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Spatial distribution pattern and diameter structure of *Protium* Burm. f. in Iratapuru river sustainable development reserve, Amapá, Brazil

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ABSTRACT. The present work aims to determine the spatial distribution pattern of *Protium* Burm. f and the diametric structure of these species in a dense tropical submontane rainforest along the Sustainable Development Reserve (SDR) of the Iratapuru river. The area of study was divided into three plateau compartments called Mane Preto Sierra, Banco Grande Sierra and Alaska Sierra. In each plateau compartment it was settled a single area transect with 1,000 x 20 m, where DAP ≥ 10 cm of the entire *Protium* population within the transects was measured. The data was processed in the specific software Mata Nativa 2. There were inventoried *Protium tenuifolium, Protium altsoni, Protium polybotryum* subsp. *blackii* and *Protium paniculatum* var. *riedelianum*. Most individuals concentrated in smaller diametric classes, decreasing progressively to a lesser extent in larger classes. It can be concluded that the population has medium size and its vertical structure is characterized by the presence of three strata, however, its phytocenoses is defined by two clear constants: the first groups individuals of up to 15 m of height and forms the uniform and dominant stratum; the second is composed by emerging up to 35 m high and whose diameter structure shows a population in dynamic balance.

Keywords: Forest Amazon; occurrence; *breu*.

Padrão de distribuição espacial e estrutura diamétrica de *Protium* Burm. f. na reserva de desenvolvimento sustentável do Rio Iratapuru, Amapá, Brasil

RESUMO. Este trabalho tem como objetivo determinar o padrão de distribuição espacial de *Protium* Burm. f e estrutura diamétrica dessas espécies em uma floresta tropical densa submontana ao longo da reserva de desenvolvimento sustentável (RDS) do rio Iratapuru. A área estudada foi dividida em três compartimentos de planaltos denominados Serra Mane Preto, Serra Banco Grande e Serra Alaska. Em cada compartimento de planalto instalou-se transecto de área única com 1.000 x 20 m, onde foi mensurado o DAP ≥ 10 cm de toda população de *Protium* dentro dos transectos. Os dados foram processados em softwares específicos Mata Nativa 2. Foram inventariados *Protium tenuifolium*, *Protium altsonii*, *Protium polybotryum* subsp. *blackii* e *Protium paniculatum* var. *riedelianum*. A maior parte dos indivíduos concentrou-se nas menores classes diamétricas, diminuindo progressivamente até atingir menor proporção nas maiores classes. Pode-se concluir que a população apresenta porte mediano, sua estrutura vertical caracteriza-se pela presença de três estratos; no entanto, sua fitocenose define-se por dois contínuos bem evidentes; o primeiro agrupa indivíduos com até 15 m de altura e forma o estrato uniforme e dominante; o segundo é composto por emergentes com até 35 m de altura e que a estrutura diamétrica evidencia uma população em equilíbrio dinâmico.

Palavras-chave: Floresta amazônica; ocorrência; breu.

Introduction

Amazon Forest constitutes the primary dispersion center of *Protium* Burm f., the main gender of Burseraceae, with its species spread over tropical and subtropical regions in South America, part of Europe, Asia and Oceania (Fine, Daly, Muñoz, Mesones, & Cameron, 2005). This gender has large distribution in South America, with a great history of use and many species adapted to each type of environment. These species are generally difficult to be identified in field and many of them are frequently reclassified, mainly for being described using untrustworthy characters (Daly, 1987).

Protium species, commonly known as *breus*, are found scattered across almost the whole State of Amapá, according to a survey conducted at the Amapá Herbarium (Hamab). The largest records of

occurrence of these species are located at the southern end of the state. They are usually large trees (10 to 31 m high), which present cylindrical trunk, with buttresses or not, and exude a clear, sticky, aromatic, volatile resin used in the varnish industry, boat caulking and as insect repellent (Daly, 1987; Otuki, Vieira-Lima, Malheiros, Yunes, & Calixto, 2004). Moreover, in popular medicine the gum and resin oils of *Protium* ssp. are used for many purposes, such as in stimulants, anti-ulcers and anti-inflammatories (Siani et al., 1999). Its leaves are alternate and rarely opposite, compodes and odd pinnate and the flowers small and unissexual, of cream, yellow green or red colour; the fruits are drupe and more rarely capsules (Souza & Lorenzi, 2008).

The community of São Francisco do Iratapuru, located around the Iratapuru river Sustainable Development Reserve (SDR), live off the sustainable exploitation of *Bertholletia excelsa* Bonpl., Lecythidaceae, (Brazil nut); *Copaifera duckei* Dwyer, Fabaceae, (copaiba) and *Protium ssp*. (white *breu*) (resin); besides the creation of small animals and artisanal fishing for subsistence. They are old residents located in the extreme south of the conservation unit, who develop their extractive activities within the latter, where they established 'colocations' that serve as exploration units. Most of these areas are certified.

In this sense, this work aims to determine the spatial distribution pattern of Protium species and the diametric structure of these species in stretches of dense tropical submontane rainforest along the Iratapuru river Sustainable Development Reserve (SDR), and then propose solutions for the sustainable use and management of this natural resource.

Material and methods

Area of study

The Iratapuru river SDR, which covers 806,184 hectares, was created by the Decree-Law n. 392, from December 11th, 1997 and is located in the Southeast region of Amapá state, covering the municipalities of Laranjal do Jari, Mazagão and Pedra Branca do Amapari, being limited by Waiãpi Indigenous Land to the North, Jari river's course to the West and part of Jari Ecologic Station to the South (Figure 1) (Rabelo, 2004). It is positioned in a region of great importance to Amapá Biodiversity Corridor, because strategically connect Tumucumaque National Mountain Park to Cajari river Extractive Reserve (Pereira, Pinto Sobrinho, & Costa Neto, 2011).

Figure 1. Location of sampled areas ('Mane Preto', 'Banco Grande' and 'Alasca') in the three field campaigns carried out in the Iratapuru River Sustainable Development Reserve (SDR).

Physical aspects

In the municipality of Laranjal do Jari, the weather is mostly tropical, being characterized by temperatures which vary between 24.5ºC (April) and 28.2ºC (October), the coldest quarter happening from February to April and the hottest quarter in the period from September to November. The rainfall presents values between 1,998.2 and 2,347.7 mm, with an average of the total accumulated of 2,158.8 mm. The rainiest quarter happens between March and May. September to November show the lowest rainfall indexes (Rabelo, 2004).

According to characterization developed by (*Zoneamento Ecológico Econômico* [ZEE], 2008), the SDR region is on the domain of Guiana Shield, constituted by crystalline rocks from Precambrian, and the North boarder of Amazon basin, composed by Paleozoic sedimentary rocks. The terrain is dissected, many times in the shape of hills.

Under SDR forests, sandy and clay latosols are predominant, which are very weathered. The hydrographic network is constituted by the Iratapuru river basin, tributary of the left bank of the Jari river, which is characterized for being a plateau

river (Carim, Guimarães, Tostes, Takiyama, & Wittmann, 2015).

Vegetation

The dominant vegetation is the Dense Ombrophilous Submontane Forest of 'Terra Firme' and Alluvial. The Terra Firme Forest corresponds to the highest proportion in the SDR, being remarkable for its individuals of high size and diversity of species with great economic value as *Bertholletia excelsa*; *Copaifera duckei*; *Diniza excelsa* Ducke - Fabaceae (angelim), *Dipteryx odorata* (Aubl.) Willd. - Fabaceae (cumaru) and others. The alluvial forest, better known as the flooded forest of 'igapó', borders the main clear watercourse formed by the Iratapuru River, with its origin in the Guinean shields. They are forests of low size, particularly *Carapa guianensis* Aubl. - Meliaceae (andiroba), *Virola surinamensis* (Role ex Rottb.) Warb. - Myristicaceae (virola), *Bombax paraensis* Ducke - Malvaceae (Mamorana) and *Pentaclethra macroloba* Willd. O. Kuntze-Fabaceae (pracaxi) (Carim et al., 2015).

Population structure

There were realized three field campaigns between 2012 and 2013. The area was divided into three compartments in North-South direction bordering Iratapuru river. The plateau areas were identified according to their local names, which are: Anani/Mane Preto Sierra (MP), 9 km away from San Francisco village on waterways and inland routes; Banco Grande Sierra (BG), 18 km away and Alaska Sierra (A), 26 km away. All of them are placed in altitudes between 200 and 300 m.

For the quantitative survey regarding the structural description of *Protium* population in the area, in each plateau compartment it was settled a single area transect with 1000 x 20 m (2 hectares), where there were sampled live individuals and taken height data and DBH (diameter at breast height) ≥ 10 cm. For the measurement of individuals it was used a metric tape and the total height was estimated with a 6 m rod marked in every meter. There were used wooden stakes to mark the parcels, and its limits were set with cotton strings, all of them being georeferenced with a GPS Garmim, using the UTM datum SAD`69 coordinate system.

Spatial distributions

Payandeh Index (Pi): Estimating this index, it is obtained the species's aggregation degree through the relationship between the variance of the number of trees per parcel and the average of the number of trees (Payandeh, 1970), according Equation 1:

$$P_i = \frac{s_i^2}{M_i};\ M_i = \frac{\sum_{j=1}^{j} n_{ij}}{u_T};\ S_i^2 = \frac{\sum_{j=1}^{j} n_{ij}^2 - \left(\frac{\sum_{j=1}^{j} n_{ij}}{u_T}\right)}{u_i - 1} \quad (1)$$

where:
Pi = 'Payandeh index' for the i-th species;
Si^2 = variance of the number of trees of the i-th species;
Mi = average of the number of trees of the i-th species;
Classif. Pi = Spatial Distribution Pattern Classification of species individuals, which obeys the following scale:
Pi < 1: random distribution or no grouping;
1 <= Pi <= 1,5: tendency to grouping;
Pi > 1,5: aggregated distribution or grouped.

Species identification and characterization

The identification and morphological study were made based on photographic registry of fruit and flowering branches of these species individuals identified by the Burseraceae specialist, Dr. Douglas Daly from the New York Botanical Garden, USA, and incorporated to the Hamab in the Amapá Scientific and Technological Research Institute (Iepa). Through the vouchers (*Protium altsonii* Sandwith - 510; *Protium polybotryum* (Turez) Engl. subst. *blackii* (Swart) Daly - 513; *Protium paniculatum var. riedelianum* (Engl.) Daly - 512 and *Protium tenuifolium* (Engl.) Engl. - 511). The data collected in field was digitized in Excel to be processed in the specific Mata Nativa 2 software for evaluation of diametric and spatial distribution.

Results and discussion

There were collected and identified four species from *Protium*, which were: *Protium altsonii* Sandwith; *Protium polybotryum* (Turez) Engl. subst. *blackii* (Swart) Daly; *Protium paniculatum var. riedelianum* (Engl.) Daly and *Protium tenuifolium* (Engl.) Engl.

There were sampled 721 live *Protium* individuals, from which *P. tenuifolium* presented the highest number of individuals, 481, distributed in all areas, with density of 80.1 ind ha^{-1}, average of 21.21 DBH, reaching the total basal area of 22.41 m^2; followed by *P. altsonii,* with 143 individuals, registered in Mane Preto and Banco Grande complex, with density of 23.3 ind ha^{-1} and average of 22.67 DBH, totaling a basal area of 7.01 m^2. *P. paniculatum var. riedelianum* occurred with 93 individuals distributed in all areas, with density of 15.5 ind ha^{-1}, average of 21.07 DBH, reaching a basal area of 3.84 m^2. Only *P. polybotryum* subst. *Blackii,* with 4 individuals, occurred in only one area, Mane Preto complex, with average of 13.85 DBH and total basal area of 0.07 m^2 (Table 1).

Table 1. Distribution of *Protium* Burm. f. species, inventoried in the Iratapuru River SDR, Amapá, Brazil. N. Ind. (number of individuals) e AB (Área Basal).

Species	Alaska		Mane Preto		Banco grande		N Total	AB Total
	N. Ind.	AB (m^2)	N. Ind.	AB (m^2)	N. Ind.	AB (m^2)		
Protium altsonii Sandwith	48	2.47	95	4.53	0	0	143	7.01
Protium paniculatum var. riedelianum (Engl.) Daly	22	0.85	65	2.60	6	0.39	93	3.84
Protium polybotryum (Turez) Engl. subst. *blackii* (Swart) Daly	0	0	4	0.07	0	0	4	0.07
Protium tenuifolium (Engl.) Engl.	54	4.89	185	7.36	242	10.15	481	22.41
Total	124	8.22	349	14.57	248	10.54	721	33.33

For the gender, it was registered absolute density of 121 ind ha^{-1} and total basal area of 33.32 m^2, approximately. Figure 2 shows the individuals distribution in different height classes, with expressive concentration of individuals until 10 m high, reaching around 70% of the total sampled. Only 44 sampled individuals (6%) exceeded 20 m of height. It is verified that most individuals are grouped until 15 m of height, with approximately 86% of the total. Approximately 13% of individuals were positioned between 15 and 25 m of height and only nine individuals are higher than 25 m, approximately 1% of the total sampled.

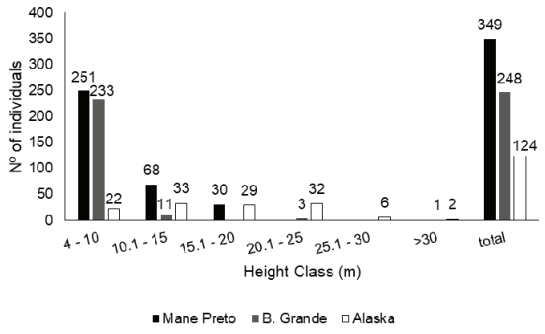

Figure 2. Distribution in different height classes of *Protium* Burm. f. individuals, inventoried in the Iratapuru River SDR, Amapá State, Brazil.

The diametric distribution of the sampled population presented an inverted 'J' shape. Most individuals concentrated in smaller diametric classes, decreasing progressively to a lesser extent in larger classes (Figure 3), highlighting the typical pattern for mature forests in natural regeneration (Blanc, Maury-Lechon, & Pascal, 2000).

Among trees, the individual growth is usually evaluated, among other variables, mainly for the diametric increase or for the basal area, being these reliable param to indicate the state of conservation of a forest. The study of these param points the growth and the changes occurred in its composition and structure.

In general, it was registered a high density in the gender population, predominating the *Protium altsonii* and *P. tenuifolium* species. Possibly, this finding must be related to the phytophysiognomy itself and the conservation degree of the environment. Thus, the high population of the gender in the SDR can be a result of the relative absence of anthropic activities. The specialized morphology and the great competitive ability of *P. tenuifolium* favor its adaption to non-disturbed environments (Daly, 1987).

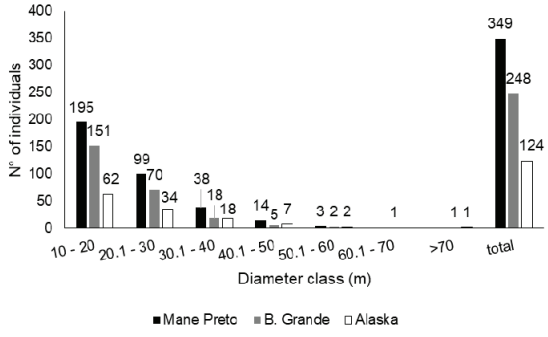

Figure 3. Diametric distribution of *Protium* Burm. f. individuals, inventoried in the Iratapuru River RDS , Amapá State, Brazil.

The constant number of trees with the same structure by class interval would be economically better. However, this is an uncommon situation in tropical forests. From a biological point of view, the structure of an uneven-aged forest tends to respond to a pattern in an inverted 'J' (Leuschner, 1984), typical of forests in dynamic balance, where most individuals take the first diameter classes. This is a fact that was confirmed by Carim et al. (2015), considering the same area of study.

In a general sense, the studied population can be considered to be medium-sized, with a minimum of 4 m and maximum of 35 m. In the same region, Carim et al. (2015) registered in his study a vegetation of high size with well-stratified and emergent individuals above 35 m.

The *Protium* species are well distributed in the forest profile. Nonetheless, they contribute differently when it comes to the number of individuals and sociological position they occupy. *P. alttsonii* and *P. tenuifolium* presented individuals in all classes, being the only ones to present individuals higher than 35 m. *P. paniculatum* var. *riedelianum* registered individuals with 25 m of height. *P.*

polybotryum subst. *blackii* placed its four individuals between 5 and 11 m of height.

The diametric distribution of the sampled population presented the same pattern found in study developed with *Protium pallidum* Cuatrec in a Terra Firme Tropical Forest in Resex Cajari, in Amapá (Rudiger, Siani, & Veiga Junior, 2007) and in Monu, Pará State (Daly, 1987) Balanced diametric distributions, where the ability to recruit compensates mortality throughout time, is the greatest guarantee for the species existence and survival. This distribution ensures that, in the dynamic process of the forest, the species renews itself, ensuring the dynamic balance of the population (Lamprecht, 1962; Felfili, 1997).

Protium species present high importance values in tropical forests. This is directly related to the large basal area and/or density of its individuals, influencing the management for commercial purposes, being able to be worked on individually or along with other species (Assis, Pereira, & Thomaz, 2004; Pereira, Cordeiro, & Araújo, 2004; Carim, Guimarães, & Tostes, 2013). Certainly, there seems to exist a strong tendency for the individual distribution curve to vary along South-North axis, decreasing the amount of individuals as it advances towards the upwind of Iratapuru river heading North. Anyhow, the species tend to assume different proportions along the analyzed stretch, possibly influenced by its own adaptive characteristics, what favors its large distribution and therefore its status in phytocenoses.

Abiotic factors

Possibly, factors connected to physical aspects in the SDR are influencing the *Protium* species distribution. Aspects related to height and lithological characteristics differences may be interfering in the adaptation of these species.

It is verified a mosaic of different lithological groups, occupying different gradients in South-North way in the SDR. In the Southern stretch of Mane Preto complex, siltstone from Trombetas Formation of Silurian age is predominant. In the North flank of Banco Grand complex, it emerges shales interspersed with siltstones and sandstones of Curuá Formation (Devonian). In Alaska complex, located in the Northern portion of the area, sandstones from the basal portion of Trombetas formation are predominantly found.

In eastern Amazon, the substrates derive mainly from stones formed in Archean (Amazon craton), which are extremely weathered and nutrient-poor. These factors cannot be analyzed individually, certainly, the low fertility in soils is common and responds in the same way for plants communities. Therefore, other factors contribute for the predominance of determined groups, associated or not to anthropic action. Preliminary data of the soil of the Submontane Forest in Iratapuru river SDR points soils with high to medium phosphorus concentration, high organic matter content, very high acidity level and aluminum saturation, high cation exchange capacity and macro nutrients poverty.

In this sense, more detailed studies on the influence of physical and chemical factors of the soil must be considered for a more concrete answer about the operating mechanisms which influence in the distribution of *Protium* species and if its effects are limiting. There is an increasing evidence that the distribution of floristic communities of Amazon region is very heterogeneous and related to soil conditions (Salovaara, Thesslerb, Malikc, & Tuomisto, 2005). The variations on the chemical composition of soils found in different analyzed plateaus indicates the low demand of *Protium* species regarding this characteristic. In a certain way, populations keep themselves balanced along the analyzed axis, with progressive increase in North direction.

Spatial distribution

Using the Payandeh index, it was verified that the distribution pattern to all species in the studied area tended to grouping, contrary to study developed by (Rudiger et al., 2007) in which it was considered a random distribution for *P. pallidum,* applying the Morisita index (MI).

Environmental differences, bio-ecological factors (predation, mortality, dispersion and birth rate) and soil and climate conditions are the main responsible for the random distribution pattern of species (Carvalho, 2002). Whereas, the grouping characteristic of the species is possibly related to its high annual seeding production, to the dispersion pattern of its species and to the absence of specific predators for them.

A plant species, although it presents a great occurrence in a determined area, its spatial distribution in different size classes can be very irregular. The grouping degree can present different values, with plants from lower size classes presenting tendency to grouping and plants from the higher size classes possibly occurring in a strongly grouped form (Carvalho, 1983).

To Kanieski et al. (2009), the spatial distribution inside the community is an important characteristic for the planning of management measures and conservation of forest formations. Anjos, Mazza,

Santos, and Delfini (2004) also confirm that the knowledge regarding the spatial distribution pattern can give information on ecology, subsidize the definition of management and/or conservation strategies, help in sampling processes or simply clarify the spatial structure of a species. In this work, it was verified that *Protium* species are established throughout a geomorphological gradient and lithologically different. However, it does not reflect in a limiting way for the establishment of these species to varied environmental conditions. These are species which adapt to variations, even coming to assume dominant patterns in the environment.

More profound studies on species autoecology, including its phenophases and reproductive biology and its abiotic relations must offer more profound answers on the operating mechanisms for the success of these species in tropical environments.

Conclusion

Protium populations present medium size and its vertical structure is characterized by the presence of three strata, however, its phytocenoses is defined by two very clear constants; the first groups individuals with 15 m high and forms the uniform and dominant stratum, the second is composed by emergent with up to 35 m of height.

The diameter structure highlights a population in dynamic balance, where the recruitment ability compensates mortality, proven by the diametric distribution curve of individuals. The *Protium* population is distributed by the Payandeh index tending to grouping in the Iratapuru river SDR.

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