Journal of Experimental Agriculture International

33(5): 1-12, 2019; Article no.JEAI.48017
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Ecological Variability Prediction Based on Functional Characteristics of an Urban Rainforest

Maria J. H. Leite[1], Valdemir F. Silva[2], Maria A. M. Silva[3], Ana C. B. Lins e Silva[2], Girlânio H. Silva[4*], Maria M. B. Aguiar[3], André L. A. Lima[3] and Maria J. N. Rodal[2]

[1]Federal University of Alagoas (UFAL), Alagoas, AL, Brazil.
[2]Rural Federal University of Pernambuco (UFRPE), Recife, PE, Brazil.
[3]Federal Institute of Ceará (IFCE), Quixadá, CE, Brazil.
[4]São Paulo State University (UNESP), Botucatu, SP, Brazil.

Authors' contributions

This work was carried out in collaboration among all authors. Author MJHL managed the literature searches and wrote the first draft of the manuscript. Author VFS designed the study and performed the statistical analysis. Authors MAMS, ACBLeS, GHS, MMBA and ALAL revised the manuscript. Author MJNR performed the final approval of the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2019/v33i530155
Editor(s):
(1) Dr. Ivan Francisco Garcia-Tejero, Instituto Andaluz de Investigacion y Formacion Agraria y Pesquera (IFAPA),Centro Las Torres-Tomejil, Alcala del Rio (Sevilla), Spain.
Reviewers:
(1) Akinyemi Bosede Kemi, Benue State University, Nigeria.
(2) Juliet U. Nwatu, University of Ibadan, Nigeria.
(3) Dr. Virendra Singh, IFTM University, India.
Complete Peer review History: http://www.sdiarticle3.com/review-history/48017

Original Research Article

Received 14 January 2019
Accepted 27 March 2019
Published 03 April 2019

ABSTRACT

The relation among basal area, light and functional characteristics variation is still an unexplored issue, especially in rainforests with different disturbance regimes. The following hypotheses were tested: 1) basal area of arboreal plants and light availability is a good predictor of the functional characteristics, once it is believed that in forest environments with a lower basal area and much light, functional characteristics values linked to the fast light resources utilization are found in leaves, stem and roots; 2) environments where there is greater light availability, the standard deviation values of the leaf characteristics will be greater. The functional characteristics values were not influenced by the geographic distance (spatial autocorrelation) neither by the species phylogeny. The prediction that in the areas with the lower basal area, values of characteristics

**Corresponding author: E-mail: girlanio_holanda@hotmail.com;*

associated with the rapid use of the light resource were confirmed for five characteristics: dry leaf matter (LMDC), stem (SDMC) and root (RDMC), the density of wood stem (WDC) and root (WDR). Significant investment was not found in structural carbon (greater dry matter values of leaf and wood) in environments with the greater basal area. It is considered that in urban fragments the disturbances are frequent, it is possible to suppose that plants with lower values of LDMC, DWC, DWR, SDMC, and RDMC have also "established" in the two areas with a greater basal area. It is concluded that in fragments in urban rainforest studied, perturbations may change the succession path due to population dynamics, especially in the area with more abundant light availability and lesser basal area ($A4_{<AB}$). the study suggests that this greater light input in the $A4_{<AB}$ environment, due to the greater perturbations, would lead plants with the strategy of using a slow resource, favoring those with fast use of the resource, and as a result, there would be less variability of the leaf characteristics in $A4_{<AB}$. The basal area and light intensity are not good predictors of variations of functional characteristics in the urban fragments studied.

Keywords: Basal area; wood density; light intensity; anthropic disturbances; leaf variability.

1. INTRODUCTION

In forest ecosystems, the basal area is one of the first parameters to recover after disturbances in the community [1-3], then there is a change in the functional characteristics of the species [4]. It is also known that these functional characteristics are good indicators of species ecology, helping to understand the responses to different environments or disturbance regimes [5,6]. However, the existing relation among basal area, light and the variation of functional characteristics is still an unexplored issue, especially in rainforests with different disturbance regimes, such as urban fragments [7].

It is known that values of functional characteristics of plants respond in different ways to the availability of resources (water, light, etc.) [8-10]. These responses are observed in distinct survival patterns as a result of their potential acquisition and use of the resource [11-13]. Therefore, the values of the functional characteristics of the species of the community help to understand the responses of the plants to the changes in the availability of the resource [14-15].

In the case of rainforests, where light is the main resource, at the beginning of the ecological succession there is greater luminosity and lower values of basal area [16,10]. In this environment, species with a high leaf area, specific leaf area and chlorophyll content [11], low wood density of stem and root, high water content in the stem and root tend to occur. This points to strategies linked to the acquisition of resources [17,18,10]. As the succession progresses the canopies are closed, what changes the amount of light that reaches the forest floor, leading to greater survival of plants more adapted to the capture of light [19,20].

The evaluation of functional characteristics in forests can be used to understand vegetation changes under different environmental pressures [21-22], mainly along the process of ecological succession and selection pressure, in which the species deal with luminosity variations, an important resource for the regeneration and growth of plants in rainforests [23-26].

Therefore, this research seeks to understand the influence of light availability and basal area variation on the values of the functional characteristics of an urban rainforest. It was assumed that the increase of the basal area and the decrease of the light intensity are measures indicative of the succession in an urban rainforest. It was hypothesized that the basal area of arboreal plants is a good predictor of functional characteristics.

In this way, it is believed that in forest environments with lower basal area and greater light intensity, values of functional characteristics linked to the fast use of the light resource are found in both leaves (larger leaf area, specific leaf area, chlorophyll concentrations, low investment in dry matter) and in the stem and root (higher amount of saturated water, lower wood density and lower contents of dry matter) [24-25]. From the perspective that the light availability is a good indicator of the variation of leaf characteristics, it was hypothesized that in the environment where there is greater light availability, the coefficient of variation of leaf characteristics will be higher. If this is true, greater variation in leaf dry matter, specific leaf area, leaf area and chlorophyll content in this environment are expected.

2. MATERIALS AND METHODS

2.1 Study Location

The study was carried out in a fragment of Ombrophylous Dense Lowland Forest [27], in the State Park of Dois Irmãos (PEDI), in the municipality of Recife-PE, Brazil, between coordinates 7°57' 21"and 8°00' 54" S; 34°55' 53" and 34°58' 38" W. In the area predominate the geological formation Barreiras and soils of the podzólico type, with subordinate latossolos, in general areno-clayey, ranging from deep to very deep [28]. The soil acidity varies from medium to high, which is in line with that expected for regions with high precipitation [29]. The local climate is As' type (tropical humid or tropical coastal), with average monthly temperatures above 23ºC, annual mean rainfall of 2460 mm and rainy season in the autumn-winter period [29].

2.2 Assembly of Plots, Inclusion Criterion and Floristic List

In the PEDI area, a module of the Biodiversity Research Program (PPBio), Mata Atlântica Network, was installed using the RAPELD method: this is a combination of rapid inventories (RAP) with long-term ecological research (PELD) [30]. The method consists in the opening of two straight tracks of 5000 m of extension, distant 1000 m. Along each trail, one-hectare plots were installed [30].

Of the two tracks installed by researchers PPBio Atlantic Forest was selected PE2, which analyzed four plots (250 × 40 m), 1000 m distant from each other, resulting in four areas. For each plot, a 250 m corridor was installed following the ground level curve [31].

Within each hectare, 20 plots of 10 × 20 m without overlap were drawn, where botanical samples and functional characteristics of the species with stem diameter at breast height (DBH) ≥ 5 cm at 1.30 m were collected. The minimum number of individuals that had their functional characteristics checked was five, and the maximum 20, when the species was present in the four areas and had five or more individuals in each area.

In area 1 there is evidence of people entering to remove wood for construction of residences and firewood, traces of hunting, tents on site; in areas (2 and 3) about 30 years ago vegetation was removed and crops were planted; in area 4 there are reports of occasional fires, as well as the removal of wood for firewood (personal communication).

The floristic classification was made through the APG IV [32] system. All material was deposited in the Vasconcelos Sobrinho *Herbarium* of the Rural Federal University of Pernambuco (UFRPE).

In order to verify if the basal area differed among the four areas studied (4000 m^2 each), we calculated the total basal area [10]. As the baseline, the data in each plot did not present normal distribution in the four areas, so Kruskal-Wallis non-parametric analysis of variance was performed, complemented by the Student-Newman-Keuls mean comparison test.

In the environment with the highest basal area ($A1_{>AB}$), species sampled for collection of the characteristics accounted for 78% of the total of individuals present, in $A2_{ABI}$ and $A3_{ABI}$, environments with intermediate basal areas the species represented 89% and 77% of the total density, respectively. In $A4_{<AB}$ environment with lower basal area, the sampled species accounted for 81% of total density.

2.3 Functional Characteristics

The measurement of the functional characteristics followed the protocol of [11]. There were measured 10 characteristics, four foliar and six linked to wood. As previously observed, to collect the characteristics, were selected at least five individuals per species to set the four areas for the collection of functional characteristics. Thus, the minimum number of individuals that had their functional characteristics checked was five and the maximum 20 for the four areas (250 × 40 m plot). From each individual, 10 mature leaves were collected at the middle of the canopy (exposed to the sun), with no evident symptoms of pathogen or herbivore attack. After being collected, the samples were wrapped in wet paper and placed in closed plastic bags and stored in Styrofoam with ice. In the laboratory the leaves (without petiole) were rehydrated and placed in deionized water in the dark for at least six hours.

Chlorophyll content was measured after collection at four points of each leaf, with the aid of a SPAD chlorophyll meter (Minolta SPAD 502

D Sprectrum Technologies Inc., Plainfield, Il, USA). After rehydration, the leaves were weighed in an analytical scale to obtain the saturated weight of water. Then, the leaves were scanned for leaf area measurement by the Image-Tool software [33] and the fresh mass was determined and then placed in an oven at 60°C for 72 hours to obtain of the leaves dry mass.

The stem samples were collected at 1.30 m incremental soil auger (300 x 5.15 mm core diameter). For the root samples, a shovel was used to facilitate the collection at 20-30 cm depth in the soil in the region closest to the colon [34]. The samples were immersed in a container with water for five days to rehydrate and reach the saturation point required for measurement. Subsequently, each sample was kept standing out of the container for about 10 minutes to remove excess of water for weighing the stem mass (Msatc) from the root (Msatr); After this, they were immersed in another container with water to obtain the volume, based on the displacement of the liquid caused by the immersion of the part [35]. Then, each sample was dried in oven at 103°C until constant weight (MS); based on these data, DMC, DMR; QAsatc; QAsatr; TMSC and TMSR were calculated.

2.4 Collection of Light Data

The total radiation (luminosity) was obtained in each of the 80 plots of 10 × 20 m drawn (20 per area). Initially hemispheric photos were taken in the center of each plot with a Nikon D50 camera with a hemispherical lens (Nikon DX 18-105 mm adapted fisheye 67-58 mm) on a tripod adjustable to one meter above the ground, horizontally leveled, positioned with the upper part aligned with magnetic north. The photographs were taken between August and December 2015, between 8:30 and 11:00 hours [36]. The image processing was done with the aid of GLA software (Gap Light Analyzer) version 2.0 [37] in order to obtain the total radiation that crosses the canopy (luminosity).

2.5 Data Analysis

In order to verify if the phylogenetically close species are similar in values of functional characteristics, their phylogenetic signal was calculated in each of the four areas. Thus, a matrix with the list of families, genus and species was constructed according to APG IV [32]. To obtain the phylogenetic trees of each area, we used the program Phylocom 4.0.1 [38]. With the trees constructed and the phylogenetic distances calculated the Blomberg K statistic was applied [39]. K values closer to zero demonstrate that the phylogenetic signal is less than expected at random, meaning that the phylogenetically close species are distinct in relation to the analyzed characteristic, the greater values suggest the existence of a phylogenetic signal. To determine if the phylogenetic signal was greater or lower than expected at random, the values obtained from K with null models, obtained in 999 randomizations were compared. These analyzes were performed using the 'phytools' package in Environment R version 3.3.1 [40].

The weighted average of the functional characteristics was calculated in the four areas to obtain the Community-Weighted Mean (CWM) by the formula: CWM = $\sum_{i=1}^{S} Wi.Xi$, where X is the total number of species, Wi is the abundance of the *ith* species (obtained by the quantitative survey of the plants in each area) and Xi is the characteristic value of the *ith* species [41]. In order to analyze if there was variation of the functional characteristics in the four areas and if this change influenced the functional structure of the community, the Kruskal-Wallis mean comparison test was applied in the CWM values. The normality of the data was tested by the Shapiro-Wilk test. As the data did not present normal distribution, so the Kruskal-Wallis non-parametric test was applied, followed by Student-Newman-Keuls test to test the differences among the areas.

To analyze whether geographic distances influenced CWM values, the Bray-Curtis index was applied to the data matrix, followed by the Mantel test [42]. The significance of the correlations was tested by means of 999 permutations [43].

Normality tests and Kruskal-Wallis non-parametric analysis were performed using the SPSS program (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0, Armonk, NY: IBM Corp.). The Mantel test was done with the help of the Vegan Package in Environment R version 3.3.1 [40].

To analyze the effect of basal area and light on the functional characteristics, Mixed Linear Models (LMMs) were constructed. The basal area and light were used as independent variables (explanatory) and the functional characteristics of the species (average of each characteristic per plot, by area) were used as independent variables. As a result of this analysis, the minimum explanatory model was obtained by removing the fixed-effect variables one by one, followed by deviation analysis [44]. All LMs were made using the Ime4 package in Environment R version 3.3.1 [40].

From the 10 characteristics studied, the coefficients of variation of four foliar characteristics was calculated: specific leaf area, leaf area, chlorophyll content and leaf dry matter content [45,46].

The coefficients of variation of leaf characteristics in the four areas were submitted to the Shapiro-Wilk test to evaluate the data normality. As the data did not present a normal distribution, the Kruskal-Wallis non-parametric variance test was performed, complemented by the Student-Newman-Keuls mean comparison test to verify if there were differences between the coefficients of variation of the characteristics in the areas (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0, Armonk, NY: IBM Corp.).

In order to analyze if the geographical distances influence the coefficient of variation of leaf characteristics in each area, the Bray-Curtis index was applied in the data matrix, followed by the Mantel test [42]. The significance of the correlations was tested using 999 permutations [43], using the vegan package in Environment R version 3.3.1 [40]

To test the hypothesis that, where there is greater light availability the coefficients of variation of leaf characteristics would be greater, Linear Models (LM) were constructed. Light was used as an independent variable and the values of the coefficients of variation for the leaf characteristics of the species (coefficients of variation values for each characteristic by area) were used as dependent variables. As a result of this analysis, the minimum explanatory model was obtained by removing the fixed-effect variables one by one, followed by deviation analysis [44]. All LMs were made using the Ime4 package in Environment R version 3.3.1 [40].

3. RESULTS AND DISCUSSION

3.1 Functional Characteristics and Basal Area

Almost all functional characteristics in all areas presented K values below that expected at random, indicating the absence of phylogenetic signal, except for stem wood density in the area $A1_{>AB}$. The fact that there is no phylogenetic signal for nine of the 10 functional characteristics indicates that the variation in values occurred due to changes in the environment and not due to the degree of kinship (Table 1).

The CWM values of the functional characteristics and the geographic distances did not present spatial autocorrelation according to the Mantel test (r = -0.05848; p <.101). The change in the values of the functional characteristics in the community, evaluated through CWM, revealed differences among the areas (Table 2). In relation to the ten characteristics, five

Table 1. Phylogenetic sign of the functional characteristics sampled in four areas of a fragment of an urban rainforest

Characteristics	$A1_{>AB}$		$A2_{ABI}$		$A3_{ABI}$		$A4_{<AB}$	
	K	p	K	p	K	P	K	P
AF (cm^2)	0.22	0.82	0.38	0.42	0.39	0.52	0.99	0.50
AFE ($cm^2.mg^{-1}$)	0.31	0.54	0.34	0.58	0.37	0.67	0.00	0.50
Cc_mass (micromol.g^{-1})	0.31	0.59	0.35	0.51	0.35	0.77	0.99	0.50
TMSF (mg.g^{-1})	0.34	0.45	0.26	0.89	0.43	0.37	0.00	0.50
DMC (mg.mm^{-3})	0.46*	0.04*	0.38	0.41	0.41	0.46	0.00	0.50
DMR (mg.mm^{-3})	0.52	0.06	0.30	0.75	0.53	0.31	0.99	0.50
QA_{satc} (%)	0.50	0.08	0.42	0.35	0.40	0.56	0.00	0.50
QA_{satr} (%)	0.48	0.16	0.42	0.32	0.48	0.37	0.99	0.50
TMSC (mg.g^{-1})	0.45	0.07	0.36	0.48	0.40	0.45	0.00	0.50
TMSR (mg.g^{-1})	0.47	0.09	0.31	0.69	0.46	0.44	0.00	0.50

** K - Bloomberg value; P - probability; AF - leaf area; AFE - specific leaf area; Cc_mass - chlorophyll concentration; TMSF - leaf dry matter content; DMC - wood stem density; DMR - root wood density; amount of saturated water from the stem; amount of saturated root water; TMSC - dry matter content of the stem; TMSR - dry matter content of the root; $A1_{>AB}$ (area with greater basal area); $A2_{ABI}$ (intermediate basal area); $A3_{ABI}$ (intermediate basal area) and $A4_{<AB}$ (area with lower basal area). * represent statistical significance (p <.05)*

Table 2. Weighted mean values of the characteristics in the community (CWM) in four environments of a fragment of an urban rainforest

Characteristics	$A1_{>AB}$	$A2_{AIB}$	$A3_{ABI}$	$A4_{<AB}$
AF (cm^2)	943.07a	996.87a	404.17b	37.09c
AFE ($cm^2.mg^{-1}$)	1214.84a	1293.34a	509.14b	165.04c
Cc_mass ($micromol.g^{-1}$)	6.13a	5.76a	2.44b	0.75c
TMSF ($mg.g^{-1}$)	5.98a	4.86a	2.71b	1.13c
DMC ($mg.mm^{-3}$)	0.59a	0.55a	0.59a	0.37b
DMR ($mg.mm^{-3}$)	0.60a	0.58a	0.62a	0.28b
QA_{satc} (%)	99.67a	95.63a	70.57a	45.71b
QA_{satr} (%)	95.30a	94.41a	86.50a	42.38b
TMSC ($mg.g^{-1}$)	0.59a	0.68a	0.88a	0.42b
TMSR ($mg.g^{-1}$)	0.60a	0.59a	0.58a	0.35b

Data presented as mean: AF - leaf area; AFE - specific leaf area; Cc_mass - chlorophyll concentration; TMSF - leaf dry matter content; DMC - wood stem density; DMR - root wood density; QAsatc - amount of saturated stem water; QAsatr - amount of saturated root water; TMSC - dry matter content of the stem; TMSC - dry matter content of the root. $A1_{>AB}$ (area with greater basal area), $A2_{ABI}$ (intermediate basal area), $A3_{ABI}$ (basal intermediate area) and $A4_{<AB}$ (area with lower basal area); CWM - weighted average of the community. Means followed by equal letters do not differ by the Student-Newman-Keuls test (p <.05)

(TMSF, DMC, DMR, TMSC and TMSR) confirmed the prediction in $A4_{<AB}$, since in this area were found values of characteristics related to the fast use of the resource: DMC (3.27 $mg.mm^{-3}$); DMR (0.28 $mg.mm^{-3}$); TMSF (1.13 $mg.g^{-1}$); TMSC (0.42 $mg.g^{-1}$) and TMSR (0.35 $mg.g^{-1}$).

The results obtained in this study were partially corroborated in the predictions, since only the environment with lower basal area ($A4_{<AB}$) presented lower values of TMSF, DMC, DMR, TMSC and TMSR as predicted for these environments [47,48,11]. It is known that plants of this environment invest in fast growth and present a shorter life cycle than those of older areas, confirming that in this environment less investment in aerial biomass occurs, which would cause to the plants of these environments to not invest in structural carbon [34,49,50].

Unlike expected, environments with higher basal area ($A1_{>AB}$ and $A2_{ABI}$) do not differ on the following characteristics: TMSF, DMC, DMR, TMSC and TMSR. The contrary was reported by [10] who found greater investment in structural carbon (dry matter of leaf and wood) in environments with greater basal areas; this study did not reveal this pattern, since there was no increase in the values of these characteristics in the two areas with greater basal areas ($A1_{>AB}$ and $A2_{ABI}$). It is assumed that in urban fragments the disturbances are more frequent, so it is possible to suggest that plants with lower values of these characteristics have also been "established" in the two environments of greater basal area.

Regarding the characteristics: AF, AFE, Cc_mass, Qasatc and Qasatr, there was no variation among the areas, as expected by the predictions; as suggested by [51] it is expected that in the environment $A4_{<AB}$ the plants would have more saturated water in the stem. Some authors observed that in environments closer to the end of the succession, such as those with greater basal area ($A1_{>AB}$ and $A2_{ABI}$), would be lower values of FA, AFE and CC_mass, which did not occur in the present study; It can be assumed that this behavior was not due to the fact that it is a fragment of a city and undergoes frequent alterations [52-53].

In relation to changes in the values of functional characteristics in environments with different degrees of perturbation, there are reports in the literature that mention that functional characteristics may behave differently from what happens according to the classic succession paradigm [10,54,55,56].

In order to verify the influence of the basal area and light on the values of the 10 functional characteristics was performed analysis of mixed linear models (LMMs). Only AFE and Cc_mass had effects, but not as expected (Table 3), since smaller values of those characteristics were found in the environment with lower basal area and greater incidence of light ($A4_{<AB}$) revealing that the basal area and light are not adequate predictors of functional characteristics.

Table 3. Mixed linear models of functional characteristics as a function of basal area and light in a fragment of an urban rainforest

Characteristics	AB				Luz				
AF (cm^2)	**D**	**P**	**E**	**EP**	**D**	**Df**	**P**	**E**	**EP**
AFE ($cm^2.mg^{-1}$)	224.65	0.90	-	-	300.75	1	0.80	-	-
Cc_mass ($micromol.g^{-1}$)	150.32	0.00^{**}	-1.20^{e-01}	5.25^{e-02}	189.32	1	0.00^{**}	-1.3^{e-01}	4.25^{e-02}
TMSF ($mg.g^{-1}$)	114.24	0.00^{**}	-0.13^{e-01}	4.00^{e-01}	224.44	1	0.00^{**}	-0.2^{e-01}	5.03^{e-01}
DMC ($mg.mm^{-3}$)	202.46	0.57	-	-	302.48	1	0.67	-	-
DMR ($mg.mm^{-3}$)	207.14	0.75	-	-	210.15	1	0.85	-	-
QA_{satc} (%)	219.44	0.86	-	-	239.55	1	0.76	-	-
QA_{satr} (%)	134.63	0.25	-	-	234.73	1	0.35	-	-
TMSC ($mg.g^{-1}$)	182.89	0.36	-	-	282.99	1	0.46	-	-
TMSR ($mg.g^{-1}$)	225.00	0.91	-	-	146.00	1	0.81	-	-

*AB - basal area; D - difference residue after removal of the variable; df - Degrees of freedom; P - associated p value; E - estimate; EP - standard error of the mean. AF - leaf area; AFE - specific leaf area; Cc_mass - chlorophyll concentration; TMSF - leaf dry matter content; DMC - wood stem density; DMR - root wood density; amount of saturated water from the stem; amount of saturated root water; TMSC - dry matter content of the stem; TMSC - dry matter content of the root. $A1_{>AB}$ (Area with greater basal area), $A2_{ABI}$ (intermediate basal area), $A3_{ABI}$ (intermediate basal area) and $A4_{<AB}$ (area with lower basal area). (** = p <.01)*

Table 4. Coefficient of variation (CV) of leaf characteristics, basal area and light intensity in the four areas of a fragment of an urban rainforest

Areas	AF	TMSF	AFE	Cc_mass	AB	Light
	CV				(4000 m^2)	(%)
$A1_{>AB}$	0.91 a	0.33 a	0.81 a	0.87 a	9.43 a	6.09 c
$A2_{ABI}$	0.83 a	0.34 a	0.92 a	0.82 a	4.14 b	12.94 c
$A3_{ABI}$	0.52 b	0.18 b	0.50 b	0.61 b	1.95 b	31.75 b
$A4_{<AB}$	0.13 c	0.07 c	0.17 c	0.10 c	1.00 c	46.97 a

AF - leaf area (cm^2), TMSF - leaf dry matter content ($mg.g^{-1}$), AFE - specific leaf area ($cm^2.mg^{-1}$), Cc_mass - chlorophyll content ($micromol.g^{-1}$). $A1_{>AB}$ (area with greater basal area), $A2_{ABI}$ (intermediate basal area), $A3_{ABI}$ (intermediate basal area) and $A4_{<AB}$ (area with lower basal area); Averages followed by the same letters do not differ by the Student-Newman-Keuls test (p <.05)

Table 5. Linear models of the coefficient of variation of the functional characteristics as a function of light intensity in a fragment of an urban rain forest

Características	Intensidade de luz (%)				
	D	**Df**	**P**	**E**	**EP**
CV_AF (cm^2)	244.65	1	0.00**	-1.74^{e-02}	2.71^{e-02}
CV_AFE ($cm^2.mg^{-1}$)	255.32	1	0.00^{**}	-1.32^{e-01}	3.25^{e-02}
CV_Cc_mass (micro $mol.g^{-1}$)	179.24	1	0.00^{**}	-0.23^{e-01}	0.33^{e-01}
CV_TMSF ($mg.g^{-1}$)	310.46	1	0.00^{**}	-2.86^{e-01}	1.34^{e-02}

*CV - Coefficient of variation; D - difference residue after removal of the variable; Df - Degrees of freedom; P - associated p value; E - estimate; EP - standard error of the mean. DP_AF - leaf area; AFE - specific leaf area; Cc_mass - chlorophyll concentration; TMSF - leaf dry matter content; $A1_{>AB}$ (Area with lower basal area), $A2_{ABI}$ (intermediate basal area), $A3_{ABI}$ (intermediate basal area) and $A4_{<AB}$ (area with lower basal area). (** = p <.01)*

Thus, the lower values of AFE and Cc_mass in $A4_{<AB}$, occurred due to these characteristics present high variability in more open areas [45,46]. The literature reports that of the organs of the plant, the leaf is the most variable because its morphology and physiology are strongly influenced by environmental factors [56,57]. It is worth mentioning that the value of CWM of leaf dry matter, one of the components of AFE, is lower in the open area ($A4_{<AB}$), confirming that this environment would present plants with lower investment in structural carbon [9,58].

3.2 Variation of Leaf Characteristics in Function of Light Availability

The analysis of the coefficient of variation of the characteristics by environment revealed that areas with less light availability ($A1_{>AB}$ and $A2_{ABI}$) did not differ among them; on the other hand, $A3_{ABI}$ and $A4_{<AB}$ differed from each other and presented lower coefficient in the characteristics (Table 4).

The prediction that there would be a greater coefficient of variation of the four characteristics (AF, TMSF, AFE and Cc_mass) in the environment with greater light availability ($A4_{<AB}$) was not confirmed, since all the characteristics exhibited lower CV values: 0.13); TMSF (0.07); AFE (0.17) and Cc_mass (0.10) (Table 5).

Contrary to the expectations, the environments with greater light availability did not present higher coefficient of variation of leaf characteristics. According to Table 4, it was observed that the area $A4_{<AB}$, where there was greater light availability, the values of the coefficient of variation were smaller.

To test the hypothesis that greater light availability will cause greater variation in the value of the coefficient of variation of leaf characteristics, linear models (LM) were constructed (Table 5). All the analyzed characteristics (AF, TMSF, AFE and Cc_mass) had an effect of light intensity, but not as expected, since in the environment with greater light availability ($A4_{<AB}$, Table 1) had smaller values of standard deviation (Table 5).

It is worth noting that when we observed the effect of the geographic distance on the coefficient of variation of the characteristics, the results showed that the space had no effect on the standard deviation ($r = -0.0567$; $p > .001$).

It was expected that in the area $A4_{<AB}$, where there was greater light intensity (Table 4), the leaf characteristics would be more variable [59], especially the physiological ones, such as the chlorophyll content [56], but showed lower values of coefficient of variation of the characteristics of AF, TMSF, AFE and Cc_mass (Table 5). This greater variability of the characteristics of the plants in environments with more light can be due to the high heterogeneity of light reception, due to plants to grow rapidly and thus change the availability of light inside the forest [60-62].

It is known that the succession in urban and peri-urban landscapes is remarkably unique, since the proximity of the urban environment increases the probability of continuous anthropic disturbances, being able to alter the variability of the characteristics in the environment with more light and consequently alteration in the classic path of the succession [8,63,64,65,66]. Similar to that was found in this study, [52] also observed that more open and disturbed areas showed less variation of characteristics.

This pattern is distinct from that reported in the literature for the area with more light, due to the fact that the dynamics of this environment is strongly altered as a result of increased mortality. According to the classical succession paradigm [54], it would be expected that in environments with greater light availability, plants with characteristics related to the rapid use of the resource would be more abundant, although plants with characteristics related to the slow use are less abundant [19,66]; As succession advances the roles would reverse [9], thus, it can be assumed that this greater light input in the environment $A4_{<AB}$, is due to the greater perturbations, what could led to a higher mortality of plants with slow use of resources, favoring even more those of quick use of the resource, or perhaps those have not even been established; as a result, the variability of the leaf characteristics of $A4_{<AB}$ would be reduced.

The LM analyzes revealed that light is not a good predictor of leaf variability of tree plants in urban fragments, since as light availability increased in $A4_{<AB}$, there was a reduction in the coefficient of variation of all leaf characteristics (FA, TMSF, AFE and Cc_mass).

4. CONCLUSIONS

Frequent disturbances can alter the classical succession path due to population dynamics, especially in the area with greater light availability, which may cause higher mortality of plants with slow use of the resource, favoring those that are quick to use or that perhaps use have not even been established, resulting in reduced variability of leaf characteristics.

The variation of functional characteristics as a function of the basal area and the availability of light in an urban rainforest fragment is different from what occurs in the classic succession commonly reported, pointing out that possible disturbances caused by the surroundings are the main agents of the functional structure of the community. In this way, it is suggested that in the next researches the intraspecific variation of the tree species in these areas should be more focused and add more functional characteristics to analyze, especially the physiological ones, such as nitrogen, phosphorus and potassium foliar, because these reflect better the behavior of the species.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Chazdon RL, et al. Rates of change in tree communities of secondary neotropical forests following major disturbances. Philosophical transactions of the royal society. 2007;362(1478):273-289. Available:https://doi.org/10.1098/rstb.2006.1990
2. Norden N, et al. Successional dynamics in neotropical forests are as uncertain as they are predictable. PNAS. 2015;112(26): 8013-8018. Available:https://doi.org/10.1073/pnas.1500403112
3. Gilman, et al. Recovery of floristic diversity and basal area in natural forest regeneration and planted plots in a Costa Rican wet forest. Biotropica. 2016;48(6): 798-808. Available:https://doi.org/10.1111/btp.12361
4. Fortunel C, Fine PVA, Baraloto C. Leaf, stem and root tissue strategies across 758 neotropical tree species. Functional Ecology. 2012;26(5):1153-1161. Available:https://doi.org/10.1111/j.1365-2435.2012.02020.x
5. Westoby MA. Leaf-height-seed (LHS) plant ecology strategy scheme. Plant Soil. 1998;199(2):213-227.
6. Méndez-Alonzo R, Paz H, Zuluaga RC, Rosell JA, Olson ME. Coordinated evolution of leaf and stem economics in tropical dry forest trees. Ecology. 2012; 93(11):2397–2406. Available:https://doi.org/10.1890/11-1213.1
7. Carreño-Rocabado G, et al. Effects of disturbance intensity on species and functional diversity in a tropical forest. Journal of Ecology. 2012;100(6):1453-1463. Available:https://doi.org/10.1111/j.1365-2745.2012.02015.x
8. Dorn LA, Pyle EH, Schmitt J. Plasticity to light cues and resources in Arabidopsis thaliana: testing for adaptive value and costs. Evolution. 2000;54(6):1982-1994. Available:https://doi.org/10.1111/j.0014-3820.2000.tb01242.x
9. Lohbeck M, et al. Successional changes in functional composition contrast for dry and wet tropical forest. Ecology. 2013;94(6): 1211-1216. Available:https://doi.org/10.1890/12-1850.1
10. Boukili VK, Chazdon RL. Environmental filtering, local site factors and landscape context drive changes in functional trait composition during tropical forest succession. Perspectives in Plant Ecology, Evolution and Systematics. 2017;24(1): 37-47. Available:https://doi.org/10.1016/j.ppees.2016.11.003
11. Pérez-Harguindeguy N, et al. New handbook for standardized measurement of plant functional traits worldwide. Australian Journal OF Botany. 2013;61(8): 167-234.
12. Lasky JR, Sun IF, Su SH, Chen ZS, Keitt TH. Trait-mediated effects of environmental filtering on tree community dynamics. Journal Ecology. 2013;101(3): 722-733. Available:https://doi.org/10.1111/1365-2745.12065
13. Menge DNL, Chazdon RL. Higher survival drives the success of nitrogen-fixing trees through succession in costa rican rainforests. New Phytologist. 2016;209(3): 965-977. Available:https://doi.org/10.1111/nph.13734
14. Lebrija-Trejos E, Pérez-García EA, Meave JA, Bongers F, Poorter L. Functional traits and environmental filtering drive community assembly in a species-rich tropical system. Ecology. 2010;91(2):386-398. Available:https://doi.org/10.1890/08-1449.1
15. Kraft NJB, Ackerly DD. The assembly of plant communities. In: monsoon, (Ed) the plant sciences: Ecology and the environment. New York: Springer; 2014.
16. Letcher SG, Chazdon RL. Rapid recovery of biomass, species richness, and species composition in a forest chronosequence in northeastern Costa Rica. Biotropica. 2009; 41(5):608-617. Available:https://doi.org/10.1111/j.1744-7429.2009.00517.x
17. Slik JWF, et al. Environmental correlates of tree biomass, basal area, wood specific gravity and stem density gradients in

borneo's tropical forests. Global ecology and biogeography. 2010;19(1):50-60. Available:https://doi.org/10.1111/j.1466-8238.2009.00489.x

18. Réjou-Méchain M, et al. Using repeated small-footprint lidar acquisitions to infer spatial and temporal variations of a high-biomass neotropical forest. Remote Sensing of Environment. 2015;169(1):93-101. Available:https://doi.org/10.1016/j.rse.2015.08.001
19. Donovan LA, Maherali H, Caruso CM, Huber H, Kroon H. The evolution of the worldwide leaf economics spectrum. Trends in Ecology and Evolution. 2011; 26(2):88-95. Available:https://doi.org/10.1016/j.tree.2010.11.011
20. Cornelissen JHC, et al. A handbook of protocols for standardized and easy measurement of plant functional traits worldwide. Australian Journal of Botany. 2003;51(4):335-380. Available:https://doi.org/10.1071/BT02124
21. Lavorel S, Garnier E. Predicting changes in community composition and ecosystem functioning from plant traits: Revisiting the holy grail. Functional ecology. 2002;16(5): 545-556. Available:https://doi.org/10.1046/j.1365-2435.2002.00664.x
22. Violle C, et al. Let the concept of trait be functional! Oikos. 2007;116(5):882-892. Available:https://doi.org/10.1111/j.0030-1299.2007.15559.x
23. Oldeman RAA. Forest elements of silvology. Berlin: Springer-verlag;1990.
24. Chevin LM, Hoffmann AA. Evolution of phenotypic plasticity in extreme environments. Philosophical transactions of the royal society. 2017;372(1823):1-12. Available:https://doi.org/10.1098/rstb.2016.0138
25. Schlichting CD, Wund MA. Phenotypic plasticity and epigenetic marking: an assessment of evidence for genetic accommodation. Evolution. 2014;68(3): 656-672. Available:https://doi.org/10.1111/evo.12348
26. Ramírez-Valiente JÁ, Valladares F, Delgado A, Nicotra AB, Aranda I. Understanding the importance of intrapopulation functional variability and phenotypic plasticity in Quercus suber. Tree genetics & Genomes. 2015;11(3):1-11. Available:www.DOI:10.1007/s11295-015-0856-z
27. Ibge, instituto brasileiro de geografia e estatística. Série: manuais técnicos em geociências: Manual técnico da vegetação brasileira, n.1, 2 ed. Rio de janeiro; 2012.
28. Pernambuco. Decreto n° 40.547, de 28 de março de 2014. Amplia os limites da unidade de conservação parque estadual de Dois Irmãos. Diário oficial do estado de Pernambuco; 2014.
29. Coutinho RQ, et al. Características climáticas, geológicas, geomorfológicas e geotécnicas da reserva ecológica de dois irmãos. In: machado, IC, Lopes A V, Pôrto KC. (orgs.). Reserva ecológica de dois irmãos: estudos em um remanescente de mata atlântica em área urbana (Recife-Pernambuco-Brasil). Recife: Editora universitária da UFPE; 1998.
30. Magnusson WE, et al. RAPELD: A modification of the gentry method for biodiversity surveys in long-term ecological research sites. Biota Neotropica. 2005; 2(2):1-6. Available:http://dx.doi.org/10.1590/s1676-06032005000300002
31. Freitas MA, Costa F, Morais A. Manual de instalação parcelas RAPELD: protocolo de instalação de parcelas terrestres. INPA. [Accessed: 05 setembro de 2017] Available:http://Ppbio.Inpa.Gov.Br/Manuais
32. APG IV. The angiosperm phylogeny group. An update of the angiosperm phylogeny group classification for the orders and families of flowering plants: APG IV. Botanical Journal of the Linnean Society. 2016;181(1):1-20. Available:https://doi.org/10.1111/boj.12385
33. O'neal ME, Landis DA, Isaacs R. An inexpensive, accurate method for measuring leaf area and defoliation through digital image analysis. Journal of Economic Entomology. 2002;95(6):1190-1194. Available:https://doi.org/10.1603/0022-0493-95.6.1190
34. Riva EG, et al. A plant economics spectrum in mediterranean forests along environmental gradients: Is there coordination among leaf, stem and root traits? Journal of Vegetation Science. 2016;27(1):187-199. Available:https://doi.org/10.1111/jvs.12341

35. Trugilho PF, et al. Comparação de métodos de determinação da densidade básica em madeira. Acta Amazonica. 1990;20(1)307-319. Available:http://dx.doi.org/10.1590/1809-43921990201319
36. Venturoli F, Franco AC, Fagg CW, Felfili JM. Regime de luz em uma floresta estacional semidecídua sob manejo, em pirenópolis, goiás. Revista Árvore. 2012; 36(1):1135-1144.
37. Frazer GW, Canham CD, Lertzman KP. Gap Light Analyzer - GLA, Version 2.0. Burnaby, Canadá: Simon Fraser University; 1999.
38. Webb CO, Ackerly DD, Kembel SW. Phylocom: Software for the analysis of phylogenetic community structure and trait evolution. Bioinformatics. 2008;24(18): 2098-2100. Available:www.DOI:10.1093/bioinformatics/btn358
39. Blomberg SP, Garland T, Ives AR. Testing for phylogenetic signal in comparative data: Behavioral Traits are More Labile. Evolution. 2003;57(4):717-74.
40. R core team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. Available:<https://www.r-project.org/> [Access: 3 Feb. 2016]
41. Pla L, Casanoves F, Di Rienzo JA. Cuantificación de la diversidad funcional. Valoración y análisis de la diversidad funcional y su relación con los servicios ecosistémicos. IN: Casanoves F, Pla L, Di Rienzo JA. (EDS.). Turrialba, Costa Rica: CATIE; 2011.
42. Mccune MJ, Mefford PC-ORD. Multivariate Analysis of ecological data. Version 6 MJM Software, Gleneden Beach, U.S.A; 2011.
43. Legendre P, Fortin MJ. Spatial pattern and ecological analysis. Vegetatio. 1989;80(2): 107-138.
44. Crawley MJ. The R book. Chichester, England: John Wiley & Sons Ltd; 2007.
45. Valladares F, Wright SJ, Lasso E, Kitajima K, Pearcy RW. Plastic phenotypic response to light of 16 congeneric shrubs from a panamanian rainforest. Ecology. 2000;81(7):1925-1936. Available:https://doi.org/10.1890/0012-9658(2000)081[1925:PPRTLO]2.0.CO;2
46. Rozendaal DM, Hurtado VH, Poorter L. Plasticity in leaf traits of 38 tropical tree species in response to light; relationships with light demand and adult stature. Functional ecology. 2006;20(2):207-216. Available:https://doi.org/10.1111/j.1365-2435.2006.01105.x
47. Wright IJ, et al. The worldwide leaf economics spectrum. Nature. 2004; 428(6985):821-827.
48. Poorter L. Leaf Traits show different relationships with shade tolerance in moist versus dry tropical forests. New Phytologist. 2009;181(4):890-900. Available:https://doi.org/10.1111/j.1469-8137.2008.02715.x
49. Freschet GT, Cornelissen JH, Van Logtestijn RS, Aerts R. Evidence of the 'plant economics spectrum' in a subarctic flora. Journal of Ecology. 2010;98(2):362-373. Available:https://doi.org/10.1111/j.1365-2745.2009.01615.x
50. Bouchet DC, Cheptou PO, Munoz F. Mowing influences community-level variation in resource-use strategies and flowering phenology along an ecological succession on mediterranean road slopes. Applied Vegetation Science. 2017;20(3): 376-387. Available:https://doi.org/10.1111/avsc.12311
51. Lima ALA, et al. Do the phenology and functional stem attributes of woody species allow for the identification of functional groups in the semiarid region of brazil? Trees. 2012;26(35):1605-1616. www.DOI: 10.1007/s00468-012-0735-2
52. Carreño-Rocabado G, et al. Effects of disturbance intensity on species and functional diversity in a tropical forest. Journal of Ecology. 2012;100(6):1453-1463. Available:https://doi.org/10.1111/j.1365-2745.2012.02015.x.
53. Carreño-Rocabado G, et al. Land-use intensification effects on functional properties in tropical plant communities. Ecological Applications. 2016;26(1):174-189. Available:www.https://doi.org/10.1890/14-0340
54. Pickett ST, Ostfield RS. The shifting paradigm in ecology. In: Knight RL, Bates SF. A new century for natural resources management. Washington, D.C.: Island Press; 1995.
55. Swenson NG, Enquist BJ. Ecological and evolutionary determinants of a key plant functional trait: Wood density and its

community-wide variation across latitude and elevation. American Journal Botany. 2007;94(1):451-459. Available:https://doi.org/10.3732/ajb.94.3.451
56. Gratani L. Plant phenotypic plasticity in response to environmental factors. Advances in botany. 2014;1(1):1-18.
57. Volis S, Ormanbekova D, Yermekbayev K. Role of phenotypic plasticity and population differentiation in adaptation to novel environmental conditions. Ecology and evolution. 2015;5(17):3818-3829. Available:https://doi.org/10.1002/ece3.1607
58. Lohbeck M, et al. Functional trait strategies of trees in dry and wet tropical forests are 40 similar but differ in their consequences for succession. Plos One. 2015;10(4):1-15. Available:https://doi.org/10.1371/journal.pone.0123741
59. Bazzaz FA, Carlson RW. Photosynthetic acclimation to variability in the light environment of early and late successional plants. Oecologia. 1982;54(3):313-316.
60. Sultan SE. Phenotypic plasticity for plant development, function and life history. Trends in Plant Science. 2000;5(12):537-542. Available:https://doi.org/10.1016/S1360-1385(00)01797-0
61. Cardoso GL, Lomônaco C. Variações fenotípicas e potencial plástico de Eugenia calycina camb. (myrtaceae) em uma área de transição cerrado-vereda. Revista Brasileira de Botânica. 2003;26(1):131-140.
62. Bradshaw AD. Unravelling phenotypic plasticity – why should we bother? New phytologist. 2006;170(4):244-248. Available:https://doi.org/10.1111/j.1469-8137.2006.01761.x
63. Van Kleunen M, Fischer M. Constraints on the evolution of adaptive phenotypic plasticity in plants. New Phytologist. 2005; 166(1):49-60. Available:https://doi.org/10.1111/j.1469-8137.2004.01296.x
64. Joppa LN, Pfaff A. Global protected area impacts. Philosophical transactions of the royal society. 2010;278(1712):1633-1638. Available:https://doi.org/10.1098/rspb.2010.1713
65. Meiners SJ, et al. Is successional research nearing its climax? New approaches for understanding dynamic communities. Functional Ecology. 2015;29(2):154-164. Available:https://doi.org/10.1111/1365-2435.12391
66. Muscarella, et al. Functional convergence and phylogenetic divergence during secondary succession of subtropical wet forests in Puerto Rico. Journal of Vegetation Science. 2016;27(2):283-294. Available:https://doi.org/10.1111/jvs.12354

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle3.com/review-history/48017