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The population structure of *Lonchocarpus cultratus* in an Atlantic Forest riparian zone of the upper Paraná River, Brazil

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ABSTRACT. The goal of this study was to evaluate the population structure of *Lonchocarpus cultratus* located in a riparian zone in the flood plain of the upper Paraná River. Data were collected on the stem diameter at breast height (DBH) and the plant height from two phytosociological inventories, which were performed with a 14-year interval, using data collected in studies conducted in 1992 and 2006 in an Atlantic Forest riparian zone remnant of Paraná State, Brazil. Class intervals for DBH and plant height were defined using the Spiegel equation, and the measured values were distributed between the different distinct classes. The distribution of individuals between the different DBH classes was analyzed using de Liocourt's quotient (*q*). For both stages of the study, the DBH distribution resulted in an inverted-J curve, as expected for uneven-aged forests. The distribution of the height values was irregular, as expected for an early succession species. The de Liocourt *q* indicated an unbalanced distribution for both stages. However, there was a tendency towards balance in the second stage. The results imply that the studied population was maturing and maintaining its self-regenerating capacity while tending towards balance and presenting behavior characteristic of early succession species.

Keywords: Diameter structure, forest dynamics, forest fragmentation, recruitment rate.

Estrutura populacional de *Lonchocarpus cultratus* em formação florestal ripária de Mata Atlântica no alto rio Paraná, Brasil

RESUMO. Com o objetivo de avaliar a estrutura populacional de *Lonchocarpus cultratus* em um trecho de floresta ripária localizado na planície de inundação do alto rio Paraná, analisaram-se os dados de diâmetro e altura obtidos a partir de dois inventários fitossociológicos realizados com intervalo de 14 anos, utilizando-se dados coletados em estudos desenvolvidos em 1992 e 2006 em um remanescente ripário de Mata Atlântica, no Estado do Paraná, Brasil. Os valores de diâmetro e de altura foram distribuídos em intervalos de classes definidos pela fórmula de Spiegel e o quociente "*q*" de Liocourt foi aplicado para a análise da distribuição de indivíduos entre as classes de diâmetro. A distribuição diamétrica, nas duas etapas do estudo, resultou em uma curva na forma de J-invertido, como esperado para florestas inequiâneas. A distribuição dos valores de altura mostrou-se irregular, característica de espécies de estágios iniciais de sucessão. O quociente "*q*" de Liocourt apresentou-se com uma distribuição não balanceada para ambas as etapas, porém observou-se uma tendência ao balanceamento na segunda etapa. Concluiu-se que a população analisada encontra-se em processo de amadurecimento, mantendo a capacidade autorregenerante, com tendência ao balanceamento e comportamento característico de espécies de estágios iniciais de sucessão.

Palavras-chave: Estrutura diamétrica, dinâmica florestal, fragmentação florestal, taxa de recrutamento.

Introduction

The patterns in the structures and dynamics of plant populations result from complex interactions between the biotic and abiotic factors that act on individual plants. Studies on this topic can focus on different plant characteristics, such as the size, age or spatial distribution of a given population. Analyses of population structures, which exist in a given environment at a given moment, can be performed using one-off surveys. However, periodic and long-term surveys are needed for population dynamics analyses because such surveys quantify demographic data such as mortality, recruitment and growth (Harper, 1990; Schiavini, Resende, & Aquino, 2001; Aquino, Oliveira, Ribeiro, & Schiavini, 2002; Aquino, Walter, & Ribeiro, 2007; Lopes, 2007).

Several authors have studied forest succession dynamics by analyzing changes in plant height and diameter at determined time intervals (Rosa & Schiavini, 2006; Braga & Rezende, 2007; Santana,

Vieira, Pacheco, & Oliveira, 2011). In this aspect, the diametric distribution analysis of forests uneven-aged[1] enables better knowledge and understanding of the species that make up the forest, allowing better planning for the establishment of appropriate strategies for the conservation and management (Batista et al., 2015). Several studies have been developed for determining the diameter distributions in uneven-aged stands forests. In this way, the diameter distribution assumes considerable importance in raising the horizontal structure of a forest by allowing characterize a forest type and also to be an inventory indicator growth species. Besides that, provides data for decision making and planning of sustainable forest management (Carim, Guillaumet, Guimarães, & Tostes, 2013; Abreu, Guedes, Guedes, & Batista, 2014; Santos et al., 2016).

These types of data have also been used to make inferences about possible past disturbances, such as selective cuttings, fires and deforestations (Arantes & Schiavini, 2011).

The flood plain of the upper Paraná River (in the States of Paraná and Mato Grosso do Sul, Brazil) is located in the Atlantic Forest (Mata Atlântica) phytogeographical domain. The plain contains riparian formations that vary from fields to forests. Floristic and phytosociological inventories, performed since 1986, have revealed a heterogeneous plant cover that is affected by variables such as exposure to flooding and anthropic influences; effects resulting from the construction of hydroelectric are particularly impactful. Fortunately, the creation of Conservation Units and the application of riparian zone protection laws have allowed ecological succession to progress in several zones (Campos & Souza, 2002, 2003; Souza et al., 2004; Corradini, Fachini, & Stevaux, 2006; Souza, Kawakita, Slusarski, & Pereira, 2009; Slusarski & Souza, 2012).

Lonchocarpus cultratus (Vell.) Azevedo-Tozzi & H. C. Lima (Leguminosae-Faboideae) is a tree species native to Brazil, where it is widely distributed (Silva & Tozzi, 2012). Its manner of seed dispersion is anemochorous (Carmo & Morellato, 2000). *L. cultratus* is classified as a heliophyte, and depending on the environment, it can behave as a pioneer (Lorenzi, 2002), early secondary (Durigan, Figliolia, Kawabata, Garrido, & Baitello, 1997) or late secondary (Ferretti et al., 1995) species. Due to its good adaptation to low fertility conditions, it has been recommended for planting in dry or humid degraded areas, where it can tolerate periodic flooding (Durigan et al., 1997).

In the Upper Paraná River Flood Plain (UPRFP), the distribution of *L. cultratus* is restricted to the left bank of the Paraná River (Slusarski & Souza, 2012). There, it presents as a phytosociological representative of a remnant forest called Mata do Araldo; the distribution's importance value index (IVI) was found to be the highest of those in two separate surveys, which were performed approximately 14 years apart (Souza, 1998; Slusarski, 2009).

Considering the high IVI observed for *L. cultratus* in those two surveys (Souza, 1998; Slusarski, 2009), the goal of the present study was to compare its population structures at the two survey times using stem diameter and plant height. This study's hypothesis is that variations in the population structure occurred during this time interval and that these variations may be associated with the succession dynamics of *L. cultratus* within the community.

Material and methods

Study site

The study site is located in the South region of Brazil and includes a fragment of disturbed forest, called Mata do Araldo (Figure 1). That forest is on a stretch of the left bank of the Paraná river belonging to the Upper Paraná River Flood Plain (UPRFP), in the municipality of Porto Rico, State of Paraná (PR), Brazil (22º47' S and 53º19' W), at an altitude of 240-260 m. The region's climate is a Cfa type, according to the Köppen climate classification, and is characterized as subtropical, humid and mesothermal, with hot summers and 1,500 mm average annual rainfall (IAPAR, 2012).

The studied forest remnant has an area of approximately 20 ha and is included in the Atlantic Forest biome (EMBRAPA, 1996; Brasil, 2006) and the Semideciduous Seasonal Forest Phytoecological Region (IBGE, 2012). It is a disturbed area that had been exposed to fires, trail construction and cattle treading before the 1990s (Souza, 1998). Phytosociological surveys of the tree components of this forest remnant were performed in a 1-hectare area in two stages. Sixty-two species were observed in Stage 1 (April to December 1992) (Souza, 1998), and 66 species were identified in Stage 2 (November 2005 to February 2006) (Slusarski, 2009). *Lonchocarpus cultratus* was found to be the dominant community in both surveys, presenting high IVI values (78.2 for Stage 1 and 83.8 for Stage 2) (Table 1).

[1] A forest is defined as even-aged when the variation of tree age is at the maximum 30% of the forest rotation time. Forests in which the variation of the tree age is higher than that limit are defined as uneven-aged or all-aged (Avery & Burkhart 1983, apud Daniels & Burkhart 1988).

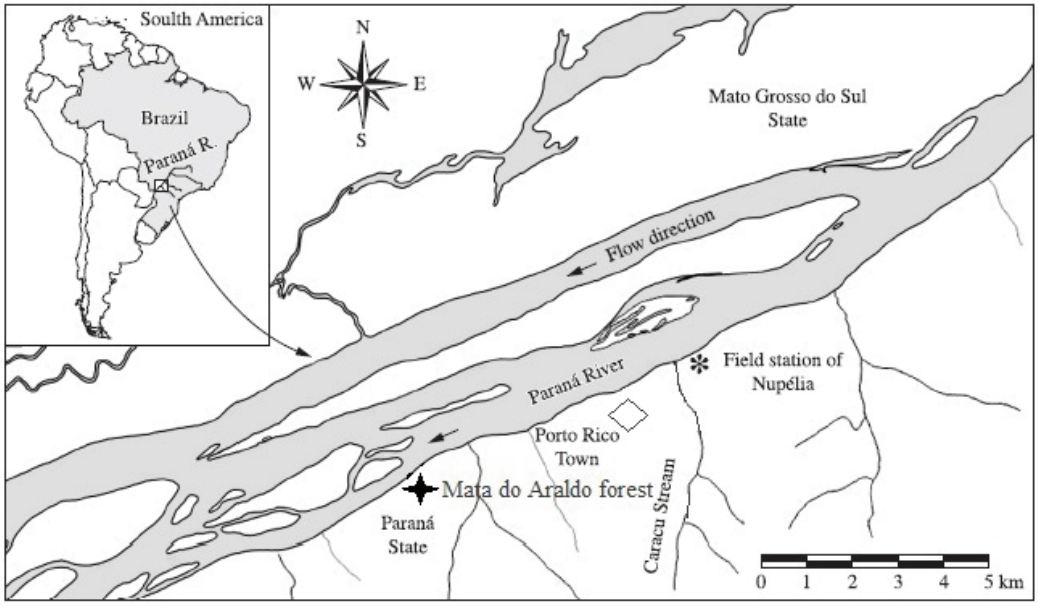

Figure 1. Mata do Araldo localization, riparian forest remnant, UPRFP, municipality of Porto Rico, PR, Brazil. (Map credit: Jaime Luis Lopes Pereira/Nupélia/UEM, 2010).

Table 1. The phytosociological parameters of *Lonchocarpus cultratus*, as obtained in two surveys performed at the same sampling site in different stages. The sampling site was the Mata do Araldo riparian forest remnant, UPRFP, municipality of Porto Rico, PR, Brazil.

Phytosociological parameters	Stage 1 (1992)	Stage 2 (2006)
Number of individuals	318	310
Relative density (%)	27.1	29.3
Relative frequency (%)	10.6	12.1
Relative dominance (%)	40.5	42.4
Importance value index (%)	78.2	83.8

Data collection and analysis

Values for the stem diameter at breast height (DBH ≥ 4.8 cm) and the plant height of *L. cultratus* individuals were obtained from two phytosociological surveys performed at an approximate 14 year interval (Table 1). The survey area was a 1 ha (100 x 100 m) plot, delimited by the river margin and subdivided in 50 subplots of 200 m² (20 x 10 m) each (Souza, 1998; Slusarski, 2009).

DBH and plant height values were distributed between different classes. Class intervals were determined using the Spiegel equation: CI = A/NC, where A = amplitude, NC (number of classes) = 1 + 3.3 log (n) and n = number of individuals (Felfili, 1995). Calculations were performed using values from Stages 1 and 2 (Arantes & Schiavini, 2011).

The recruitment of individuals from one class to another was determined based on DBH data and using the de Liocourt *q*, which was calculated by dividing the number of individuals in one class by the number of individuals in the class immediately before (Carvalho & Nascimento, 2009; Carvalho, Jacobson, Costa, Santos, & Hay, 2009). The de Liocourt *q* is based on the decline in number of trees of a given diameter class relative to the higher diameter found (Alves Júnior et al., 2010).

Results

During Stage 1, 318 individuals were sampled, with 18.4 cm and 12.8 m average values of DBH and plant height, respectively. During Stage 2, 310 individuals were sampled, with 21.7 cm and 20.8 m average values of DBH and plant height, respectively (Table 2). With time, an increase was observed in the maximum values of both DBH (from 76.5 to 84.6 cm) and plant height (from 27.0 to 37 m).

Table 2. The stem diameter and height of *Lonchocarpus cultratus*, as determined by phytosociological surveys performed in two stages with an approximate 14 year interval. The sampling site was the Mata do Araldo riparian forest remnant, UPRFP, municipality of Porto Rico, PR, Brazil (SD = standard deviation).

Survey	diameter (cm)				height (m)			
	minimum	maximum	average	SD	minimum	maximum	average	SD
Stage 1	4.8*	76.5	1.4	12.7	1.7	27.0	12.8	6.2
Stage 2	4.8*	84.6	21.7	15.1	2.0	37.0	20.8	10.8

* Minimum value established in the sampling criteria

A 10.5 cm class interval was determined for the DBH, establishing eight different classes (Table 3). It should be highlighted that class eight exclusively included individuals from Stage 2. Negative exponential curves (inverted-J shape) were obtained for the distribution of the number of individuals per class in each of the two survey stages. This result indicates a decrease in the smaller classes in favor of the larger classes over time.

Table 3. The stem diameter (DBH) classes with their respective intervals and numbers of *Lonchocarpus cultratus* individuals. The sampling site was the Mata do Araldo riparian forest remnant, UPRFP, municipality of Porto Rico, PR, Brazil.

Classes	Diameter (cm)	Individuals number	
		Stage 1	Stage 2
1	4.8 - 15.3	166	129
2	15.4 - 25.9	80	84
3	26.0 - 36.5	45	48
4	36.6 - 47.1	15	29
5	47.2 - 57.7	8	10
6	57.8 - 68.3	2	5
7	68.4 - 78.9	2	3
8	80.0 - 90.5	-	2
Total		318	310

A 22.3% decrease in the number of individuals belonging to the first class was observed between Stages 1 and 2, whereas the remaining classes increased in population with class 4 being the largest (93%).

The average value of q, which indicates the recruitment of individuals from one class to another, was different for the two stages (0.45 for Stage 1 and 0.56 for Stage 2) (Figure 2). In Stage 1, the class q value closest to the overall average was 0.48, found for q_1 (classes 1-2). The values obtained for q_3 and q_5 were lower than the average, and higher values were found for q_2, q_4 and q_6. This indicates that q_1 presented balanced recruitment rates and mortality during Stage 1. For the remaining classes, the values differed from the average without a continuity pattern, indicating low recruitment rates in q_2, q_4 and q_6 and high rates in q_3 and q_5. During Stage 2, however, values closer to the average were observed in multiple classes (0.57 for q_2 and 0.60 for q_3 and q_6). Values lower than the stage average were found for q_4 and q_5, and higher values were found for q_1 and q_7. This observation indicates that the population was more balanced during the second stage, as it presented class values closer to the overall average (Figure 2).

A 3.7 m interval was determined for plant height using the Spiegel equation, establishing ten different classes. Classes 8, 9 and 10 exclusively included individuals from Stage 2. Higher evenness in the distribution of the number of individuals per class was observed in Stage 1; those population values increased up to class 3, where a peak in number of individuals was reached (23.6%), and then decreased for higher classes (Table 4).

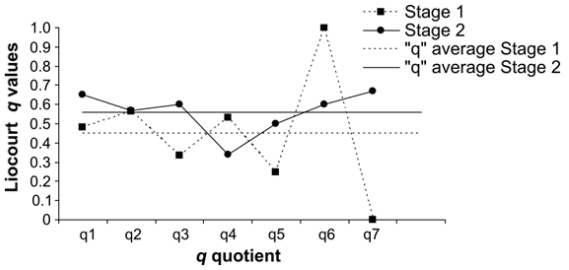

Figure 2. The de Liocourt q values and averages (Stage 1 = 0.45 and Stage 2 = 0.56) for a *Lonchocarpus cultratus* population, which was surveyed in two stages with an approximate 11-year interval. The sampling site was the Mata do Araldo riparian forest remnant, UPRFP, municipality of Porto Rico, PR, Brazil.

In both stages, the individual distribution was observed to be uneven for higher classes. Up to class 6, there was a decrease in the number of individuals, but increases were observed from classes 7 and up, particularly for class 9 and its 56 individuals (Table 4).

Table 4. The distribution of individuals of a *Lonchocarpus cultratus* population between different plant height classes with 3.7 m intervals. The sampling site was the Mata do Araldo riparian forest remnant, UPRFP, municipality of Porto Rico, PR, Brazil.

Classes	Height (m)	Individuals number	
		Stage 1	Stage 2
1	1.3 - 5.0	38	27
2	5.1 - 8.8	60	40
3	8.9 - 12.6	75	22
4	12.7 - 16.4	49	31
5	16.5 - 20.2	54	41
6	20.3 - 24.0	39	14
7	24.1 - 27.8	3	23
8	27.9 - 31.6	0	38
9	31.7 - 35.4	0	56
10	35.5 - 39.2	0	18
Total		318	310

Discussion

The *L. cultratus* population studied presented increasing averages and maximum values of DBH between Stages 1 and 2. The sampling space was occupied by a higher number of individuals with a higher stem diameter, regardless of the decrease in the total number of individuals found during the studied period. This evidence indicates that the population is maturing (Schaaf, Figueiredo-Filho, Galvão, & Sanquetta, 2006). The area occupied by *L. cultratus* increased exclusively due to the higher number of individuals with larger stem diameters, as the total number of individuals decreased between Stages 1 and 2.

In both stages, the distribution of individuals between the different diameter classes presented the expected behavior for uneven-aged forests, i.e., a negative exponential distribution (Harper, 1990; Felfili, 1997; Felfili, Silva Júnior, & Nogueira, 1998; Silva Júnior, 2004; Schaaf et al., 2006). This distribution indicates a self-regenerating population because it presents individuals in all stem diameter classes and shows a higher number of individuals in the lower stem diameter classes (Arantes & Schiavini, 2011), which guarantees the survival of natural plant populations (Santana et al., 2011). However, the structure data are not sufficient to predict a possible expansion of the species at the studied site, and further long term studies of the population dynamics are needed (Arantes & Schiavini, 2011).

The obtained results indicated the success of the *L. cultratus* regeneration. However, the de Liocourt *q* values obtained for the two stages of the study, with values differing from the average, indicated that the recruitment and mortality rates were not balanced between the different DBH classes. Thus, the forest structure changes over time, a result of the discrepancy between its mortality and recruitment rates (Felfili et al., 1998).

The de Liocourt *q* determines the shape of the stem diameter distribution curve (Felfili et al., 1998). This parameter has been used to infer recruitment and mortality rates in forests and to estimate whether the community or the population is balanced (Alves Júnior et al., 2010). The stem diameter distribution is considered balanced when the decrease in the number of individuals from one class to the following class occurs at a constant rate (Felfili, 1997; Nascimento, Felfili, & Meirelles, 2004; Alves Júnior, Ferreira, Silva, Maragon, & Costa Júnior, 2009; Alves Júnior et al., 2010). The diameter distribution of the population behaved as expected for uneven-aged stands forests due to present diametric distribution curve, resembling a "J-reverse", showing that, in native forests, there is a tendency of balance between mortality and recruitment (Meira, Cabacinha, Gama, Martins, & Figueiredo, 2016). The presence of *q* values lower than the calculated average indicates a high capacity for population regeneration, whereas *q* values above the average indicate low recruitment rates (Carvalho & Nascimento, 2009). According to Alves Júnior et al., (2010), most of the studies on the diameter structure of natural forests in Brazil only describe and discuss the shape of the curve (inverted-J), while few report *q* values.

The distribution of individuals between the different plant height classes varied in the two studied stages. Individuals recruited in previous years were observed to move to the following, higher, plant height classes. The variation in distributions between the different plant height classes may be related to the natural dynamics of *L. cultratus*, which invests in stem elongation to the detriment of stem diameter, presenting many tall and thin individuals at Stage 1 (Souza, 1998). This characteristic is associated with species of early succession stages, which are light demanding but can tolerate shade in the early phases of development, presenting moderate to fast initial growth (Renner, Bittencourt, Oliveira, & Radomski, 2010). At the interior of the Mata do Araldo, *L. cultratus* presents the behavior of an early secondary species, germinating in the shade, with individuals that can outgrow the canopy height (Souza, 1998).

The expansion of the studied population seems to be favored by the forest maintenance process. However, it cannot be concluded that the studied population is in continuous expansion based only on the collected data, and periodic monitoring of recruitment and mortality events over several years of study is needed to establish the population dynamics.

Conclusion

In both stages, the studied *Lonchocarpus cultratus* population presented behavior characteristic of early succession species. The population was also observed to be maturing, maintaining the capacity for self-regeneration and non-compensatory recruitment rates but with a tendency towards balance. The results suggest that the Mata do Araldo *L. cultratus* population tends towards a community equilibrium, which supports our initial hypothesis. Further periodic evaluations, including other species of the community with higher IVI values, are essential to a better understanding of the succession dynamics of the studied forest remnant.

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