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ECOLOGY OF THE JARI-PARU MICROREGION II. ECOLOGICAL DISTANCES BETWEEN EIGTH FOREST COMMUNITIES

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ABSTRACT - *The ecological distances between eight primary forest communities located in the microregion of the Jari-Paru Rivers, Pará, Brazil, were calculated by the cluster analysis of eight ecological variables: (1) altitude (ALT), (2) soil pH (PH), (3) percentage of sand (SAND), (4) percentage of organic matter (OM), (5) exchangeable phosphorus (P), (6) maximum flowering percentagem (MAXFL), (7) maximum fruiting percentage (MAXFR) and (8) index of diversity (DIV). Secondly, three models were investigated to test the dependency of the variables "diversity index" (DIV), "maximum flowering" (MAXFL) and "maximum fruiting" (MAXFR) upon the remaining ones.*

KEY WORDS: Tropical forests; Amazon; Cluster analysis; Ecological classification.

RESUMO - *As distâncias ecológicas entre oito comunidades de florestas primárias localizadas na microregião dos rios Jari-Paru foram calculadas pela análise "cluster" de oito variáveis ecológicas: (1) altitude (ALT), (2) pH do solo (PH), (3) percentagem de areia no solo (SAND), (4) percentagem de matéria orgânica no solo (OM), (5) fósforo utilizável (P), (6) percentagem de floração máxima (MAXFL), (7) percentagem de frutificação máxima (MAXFR) e (8) índice de diversidade (DIV). Em seguida, três modelos foram investigados para testar a dependência das variáveis índice de diversidade (DIV), percentagem de floração máxima (MAXFL), e percentagem de frutificação máxima (MAXFR) sobre as restantes.*

PALAVRAS-CHAVE: Florestas tropicais; Amazônia; Análise de clusters; Classificação ecológica.

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INTRODUCTION

The microregion of Jari includes an area east of the Paru River basin as well as the Jari River basin itself. The Jari and Paru Rivers are the two easternmost tributaries on the northern bank of the Amazon River before it reaches the Atlantic Ocean (Figure 1). The area studied is located near the town of Monte Dourado (County of Almeirim, Pará) and it also envolves an area in the County of Mazagão (Amapá). Geographically the studied sites are close to the Equator, ranging from 0°27' to 1°6' latitude South and 52°51' to 52°25' longitude West.

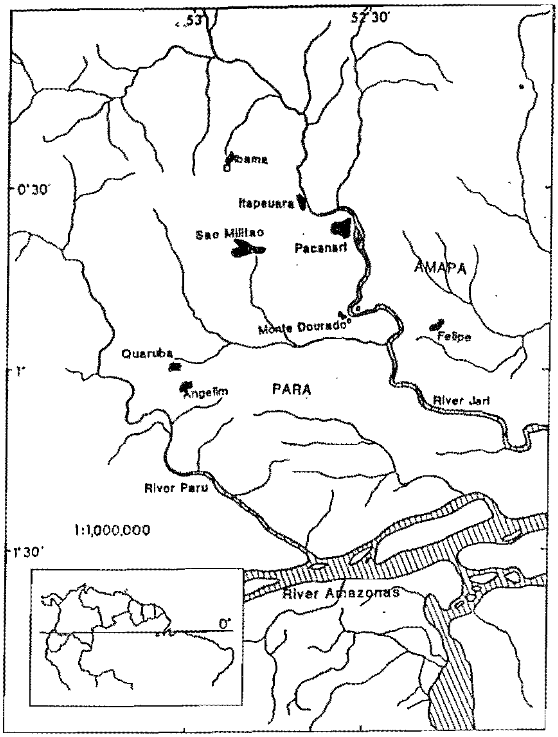

Figure 1 - Map of the Jari-Paru microregion showing the eight forest communities studied.

This study was carried out in eight different communities of primary forests reserves which were set aside and maintained by the Jari Company (Figure 1). Except for the forest called "Ibama" (at the Jari Ecological Station), the other seven reserves studied belong to the Jari Company. These reserves are part of the Jari Genetic Reserve, aimed to promote "in situ" conservation of forest genetic resources, which the Jari Company has implemented through a cooperative agreement with the National Genetic Resources Center (EMBRAPA/CENARGEN), Brasília, since 1984. Table 1 presents the coordinates of each forest studied as well as a summary of other relevant information. Details about environmental factors of the area are given further.

Table 1 - Geographical gradient of the forest sites studied at Jari, Brazil.

Side Name	Coordinates		Altitude (m)	Size (ha)	Florest Type
Angelim	01°06'S	52°25'W	77	400	Savanna
Quaruba	01°02'S	52° 0'W	141	987	Savanna
Mt. Dourado	01°01'S	52°33'W	76	150	Semi-open
Mt. Felipe	00°52'S	52°23'W	150	306	Semi-open
S. Militão	00°46'S	52°40'W	113	1,973	Semi-open
Pacanari	00°39'S	52°35'W	107	750	Semi-open
Itapeuara	00°35'S	52°39'W	37	300	'Várzea'
IBAMA	00°27'S	52°51'W	449	500	Dense

PHYSICAL ASPECTS OF THE JARI-PARU MICROREGION

Climate and water relations. The area of Jari has a climate formula B1rA 'a' on the Thornthwaite system, or 'Amw' on the Köppen system, meaning that its climate is hot and humid, with average temperatures in the order of 26.4°C. The average yearly precipitation is 2,115 mm. Such high average precipitation compensates for a mild dry season which takes place from August to December. The driest months, September to November, contribute with only 8% of the annual volume of rain in the region (Companhia Florestal Monte Dourado 1989). The Jari Company maintains six thermopluviometric stations throughout its area. The information in Figure 2 was compiled from data obtained at these stations during the period when the phenological observations took place.

Geology and relief. The Jari microregion is located within the Amazon River basin and thus shares the same geological history of the Amazon region. Several overviews are now available on Amazon geology such as that of Fittkau (1974), Schubart (1983), Pützer (1984), Projeto... (1972-78) and Daly & Prance (1989). Therefore, in this section only the geological features characteristic of the Jari area are described. The Jari region is located between the Purus and Gurupá arches. These are areas of orogenic uplift formed on the underlying crystalline rocks of the Precambrian shield which appeared some 3,500 million years ago (Pützer 1984). On the north of the studied area, somewhat in the midcourse of the Jari-Paru Rivers there are outcrops of Paleozoic sand and siltstone sediments forming a sequence known as the Trombetas-Maccuru Formation, occurring over a 450-600m plateau. Its altitude corresponds to the level of the Plio-Pleistocenic pediplane (Pd2), which was preserved by an existing iron duricrust (Pires-O'Brien 1992). These Paleozoic sediments overlay the even older crystalline rocks of the Uatumã Series, which occur as twin bands on both sides of the Amazon River. The northern strip extends between the Negro and Jari Rivers. The Uatumã Series is thought to have resulted from a series of volcanisms that pierced the Guiana craton still extending to that area (Pützer 1984). A remarkable feature of the Jari landscape is a 50Km long scarp formed in the E-NW direction along the outcropped Paleozoic sand and siltstones (Figure 3).

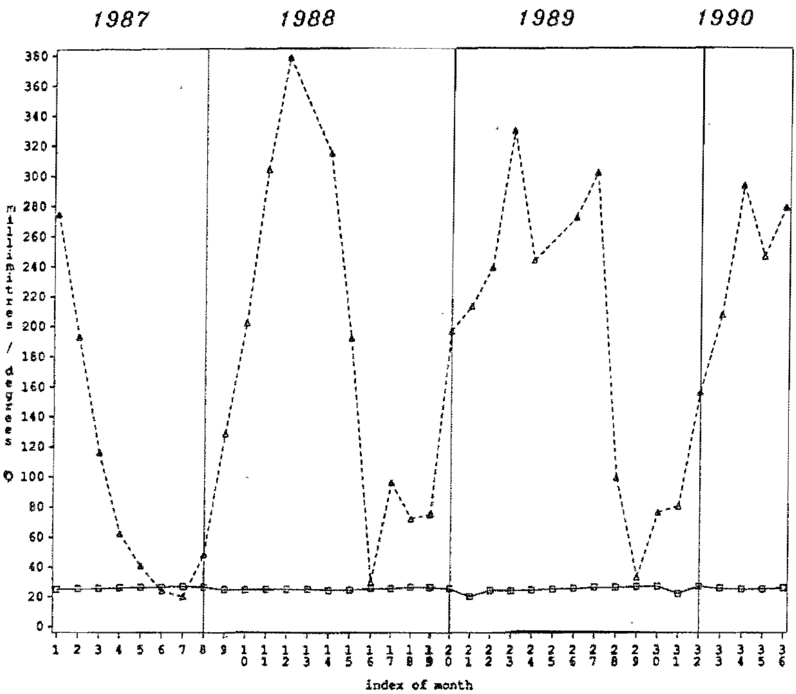

Figure 2 - Rainfall and temperature of the Jari microregion during a phenological study by the author.

Most of the sediments found in the area of Jari are of Tertiary origin being part of the Alter do Chão / Barreiras formation. Spread among these Tertiary terrains are two types of terraces or table-top hills which are considered part of the Belterra Formation (Tertiary-Quaternary) (Figura 3). The first type of terrace with altitude between 135 and 200m (Pd1) was made by eroded Pliocene and Pleistocene surfaces. The second type, made by irregular and dissected hills of altitude between 68 and 74m (P2), was made by sediments of the former (Klammer 1971, 1978). Quaternary deposits occur only at the margins of both the Amazon and the Jari and Paru Rivers.

The relief types found in the area of Jari permit the separation of the various geological formations and consequently of the soil types found there. For this reason the altitude of the eight sites studied as well as that of some other important reference points was recorded by a series of measurements taken with two portable altimeters (Table 1).

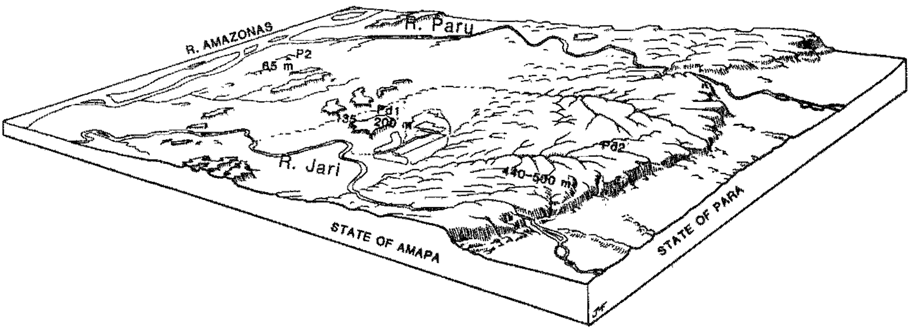

Figure 3 - Diagram of the Paru-Jari landscape showing relief and geology.

Soils. A large-scale soil survey of the Jari-Paru area was completed in 1987 by researchers of the Jari Company and EMBRAPA/SNLCS (Companhia... 1989), covering only soils of the plantation areas. However, the soil data used in the present study was obtained in the eight forest communities studied. Samples for the physical and chemical analysis were taken from selected pits dug in the eight forests where phenological observations were taken place. Details of this soil study are published in the first paper of this series (Pires-O'Brien 1992).

Relief and climate have been the essential factors controlling rates of decomposition, transport and sedimentation (Pützer 1984), which influence the landscape. The Jari-Paru landscape results from complex interactions between its geology, rivers and climate. The soils of the Jari basin are related to the overall landscape of the area, which in turn is much influenced by the area's geology as well as by certain aspects of the Jari and Paru Rivers. These rivers cut through the ancient uplands of the Guyana Shield bringing sediments which are mixed with those carried by the Amazon River. The water from the Jari and Paru rivers are intermediate from black to clearwater, suggesting that the soils found in these basins are among the poorest in the Amazon. Botanical inventories carried out by the author and assistants in the various forest communities of Jari, from May 1985 to August 1988, showed an appreciable degree of variation. As shown in Table 1 the eight forest sites studied had different physionomies, including a seasonally flooded forest (Itapeuara), one forest in a 68-74 m alluvial valley (Angelim), two on a 145-200 m terrace (Felipe and Quaruba), three on intermediate hills (Monte Dourado, São Militão and Pacanari) and one on the 450 m planation surface (IBAMA - Jari Ecological Station).

This paper aims to analyse the major soil variables as well as altitude, diversity index and phenology to assess the ecological distances or degree of similarity between the forest communities. The chosen variables were: (1) altitude (ALT), (2) soil pH (PH), (3) percentage of sand (SAND), (4) percentage of organic matter (OM), (5) exchangeable phosphorus (P), (6) maximum flowering percentage (MAXFL), (7) maximum fruiting percentage (MAXFR) and (8) index of diversity (DIV). The correlation coefficients were used to test a null hypothesis of zero correlation between variables. Correlation coefficients range from -1.0 to +1.0, the values close to zero indicating little correlation while the values close to -1 or 1 indicating strong correlation.

METHODS

From May 1987 to April 1990 an extensive phenology study took place at Jari in the eight forests mentioned, involving 1,508 trees (Pires 1991). In addition to the phenological observations, studies on the soils and on the altitude of these forests were also carried out in order to explain possible deviations in the phenological responses of the communities investigated. The index of diversity from each forest was calculated by dividing the number of tree species found in each site by the square root of the number of trees sampled. Rainfall and temperature were assumed constant among the forests since the eight sites studied occur within only one latitudinal degree. If such premise is correct, then the vegetational variation encountered could only be attributed to soil and related factors.

In this paper maximum flowering and fruiting refer to the highest percentage of the event shown by a given forest community, and the data was extracted from Pires (1991). Their importance was assumed from the observation that the more open forests had a much higher percentage of flowering and fruiting among their trees than dense close forests.

Particle size analysis was carried out by the Hydrometer method. The pH was calculated by immersing the electrode of a previously calibrated pH-meter into a beaker containing the soil solution. The total organic matter determination was carried out by the loss on ignition method. Exchangeable Phosphorus or Phosphate was determined by an auto-analyzer, using ammonium molybdate as a reagent, and calculated in meq/100g. The values shown in Table 2 refer to the mean of each forest, sampled at 15cm. Complete soil methodology is given in the first paper of this series (Pires-O'Brien 1992).

The cluster analysis was performed through the Proc Cluster procedure of SAS-5.18 for methods based on the agglomerative hierarchical clustering approach. The single linkage method was the best of three possibilities and allowed the four level classification for the forest sites of Jari displayed in Figure 4, what was done by providing the values for the minimum distance between the clusters.

RESULTS

The ecological classification of the Jari forest communities was done by the cluster analysis of the parameters listed on Table 2. The phenology data on maximum flowering and fruiting is found in Pires (1991). Note that the column of maximum flowering percentage (MAXFL) contains some discrepancies in the sense that these values should not be smaller than their counterparts in the column of maximum fruiting percentage (MAXFR). This is due to unrecorded flowering events. However these discrepancies were very small and the values were recorded unchanged. Figure 4 gives the classification of the forests studied based on the ecological data listed in Table 2.

Table 2 - Ecological data of the eight forest communities studied at Jari.

SITE		ALT (m)	PH	SAND (%)	DIV (ndx)	OM (%)	P (meq/100g)	MAXFL (%)	MAXFR (%)
ANG	(Angelim)	77	4.2	87	4.6	4.3	2.9	23	18
QUA	Quaruba)	141	4.3	89	3.5	8.0	6.0	34	28
MTD	(Mt. Dourado)	76	4.4	82	5.3	5.7	5.3	43	32
FEL	(Mt. Felipe)	150	4.7	36	5.5	22.2	4.7	15	19
SML	(São Militão)	113	4.0	73	5.7	5.0	4.0	22	23
PAC	(Pacanari)	107	4.2	38	5.9	16.6	4.2	18	31
ITA	(Itapeuara)	37	4.0	18	6.0	17.4	4.0	30	40
IBA	(Ibama=Sema)	449	4.7	71	7.5	14.4	4.7	19	18

Figure 4 shows clearly the larger ecological distance of the Ibama forest from all others. The well structured dusk red soils found there contrast with the sandy to sandy-clay brown or yellow soils found in the other forests. Other important ecological difference between the Ibama forest and the others is the higher tree diversity of the former (Pires 1991). The relative ecological distance among the other forest communities were not so obvious. This can be attributed to the effect of variables counteracting one another, or, alternatively there is not a great ecological distance between them.

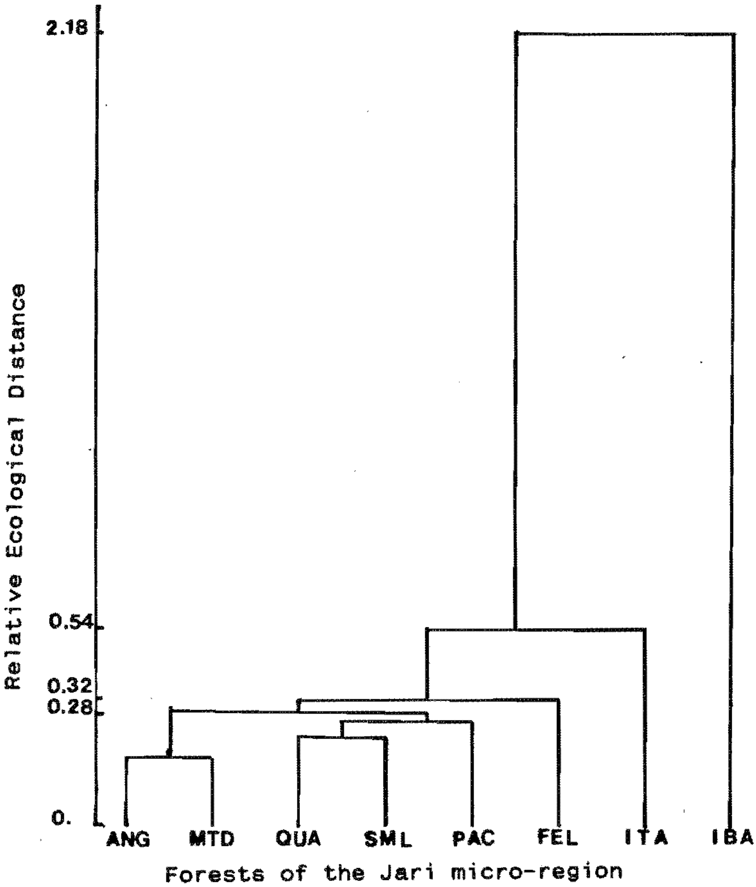

Figure 4 - Ecological distances between the eight forest communities studied at Jari.

Models of correlation between variables. The Spearman method of rank correlation coefficient was used to examine the correlation between the ecological data of the eight forest communities studied is displayed in Table 3. In this table, the first line of each pair gives the correlation coefficient while the line below gives the calculated probability for a null hypothesis of no correlation between variables.

Table 3 - Spearman rank correlation coefficients on community variables from Table 2, together with the calculated probability for a null hypothesis of zero correlation.

	ALT	PH	SAND	OM	P	MAXFL	MAXFR	DIV
ALT	1.00 0.00							
PH	0.63 0.09	1.00 0.00						
SAND	0.07 0.87	0.07 0.86	1.00 0.00					
OM	0.19 0.65	0.28 0.50	-0.81 0.01	1.00 0.00				
p	0.40 0.33	0.67 0.07	0.27 0.53	0.24 0.57	1.00 0.00			
MAXFL	-0.57 0.14	-0.23 0.58	0.55 0.16	-0.48 0.23	0.24 0.57	1.00 0.00		
MAXFR	-0.68 0.06	-0.41 0.31	-0.28 0.51	0.29 0.49	0.18 0.68	0.48 0.23	1.00 0.00	
DIV	0.10 0.82	-0.07 0.86	-0.76 0.03	0.48 0.23	-0.27 0.53	-0.45 0.26	0.07 0.87	1.00 0.00

Very few significant correlations were found among the environmental variables examined, according to Table 3. The variable percentage of organic matter (OM) correlated with percentage of sand in soil (SAND), which in turn correlated with diversity index (DIV).

Three models were investigated to test the dependency of the variables "diversity index" or DIV (Table 4), "maximum flowering" or MAXFL (Table 5) and "maximum fruiting" or MAXFR (Table 6) upon the remaining ones. This was done by calculating the mean error of the linear regression for models with different number of independent variables. The mean square error is the basis for an estimate of the error in fitting a regression line. Several models were compared to explain the relationship between the dependent variable and the independent ones. The best model of each dependent variable is that which uses the least number of independent variables with the smallest square error accepted.

Table 4 - Mean square error for model 1 of "diversity index"(DIV) as dependent variable.

Nº of Inf. Variables	Ind. Variables	R-square	Mean Square Error
1	alt,	0.35	1.00
2	alt, sand	0.65	0.65
3	alt, sand, om	0.86	0.33
4	alt, sand, om, pH	0.97	0.08
5	alt, sand, om, pH, maxfl	0.98	0.09
6	alt, sand, om, pH, maxfl, maxfr,	0.99	0.00
7	alt, sand, om, pH, maxfl, maxfr, P	1.00	0.00

Table 5 - Mean square error for model 2 of "maximum flowering" (MAXFL) as dependent variable.

Nº of Ind. Variables	Ind. Variables	R-square	Mean Square Error
1	maxfr	0.33	69.98
2	maxfr, sand	0.84	20.48
3	maxfr, sand, om	0.94	10.01
4	maxfr, sand, om, pH	0.96	9.31
5	maxfr, sand, om, pH, div	0.97	10.62
6	maxfr, sand, om, pH, div, alt	0.99	0.23
7	maxfr, sand, om, pH, div, alt, P	1.00	

Table 6 - Mean square error for model 3 of "maximum fruiting" (MAXFR) as dependent variable.

Nº of Ind. Variables	Ind. Variables	R-square	Mean Square Error
1	maxfr	0.33	49.95
2	maxfr, sand	0.85	13.56
3	maxfr, sand, om	0.95	5.57
4	maxfr, sand, om, pH	0.96	5.46
5	maxfr, sand, om, pH, div	0.97	6.88
6	maxfr, sand, om, pH, div, alt	0.99	0.19
7	maxfr, sand, om, pH, div, alt, P	1.00	0.00

In Table 4, where "diversity index" (DIV) is the dependent variable, the best fit model was that which included percentage of sand (SAND), percentage of organic matter (OM), altitude (ALT) and pH (PH). In Table 5 where "maximum flowering" (MAXFL) is the dependent variable the best fit was the model which included percentage of organic matter (OM), pH, diversity index (DIV) and maximum fruiting (MAXFR). In Table 4, where "maximum fruiting" (MAXFR) is the dependent variable, the best fit model was one which included organic matter (OM), pH, diversity index (DIV) and maximum flowering (MAXFL). Here, a simpler model ommitting diversity index (DIV) could also be considered since the inclusion of the remaining variables added very little to it.

CONCLUSIONS

Due to the initial assumption that the climate of the eight forest communities investigated at the Jari-Paru microregion was homogeneous, edaphic factors were looked upon to explain the differences in species composition and richness found in the various forest sites studied. Although a vegetational uniformity is expected within a hydrographic basin many variations were found due to variation of the soil (Figure 4). However, with the exception of the forest Ibama (Jari Ecological Station), the differences between the various forest communities were small. The former forest stood out from all others in a cluster of its own while the remaining sites showed relatively small ecological distances from one another, including the flooded ("várzea") forest. This can be explained by the different geomorphology of the area where the Ibama forest is located. While all other forests are over Tertiary or early Quaternary terrains, the Ibama forest occurs over exposed Paleozoic sediments. The distances shown in Figure 4 confirm studies done both in soils and in the vegetation of the various forest communities. The Ibama community (Jari Ecological Station) is more related to the "highland" forests such as those found in the Guianas, while the others, including a "várzea" forest are typical "lowland" forests. In order to get a better separation among the seven "lowland" forests additional variables could be introduced and the cluster analysis repeated without including the deviant one.

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