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A novel method for monetary valuation of street trees: a case study in a Brazilian city

Um novo método para valoração monetária de árvores de rua: um estudo de caso em uma cidade brasileira

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ABSTRACT
Street trees offer numerous ecosystem benefits when well managed by the municipal administration. However, quantifying these benefits is complex, which contributes to the negligence and undervaluation of afforestation by municipal managers and the population as a whole. Thus, the valorization of urban afforestation emerges as a strategic awareness tool, capable of translating the importance of each individual tree within the urban green infrastructure for citizens and municipal managers, in addition to assisting in the process of choosing the best guidelines and practices for urban forest management. When applied to street tree planting, these methods fail to consider the most important aspect of a tree in the urban environment: its canopy. Thus, this research aimed to propose a new method for the monetary valuation of street trees, focusing on the benefits of the canopy and applying this method in a case study. Tree species, condition, location, biometric value and implementation cost were considered. The case study results reached US$ 600 million, with individual trees between US$ 213.93 and US$ 483,615.19. The main limiting factors for the evaluation of the street tree planting were the location of the plating and the low height of the bifurcation.
Keywords: ecosystem services; nature economy; tree canopy; tree economic value; urban forest.

RESUMO
As árvores de rua oferecem inúmeros benefícios ecossistêmicos quando bem geridas pela administração municipal. No entanto quantificar esses benefícios é complexo, o que contribui para o descaso e a desvalorização da arborização por parte dos gestores municipais e da população como um todo. Assim, a valorização da arborização urbana surge como uma ferramenta estratégica de sensibilização, capaz de traduzir a importância de cada árvore individual na infraestrutura verde urbana para os cidadãos e gestores municipais, além de auxiliar no processo de escolha de melhores diretrizes e práticas de gestão florestal urbana. Quando aplicados à arborização de ruas, tais métodos deixam de considerar o aspecto mais importante de uma árvore no ambiente urbano: sua copa. Desse modo, a presente pesquisa teve como objetivo propor um novo método para a avaliação monetária de árvores de rua, focando nos benefícios da copa e aplicando o método em um estudo de caso. Consideraram-se espécies arbóreas, condição, localização, valor biométrico e custo de implantação. Os resultados do estudo de caso atingiram US$ 600 milhões, com árvores individuais entre US$ 213,93 e US$ 483.615,19. Os principais fatores limitantes para a avaliação da arborização das ruas foram a localização do plaqueamento e a baixa altura da bifurcação.
Palavras-chave: copa das árvores; economia da natureza; floresta urbana, serviços ecossistêmicos; valor econômico das árvores.

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INTRODUCTION

Encouraging urban forest implementation has become a common practice in recent decades, especially in large cities centers. Urban forests differ from rural forests by their lower vegetation cover and tree density, as well as by their closer proximity to human structures and housing (NOWAK & GREENFIELD, 2018).

Street trees, the set of trees that grow along the sidewalks, are an important part of the urban forest (MCPHERSON *et al.*, 2016). These trees are the closest vegetation to the urban population and, therefore, have a great impact on the daily lives of city inhabitants (DERKZEN *et al.*, 2015), providing several essential ecosystem services such as air pollution reduction, biological carbon fixation, decrease in air temperature, aid in stormwater management, aesthetic beauty, improvement in the overall quality of life of the urban population (KADIR & OTHMAN, 2012), and contribution to the real estate valuation of their surroundings (MARIA, 2017).

Thus, street trees can be monetarily valuated, based on the ecosystem services these plants provide (VOGT *et al.*, 2015). Different methods are used to calculate the value of these plants, such as the contingent valuation and the hedonic regression methods, as well as equations that consider features of the trees and the physical environment of theses plants, depending on the particular characteristics of the urban forest of each municipality (VIANA *et al.*, 2012).

The monetary valuation of street trees results from the implementation costs and the quality of the individual planted (SILVA FILHO & TOSETTI, 2010). It is a strategic tool to represent the importance of each individual tree, within the urban green infrastructure to citizens and municipal managers, assisting in their decision-making process.

Viana *et al.* (2012) mention that the monetary valuation of trees can raise awareness, of the general population, the public and private sectors, to the importance and benefits provided by these plants within the urban forest, ensuring the place of these plants in the planning of the structure of cities.

Moreover, the value of trees informs the application of fines and compensation in the event of tree degradation, facilitates the development of urban tree financing strategies and management programs and allows the calculation of potential losses caused by pests and diseases (ESTELLITA & DEMATTÊ, 2006; ROGERS *et al.*, 2017; FRUTH *et al.*, 2019).

Song *et al.* (2018) assessed studies of monetary valuation of urban trees and found that most of the research published between 1992 and 2016 analyzed the ecosystem services provided by street trees, with 36.84% concerning other components of the urban forest. However, they indicated that there is a lack of information on the monetary valuation of street trees in Brazilian cities.

Furthermore, as street tree valuation is a still unregulated practice, many cities seem to have differences in the distribution and maintenance of street trees, considering their specificities (RANDRUP & PERSSON, 2009; KADIR & OTHMAN, 2012). Nowak & Greenfield (2018) add that planning and managing the urban forest benefits tree health and maximizes the environmental benefits of these plants, consequently raising the monetary values of these plantas, considering the continuous expansion of urban areas.

Most methods of monetary valuation currently applied for street trees fail to consider the most important aspect of the ecosystem services given by street trees: their canopy. In light of this, this study proposes a novel method for the monetary valuation of street trees, combining factors such as the real structure of urban trees and the benefits provided by these plants. We applied our valuation method to a case study in the municipality of Itanhaém, located in the state of São Paulo, Brazil. Thereby, through this method, we hope to provide subsidies for the better management of urban forests.

MATERIAL AND METHODS

STUDY AREA

Our case study was based on street tree data from the municipality of Itanhaém, located on the southern coast of the state of São Paulo, Brazil (figure 1). Itanhaém has 40.8 km² of urbanized area and a total territorial extension of 601.7 km², with approximately 97,000 inhabitants and 99% of them residing in the urban area (IBGE, 2010).

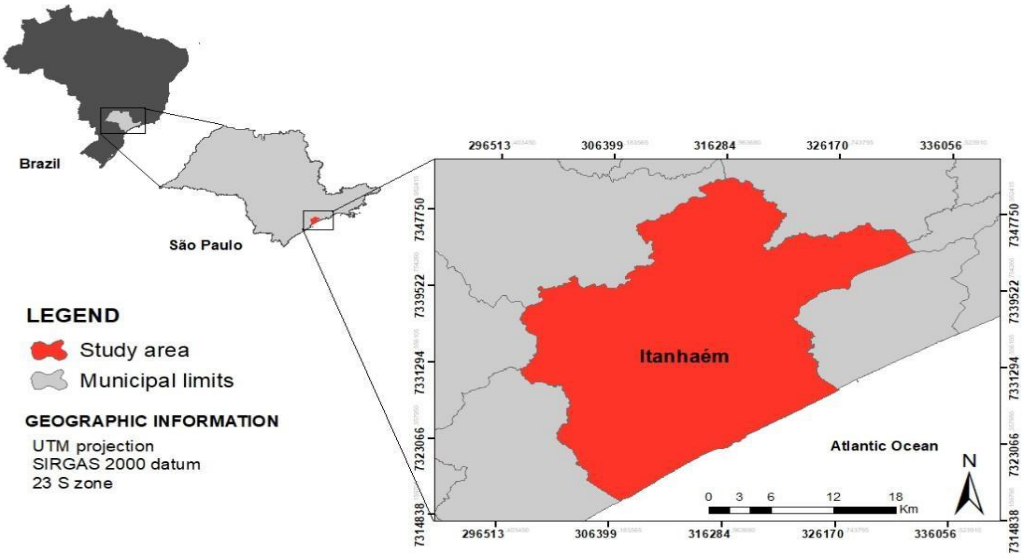

Figure 1 – Location of Itanhaém, São Paulo, Brazil. Source: primary.

Itanhaém is subdivided into 15 administrative regions. For this study, we considered 13 of them: Belas Artes, Bopiranga, Cibratel, Centro, Gaivota, Guapiranga, Ivoty, Loty, Monastery, Praia dos Sonhos, Savoy, Suarão, and Umuarama. The two remaining regions, Guapura and Oasis, were excluded since they do not have street trees.

Street trees in Itanhaém add up to 18,128 individuals, distributed in 109 species, 60.5% of which are exotic to the Brazilian territory (MARIA *et al.*, 2016). The 13 administrative regions differ significantly in their urban forest and urbanization, ranging from 15 to 90 trees per km, and from 1.98 to 3.64 m wide sidewalks (MARIA *et al.*, 2017). For the monetary valuation study case, 1,265 street trees were considered and selected by stratified random sampling, which were defined by administrative region.

METHODOLOGICAL PROCEDURES

Our novel monetary valuation method was adapted from the method proposed by Silva Filho & Tosetti (2010), in which values associated with trees, their cost of implantation, frequency of species, and physical environment are calculated for later conversion into currency value (table 1).

Table 1 – Valuation parameters for urban forests according to the method proposed by Silva Filho & Tosetti (2010). Legend: SV = species value; Av = availability; Dp = desirable parts; De = development; Ad = adaptability; BV = biometric value; DBH = diameter at breast height; BH = bifurcation height; LV = location value; I = individuality; A = accessibility; TN = treatment need; II = importance index; CV = condition value; RII = relative importance index; RF = relative frequency; k = constant value; C = implementation cost; IV = individual value; RV = relative value; * = base index with subsequent adaptation.

Phase	Description	Assigned value calculation	Results amplitude
Species value*	Considers the average between availability, desirable parts, development, and adaptability	$SV = \frac{Av + Dp + De + Ad}{4}$	0-4
Condition value*	Considers the condition of the individual tree	Great = 4; good = 3; regular = 2; bad = 1; dead = 0	0-4
Biometric value*	Considers the weighting between the diameter at breast height and the bifurcation height of trees	$BV = DBH * 0{,}6 + BH * 0{,}4$	0-∞
Location value*	Considers the sum of individuality standards, accessibility conditions, and the need for maintenance treatment	$LV = I + A + TN$	0-3
Importance index	Multiplication between assigned values	$II = SV * CV * BV * LV$	0-∞
Relative importance index	Importance index weighted by its frequency	$RII = \frac{II}{RF}$	0-∞
Individual constant value	Considers the weighting between implementation cost and the lowest importance index	$ki = C/II^i$	0-∞
Relative constant value	Considers the weighting between implementation cost and the lowest index of relative importance	$kr = C/RII^i$	0-∞
Individual value	Considers the weighting between the importance index and the constant ki	$IV = II * kIV = II * k_i$	0-∞
Relative value	Considers the weighting between the relative importance index and the constant kr	$RV = RII * kr$	0-∞

Source: adapted from Silva Filho & Tosetti (2010).

As seen in table 1, the method proposed by Silva Filho & Tosetti (2010) has gaps in the practical valuation of the benefits provided by urban trees, requiring adaptations that consider important features to determine good urban trees. As an example, the importance index of the method proposed by Silva Filho & Tosetti (2010) considers values based on phytosociology and classical biometrics to quantify both the value of the species and the biometric value of the trees. However, Bobrowski *et al.* (2016) observed that changes have been occurring in the pattern of phytosociological analysis of urban forests, where the canopy cover area and leaf density assume more importance than the basal area.

This change in the valuation of urban trees is due to the difference between the products generated by forests planted for commercial purposes such as biomass production, in comparison to those provided by urban forests, which are associated with ecosystem services – mainly the improvement of the population's well-being. In this sense, Bobrowski & Biondi (2012) emphasize that the treetop or canopy is of utmost relevance in street trees due to its association with the main ecosystem services provided by the trees such as the reduction of thermal amplitude, the aesthetic beauty, and the rainwater infiltration.

Thus, our study proposes to calculate the trees' value with methodological changes that represent the value of the urban forest more realistically, adding features related to the canopies and the physical environment surrounding the trees.

The variable Leaf Density of the Species (Ld) was added to the species value based on the description of the species in the literature, with the calculation described by the following equation:

$$SV' = \frac{Av + Dp + De + Ad + Ld}{5}$$

Where:
SV' = new proposed species value;
Av = availability;
Dp = desirable parts;
De = development;
Ad = adaptability;
Ld = leaf density of the studied species.

To determine the values of availability, desirable parts, development, adaptability, and leaf density, the characteristics described in table 2 were followed. The items in table 2 will be explained later in relation to their score values.

Table 2 – Parameters attributed to the quantification of the species value.

Points	Availability	Desirable parts	Development	Adaptability	Leaf density
4	Not found on the market and/or unknown or uninitiated breeding techniques	No parts are undesirable	Very slow	Difficult to adapt, demanding species	Dicotyledonous, high-density foliage
3	Found with difficulty; difficult reproduction	One of the parts is undesirable	Slow	Indigenous species	Dicotyledonous, medium-density foliage
2	Easily found	Two of the parts are undesirable	Normal	Exotic species	Monocotyledonous
1	Seedlings on-site	Three or more parts are undesirable	Fast	Invasive species	Dicotyledonous, thin foliage

Source: adapted from Silva Filho & Tosetti (2010).

In relation to the parameters attributed to the quantification of the species value in table 2, for Availability, our proposed method adds a higher value to the native species within the street trees, as a way of encouraging the maintenance of biodiversity and reducing changes in the floristic composition of the local landscape.

For the parameter Desirable parts, we consider that undesirable parts were those whose characteristics resulted in risks to the population, such as large fruits, parts of the plant presenting toxicity or allergenic components, thorns, superficial roots, and monopodial orthotropic vertical growth due to it not accepting pruning.

For the parameter Development, we think that trees with fast development, despite shading faster, tend to have lower quality wood, are more susceptible to attack by pests and diseases and have a shorter useful life.

In what it refers to Adaptability, our proposed method adds a higher value to hard-to-adapt species and demanding species, followed by native species, exotic and exotic invasive species. We propose this method to value native and/or rare species.

For leaf density, we think that the greater the density of leaves in the canopy, the greater the proportion of microclimatic benefits provided to the environment, due to the higher rate of shading and evapotranspiration, in addition to the greater production of oxygen.

We established that species with values between 1 and 2 are inadequate, with few benefits to the urban environment; species with values between 2 and 3 are satisfactory to the urban environment; and species with values between 3 and 4 are very beneficial to the environment.

Our study proposed that the biometric value of the trees is no longer related to the Diameter at Breast Height (DBH), but to the canopy volume, as described in the following equation:

$$BV' = |Log(CV * BH)|$$

Where:
BV' = new proposed biometric value;
CV = canopy volume;
BH = bifurcation height.

The weighting was attributed by the logarithmic function to normalize the data and decrease the amplitude of the variable, making it more compatible with the biometric value obtained by Silva Filho & Tonetti (2010).

The canopy volume was calculated by averaging the tree canopy radius (CR) and half the canopy length (CL/2), resulting in a mean radius for calculating the volume of a sphere (figure 2).

Figure 2 – Variables used to calculate canopy volume. Legend: CR = canopy radius; CL/2 = half the canopy length. Source: primary.

This calculation causes trees with voluminous but low crowns to have their biometric value reduced, since low crowns have low value in urban afforestation, due to interference in accessibility and pedestrian circulation. In this sense, our method proposes that trees with a larger canopy and higher bifurcation height have a greater biometric value.

The physical and phytosanitary conditions of the trees were evaluated on a scale. For the assessment of the physical condition and plant health, the scale was 4 for great trees (considering vigorous trees with no structural defects), 3 for good trees (vigorous with defects that can be corrected and that do not interfere with tree development), 2 for regular trees (with structural and physiological problems that compromise part of the physical structure or physiological conditions), 1 for bad trees (with structural or physiological problems that compromise the health and stability of the entire tree), and 0 for dead trees.

Figure 3 – Physical and phytosanitary conditions of the street trees. Legend: A – great condition tree; B – good condition tree; C – regular condition tree; D – bad condition tree; E – dead tree. Source: primary.

The variable Distance from Power Distribution Lines (DL) was added to the location value. This variable is directly linked to the maintenance or removal of urban trees (MAYER *et al.*, 2014; SILVA *et al.*, 2020) when the minimum distance of 1 meter between the tree and the power line is disrespected (COPEL, 2020).

The Location Value (LV) was calculated by weighting the sum of the quantification parameters (table 3), ensuring the amplitude of the results was similar to the base method. The location value was obtained by the following equation:

$$LV' = \frac{(I + A + TN + DL)}{4} * 3$$

where:
LV' = new proposed location value;
I = individuality;
A = accessibility;
TN = treatment need;
DL = distance from power lines.

The items in table 3 will be explained later in relation to their score values.

Table 3 – Parameters assigned to the quantification of the location value.

Points	Individuality	Accessibility	Treatment need	Distance from power lines
1	More individuals of the same species in the plot	Distance from the property higher than 1.20 m	No	Distance higher than 1.00 m
0	Only 1 individual of the species in the plot	Distance from the property lower than 1.20 m	Yes	Distance lower than 1.00 m

Source: adapted from Silva Filho & Tosetti (2010).

In relation to the parameters attributed to the quantification of the location values in table 3, for Individuality, Silva Filho *et al.* (2002) say that the presence of another individual of the same species can add landscape value to the environment.

For the parameter Accessibility, we consider that a tree in the correct position, respecting the minimum distances to ensure accessibility on the sidewalks, must have its value enhanced, in comparison with incorrectly located trees, which hinder the movement of people with reduced mobility.

As for Treatment need, we think that trees that need treatment, must present less value because they will demand greater financial and logistical investments for their better adaptation to the environment.

Regarding the Distance from power lines, our proposed method adds a higher value to trees that maintain the minimum recommended distances from power transmission lines and poles, considering that the interference of trees in the distribution of energy is one of the main factors indicating pruning and, therefore, require more investment of financial resources.

The implementation cost present a greater amplitude between different municipalities and countries, mainly due to the lack of urban tree planting regulation and the absence of standardization in the seedlings' origin and management. Therefore, for calculating the implantation cost, the value available at the municipal plant nurseries must be considered. In the case of cities where trees are mainly planted by the population, the value invested by people should be considered, such as the cost of seedling acquisition and the supplies needed for planting.

The monetary valuation of urban trees is also complex since many of the diverse ecosystem services provided are public goods and, therefore, not commercialized in the market, meaning there is a lack of data on the prices and quantities demanded (FRUTH *et al.*, 2019). Furthermore, Leal *et al.* (2008) recommend that the monetary values of street trees, mainly the costs related to their implementation and maintenance, should be managed by the public administration, aiming to raise the population's awareness on the importance of street trees.

In our case study, the municipal government of Itanhaém does not have specific funds for the planting and maintenance of street trees and, consequently, the trees are planted and managed by the population. Hence, the implementation costs considered in this study case were based on the residents' investment in planting. The average commercial value of a 1.80 m seedling is USD 19.00 in the plant nurseries of the city, and 10 kg of black soil represent USD 4.40. Both costs were considered in this study. The costs of fertilizers or other supplies were not considered, meaning that the total average planting cost was USD 23.40 per tree.

Calculation of Importance index (II) and Relative Importance Index (RII), Individual and Relative Constant (ki and kr), and Individual value (IV) and Relative value (RV) followed the method proposed by Silva Filho & Tosetti (2010), presented in table I.

To calculate the final value of the street tree, we used the equation developed by Potenza (2016), who replicated the valuation method proposed by Silva Filho & Tosetti (2010). Potenza observed that the calculation of relative valuation presented in most cases shows an overvaluation of the less frequent species and an undervaluation of the more frequent species.

Thus, the equation that best expresses the real value of trees is the weighting between their individual and relative value. The final tree valuation was calculated using the following equation:

$$STV = \frac{(IV + RV)}{2}$$

where:
STV = street tree value (in currency);
IV = individual value;
RV = relative value.

The relative constant value (kr) was calculated based on the value of the lowest relative importance index (0.01) attributed to a tree and on the average planting cost in USD per tree for the study area which enabled the conversion of the relative importance index into monetary value.

All calculations were firstly done in the local currency (Brazilian Real – BRL) and, later, converted to United States Dollar (USD), according to the exchange rate on December 8th, 2020, when BRL 1 was equal to USD 0.20.

RESULTS AND DISCUSSION

Of the 1,265 individuals in the sample, 80 had died. Thus, the evaluation considered 1,185 trees located in the streets of Itanhaém, São Paulo, Brazil, distributed among 91 species. The average value of the tree species implanted in the municipality's streets was 2.4, with a variation range between 1.8 and 3.2, with the ten species with the highest value, described in table 4.

Table 4 – Ranking of street tree species present in the study area according to the highest species value. Legend: Av = availability; Dp = desirable parts; De = development; Ad = adaptability; Ld = leaf density; FR (%) = species relative frequency in percentage; SV' = species value.

Ranking	Species	Av	Dp	De	Ad	Ld	SV'	FR (%)
1°	*Coccoloba uvifera* L.	3	4	3	2	4	3.2	0.17
2°	*Bertholletia excelsa* Bonpl.	2	4	3	3	4	3.2	0.08
3°	*Annona muricata* L.	2	4	2	3	4	3.0	0.42
4°	*Mimusops coriacea* (A. DC.) Miq.	3	4	2	2	4	3.0	0.33
5°	*Paubrasilia echinata* Lam.	2	3	3	3	4	3.0	0.25
6°	*Averrhoa carambola* L.	2	4	2	3	4	3.0	0.25
7°	*Annona squamosa* L.	2	4	2	3	4	3.0	0.16
8°	*Caesalpinia pluviosa* var. *peltophoroides* (Benth.) G.P.Lewis	2	4	2	3	4	3.0	0.16
9°	*Hymenaea courbaril* L. var. *courbaril*	2	4	2	3	4	3.0	0.08
10°	*Syzygium samarangense* (Bl.) Merr. Et Perry	3	4	2	2	4	3.0	0.08

Among the ten species with the highest ranking, only *P. echinata* presented one of the undesirable parts, which are thorns on the trunk. However, as it is native to Brazil and has slow development and high leaf density, the species obtained a high value.

Although the proposed method has valued native species, we observed that adapted exotic species are capable of presenting similar added value. They have high leaf density and slow to moderate development, and all parts of the plant are desirable – all advisable features for trees in the urban environment. However, although the presence of exotic species is common in Brazilian cities, the relevance of native species for the conservation of biodiversity must be encouraged. The relevance of native species is reflected in its monetary value.

Silva *et al.* (2020) explain that the seeds produced by exotic species can easily be dispersed in urban spaces and in forest remnants, which increases the risk of biological invasions and can put native plants at risk. For this reason, the monetary valuation of exotic species must consider the negative impacts these species may cause in natural environments, even if these plants are not considered invasive.

In the classification of the 91 evaluated species, the mean value of availability was 2.0, with a variation range between 1.0 and 3.0. This result demonstrates that the majority of species is offered by the municipality or is easily found in local commerce, with little incentive for species with difficult reproduction. However, the planting of native species of difficult reproduction should be encouraged since this allows a greater diversity of native species in the urban flora, favoring those that are more environmentally sensitive.

The mean value of the desirable parts was 3.9, with a variation range between 2.0 and 4.0, indicating that, overall, the chosen species present no undesirable parts. This results in a greater probability of the community accepting and caring for the trees.

The mean adaptability value was 2.8, with a variation range between 1.0 and 4.0, demonstrating that the majority of the species are native or exotic trees adapted to the characteristics of the region. Zamproni *et al.* (2016) state that the balance between adaptability and species frequency is an important factor that must be considered when planning the urban forest.

The biometric value of the species varied between 0.01 for *E. brasiliensis* (a species that was not included in the table because only the 10 species with the highest biometric values were presented) and 3.61 for *Terminalia catappa,* with a mean of 1.05. The 10 species with the highest biometric values, above 0.25, are presented in the table 5. Among the ten species with the highest biometric value, two of them were palm trees, namely *A. cunninghamiiana* and *C. urens*.

Table 5 – Ranking of the street tree species in the study area by the highest biometric value. Legend: Rk = Ranking; BH = bifurcation height; CV = canopy volume; BV' = biometric value; min = minimum; max = maximum.

Rk	Species	BH (m)	CV (m^3)	BV'		
				mean	min	max
1°	*Eucalyptus* sp.	6.33	356.22	3.34	3.25	3.44
2°	*Archontophoenix cunninghamiiana* H. Wendl. & Drude	6.68	91.80	2.55	1.29	3.37
3°	*Leucaena leucocephala* (Lam.) de Wit	2.03	141.74	2.46	2.39	2.52
4°	*Delonix regia* (Bojer ex Hook.) Raf.	2.24	221.06	2.42	0.50	3.22
5°	*Terminalia catappa* L.	2.56	198.28	2.33	0.25	3.61
6°	*Tipuana tipu* (Benth.) Kuntz	2.03	160.83	2.23	1.09	2.66
7°	*Hymenaea courbaril* L. var. *courbaril*	0.80	204.74	2.21	2.21	2.21
8°	*Clitoria fairchildiana* R.A.Howard	0.58	215.07	1.96	1.68	2.27
9°	*Caryota urens* L.	3.80	26.49	1.90	1.30	2.64
10°	*Calophyllum brasiliense* Cambess.	2.09	52.56	1.89	1.22	2.37

A. cunninghamiiana was the species with the highest bifurcation height – in this case, it was characterized by the height of the stem. Although the species has achieved a high biometric value, palm trees have orthopedic monopodial canopy architecture, making them intolerant to pruning. For this reason, these palm trees must be implanted exclusively in locations with sufficient space for their development and that are free from power lines or other structures that may cause conflict.

Among the ten species with the highest biometric value, only *H. courbaril* and *C. fairchildiana* had a mean bifurcation height below the minimum of 1.80 m recommended in the literature (LIMA NETO *et al.*, 2012). This result shows that, if the individuals had been correctly maintained during their development, they could have reached a higher biometric value. In this sense, Estellita & Demattê (2006) explain that individuals of the same species may be suitable for some places and unsuitable for others, comparing, for example, the different characteristics between sidewalks and green areas.

The mean location value of the trees was 2.01, with a variation range between 0.75 and 3.0, and the most frequent value (2.25) was attributed to 34.7% of the trees, showing that 3 of the 4 attributes of good location were found. The features that contributed to the location value are described in table 6.

Table 6 – Number of trees per classification parameter of the location value.

Point	Individuality	Accessibility	Treatment need	Distance from power lines
0	415	294	583	500
1	770	891	602	685

At the same time, 16.5% of the valuated street trees obtained a location value of 3.0, indicating that all variables of good location were found, whereas 14.43% showed only one variable of good location.

Accessibility was the variable that most contributed to the location value, with approximately 75.2% of the trees being planted respecting accessibility laws, with a distance of 1.20 m or more from the property.

The lowest importance index found was 0.44 for *E. brasiliensis* (a species that was not included in the table because only the 10 species with the highest biometric values were presented) and the mean value of the species was 14.7. However, the ten species with the highest importance index had their mean value between 30.3 and 60.8 (table 7).

Table 7 – Ranking of the street tree species in the study area by the highest importance index. Legend: Rk = Ranking; SV' = species value; CV = condition value; BV' = biometric value; LV' = location value; II = importance index.

Rk	Species	SV'	CV	BV'	LV'	II		
						mean	min	max
1º	*Archontophoenix cunninghamiiana* H. Wendl. & Drude	2.4	4.0	2.5	2.4	60.8	28.1	97.3
2º	*Leucaena leucocephala* (Lam.) de Wit	2.0	4.0	2.5	3.0	58.9	57.2	60.6
3º	*Spondias purpurea* L.	2.8	4.0	1.6	2.3	40.6	40.6	40.6
4º	*Coccoloba uvifera* L.	3.2	4.0	1.0	3.0	37.8	35.2	40.5
5º	*Hymenaea courbaril* L. var. courbaril	2.8	4.0	2.2	1.5	37.2	37.2	37.2
6º	*Terminalia catappa* L.	2.6	3.0	2.3	2.0	36.9	4.0	106.2
7º	*Delonix regia* (Bojer ex Hook.) Raf.	2.8	3.2	2.4	1.5	36.2	2.1	105.0
8º	*Pseudobombax marginatum* (A.St.-Hil.) A. Robyns	2.6	4.0	1.5	2.3	34.2	34.2	34.2
9º	*Tipuana tipu* (Benth.) Kuntz	2.6	3.5	2.2	1.5	31.3	8.5	46.4
10º	*Calophyllum brasiliense* Cambess.	2.6	3.3	1.9	1.9	30.3	9.5	41.5

Table 7 shows that the valuation of street tree individuals and species is complex and does not depend on a single factor. For example, although *C. uvifera* has the highest species value, it has a low biometric value, which reduces its importance when compared to other species. In contrast, *L. leucocephala* has low species value but high condition and location values. This result demonstrates the importance of urban tree management, as species of excellent intrinsic quality may have their value depreciated when implanted in inappropriate locations or when they lack proper maintenance.

The relative constant value (kr) was calculated based on the value of the lowest relative importance index (0.01) attributed to a *F. benjamina* tree and on the average planting cost of USD 23.40 per tree for the study area. We obtained kr = 9,261, which enabled the conversion of the relative importance index into monetary value.

This relative constant value found in our study is approximately 25 times higher than those found for the valuation of the urban forest of three other studies, one in the Jaboticabal municipality, also in the state of São Paulo (SILVA FILHO *et al.*, 2002), and two in different parts of São Paulo City: Ibirapuera Park (SILVA FILHO & TOSETTI, 2010) and Córrego do Sapateiro watershed (TOSETTI, 2012) (table 8).

Table 8 – Relative constant value of the urban forest in São Paulo state (SP), Brazil. Legend: IC = implementation cost; RII^{l} = lowest relative importance index; kr = relative constant value; FSTV = final street tree value; AVST = average value per street tree.

Reference	Area	IC (USD)	RII^{l}	kr	FSTV (USD)	AVST (USD)
This study	Itanhaém – SP	23.40	0.01	1852	600,000,000.00	40,469.47
Silva Filho *et al.* (2002)	Jaboticabal – SP	2.40	0.03	400	-	-
Silva Filho & Tosetti (2010)	Ibirapuera Park, São Paulo – SP	1.89	0.03	315	18,800,000.00	1,247.84
Tosetti (2012)	Córrego do Sapateiro, São Paulo – SP	3.67	0.05	367	220,440.7	400.00
Potenza (2016)	Córrego do Sapateiro, São Paulo – SP	46.89	0.02	9018	15,007,300.24	13,934.35
Potenza (2016)	Cambui neighborhood, Campinas – SP	20.80	0.02	4727	12,097,672.07	697,272.00

Table 8 shows that the values of the relative constant differ between studies due to the influence of the relative importance index and the cost of implementation, which vary according to the particularities of each study area, directly affecting the average value of the tree. However, we emphasize that, in view of the minimum silvicultural treatments, the implementation cost was considered a low value in our study, since well-produced seedlings with adequate parameters to the urban composition would require fertilization and pruning, which focus on the highest planting cost.

The amplitude of the implementation value was 1,953%, a very high value that makes expanding the valuation to other municipalities difficult. The values described by Silva Filho *et al.* (2002) and Silva Filho & Tosetti (2010) are far from the current reality of implementation in many Brazilian municipalities as the plantation cost would be approximately USD 23.06 – which varies according to the development of seedlings, even though the methods of obtaining seedlings were primary, that is, their production is carried out by municipal government and nurseries.

Thus, considering the constant kr calculated for the study area, the mean value of the street trees in Itanhaém is USD 32,932.43, with the average for the ten individuals with the highest final value reaching USD 3,576,977.45 (table 9).

Table 9 – Ranking of street trees species in the study area by the highest monetary value. Legend: II = importance index; RII = relative importance index; IV = individual value; RV = relative value; FSTV = final street tree value.

Species	II	RII	IV (USD)	RV (USD)	FSTV (USD)
Spondias purpurea	40.61	481.59	75,212.32	892,018.07	483,615.19
Hymenaea courbaril	39.86	472.71	73,825.57	875,571.24	474,698.41
Pseudobombax marginatum	36.82	436.74	68,208.23	808,949.59	438,578.91
Leucaena leucocephala	60.60	359.36	122,245.65	665,616.73	388,931.19
Leucaena leucocephala	57.25	339.47	106,033.05	628,775.97	367,404.51
Archontophoenix cunninghamiiana	97.26	230.69	180,144.68	427,303.17	303,723.92
Syzygium samarangense	25.13	298.01	46,541.51	551,982.30	299,261.90
Dypsis decaryi	23.47	278.36	43,473.15	515,519.51	279,532.33
Pachira glabra	42.60	252.64	78,913.44	467,956.71	273,435.07
Archontophoenix cunninghamiiana	85.75	203.40	158,833.93	376,754.09	267,794.01

The individual trees with the highest value found in other monetary valuation studies were significantly lower than in our study area - the final value closest to Itanhaém was found in the Cambuí neighborhood in Campinas, São Paulo state, where a specimen of *Cordia trichotoma* (Vell.) Arráb. ex Steud. reached an estimated value of USD 226,518.07 and a relative importance index of 452.93 (POTENZA, 2016).

Regarding the street tree value for the valuated species, the ten species with the highest accumulated values include the three most frequent species in the study area: *T. catappa*, *F. benjamina*, and *D. lutescens* (table 10).

Table 10 – Ranking of street tree species in the study area by the highest street tree total value. Legend: IV = individual value; RV = relative value; STV = street tree value; RF = relative frequency; SV = species value; BV = biometric value.

Species	IV (USD)	RV (USD)	STV (USD)	RF (%)	SV	BV
Terminalia catappa	14,882,431.41	809,658.88	7,846,045.15	18.38	2.25	1.19
Dypsis lutescens	7,138,011.73	617,932.99	3,877,972.36	11.55	2.50	0.97
Cocos nucifera	5,096,579.77	657,015.91	2,876,797.69	7.76	2.25	1.26
Ficus benjamina	4,674,268.22	270,423.52	2,472,345.87	17.28	2.00	0.41
Cocos nucifera var. *nana*	1,838,333.63	622,932.48	1,230,633.05	2.95	2.25	0.79
Delonix regia	1,473,458.16	794,327.90	1,133,893.03	1.85	2.50	1.10
Archontophoenix cunninghamiiana	563,381.67	1,336,341.32	949,861.49	0.42	2.50	2.94
Leucaena leucocephala	218,278.70	1,294,392.70	756,335.70	0.17	1.75	0.94
Syagrus romanzoffiana	884,106.53	616,794.32	750,450.43	1.43	2.00	1.68
Handroanthus heptaphyllus	654,746.61	485,330.93	570,038.77	1.35	2.00	0.65

Of the species with the highest street tree value, 80% are exotic in Brazil, some with known invasive potential, and all commonly found in urban forests surveys worldwide, such as *T. catappa*, *F. benjamina*, *D. lutescens*, *D. regia*, *C. nucifera*, *A. cunninghamiiana*, and *L. leucophala* (GUZMÁN-MORALES *et al.*, 2011; PHULWARIA *et al.*, 2012; ZHANG & JIM, 2014a; 2014b). This percentage is considered high since the Brazilian biodiversity is prodigious but still underrepresented in urban areas. Exotic species, particularly invasive ones, tend to cause damage to the provision of ecosystem services, which decreases the monetary value of each tree specimen.

The biometric value of the trees influenced the sum of the final street tree value, as the individuals of *F. benjamina*, the second most frequent species, ranked fourth in the sum of their individuals, and also presented the lowest biometric index for the species shown in table 10. This may have occurred due to the reduction in the total height of *F. benjamina* individuals, which, according to Maria *et al.* (2017), are often pruned to be compatible with the space they occupy in the urban forest.

Concerning the monetary valuation by administrative regions of Itanhaém, Suarão has the highest final street tree value, while Umuarama has the region with the lowest average value per street (table 11).

Table 11 – Monetary valuation of street trees in the study area by administrative region. Legend: NVI = number of valuated individuals; SAV = species average value; CAV = condition average value; BAV = biometric average value; LAV = location average value; AVST = average value of street trees; FSTV = final street tree value.

Administrative Region	NVI	SAV	CAV	BAV	LAV	AVST (USD)	FSTV (USD)
Cibratel	169	2.40	3.12	0.98	1.42	29,787.02	2,472,322.53
Centro	130	2.42	3.58	1.29	1.87	38,303.40	2,030,079.96
Loty	172	2.50	3.21	1.60	1.99	38,277.50	4,969,575.53
Suarão	160	2.45	3.28	1.54	2.03	35,078.09	5,928,196.73
Gaivota	109	2.33	3.50	1.34	2.10	32,618.31	3,555,396.29
Savoy e Nova Itanhaém	88	2.45	3.34	1.37	1.60	31,015.61	1,178,593.07
Praia dos Sonhos	66	2.41	3.02	1.08	1.63	22,896.03	1,442,449.91
Belas Artes e Corumbá	83	2.42	3.47	1.22	2.02	27,787.27	4,779,409.68
Bopiranga	53	2.49	3.11	1.75	1.83	37,790.59	1,322,670.75
Ivoty	63	2.42	3.17	1.73	1.59	40,568.58	2,677,526.34
Mosteiro	35	2.43	3.73	1.27	1.98	36,290.41	3,193,556.26
Guapiranga e Sabaúna	38	2.45	3.29	1.39	1.71	28,350.74	4,536,119.18
Umuarama	19	2.38	3.11	1.10	1.53	16,794.38	319,093.15
Total	**1,185**	**2.43**	**3.33**	**1.37**	**1.86**	**32,924.43**	**39,015,455.23**

Regarding the size of the trees, when we related our results with the data described by Maria (2017), we found that a tree with average standards for our study area (with 4.6 m height and 16.8 cm DBH) has an approximate value of USD 32,932.43.

When using a stratified random sampling method and considering the 1,185 street trees valuated, to extrapolate the results to the 18,128 street trees present in the study area, we found that Itanhaém has a street tree value estimated at approximately USD 600 million. For comparison, in several cities in the United States, street trees were valuated as follows: USD 101 million for Jersey City, NJ; USD 1.2 billion for Boston, MA; and USD 5.1 billion for New York, NY (NOWAK *et al*., 2002).

The data and results of our study and, importantly, our proposed method, can be replicated to monetize street trees and urban forest of different cities around the world, in addition to functioning as a tool for punitive fines related to the degradation of trees in the urban environment. With this study, we hopefully contribute to better management practices and to optimize financial resources.

CONCLUSION

With our proposed new evaluation method, we were able to clearly observe the effects of good urban forest management and to identify where trees have their added or depreciated value, indicating the necessary measures for better maintenance and appreciation of street trees.

The street trees of Itanhaém have a value of USD 600 million, with the highest total street tree value belonging to the administrative region Suarão and the highest average value per tree belonging to Loty.

Most of the sampled species have a Species Value (SV) higher than 2.0, indicating a satisfactory relation regarding the offer of benefits to the urban environment. However, the average location value (LV) shows that street trees of the study area are not in the best locations for their siting, according to the physical environment, indicating that most sitings do not meet at least one of the recommended minimum distances, which negatively influences their value. Moreover, the low bifurcation height was the main responsible for reducing the Biometric Value (BV) of the street trees, also decreasing their value.

Thus, the municipality of Itanhaém has a good species selection, although it fails in quality and implementation, as well as in the selection of seedlings, which prevents the increase of the final street tree value. Furthermore, an excess of exotic species was found, which also tends to decrease the monetary value of the city's urban trees.

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REFERENCES

Bobrowski, R. & Biondi, D. Distribuição e dinâmica da área de copa na arborização de ruas de Curitiba, Paraná, Brasil, no período de 1984-2010. Árvore. 2012; 36(4): 625-635.

Bobrowski R., Ferreira R. L. C. & Biondi D. Descrição fitossociológica da arborização de ruas por meio de diferentes formas de expressão da dominância e da densidade. Ciência Florestal. 2016; 26(4): 1167-1178.
doi: https://doi.org/10.5902/1980509825107

Copel – Companhia Paranaense de Energia. Arborização de vias públicas. 2020. [Acesso em: 6 set. 2020]. Disponível em: https://www.copel.com/hpcopel/guia_ arb/depois_de_plantar2.html.

Derkzen, M. L., van Teeffelen, A. J. A. & Verburg, P. H. Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands. Journal of Applied Ecology. 2015; 52(4): 1020-1032.
doi: http://dx.doi.org/10.1111/1365-2664.12469

Estellita M. & Demattê, M. E. S. P. Índice de valor paisagístico para árvores em ambiente urbano. Ornamental Horticulture. 2006; 12(2): 103-111.
doi: https://doi.org/10.14295/ rbho.v12i2.192

Fruth, E., Kvistad, M., Marshall, J., Pfeifer, L., Rau, L., Sagebiel, J., Soto, D., Tarpey, J., Weir, J. & Winiarski, B. Economic valuation of street-level urban greening: a case study from an evolving mixed-use area in Berlin. Land Use Policy. 2019: 89: 1-12.
doi: https://doi.org/10.101 6/ j.landusepol.2019.104237

Guzmán-Morales, J., Hernandez-Alvarez, E. & Garcia-Arreola, M. E. Assessment of atmospheric metal pollution in the urban area of Mexico City, using *Ficus benjamina* as biomonitor. Bulletin of Environmental Contamination and Toxicology. 2011; 86: 495-500.

IBGE – Instituto Brasileiro de Geografia e Estatística. Censo 2010. [Acesso em: 17 jun. 2021]. Disponível em: http://censo2010.ibge.gov.br/noticiascenso?view=noticia&id=3&idnoticia=1766&busca=1&t=censo-2010-populacao-brasil-190-732-694-pessoas.

Kadir, M. A. A. & Othman, N. Towards a better tomorrow: street trees and their values in urban areas. Procedia – Social and Behavioral Sciences. 2012; 35: 267-274.

Leal, L., Biondi, D. & Rochadelli, R. Custos de implantação e manutenção da arborização de ruas da cidade de Curitiba, PR. Árvore. 2008; 32(3): 557-565.

Lima Neto, E. M., Biondi, D., Araki, H. & Bobrowski R. Fotografias aéreas para mensuração da área de copa das árvores de ruas de Curitiba – PR. Floresta. 2012; 42(3): 577-586.

Maria, T. R. B. C. Inventário quali-quantitativo da arborização viária do município de Itanhaém – SP. [Master Thesis]. Curitiba: Federal University of Paraná; 2017.

Maria, T. R. B. C., Biondi, D. & Bobrowski, R. Inventário florístico quali-quantitativo das vias públicas de Itanhaém – SP. Revista da Sociedade Brasileira de Arborização Urbana. 2016; 11(4): 79-97.

Maria, T. R. B. C., Biondi, D. & Zamproni, K. Proposta de calçadas acessíveis em consonância com a arborização viária estabelecida em Itanhaém – SP. Revista da Sociedade Brasileira de Arborização Urbana. 2017; 12(4): 87-101.
doi: http://dx.doi.org/10.5380/revsbau.v12i4.635 55

Maria, T. R. B. C, Biondi, D. & Zamproni, K. Spacial indexes and biological diversity of Itanhaém, São Paulo, Brazil. Floresta. 2019; 49(2): 267-276.

Mayer, C. L. D., Oliveira Filho, P. C. & Bobrowski, R. Análise espacial de conflitos da arborização de vias públicas: caso Irati, Paraná. Floresta. 2014; 45(1): 11-20.

McPherson, E. G., Doorn, N. & Goede, J. Structure, function and value of street trees in California, USA. Urban Forestry & Urban Greening. 2016; 17(1): 104-115.

Nowak, D. J., Crane, D. E. & Dwyer, J. F. Compensatory value of urban tees in the United States. Journal of Arboriculture. 2002; 28(4): 194-199.

Nowak, D. J. & Greenfield, E. J. US urban forest statistics, values, and projections. Journal of Forestry. 2018; 116(2): 164-177.

Potenza, R. F. Métodos de fórmula para valoração econômica das árvores nas cidades. [Master Thesis]. São Paulo: Federal University of São Paulo; 2016.

Phulwaria, M., Ram, K., Harish, G. A. K. & Shekhawat, N. S. Micropropagation of mature *Terminalia catappa* (Indian Almond), a medicinally important forest tree. Journal of Forest Research. 2012; 17(2): 202-207.

Randrup, T. B. & Persson, B. Public green spaces in the Nordic countries: development of a new strategic management regime. Urban Forest & Urban Greening. 2009; 8(1): 31-40.

Rogers, K., Andreucci, M. A., Jones, N., Japelj, A. & Vranic, P. The value of valuing: recognising the benefits of the urban forest. In: Pearlmutter, D., Calfapietra, C., Samson, R., O'Brien, L., Ostoić, S. K., Sanesi, G. & Amo, R. A. The urban forest: cultivating green infrastructure for people and the environment. Cham: Springer; 2017. p. 283-302.

Silva, D. A., Biondi, D., Batista, A. C., Behling, A., Rios, J. F., Reis, A. R. N. & Ho, T. L. Motivos de corte de árvores urbanas de Curitiba no período de 2013-2016. Revista da Sociedade Brasileira de Arborização Urbana. 2020; 15(2): 1-12.
doi: http://dx.doi.org/10.5380/revsbau.v15i2.69151

Silva Filho, D. F., Pizetta, P. U. C., Almeida, J. B. S. A. D., Pivetta, K. F. L. & Ferraudo, A. S. Banco de dados relacional para cadastro, avaliação e manejo da arborização em vias públicas. Árvore. 2002; 26(5): 629-642.

Silva Filho, D. F. & Tosetti, L. L. Valoração das árvores no Parque Ibirapuera – SP: importância da infraestrutura verde urbana. LabVerde. 2010; 1: 11-25.

Silva, J. L. S., Oliveira, M. T. P., Oliveira, W., Borges, L. A., Cruz-Neto, O. & Lopes, A. V. High richness of exotic trees in tropical urban green spaces: reproductive systems, fruiting and associated risks to native species. Urban Forestry & Urban Greening. 2020; 50: 1-10.
doi: https://doi. org/10.1016/j.ufug.2020.126659

Song, X. P., Tan, P. Y., Edwards, P. & Richards, D. The economic benefits and costs of trees in urban forest stewardship: a systematic review. Urban Forestry & Urban Greening. 2018; 29: 162-170.

Tosetti, L. L. Valoração arbórea em bacia hidrográfica urbana. [Master Thesis]. São Paulo: Federal University of São Paulo; 2012.

Viana, S. M., Tosetti, L. L., Rollo, L. C. P. & Silva Filho, D. F. Valoração monetária: pesquisas em floresta urbana. Revista da Sociedade Brasileira de Arborização Urbana. 2012; 7(1): 76-88.

Vogt, J., Hauer, R. J. & Fischer, B. C. The costs of maintaining and not maintaining the urban forest: a review of the urban forestry and arboriculture literature. Arboriculture & Urban Forestry. 2015; 41(6): 293-323.

Zamproni, K., Biondi, D. & Bobrowski, R. Avaliação quali-quantitativa da espécie *Licania tomentosa* (Benth.) Fritsch. na arborização viária de Bonito – MS. Revista da Sociedade Brasileira de Arborização Urbana. 2016; 11(2): 45-58.

Zhang, H. & Jim, C. Y. Contributions of landscape trees in public housing estates to urban biodiversity in Hong Kong. Urban Forestry & Urban Greening. 2014a; 13(2): 272-284.
doi: https://dx.doi. org/10.1016/j.ufug.2013.12.009

Zhang, H. & Jim, C. Y. Species diversity and performance assessment of trees in domestic gardens. Landscape and Urban Planning. 2014b; 128: 23-34.
doi: https://doi.org/10.1016/j.landurbplan.2014. 04.017