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Supplying Sawmills with Native Species from Ecological Restoration in Southeastern Brazil: Analysis of Potential

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Abstract

The objective of this work was to evaluate the potential of native species used in ecological restoration in Brazil (*Peltophorum dubium* - canafístula, *Hymenaea courbaril* – jatobá, *Jacaranda cuspidifolia* – jacarandá, and *Enterolobium contortisiliquum* – timboril) as raw material for the supply of sawmills. Due to the difficulties in sampling trees of native species, four trees per species were collected, at age of 12 years, in a legal reserve area. The sampled trees were evaluated as being quite characteristic of trees of the same genetic material. The trees' diameter was measured, the percentage of bark and the taper were measured, and the lumber yield of each species was calculated. The boards were air-dried. Based on the DBH, timboril had the greatest potential for biomass production, but its wood quality was unsatisfactory. To supply raw material for sawmills, in addition to jatobá, we suggest investing in plantations of canafístula and jacarandá.

Keywords: Legal Reserve, Atlantic Forest Species, Dendrometric characteristics, Sawmilling.

1. INTRODUCTION AND OBJECTIVES

Most of the cultivated land in Brazil as well as the largest population, about 125 million inhabitants, is in the Atlantic Forest biome (Lapola et al., 2014), that is, approximately 59% of the country's population. At the beginning of Brazilian colonization, the Atlantic Forest covered about 150 million hectares in highly heterogeneous environmental conditions (Ribeiro et al., 2009) and was considered one of the largest tropical forests on the planet (Barbosa & Mansano 2018). It is believed that the Atlantic Forest had 1% to 8% of the world's biodiversity (Barbosa & Mansano 2018).

After several economic cycles that resulted in the current degradation (Pinto et al., 2014), the remaining coverage is estimated at 22%, of which only about 8.5% is conserved in fragments larger than 100 hectares (Ministério do Meio Ambiente do Brasil, 2018). This makes the Atlantic Forest an extremely threatened biodiversity hotspot (Lapola et al., 2014).

Degradation of extensive tropical landscapes justifies the need for large-scale restoration initiatives (Pinto et al., 2014), as it is one of the suggested measures for the conservation of biomes (Ribeiro et al., 2009). Altogether, the valorization of wood from the Atlantic Forest, due to the significant reduction in the supply of this material, may make timber production from restored areas economically viable (Brancalion et al., 2012).

The species *Peltophorum dubium* (Spreng.) Taubert – canafístula, *Hymenaea courbaril* L. – jatobá, *Jacaranda cuspidifolia* Mart. – jacarandá and *Enterolobium contortisiliquum* (Vell.) Morong. – timboril have been traditionally used in ecological restoration projects (Campoe et al., 2014). There are several studies of these species regarding germination and survival of seedlings in the field, mainly because of their potential for restoration projects (Campoe et al., 2014, Dutra et al., 2016, Medeiros et al., 2016, Morozesk et al., 2014, Silva et al., 2017).

There are also studies of the toxic properties of *Enterolobium contortisiliquum* (Miranda et al., 2015, Olinda et al., 2015)

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and the medicinal properties of *Jacaranda cuspidifolia* (Mostafa et al., 2015, Yuan et al., 2017). However, there is not much information regarding the wood properties of species used in ecological restoration.

To make up for the lack of information on the timber potential of ecological restoration areas, some studies have been conducted using nondestructive assessments. Silva et al. (2017) confirmed the good phytosanitary status of *Cedrela fissilis* Vell. trees, and Xavier et al. (2018) found that the wood of *Peltophorum dubium* (Spreng.) Taub. has longitudinal residual tension, similar to that of eucalyptus clones.

Therefore, initial studies have indicated the potential of native species from restoration areas. However, it is still necessary to know the properties of the wood (anatomical, chemical, physical, and mechanical), as well as its behavior during processing.

Log breakdown is affected by several factors, such as log diameter and length, log shape (taper, flattening, bending), cutting pattern, lumber dimensions, attack of xylophages and hollows, pith eccentricity, growth stresses, top cracks, and machinery and labor requirements (Ferreira et al., 2004, Garcia et al., 2012, Iwakiri 1990, Juizo et al., 2014, Marchesan et al., 2014, Rongrong et al., 2015, Steele et al., 1992). Natural drying is a simple process that consists of stacking the lumber in yards, leaving it exposed to environmental factors (temperature, relative humidity, and air circulation). It is a slow process that enables drying the lumber to the moisture content of the environment (Susin et al., 2014).

The objective of this study was to evaluate the potential of four native species used in ecological restoration (*Peltophorum dubium, Hymenaea courbaril, Jacaranda cuspidifolia* and *Enterolobium contortisiliquum*) as a raw material for the supply of sawmills.

2. MATERIALS AND METHODS

2.1. Material collection and sampling

The trees were collected in a 12-year-old plantation, with 3 x 2 m spacing, in an ecological restoration area bordering a hydropower reservoir (legal reserve), in the municipality of Anhembi (22º40 'S, 48º10' O, 455 m altitude) (Figure 1). The weather is Cwa, according to the Köppen classification, with average annual temperature of 23 ºC and precipitation of 1,100 mm. The predominant soil in the area is dystrophic yellow latosol (Empresa Brasileira de Pesquisa Agropecuária, 1999).

Due to the difficulties, such as high cost, difficulties in transport and movement, rough terrain, in sampling trees of native species in areas of heterogeneous plantations, which simulate a natural forest, four trees per species were collected, at age of 12 years, in a legal reserve area in Brazil. The sampled trees were evaluated as being quite characteristic of trees of the same genetic material existing in that area. Four trees were collected of each species: *Peltophorum dubium* (Spreng.) Taubert – canafístula, *Hymenaea courbaril* L. – jatobá, *Jacaranda cuspidifolia* Mart. – jacarandá and *Enterolobium contortisiliquum* (Vell.) Morong. – timboril. The diameter at breast height (DBH) was measured and two logs were produced per tree, ranging from 0.73 to 1.59 m, except timboril, from which only one log was produced because of its short trunk height.

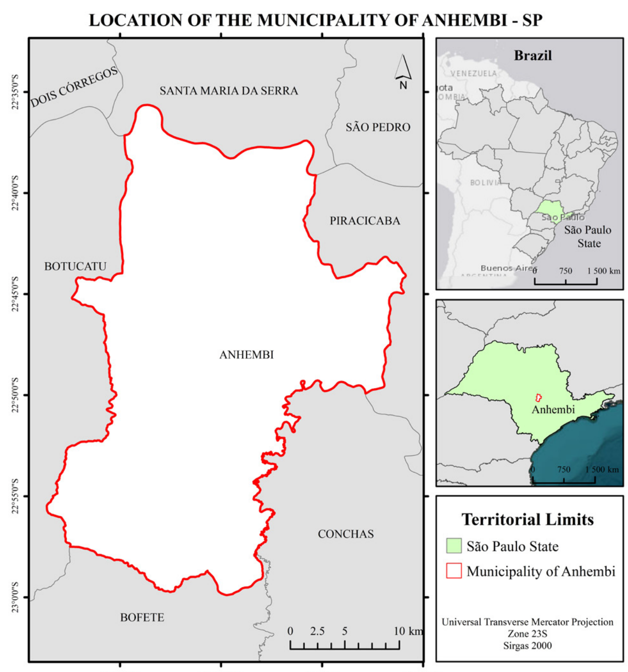

Figure 1. Study area location, in Anhembi-SP, Brazil.

2.2. Log measurement and breakdown

The logs were broken down 120 days after felling, of which 45 were spent in the field. Previously, the volume (with bark) of the logs was measured using the method of Smalian. The bark thickness was measured at the tops of the logs with a digital caliper (0.01 mm), at three equidistant points, representing the average thickness. The taper of each log was calculated with Equation 1, according to the Brazilian Institute of Forest Development (IBDF 1984), where T is the taper ($cm.m^{-1}$); D is the largest diameter of the log without bark (cm); d is the smallest diameter of the log without bark (cm), and L is the log length (m).

$$T = \frac{(D - d)}{L} \quad (1)$$

The breakdown was carried out with a portable sawmill (horizontal bandsaw), with a Honda GX 390 four-stroke gasoline engine rated at 13 HP, with 600 mm wheel diameter, equipped with a steel blade with width of 45 mm, spring-set teeth and kerf of 1.3 mm. The live sawing pattern was adopted, resulting in a variable amount of boards per log, with different widths, according to the diameter of the logs. No slab resawing was performed. The boards were edged to the largest width, using a circular saw equipped with a 100 mm diameter blade, with tungsten carbide-inserted teeth and kerf of 3 mm. The breakdown resulted in boards with 30 mm thickness and width from 97 mm to 255 mm.

The lumber yield was calculated with Equation 2, where Y is the yield (%); Vl is the lumber volume (m³) and Vt is the log volume without bark (m³).

$$Y = \left(\frac{V_l}{V_t}\right).100 \quad (2)$$

2.3. Evaluation of drying defects and knots

The lumber was stacked (two stacks) for natural drying in the municipality of Seropédica, Rio de Janeiro. Three samples were used to measure moisture content to control the natural drying, which ended after 173 days when the samples reached equilibrium with the environment (15% moisture content). The drying defects were evaluated according to the standard NBR 9487 (Associação Brasileira de Normas Técnicas, 1986), with some modifications according to Rocha & Trugilho (2006).

The index of end splits was assessed according to the method of Rocha & Trugilho (2006) and calculated with Equation 3, where is the index of end splits (%); sl_1 and sl_2 are the lengths of the longest end split of both tops (cm); and lt is the board length (cm).

$$IES = \frac{(sl_1 + sl_2)}{l_t}.100 \quad (3)$$

Regarding warping, we measured bowing, spring and cupping. Percentage indices of warping were calculated based on the point of greatest deflection (arrow), using the total length of the boards for bowing and spring, and the total width for cupping. For equivalent comparison between species, cupping was calculated using only boards from 25 to 35 mm thick and from 100 to 200 mm wide, regardless of length. The same boards were used for calculating the index of splits, bowing and spring, but only those between 800 and 1,200 mm in length.

Some drying defects were analyzed considering only their presence or absence, in % of boards. All boards were evaluated, regardless of dimensions, for the following defects: longitudinal surface cracks, twisting, complex bowing, and collapse. Likewise, the presence of knots in the boards was evaluated *Statistical analysis*.

For the statistical analysis of DBH, percentage of bark, taper, and lumber yield, Student's t-test was performed to compare the species. For these variables, the species were separated into similarity groups. The level of significance adopted was 5% for all tests and statistical analysis was performed using the Action Stat software.

IES (%), bowing (%), spring (%) and cupping (%) were presented in terms of descriptive statistics and board frequency (%), according to the magnitude of the defect. The classes were defined according to the magnitude of the defects. For longitudinal surface cracks, twisting, complex bowing, collapse, and knots, data are presented and discussed in terms of percentage of boards per species.

3. RESULTS AND DISCUSSION

3.1. DBH, percentage of bark, taper and yield

According to the results presented in Table 1, timboril had the highest mean DBH and jatobá had the lowest, with a significant difference between them. The log diameter is an important feature for the supply of sawmills, as it indicates not only the forest productivity ($m^3.\ ha^{-1}$) but also the volume of lumber, since logs with larger diameters tend to have higher yield.

The mean DBH values of canafistula and jatobá were higher than those reported by Silva (2013), even for high productivity sites. Silva (2013) evaluated the same species in 15-year-old ecological restoration plantations, in various regions of the state of São Paulo. The results (Table 1) indicated good potential of both of these species.

The mean DBH of timboril (24.0 cm) was in the range (13.8 cm to 29.0 cm) reported by Silva (2013) for sites of low to medium fertility, but it reached only around half of that reported for sites of high fertility (46.8 cm). Thus, it is possible to obtain higher forest productivity for this species with the selection of genetic materials and higher quality sites, as well as with the management of soil fertility.

A mean DBH of of 21 cm was reported for jatobá at the age of five years in an ecological restoration area in the Cerrado biome of the Distrito Federal (Oliveira et al., 2015), higher than the 17.3 cm in this study. This can be explained by the larger spacing (3 x 3 m), since greater spacing results in larger diameters (Schneider et al., 2015).

Table 1. Means of DBH, percentage of bark, taper and yield per species.

Species	DBH (cm)	Percentage of bark (%)	Taper ($cm.m^{-1}$)	Yield (%)
Canafístula	21.6 ab (10.74)	6.2 b (16.32)	2.7 (78.95)	56.5 (10.94)
Jacarandá	18.8 ab (16.29)	5.4 b (15.85)	1.7 (35.29)	61.3 (15.52)
Jatobá	17.3 b (14.55)	11.2 a (45.64)	2.0 (72.31)	53.5 (19.13)
Timboril	24.0 a (43.20)	9.7 a (11.13)	1.5 (92.74)	55.9 (15.11)

Means followed by a same letter in a same column, do not differ significantly (Student's t-test, p> 0.05); coefficient of variation (%) in parentheses.

The edaphoclimatic conditions and genetic material are factors that can explain the discrepancy between the results obtained in this work and those reported in the literature. It is important to note that the area in which the trees were collected was not intended for lumber production. Therefore, the mean diameter of all species can be better in favorable conditions of silvicultural development, for example, with liming and fertilizing the soil, in addition to the silvicultural treatments suitable for each species.

None of the four species showed significant top cracks or spots between logging and breakdown (120 days). In the case of top cracks, they can result in losses of raw material, and in some cases may make the use of the material unfeasible (Müller et al., 2017). In turn, stains affect the wood appearance, often reducing its commercial value. Moreover, they can indicate the presence of xylophagous agents, which can compromise the strength and affect processing.

As for the percentage of bark, jacarandá and canafistula had the lowest means, while jatobá and timboril had the highest. Bark is one of the worst residues of sawmills, especially small and medium-sized ones, which do not consume it internally. It is a waste that is difficult to sell in Brazil, requiring an environmental solution.

Despite being a defense for trees, bark is not desirable for the production of wood biomass or as raw material for sawmills. Because the trees studied here are native species used in ecological restoration, the bark can be an alternative to generate income and maintain the benefits of the forest. This information is important for timboril, whose bark has anti-inflammatory properties (Agra et al., 2007), and for jatobá, whose bark has antimicrobial (Gonçalves et al., 2005) and antioxidant effects (Vencato et al., 2016).

For *Pinus patula* var. *tecunumanii* planted in the same area as the species of this study and at the same age, the mean percentage of bark from the base to the DBH was 17.6% (Silva Júnior et al., 1994), higher than all the species in this study. The analyzed species also had a lower percentage of bark than a 94-month-old hybrid of *Pinus ellotti* var. *elliottii* x *Pinus caribaea* var. *hondurensis*, planted in Buri in the state of São Paulo (Almeida et al., 2014). These results are good since pine is the main raw material for Brazilian sawmills.

For canafistula logs the diameter ranged from 19.00 cm to 26.50 cm and the length from 0.73 m to 1.16 m; for jacarandá the diameter varied from 14.58 cm to 19.68 cm length from 0.53 m to 0.58 m; for jatobá the diameter raged from 14.55 cm to 22.44 cm and length from 1.06 m to 1.35 m; and for timboril the diameter ranged from 14.55 cm to 33.46 cm and length from 0.91 m to 1.59 m. No comparison was performed for taper and lumber yield among the species due to the differences in log diameter and length.

The mean taper of all species was less than 3 $cm.m^{-1}$, receiving the "high" classification, considered the best according to the Instituto Brasileiro de Desenvolviemento Florestal (IBDF 1984). This result is positive since taper has a negative correlation with lumber yield (Juizo et al., 2014, Rongrong et al., 2015). It is noteworthy that the logs were shorter than those commonly processed in Brazilian sawmills (less than two meters in length), which also favors low taper.

On the other hand, Grosser (1980), cited by Valério et al. (2007), stated that taper negatively affects the lumber yield from 1 $cm.m^{-1}$. Thus, all species are affected by taper to some extent. Given the limitations of the material analyzed (number and length of logs), further studies should be carried out to obtain conclusive results regarding the effect of taper on lumber yield.

For the adopted sawing pattern, all species had satisfactory lumber yield, above 50%. All the produced boards were considered, with no discrimination in quality standards. The breakdown was carried out looking for the best possible use of the logs, using live sawing followed by the edging of the boards to the largest possible width, which demands more processing time.

Only timboril had cracks during log breakdown. Canafístula, jacarandá and jatobá performed well during log breakdown, without cracking or warping, indicating good quality of the raw material in terms of growth stresses.

3.2. Drying defects

Table 2 shows the results of IES (%), where the boards were grouped in frequency classes. According to the criteria of the Associação Brasileira de Normas Técnicas (ABNT, 1986) for the "general market", boards with IES up to 10% are ranked from first to third class, depending on other types of defects. Above 10% IES, the boards are classified as fourth class (the worst).

Table 2. Results of index of end splits (IES%) per species.

Species	Frequency classes (%)					Means of IES
	0	0.01 –10.00	10.01 – 30.00	30.01 – 60.00	100	(%)
Canafístula	31	15	23	23	8	23.98 (120)
Jacarandá	62	13	25	0	0	5.67 (194)
Jatobá	20	10	70	0	0	11.74 (73)
Timboril	17	0	66	17	0	16.09 (70)

Coefficient of variation (%) in parentheses.

For jacaranda, 75% of the boards were ranked up to 10% IES, which resulted in the lowest absolute mean (5.67%). Although canafístula had a higher absolute mean, it was the second-best species regarding the frequency of boards ranked up to 10% IES. On the other hand, only 17% of the timboril boards had the same ranking, which had a higher frequency (83%) of boards ranked above 10% IES.

End splits are related to the shrinkage anisotropy and the fragility of the wood rays (low density, parenchyma tissue), among other factors. As mentioned before, timboril had the highest frequency of boards with IES% above 10%, resulting in low-quality wood. This behavior may have occurred due to the low density of the material and release of growth stresses during the processing, as previously mentioned.

End splits can considerably limit the use of lumber, meaning a reduction of the effective yield due to the trimming losses. However, it must be considered that the material analyzed consisted of juvenile wood, so better results can be expected for adult wood.

According to the criteria of the ABNT (1986) for the "general market", bowing and spring are permitted up to 0.50% and only up to 5% of the boards in a lot can have these kinds of warping. For spring (Table 3), 100% of the canafistula, jacarandá, and jatobá boards were ranked as having up to 0.50% spring. Canafistula had the best results, because 62% of its boards were ranked as having 0% spring.

Table 3. Results of spring per species.

Species	Frequency classes (%)			Means of spring (%)
	0	0.01 – 0.50	0.51 – 0.60	
Canafístula	62	38	0	0.08 (130)
Jacarandá	13	87	0	0.08 (141)
Jatobá	10	90	0	0.14 (77)
Timboril	0	83	17	0.23 (70)

Coefficient of variation (%) in parentheses.

However, in general the results of spring were good for all species, even for timboril, which had only one board (17%) with spring higher than the maximum established by the standard. The same behavior was verified for bowing (Table 4), which was expected because both kinds of warping consider lengthwise deviations. The highest frequency of boards with up to 0.50% bowing was found for canafistula (77%), which also had the highest frequency of boards without this warping (46%). Timboril had the highest frequency of boards (33%) with bowing greater than 0.50%. Compared to spring, bowing was more severe, with the highest frequency of boards above the maximum value established by the standard for all species.

Cupping was not analyzed according to the criteria of the ABNT (1986), so it is not possible to present same type of discussion as for the previous warping types. No boards of jacarandá and timboril were cupped (Table 5), while for canafístula and jatobá, 57% and 69% of the boards were not cupped, respectively. According to the criterion of the highest absolute mean, however, jatobá had the worst performance for cupping. But even so, the mean was less than 1%, so cupping was not a severe problem for the assessed boards.

No twisting, complex bowing or collapse was verified in any board, but canafistula and jatobá had longitudinal surface cracks (Table 6). Knots were found in all species, which was expected because of the young age, resulting in trees with small diameters, which thus have a strong effect of the first branches developed in the initial development stage, which results in knots close to the pith. Jatobá and jacarandá had the highest and lowest frequency of boards with knots, respectively. Besides young age, the trees had not been pruned for timber production.

Table 4. Results of bowing per species.

Species	Frequency classes (%)				Means of bowing (%)
	0	0.01 – 0.50	0.51 – 1.00	1.01 – 1.14%	
Canafístula	46	31	15	8	0.21 (125)
Jacarandá	0	75	25	0	0.26 (82)
Jatobá	10	60	20	10	0.44 (74)
Timboril	0	67	33	0	0.33 (57)

Coefficient of variation (%) in parentheses.

Table 5. Results of cupping per species.

Species	Frequency classes (%)					Means of cupping (%)
	0	0.01 – 1.00	1.01 – 2.00	2.01 – 3.00	3.01 – 4.0	
Canafístula	57	7	29	7	0	0.69 (124)
Jacarandá	100	0	0	0	0	0.00 (0)
Jatobá	69	0	15	8	8	0.79 (179)
Timboril	100	0	0	0	0	0.00 (0)

Coefficient of variation (%) in parentheses.

Table 6. Percentage of boards with longitudinal surface cracks and knots per species.

Species	Longitudinal surface cracks	Knots	No defects*
Canafístula	20%	28%	59%
Jacarandá	0	17%	83%
Jatobá	22%	43%	30%
Timboril	0	25%	64%

*Regarding longitudinal surface cracks and knots.

Considering longitudinal surface cracks and knots, jacaranda had the highest frequency of boards with no defects (83%), while jatobá had the lowest frequency (30%). Considering the natural heterogeneity of the wood, the use of juvenile wood of native species, and that the trees were not managed for timber purposes, the quality of the wood after natural drying was satisfactory.

4. CONCLUSIONS

- Based on the DBH, timboril had the greatest potential for volumetric production of biomass, but it had unsatisfactory wood quality.
- The species' performance was satisfactory for the percentage of bark content, taper, and lumber yield. However, it is necessary to carry out further studies with longer logs.
- Considering end splits and warping (bowing, spring, and cupping), canafístula and jacaranda had the best performance. The index of end splits was the drying defect posing the greatest limitation for the use of wood, so this parameter can be used in future studies as a drying quality index. Cupping was not a problem for any species.
- Jatobá is a wood species consolidated in the international market. To supply raw material for sawmills, in addition to jatobá, we suggest investing in plantations with the species canafístula and jacarandá.

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Alexandre Miguel do Nascimento: Investigation (Supporting), Methodology (Equal), Writing – review & editing (Supporting).

Alexandre Monteiro de Carvalho: Conceptualization (Equal), Funding acquisition (Lead), Methodology (Equal), Project administration (Lead), Supervision (Equal), Writing – review & editing (Supporting).

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