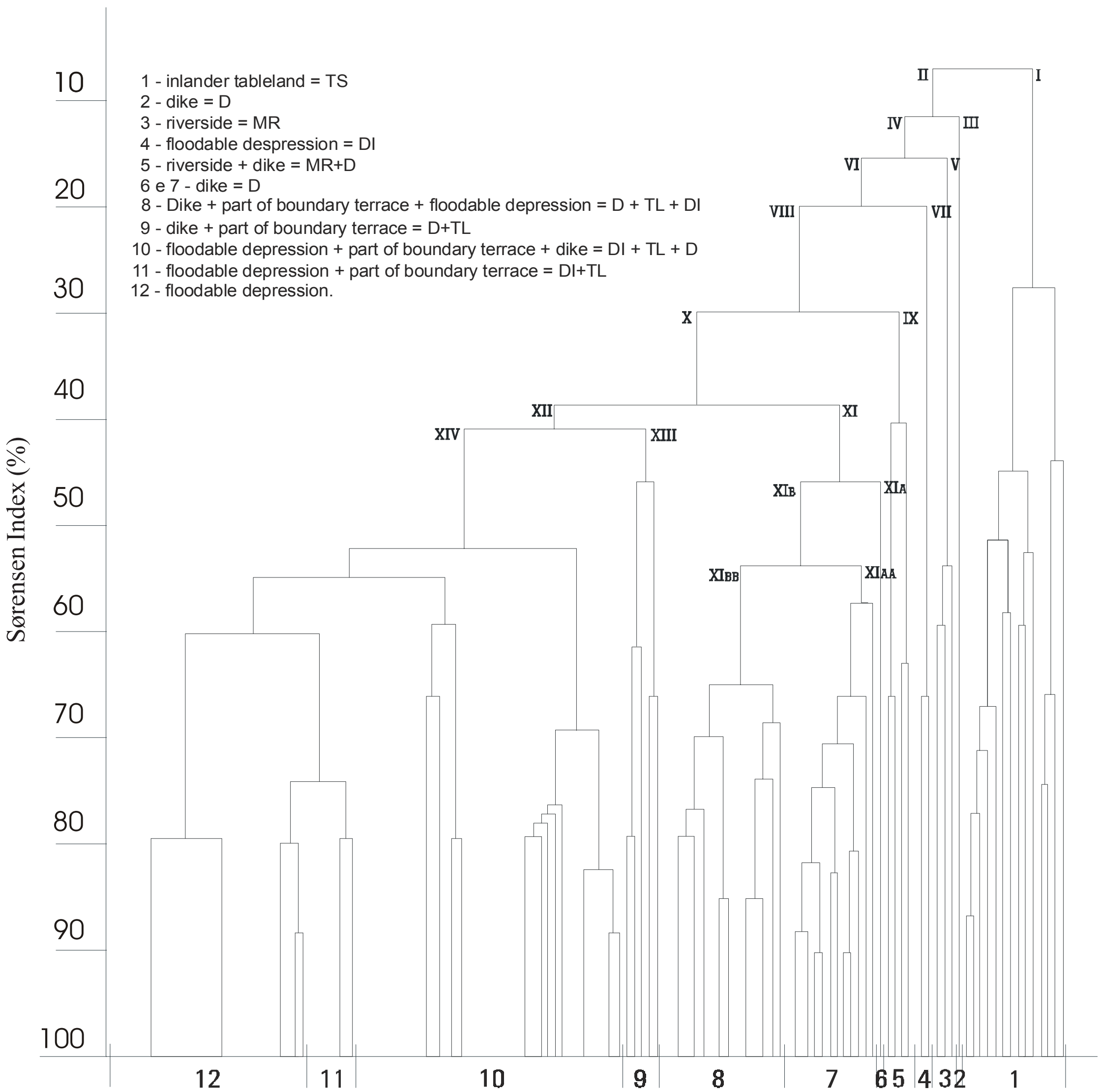

Figure 4. Floristic similarity of the vegetation in five topographic environments on a caatinga remaining area at the São Francisco river margin. Embrapa-SPSB, Petrolina, Pernambuco.

Physiognomy and structure - Table 3 allows to evaluate the variations of vegetation physiognomy occurring along the transect.

As it can be seen on table 3, among all environments in the fluvial terrace, MR participates with the highest values for basal area and total density, maximum height and diameter and mean height. Depending on the analyzed parameter, the other phytogeoenvironments (D + TL, DI + TL and TS) showed somewhat similar values, with a tendency to lower values in DI + TL, especially as they relate to total density and basal area and mean height and diameter. As woody vegetation is sparse in the DI depression area, the result is a lower total density in the DI + TL environments. Highest mean diameter was found in the TS environment along with the second highest total density (1.843 $ind.ha^{-1}$) and total basal area (17.89 $m^2.ha^{-1}$). These values are lower than those found in the arboreal xerophytic woodland studied by Alcoforado Filho (1993), who found 3.810 $ind.ha^{-1}$ and 24.92 $m^2.ha^{-1}$, but higher than those registered in a bush-arboreal xerophytic woodland area studied by Rodal (1992) with 1.076 $ind.ha^{-1}$ and 15.62 $m^2.ha^{-1}$. The values indicate that the variations on vegetation structure are directly related to soil and climatic conditions in each environment of the caatinga ecosystem.

Figure 5 shows the distribution of individuals per diameter class for the four phytogeoenvironments. It was found that MR, D + TL, DI + TL and TS showed dissimilar amplitude distribution. Highest amplitude, 96 to 99 cm, occurred in MR which also presented a bimodal distribution, 3 to 6 cm and 18 to 21 cm, whereas the lowest amplitude, 33 to 36 cm, occurred in TS, whose bimodal amplitude was 3 to 6 cm and 30 to 33 cm. D + TL had bimodal distribution, 3 to 6 cm and 18 to 21 cm. As for the form, only DI + TL had a diametric one mode distribution, showing 80% of species concentration, with mode between 3 and 6 cm, indicating strong diametric padronization in the phytogeoenvironment and a gradative decrease of the percentage of species in the subsequent classes.

In the distribution analysis per height in the four phytogeoenvironments (figure 6), it can be observed that MR and DI + TL showed the most dissimilar distribution both in height and in form. In the MR phytogeoenvironment, height distribution was found to be multimodal with modes between 2 and 3 m, 4 and 5 m and 9 and 10 m and also had the highest amplitude, at 13 to 14 m. In DI + TL, major height concentration occurred between 2 and 3 m. The least amplitude, 7 to 8 m, occurred in TS, which also had the highest concentration of 3 to 4 m.

Although having the smallest number of plots (eight), MR showed 8.1% of individuals with height over 8 m, against 0.6%, 0.2% and 0%, respectively in D + TL, DI + TL and TS, probably due to proximity of the river. Andrade-Lima (1961) found that among the subdivisions of Brazilian Northeast caatingas, the bushy caatinga is always found where moisture is more favorable, creating denser populations.

Comparing individual distribution per classes of diameter and height (figures 5, 6) in the four phytogeoenvironments, it was observed that there was a concentration of individuals, around 90%, among classes from 3 to 12 cm in diameter and 1 to 6 m in height. In the fluvial terrace, the physiognomy of DI + TL should be noted since it is formed by 79.8% of individuals with 3 to 6 cm in diameter and 51.5% of individuals with 2 to 3 m in height. These individuals are basically represented by the species *Ipomoea carnea* subsp. *fistulosa*, which is basically constituted by individuals with thin diameters in the adult state, and

Table 3. Results of the physionomic variables and standard deviation of four environments on a caatinga reminiscent at the São Francisco river margin. MR: riverside; D + TL: dike + part of boundary terrace; DI + TL: floodable depression + part of boundary terrace e TS: inlander tableland. Embrapa-SPSB, Petrolina, Pernambuco.

Variables	Phytogeoenvironments			
	MR ± sD	D+TL ± sD	DI+TL ± sD	TS ± sD
Total density ($ind.ha^{-1}$)	3.100 ± 1.449	1.720 ± 1.005	1.452 ± 1.434	1.843 ± 8.64
Total basal area ($m^2.ha^{-1}$)	33.34 ± 0.37	12.22 ± 0.79	11.41 ± 0.10	17.89 ± 0.08
Maximum height (m)	13.20 ± 1.95	8.30 ± 0.95	9.00 ± 1.11	7.90 ± 0.92
Mean height (m)	4.70 ± 1.04	3.71 ± 0.40	3.01 ± 0.49	3.51 ± 0.59
Maximum diameter (cm)	97.70 ± 37.95	47.00 ± 8.11	68.17 ± 15.76	58.22 ± 11.97
Mean diameter (cm)	7.22 ± 1.03	8.06 ± 1.72	6.80 ± 6.60	8.35 ± 3.61

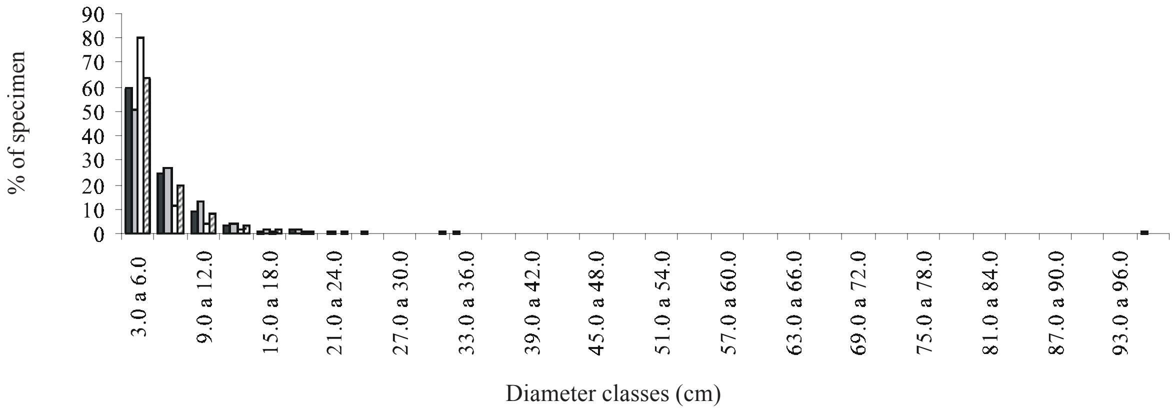

Figure 5. Population distribution by class diameter at 3 cm interval on a caatinga remaining area at the São Francisco river margin. Embrapa-SPSB, Petrolina, Pernambuco. ■ riverside (MR); ■ dike + part of boudary terrace (D + TL); □ floodable depression + part of boudary terrace (DI + TL); ▨ inlander tableland (TS).

Mimosa bimucronata, which have thin and young individuals what might account for their frequent regeneration.

Figures 5 and 6 show that there is a discontinuity in the number of individuals in the upper classes, and that highest diameter class (96 to 99 cm) and height class (13 to 14 m) were found in MR represented by only one individual from *Inga vera* subsp. *affinis*. Zipparo & Schlittler (1992) cited this species as the most frequent in the fringe forest of Rio Claro-SP.

There are 10 species listed in MR besides de Dead category (table 4). Among these, *Inga vera* subsp. *affinis*, followed by *Celtis membranacea*, *Geoffroea spinosa* and *Croton campestre*, are noted with 79.45% total importance value (IV*e*), but *Inga vera* subsp. *affinis* accounted for almost half of total IV*e* (47.41%). Together, the first three accounted for 77.42% and 95.02% of total density and relative dominance, respectively.

The importance of the *Inga* genus in water body fringe vegetation in the semi- arid northeastern region of Brazil had already been noted by Tigre (1974) and Vasconcelos Sobrinho (1970).

Mencacci & Schlittler (1992) found the highest *Inga vera* density values, frequency and dominance in Rio Claro, São Paulo. Mantovani *et al.* (1989) observed the

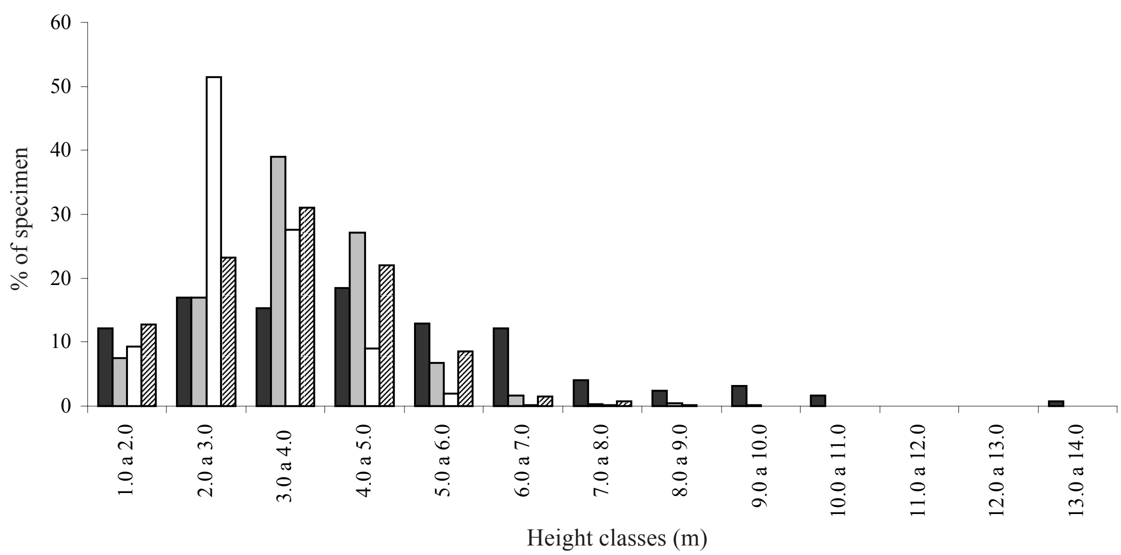

Figure 6. Population distribution by class height at 1 m interval on a caatinga remaining area at the São Francisco river margin. Embrapa-SPSB, Petrolina, Pernambuco. ■ riverside (MR); ■ dike + part of boudary terrace (D + TL); □ floodable depression + part of boudary terrace (DI + TL); ▨ inlander tableland (TS).

Table 4. Species sampled in the riverside (MR) and phytosociologic parameters and percentage of the importance value (IV*e*) in a caatinga reminiscent area at the São Francisco river margin. N*e*: number of individuals by species per sampled area; DR*e*: relative density of species (%); DoR*e*: relative dominance of species (%); FR*e*: relative frequency of species (%). Embrapa-SPSB, Petrolina, Pernambuco.

Species	N*e*	DR*e*	DoR*e*	FR*e*	IV*e*
Inga vera subsp. *affinis*	68	54.84	73.12	14.29	47.41
Celtis membranacea	13	10.48	17.43	19.05	15.66
Geoffroea spinosa	15	12.10	4.47	14.29	10.29
Croton campestre	9	7.26	1.48	9.52	6.09
Mimosa bimucronata	7	5.65	1.44	9.52	5.54
Mimosa pigra	3	2.42	0.27	9.52	4.07
Zizyphus joazeiro	3	2.42	1.24	4.76	2.81
Gaya aurea	2	1.61	0.19	4.76	2.19
Dead	2	1.61	0.17	4.76	2.18
Phyllanthus cf. *chacoensis*	1	0.81	0.10	4.76	1.89
Paullinia pinnata	1	0.81	0.08	4.76	1.88
Total	124	100	100	100	100

importance of this species in Mogi-Guaçu, São Paulo, due to the presence of tall individuals. Carvalho *et al.* (1992) and Mazzoni-Viveiros & Luchi (1989) also found *Inga vera* in fringe forests in the Rio Grande river, Minas Gerais and Mogi-Guaçu. Salis *et al.* (1994) observed that in fringe forests in Brotas, São Paulo, *Inga affinis*, actually *Inga vera* subsp. *affinis*, showed pioneering characteristics occurring alone or with other species in small remains of fringe forests.

Andrade-Lima (1989) wrote that *Gaya aurea*, another species found in MR, is very common in the São Francisco area, representing as much as 30% to 40% of vegetal soil covering in some environments. Rocha (1984) cited *Mimosa pigra* in the São Francisco delta, in extreme southern Alagoas, whereas Braga (1976) defined it as an invasive species found in shoals, riverbanks, ponds, lagoons and rivers. This author also wrote that *Paullinia pinnata* is commonly found in shady areas of forests in the Brazilian Northeast, which confirms the amount found in MR.

Twenty species were sampled in D + TL as well as the Dead category (table 5). Five species and the Dead category accounted for 76.39% of total IV*e*. *Mimosa bimucronata* and *Mimosa arenosa* accounted for 55.04%, 51.14% and 37.85% of density, dominance and relative frequency, respectively.

There are seven species listed in DI + TL plus the Dead category (table 6). Among these, *Mimosa bimucronata* had the highest total IV*e*, followed by *Ipomoea carnea* subsp. *fistulosa*. These species accounted for 76.79% of total IV*e* and 88.84%, 78.62% and 62.90% of density, dominance and relative frequency, respectively.

There is low floristic richness in DI, where no more than five species, are found with predominance of three: two arboreal (*Geoffroea spinosa* and *Mimosa bimucronata*) and one bush (*Ipomoea carnea* subsp. *fistulosa*). In phyto-ecological surveys conducted in intradune and intersandline lagoons of the São Francisco river delta, in Alagoas, Rocha (1984) found low richness of vegetation in those environments, an average of five species, among them low herbaceous and wood. Similar behavior was registered by Silva (1985) in the floodable depressions of the Ouricuri region, Pernambuco state. This area remains flooded for long periods, more than six months, confirming the observations of Miranda & Silva (1989).

The physiognomy of the DI + TL environment is characterized by dense groupings of *Ipomoea carnea* subsp. *fistulosa*, a common species in the swampy environments of the semi-arid (Braga 1976) and by disperse *Mimosa bimucronata* trees. These have branched trunks at soil level and reach a mean height of 3 to 4 m. Although no botanical material was collected, it was possible to observe that in this environment, the soil is covered by herbaceous vegetation, especially grass-like vegetation. The importance of this type of vegetation in the swampy depressions was noted by Miranda & Silva (1989) in the floodable depressions of the xerophytic woodland near Ouricuri.

Table 5. Species sampled in the dike + part of boundary terrace (D + TL) and phytosociologic parameters and percentage of the importance value (IV*e*) in a caatinga reminiscent area at the São Francisco river margin. N*e*: number of individuals by species per sampled area; DR*e*: relative density of species (%); DoR*e*: relative dominance of species (%); FR*e*: relative frequency of species (%). Embrapa-SPSB, Petrolina, Pernambuco.

Species	N*e*	DR*e*	DoR*e*	FR*e*	IV*e*
Mimosa bimucronata	179	25.39	27.65	20.34	24.46
Mimosa arenosa	209	29.65	23.49	17.51	23.55
Dead	48	6.81	5.18	13.56	8.52
Zizyphus joazeiro	31	4.40	11.91	4.52	6.94
Poeppigia procera	58	8.23	6.64	5.08	6.65
Capparis cynophallophora	42	5.96	1.55	11.30	6.27
Geoffroea spinosa	39	5.53	7.86	5.08	6.16
Celtis membranacea	18	2.55	5.62	2.82	3.67
Mimosa tenuiflora	14	1.99	5.49	2.82	3.43
Harrisia adscendens	28	3.97	1.50	4.52	3.33
Cordia verbenacea	10	1.42	0.45	4.52	2.13
Caesalpinia ferrea	6	0.85	1.92	1.69	1.49
Tournefortia rubicunda	8	1.13	0.28	1.13	0.85
Wilbrandia sp.	5	0.71	0.15	1.13	0.66
Phyllanthus cf. *chacoensis*	3	0.43	0.18	0.56	0.39
Jatropha mutabilis	2	0.28	0.04	0.56	0.30
Senna spectabilis	1	0.14	0.02	0.56	0.24
Pithecellobium parviflorum	1	0.14	0.02	0.56	0.24
Croton campestre	1	0.14	0.02	0.56	0.24
Acacia farnesiana	1	0.14	0.01	0.56	0.24
Cardiospermum halicacabum	1	0.14	0.01	0.56	0.24
Total	705	100	100	100	100

Twenty-three species plus the Dead category were sampled in TS (table 7). Of these, seven and the Dead category accounted for 76.20% of total IV*e*. *Mimosa tenuiflora, Aspidosperma pyrifolium, Caesalpinia microphylla, Croton sonderianus* and *Zizyphus joazeiro* had 62.80%, 78.29% and 38.95% of density, dominance and relative frequency, respectively.

Ferreira (1988), in his survey of xerophytic woodland in Açu, Rio Grande do Norte, noted that *Aspidosperma pyrifolium* and *Caesalpinia pyramidalis* were predominant, accounting for highest density, frequency and dominance. Taken individually, the species found in TS were also important in several other xerophytic woodland phytosociological surveys (Rodal 1992, Araújo *et al.* 1995).

Topographic and soil type data along the transect indicate that the study area is environmentally heterogeneous. In the elevated areas, in the so-called inlander tableland, occur soils of the sandy/medium textured Red-Yellow Argisol euthrophic plinthic type, whereas in the lower areas, being topographic environments of the fluvial terrace such as riverbanks, dike, floodable depression and boundary terrace, there are soils of the Fluvic Neosol and Haplic Cambisol types with euthrophic silty texture.

Floristic results show that there are two groups: one formed by species such as *Mimosa bimucronata* and *Geoffroea spinosa*, among others, related to the several topographic environments of the fluvial terrace and another, formed by *Mimosa tenuiflora*, *Aspidosperma pyrifolium*, *Caesalpinia microphylla*, *Commiphora leptophloeos*, *Schinopsis brasiliensis* var. *brasiliensis*, and so on, more related to the inlander tableland.

From the results obtained with topographic, pedological and floristic variations found in each topographical environment and from analyses of floristic similarities among plots along the transect, it was possible to define four phytogeoenvironments: three of them in the fluvial terrace, riverside (MR), dike + part of boundary terrace (D + TL), floodable depression + part of boundary terrace (DI + TL) and one in the inlander tableland (TS).

Table 6. Species sampled in the floodable depression + part of boundary terrace (DI + TL) and phytosociologic parameters and percentage of the importance value (IV*e*) in a caatinga reminiscent area at the São Francisco river margin. N*e*: number of individuals by species per sampled area; DR*e*: relative density of species (%); DoR*e*: relative dominance of species (%); FR*e*: relative frequency of species (%). Embrapa-SPSB, Petrolina, Pernambuco.

Species	N*e*	DR*e*	DoR*e*	FR*e*	IV*e*
Mimosa bimucronata	469	40.89	71.64	40.86	51.13
Ipomoea carnea subsp. *fistulosa*	550	47.95	6.98	22.04	25.66
Geoffroea spinosa	53	4.62	14.74	15.05	11.47
Dead	53	4.62	2.12	12.90	6.55
Mimosa arenosa	14	1.22	0.91	4.84	2.32
Acacia farnesiana	6	0.52	1.45	3.23	1.73
Poeppigia procera	1	0.09	2.14	0.54	0.92
Capparis cynophallophora	1	0.09	0.01	0.54	0.21
Total	1147	100	100	100	100

Table 7. Species sampled in the inlander tableland (TS) and phytosociologic parameters and percentage of the importance value (IV*e*) in a caatinga reminiscent area at the São Francisco river margin. N*e*: number of individuals by species per sampled area; DR*e*: relative density of species (%); DoR*e*: relative dominance of species (%); FR*e*: relative frequency of species (%). Embrapa-SPSB, Petrolina, Pernambuco.

Species	N*e*	DR*e*	DoR*e*	FR*e*	IV*e*
Mimosa tenuiflora	45	17.44	30.50	11.58	19.84
Aspidosperma pyrifolium	41	15.89	23.61	10.53	16.68
Caesalpinia microphylla	43	16.67	6.18	9.47	10.77
Dead	23	8.91	2.83	12.63	8.12
Croton sonderianus	31	12.02	4.12	5.26	7.13
Zizyphus joazeiro	2	0.78	13.88	2.11	5.59
Commiphora leptophloeos	12	4.65	2.45	5.26	4.12
Schinopsis brasiliensis var. *brasiliensis*	8	3.10	2.43	6.32	3.95
Erythroxylum pungens	11	4.26	1.07	5.26	3.53
Spondias tuberosa	2	0.78	5.87	2.11	2.92
Senna macranthera	6	2.33	0.89	5.26	2.83
Pilosocereus gounellei	9	3.49	1.83	3.16	2.82
Wilbrandia sp.	6	2.33	0.22	5.26	2.60
Jatropha mutabilis	6	2.33	0.25	3.16	1.91
Pithecellobium parviflorum	2	0.78	1.78	2.11	1.55
Jatropha ribifolia	3	1.16	0.39	2.11	1.22
Cnidoscolus phyllacanthus	1	0.39	1.05	1.05	0.83
Senna spectabilis	1	0.39	0.30	1.05	0.58
Capparis cynophallophora	1	0.39	0.08	1.05	0.51
Croton conduplicatus	1	0.39	0.08	1.05	0.51
Tabebuia spongiosa	1	0.39	0.06	1.05	0.50
Sapium scleratum	1	0.39	0.06	1.05	1.50
Croton campestre	1	0.39	0.04	1.05	0.49
Harrisia adscendens	1	0.39	0.03	1.05	0.49
Total	258	100	100	100	100

From the floristic point of view, MR is distinct from the other environments. The same can be said of its physiognomy, which presents the highest total density, total basal area, maximum diameter, maximum and mean height, as well as 8.1% of individuals with heights above 8 m as compared to 0.6% for D + TL, 0.2% for DI + TL and 0% for TS.

DI + TL are characterized by the lowest number of species among the four phytogeoenvironments and by the highest concentration of individuals in the lower classes of diameter (3-6 cm) and height (2-3 m).

The species with the highest importance value in MR (*Inga vera* subsp. *affinis*) and in TS (*Mimosa tenuiflora*) were distinct, thus reinforcing the differences between these two environments. *Mimosa bimucronata* was the species with the highest IV*e* in D + TL and DI + TL, which showed its importance in the central areas of the fluvial terrace used in this study.

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