Albizia procera IN THE CITY

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Abstract

This study addresses the growth and ecological importance of *Albizia procera*, a nonnative tree species, in urban environments. Four-year-old trees of this species grew in height at a rate of 2.2 m/yr (suppressed trees) to 4.4 to 5.7 m/yr (dominant trees) and exhibited a mean basal area of 45.01 to 93.62 cm^2/tree after 2 and 4 years of age, respectively. At two years of age trees formed a stand with a density of 5,755 trees/ha and a basal area of 27.2 m^2/ha. At four years of age the tree density was 5,373 trees/ha, and the basal area increased to 54.3 m^2/ha. These high growth rates were attained on a site that had been bulldozed, and after four years, both native and nonnative plant species entered the stand. A literature review revealed that *A. procera* grows faster in height in the city than it does in monoculture plantations of similar age. Moreover, the species attains its highest abundance in the urban environment, where it acts as a carbon sink and sequesters other chemical elements. Within the city, *A. procera* colonizes abandoned lots and bulldozed areas by roads and highways. By doing so, it provides multiple ecological services in locations where these services are least expected.

Keywords: carbon sink, nonnative species, novel forests, tree growth, urban forests.

Resumen

Este estudio enfoca el crecimiento e importancia ecológica de *Albizia procera*, una especie arbórea no nativa, en ambientes urbanos. Árboles de cuatro años de esta especie crecieron a razón de 2.2 m/año (los suprimidos) y 4.4 a 5.7 m/año (los dominantes) y exhibieron un área basal promedio de 45.01 a 93.62 cm^2/árbol después de dos y cuatro años, respectivamente. A los dos años los árboles formaron rodales con una densidad de 5,755 árboles/ha y un área basal de 27.2 m^2/ha. A los 4 años la densidad de árboles fue de 5,373 árboles/ha y el área basal aumentó a 54.3 m^2/ha. Estas altas tasas de crecimiento ocurrieron en un lugar que había sido aplanado y compactado con maquinaria y que luego de cuatro años fue colonizado por especies de plantas nativas y no nativas. Una revisión de la literatura estableció que *A. procera* crece más rápido en altura en la ciudad que en plantaciones de monocultivos con edad similar. Más aún, la especie exhibe su máxima abundancia en la ciudad, donde funciona como un sumidero de carbono y elementos químicos. En la ciudad, *A. procera* coloniza espacios abandonados y áreas aplanadas por maquinaria a lo largo de calles y carreteras. Al así hacerlo, esta especie provee múltiples servicios ecológicos en lugares donde estos servicios no se anticipan.

Palabras clave: bosques noveles, bosques urbanos, crecimiento de árboles, especies no-nativas, reservorios de carbono.

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INTRODUCTION

Albizia procera (Roxb.) Benth. (tall albizia or "siris blanco") is a lowland deciduous pioneer tree species that grows up to 1,200 m in its native range in tropical and subtropical moist forests in Asia (Parrotta 2000). In its native habitat, *A. procera* is used as an ornamental tree and for providing shade to tea plantations. The species was introduced to Puerto Rico in 1924, where it has become a common tree. Based on its Importance Value, calculated by its density, basal area, and frequency in forest inventory plots of 2014, it was ranked 18th in the archipelago of Puerto Rico (Marcano Vega 2019). In Puerto Rico, *A. procera* grows in the subtropical moist and subtropical wet life zones, with its clear predominance in the subtropical moist forest life zone, where it ranked 11th in Importance Value (Table 1). Both in its native range and in Puerto Rico, *A. procera* grows well along roads and highways and on the edges of agricultural fields (Parrotta 2000). In a publication about the urban trees of Puerto Rico, Shubert (1979) does not recommend planting *A. procera* in urban areas because of its susceptibility to root fungus. However, *A. procera* is a common component of the urban forest (Brandeis et al. 2014), and our objective in this article is to explore its growth and distribution in the city with a focus on defining the ecological importance of this naturalized tree species to the ecology of the city. To achieve these goals, we measure trees in a pure stand of *A. procera* in an urban area and review the available literature to establish the structure and productivity of this species in both the urban and non-urban environments in Puerto Rico.

Table 1. Importance Value of *Albizia procera* in the archipelago of Puerto Rico, including Vieques, Culebra, and the main island (Marcano Vega 2019). Data are for trees with diameter at breast height ≥ 12.5 cm. The ranked position relative to all species in the group is in parenthesis.

Cover area or life zone	Relative			0–300 Importance Value
	Density	Basal Area	Frequency Percent	
Puerto Rico, Culebra, and Vieques	1.49	1.02	0.99	1.17 (18)
Subtropical moist forest	2.69	1.97	1.75	2.14 (11)
Subtropical wet and rain forest*	0.11	0.18	0.16	0.15 (68)

*While the data include stands in the rain forest life zone, it is unlikely that *Albizia* grows there.

METHODS

Study Site

The coordinates (centroid) of the forest stand of *Albizia procera* are 18.392955°N and 66.058057°W (WGS 84) at an elevation of 15 m above sea level in Río Piedras, San Juan, northern Puerto Rico (Figure 1). The climate is subtropical moist *sensu* Holdridge (1967) with a mean annual rainfall of 1,755 mm and a mean annual temperature of 25.7 C°. The stand was located next to a major highway in the city and was selected because we had witnessed the demolition and infrastructure construction that took place at the site before it was abandoned as a strip of vacant land within the city. *Albizia procera* stands develop on these sites when the maintenance frequency is insufficient to prevent the development of forest stands. After a certain point of stand development, maintenance by trimmer is not feasible, and maintenance workers usually lack training and equipment for tree pruning or harvest. The stands are then allowed to grow without maintenance, resulting in the proliferation of pure stands of *A. procera* throughout the city.

As a land cover type, vacant land represents 14.7 percent of the total cover of San Juan and, as such, is a place where ecological processes of ecesis (*sensu* Clements 1928) and succession take place within the city. Because of the location of vacant land covers relative to city avenues and corridors, a dynamic develops between the advancement of the ecological succession and the return interval of city maintenance workers responsible for the city's ornamental landscape program. A common practice of the program involves the use of string trimmers (e.g., weed whacker) to limit vegetation growth and maintain the graminoid cover as close to the ground as possible.

Figure 1. Google Earth© images dated April 8, 2016 (top) and November 7, 2022 (bottom), showing the polygon of the study area before and after the establishment of the *Albizia procera* stand. In 2016, the study area was bare land recently bulldozed by the Highway Authority, and the tall canopy of surrounding trees casts a shadow over the bulldozed plot. Vegetation appeared at the site several years later and by 2022 the canopy was closed.

Measurements of trees and statistical analyses

The stand we selected had a perimeter of 151 m and an area of 948 m^2. Within this stand, we established a 41-m × 7-m plot (288 m^2) and measured the circumference of all trees within the plot. Measurements were done at breast height and the base of the trees at about 10 cm from the ground unless multiple branching and swelling required a different height to account for trunk deformities. The basal area at breast height and base level were estimated from tree diameter as follows:

$$\text{Tree diameter (at the base or at breast height)} = \text{circumference}/3.14.$$

$$\text{Area (at dbh or at the base)} = ((\text{dbh}/2)^2)(3.14).$$

The taper of stems could be estimated by dividing the area of the base by the area at breast height. We measured all stems that reached breast height but kept a record of the number of individual trees in the all-stem count.

To estimate the age of the stand, we analyzed Google Earth© images for different dates: April 8, 2016; April 28, 2018; February 28, 2019; July 26, 2019; August 1, 2019; August 29, 2019; and April 20, 2020. From these images and personal observations of the site, we estimated the age of vegetation at 1.6 to 2 years when we first measured the trees on February 14, 2021. We visited and remeasured the trees on June 5, 2023, to obtain a second growth rate. At the same time, we measured tree height with a Haglög Vertex IV hypsometer and listed some of the plant species regenerating in the understory of the forest. Tree height measurements were focused on the tall dominants and suppressed trees, which formed clear vertical stratification, with intermediate trees exhibiting heights between those two levels.

For the purpose of calculating growth rates, we estimated that a period of two years elapsed between the onset of growth and our first measurements on February 14, 2021, and 4.3 years for the measurement recorded on June 5, 2023. For the analysis of data, we used Stat Plus:mac Pro. Data were tested for homogeneity of variance and subjected to oneway ANOVA to determine statistical significance and the Scheffé test for group comparison at $p \leq 0.05$.

Table 2. Structural parameters of *Albizia procera* populations in this study and in triplicate monoculture plantations of similar age in Lajas, Puerto Rico. Plantations were established in the subtropical dry life zone and the data are from Lugo et al. (1990).

Parameter	In plantation	In the city
Tree density (trees/ha) @ 2 yr	6,400	5,755
Tree density (trees/ha) @ 4 yr	–	5,373
Stem density (stems/ha) @ 2 yr	–	6,032
Stem density (stems/ha) @ 4 yr	–	5,859
Basal area @ DBH (m^2/ha) @ 2 yr	–	27.2
Basal area @ DBH (m^2/ha) @ 4 yr	–	54.3
Basal area of the base (m^2/ha) @ 2 yr	–	53.9
Basal area of the base (m^2/ha) @ 4 yr	–	87.3
Aboveground biomass (Mg/ha) @ 5.5 yr	124	–
Loose litter (Mg/ha) @ 5.5 yr	10.2	11.0*
Fine roots to 30 cm depth (Mg/ha)	–	6.5*

*Gil de Rubio et al. 1983; the age was 10 to 20 yr.

RESULTS

The tree density of the stand was high but not as high as used in plantations of *Albizia procera* (Table 2). While the tree density (both in number of stems and trees) was similar among dates, the basal area changed significantly (Table 3). Both basal area measurements (at the tree base and breast height) were high and increased during the study to even higher values, typical of mature native forests (Table 2). The difference is that a mature forest accumulates basal area in large trees, while this *A. procera* stand accumulates a similar basal area with thousands of small trees.

Trees increased in diameter and basal area between measurements, but the taper did not change (Table 3). Most of the trees (81 and 72 percent in 2021 and 2023, respectively) shared a similar diameter class, suggesting they all grew as a cohort, but the residual trees were responsible for the high standard deviation of the data. These trees were the larger trees, which represented a greater proportion in 2023 that initially colonized and became dominant and codominant trees above the intermediate and suppressed ones. These larger and older trees are mostly responsible for the high growth rates that we found (Table 4).

Dominant trees in the city grew faster in height but slower in diameter than trees in plantations (Table 4). In 2023, dominant trees ranged in height between 17 and 21 meters, while suppressed trees were 8 to 9 meters in height. At four years of age, these heights correspond to 2.2 m/yr for suppressed trees and a range of 4.4 to 5.7 m/yr for the dominant trees. The diameter growth rate in the city declined by 70 percent between two and four years of age, but increments in the basal area declined to only 6 percent (Table 4). The reduction in basal area increment for the stand as a whole between two and four years of age was 13.2 and 46 percent for measurements at breast and base height, respectively.

Table 3. Mean allometric tree attributes (± Standard Deviation) at two different dates: February 14, 2021 (at 2-yrs old), and June 5, 2023 (at 4-yrs old). The number of measurements is in parenthesis. Mean tree diameter units are in centimeters and mean tree basal area units are in cm^2. Taper is the ratio of the base diameter to diameter at breast height. Not significant is NS for the difference in the mean between dates. The p-value is based on the Scheffé test and correspond to the comparison of attributes in 2021 with 2023.

Attribute	2 yrs (2021)	4 yrs (2023)	p-value
Diameter at breast height	6.83 ± 3.27 (174)	9.05 ± 6.12 (166)	3.96E-5
Basal diameter	9.62 ± 5.37 (163)	11.82 ± 8.14 (156)	4.59E-3
Taper	1.29 ± 0.08 (127)	1.29 ± 0.16 (155)	NS
Basal area at breast height	45.01 ± 44.09 (174)	93.62 ± 131.20 (166)	5.41E-6
Basal area at the base	95.20 ± 103.78 (163)	161.34 ± 221.87 (156)	6.75E-4

Table 4. Rates of mean tree and stand growth of *Albizia procera* at two ages and under contrasting condition in Puerto Rico. 'In plantation' refers to Lugo et al. (1990) and 'In the city' refers to this study. Diameter at breast height is dbh. The plantation data are based on triplicate monoculture stands in Lajas Puerto Rico (from Lugo et al. 1990 and Wang et al. 1991). Stands were planted at 1-m × 1-m spacing with a 3-m unplanted buffer between stands.

Parameter	In plantation	In the city
Trees		
Height growth (m/yr) at 4 yrs, dominant trees	3.5	4.4-5.7
Diameter growth at dbh (cm/yr) at 2 yrs	6.3	3.4
Diameter growth at dbh (cm/yr) at 4 - 5.5 yrs*	2.3	1.0
Basal area growth at dbh (cm^2/yr) at 2 yrs	—	22.5
Basal area growth at dbh (cm^2/yr) at 4 yrs	—	21.1
Stand		
Basal area growth at dbh (m^2/yr) at 2 yrs	—	13.6
Basal area growth at dbh (m^2/yr) at 4 yrs	—	11.8
Base area growth (m^2/ha.yr) at 2 yrs	—	27.0
Base area growth (m^2/ha.yr) at 4 yrs	—	14.5
Net aboveground biomass accumulation (Mg/ha. yr) at 5.5 yrs	22.5	—

*5.5 years refers to the age of the plantation.

DISCUSSION

Our results help explain the success of *Albizia procera* in vacant lands within the city and along roadsides. Specifically, the rapid height growth rate allows individuals of this species to outgrow and then shade grasses and other successional trees. In our study site, *A. procera* had outgrown the common non-native guinea grass (*Megathyrsus maximus*, previously known as *Urochloa maxima* or *Panicum maximum*) and the non-native Asian kudzu *Pueraria phaseoloides*, now known as *Neustanthus phaseoloides*. However, other species enter the *Albizia* stand, including suppressed saplings of the naturalized tree *Spathodea campanulata*, the native tree *Tabebuia heterophylla*, the non-native shade-tolerant tree *Catalpa longissima*, and the native shrub *Lantana camara* (Table 5).

Many individuals of fast-growing species other than *Albizia procera* were located at the ecotone with the roadside, where lateral light penetrates the stand, particularly in the afternoon, and sustains the suppressed individuals. Because most stands in the city are small in area, edge effects on light penetration become an important ecological factor for supporting suppressed trees in the understory. The only tree species reaching the canopy at our site, other than *A. procera*, was *Triplaris cumingiana*. This tree, with large oblong leaves, thrived in the understory of the stand and reached the lower level of the dominant canopy. *Triplaris* is a non-native species introduced from South America and planted in Puerto Rico, but is now naturalized in the city and elsewhere on the island. It appears that this species can reach maturity within *A. procera* stands.

An advantage of *Albizia procera* in the city and along roadsides is its capacity to grow in highly compacted bulldozed soils. Chinea (2002) demonstrated this capacity using tree species ordinations based on a diversity of land covers after the abandonment of agricultural activities in eastern Puerto Rico. *Albizia procera* was the only species that could colonize bulldozed lands, a capacity attributed to its ability to fix nitrogen and thus overcome the limitation of compacted and bulldozed soils. Gil de Rubio et al. (1983) found a bulk density of 1.3, 1.2, and 0.8 g/cm^3 at 0–10, 10–20, and 20–30 cm depth, respectively, in a stand of *A. procera* growing next to a road in Caguas. Those results are similar to the bulk density values measured by Cusack and McCleery (2014) in urban forests in San Juan. Notably, the compacted soils of the *Albizia* stand in Caguas also had a high percentage of organic matter (22, 20, and 37 percent at 0–10, 10–20, and 20–30 cm depth, respectively). Our study site was bulldozed just before our study (Figure 1). Similarly,

Table 5. Plant species observed growing in the study plot (288 m^2). We did not conduct a systematic inventory of plant species in the study site. We used Axelrod (2011) for plant names, status, and authorities.

Species	Common Name	Status
Albizia procera (Roxb.) Benth.	tall albizia, white siris	Nonnative
Catalpa longissima (Jacq.) Dum. Cours.	Haiti catalpa	Nonnative
Lantana camara L.	pink sage	Native
Panicum maximum (Jacq.) B.K. Simon & S.W.L. Jacobs.	guinea grass	Nonnative
Pueraria phaseoloides (Roxb.) Benth	tropical kudzu	Nonnative
Spathodea campanulata P. Beauv.	African tulip tree	Nonnative
Tabebuia heterophylla (DC) Britton	white cedar	Native
Triplaris cumingiana Fisch. & C.A. Mey ex C.A. Mey.	ant tree	Nonnative

those city environments where *A. procera* grows well, such as vacant land and industrial-commercial-transportation corridors (Table 6), are the land cover types of the city most likely to have compacted and bulldozed substrates. Cusack and McCleery (2014) found that the level of soil nitrogen percent in urban areas of San Juan was inversely correlated with bulk density and that both bulk density and soil nitrogen level changed in stands dominated by nitrogen fixers such as *A. procera*. Bulk density declined, and nitrogen level increased in those stands with nitrogen fixers. The above discussion suggests that belowground ecological functions of *A. procera* stands can influence soil fertility and deserve more scientific attention.

Table 6. Number of trees, stored carbon, and rate of carbon sequestration of *Albizia procera* on the urban landscape of San Juan, Puerto Rico. The percent column refers to the total for each land cover. These results are from Brandeis et al. (2014).

Land Cover	Number of Trees		Stored Carbon		Net Sequestration	
	Total	%	Total (Mg)	%	Total (Mg/yr)	%
All the city	127,948	1.3	33,580	10.5	1,377	5
Commercial/industrial/transportation	17,246	7.1	10,985	41.3	286	18.5
Vacant	90,147	5.0	14,154	21.8	823	14.2
Residential	20,555	3.2	8,441	9.7	268	6.1

Table 7. Nutrient concentration and storage in 5.5 yrs-old *Albizia procera* plantation in Lajas, Puerto Rico (from Wang et al. 1991).

	Concentration (mg/g)					
Component	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sodium
Wood	1.96	0.56	2.10	3.10	0.55	0.36
Bark	16.30	2.14	5.60	21.30	3.96	0.83
Small branches	8.20	2.16	8.25	9.00	2.53	0.41
Leaves	32.80	3.04	15.00	9.60	4.35	0.25
Litter	1.55	—	1.07	7.50	2.23	0.34
	Storage after 5.5 yrs of growth (kg/ha)					
Bole	380	81	280	560	100	46
Whole tree	540	102	370	690	132	51
Litter	159		11	77	23	4

Another important ecological function of *Albizia procera* is its carbon storage capacity (Table 6). The data from our literature review show two aspects of the carbon sink function of *A. procera* in the city. First, it stores carbon in disproportion to its importance value. This means that it has a higher-than-normal rate of carbon storage, as suggested by the high rate of biomass accumulation in plantation experiments (Table 2). In a study by Lugo et al. (1990), the rate of biomass accumulation in *A. procera* had not stabilized when the study ended at age 5.5 yr. Second, *A. procera* is responsible for 10 percent of the carbon storage measured in the municipality of San Juan (Brandeis et al. 2014), but most of the contribution of this species corresponds to the land covers with the least forest area, i.e., the most urbanized, where one would expect a low level of carbon sequestration.

In addition to the facilitation of succession within the city, the stands of *Albizia procera* also have a significant role in the accumulation of nutrients in biomass and the enrichment of the soil with both organic matter and essential nutrients for plant productivity (Table 7). Plant parts of *A. procera* exhibited a wide range of nutrient concentrations with notably high concentration values for nitrogen and phosphorus in leaves. Similarly, the total storage of these nutrients was high after only 5.5 years of growth. Wang et al. (1991) found that in the 5.5 yr-interval of growth, stands of *A. procera* improved soil organic matter and soil nitrogen concentration to a depth of 3 cm.

Albizia procera is an urban tree that forms viable forest stands in the most compacted, less likely soils to sustain forest stands. In the very short interval of two years, *A. procera* establishes a dense stand with a tall canopy that accumulates carbon to levels as high as those of forests growing under favorable soil conditions. Both the fixation of nitrogen and the accumulation and circulation of biomass by *A. procera* represent a quick start to the restoration of highly compacted and bulldozed soils and eventually to the accumulation of plant and animal species in the most urbanized zones of cities. In fact, the presence of nitrogen fixers in urban areas was associated with the facilitation of native species regeneration as the restoration of site conditions improved by the accumulation of nutrients and organic matter in previously degraded soils (Cusack and McCleery 2014).

In summary, the rapid growth of *Albizia procera* stands in the city is manifested in rapid height, basal area, biomass, and nutrient accumulation, including nitrogen and phosphorus. This rapid growth rate results in the following:

- The establishment of carbon and other elements sinks;
- The improvement of soils in terms of lower bulk density and high concentration and accumulation of nitrogen and other nutrients;
- The establishment of a stand structure, which lowers air temperature and improves conditions for the establishment of plant species that could not grow under the conditions at the time of land abandonment.

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