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What do the inventories say about the urban trees of cities that were originally occupied by tropical forests?

Daniela Castelo Branco Manfrim
Master's studant, ESALQ, USP, Brazil
dmanfrim@usp.br

Talita dos Santos Angélico
Doctoral student, ESALQ, USP, Brazil
tangelico@usp.br

Demóstenes Ferreira da Silva Filho
Professor Doutor, ESALQ, USP, Brazil
dfilho@usp.br

ABSTRACT

Trees provide the urban population with many benefits as mental and physical well-being, property valorization, and climate change mitigation. To evaluate these benefits, it is necessary to know the species composition and distribution of trees in the urban landscape. For this purpose, the tree inventory is a fundamental instrument. This study aims to present an overview of scientific publications based on the street trees inventory of Brazilian municipalities. We expected to find information about the species composition and contributed to managers and decision-makers for species selection in new planting programs. We consulted four databases, initially identifying 322 articles published between 2000 and 2021. We considered 27 of them eligible for the systematic review. The studies are concentrated in cities in the Southeast and South regions. The authors of 21 articles reported quantifying or qualifying the street trees by focusing on planning. In general, species diversity was considered low, and the species mentioned as more abundant are *Ficus benjamina, Moquilea tomentosa*, and *Cenostigma pluviosum*. Exotic was predominant in 11 of 14 surveys that evaluated the origin of the species. These findings show that native flora is severely underrepresented on the streets in Brazilian cities. The alternative path for this scenario would be for the public managers to prioritize long-term actions and public policies starting from inventories that generate information about species composition and the potential environmental services provided by urban trees.

KEYWORDS: Brazilian street trees; public environmental management; tree inventory; urban trees.

1. INTRODUCTION

Urban trees provide the population of the cities with shade, cool air, fruits, mental and physical well-being, property valorization, food and support to the fauna, water flow drainage, and climate change impact mitigation (FAO). Urban trees can also mitigate the environmental impacts of the urbanization process, which has caused significant changes in the structure and composition of the original tropical forests.

Throughout the urbanization process, the fragmentation of the original forests and the introduction of exotic species in cities triggered problems such as loss of diversity and functionality of urban trees (Hunte et al. 2019; Pyles et al. 2020). Considering the suppressed trees and the implanted ones during this process, do the urban trees of the contemporary urban forest represent the species richness of the original forests?

To answer this question, we performed an overview of scientific studies based on street tree inventory (SBSTI) in Brazilian cities, once the main information that is recurrently collected in the inventories is the tree species composition. The urban trees inventory enables quantifying and qualifying the structural aspects of the trees, i.e., the spatial and temporal distribution of the arboreal vegetation in the urban landscape, and the benefits that the urban trees provide (McPherson et al. 2016).

Typically, an urban tree inventory can be a total counting of all trees (census) or a sampling of selected areas. The sampling inventory allows identifying patterns and detecting trends from a sample at an acceptable accuracy level. The sampling inventory design is classified as: simple random sample; cluster sample; systematic sample; and stratified sample, depending on the selection method and the distribution of the sampling units (Kohl 2004; Soares F.; Souza, A.L. 2011). Census is financially viable in small cities, although opting for the sampling inventory is advantageous because the resources (staff, money) required for counting all trees can be reallocated to update information in future inventories (Jaenson et al. 1992)

Usually, the urban tree inventory is carried out through the following steps: (1) the choice of base-map or aerial image; (2) the establishment of the sampling unit (street or block) and the sampling size; (3) the establishment of the qualitative and quantitative parameters of the trees and the surrounding environment; (4) the collection and the processing of the information in field sheets and databases. The optioning for the survey method depends on the availability of time and financial resources, as well as the inventory goal: vegetation registration, a plan for trees increment, or trees management (Milano and Dalcin 2000; Maco and McPherson 2003; Tait et al. 2009).

Considering the need to know if Brazilian flora is represented in urban tree species composition, we propose a systematic review to elucidate questions such as: How have urban tree inventories been carried out? What results did they find? Do the street trees currently reflect the characteristic species richness of the primary forests in Brazil? How the information of the preexisting street trees inventory could contribute to urban tree management and the increment of the urban forest biodiversity? Thus, we hope to find information about the species composition of Brazilian street trees and contribute to managers and decision-makers for the selection of species in new planting programs.

2. METHODOLOGY

We have selected Portuguese and English peer-review articles, published from 1999 to 2021, in national and international journals indexed in the databases Science Direct, Scopus, Periódicos CAPES e CAB Abstracts. We excluded book sections, thesis, and proceedings. We have combined the following English terms: inventory, tree, arboreal or arboreum, street, urban, city, country, survey, and the possible spelling variations. It was unnecessary to include the term “Brazil” because one of the research filters was the study location.

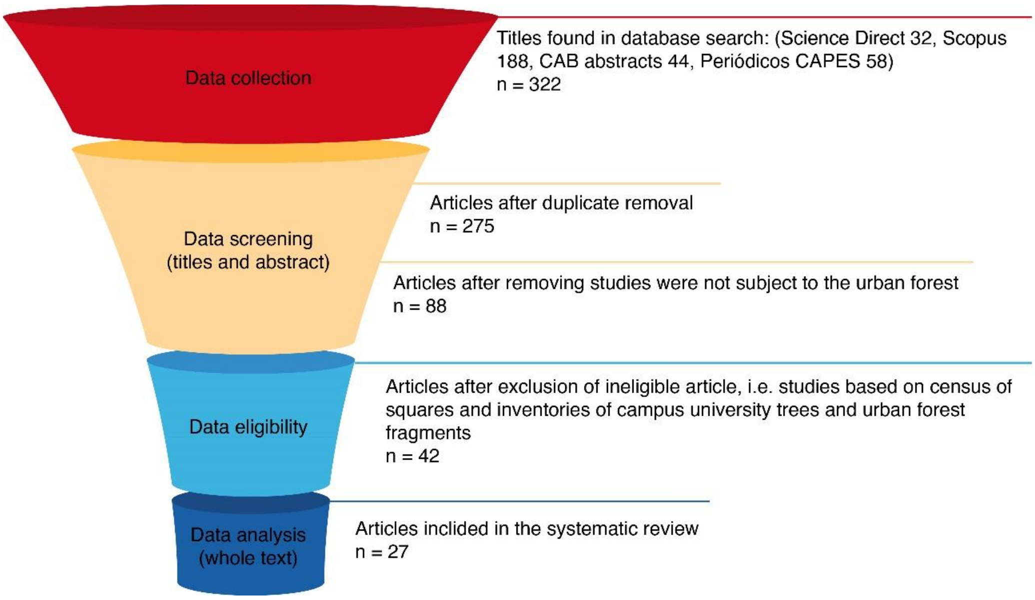
We have defined the inclusion and exclusion criteria according to the recommendations of Pullin and Stewart (2006), selecting studies of street tree inventory or studies based on collected data from preexisting street trees inventory research. First, we selected titles and abstracts and removed duplicates. We then excluded ineligible articles, i.e., studies based on a census of squares and inventories of trees on the university campus and urban forest fragments.

Once we had read the entire text of the eligible articles, we were able to identify relevant information in studies based on the street trees inventory. We also compiled the objectives, the content of the "material and methods", "results" and “discussion” sections, and the recommendations suggested by the authors, using Excel spreadsheets to facilitate their visualization, analysis, and understanding.

3. RESULTS

We initially found 322 articles in 4 databases and selected 275 after removing duplicates. Then, we looked for which ones were related to the urban forest theme. First, we evaluated the title, then the abstract and, finally, the entire article, selecting, respectively, 88, 42 and 27 articles. Figure 1 presents the search strategy and the number of articles selected in each phase.

Figure 1 – Search strategy and number of articles selected

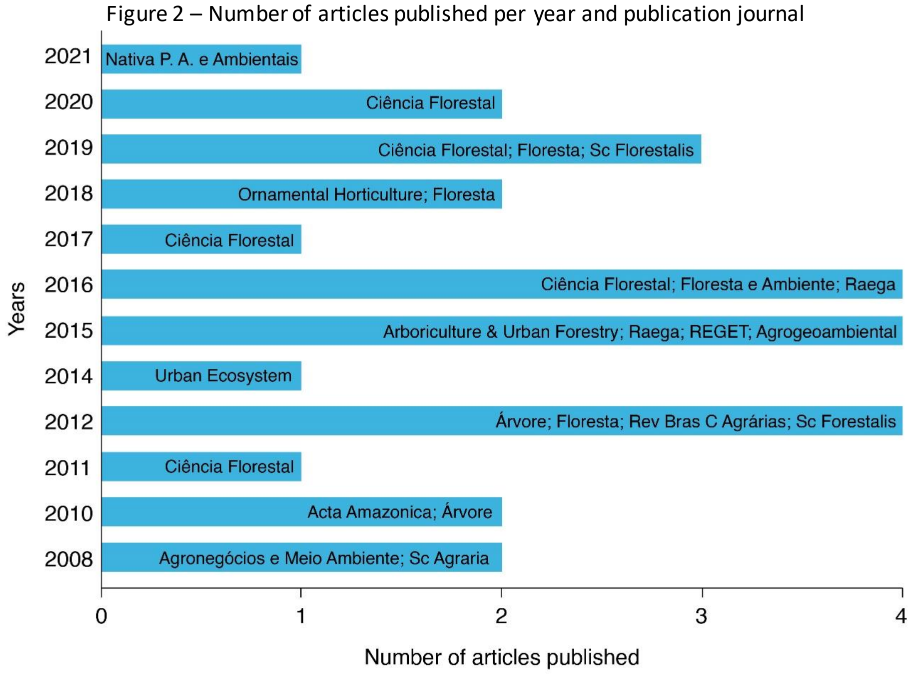


Source: The authors, (2022).

3.1 The Brazilian studies based on street trees inventory

Figure 2 presents the number of found articles published annually from 1999 to 2021. Articles published before 2008 were not found in this systematic review. In addition, Figure 2 summarizes the journals in which the selected articles were published. Out of 27 SBSTI, 25 were published in national journals and 2 in international journals (Urban Ecosystem and Arboriculture & Urban Forestry).

Figure 2 – Number of articles published per year and publication journal



Source: The authors, (2022).

Figure 3 shows most of the studies were conducted in the Southeast and South regions, highlighting cities from Parana State and Sao Paulo State. The North was the least represented region.

Figure 3 - Indication of Brazilian cities where the analyzed studies based on street trees inventory were performed.

Source: Center of Quantitative Methods – CMQ/USP (2022)

Table 1 displays a list of cities where the street trees inventory of the analyzed studies was performed. Table 2 summarizes relevant content on “objective”, “material and methods”, “results” and “discussion” sections, and author recommendations.

Out of 27 papers, 37% executed census, 52% inventories, and 11% accomplished both the census for quantifying and the inventory for qualifying trees. Six articles compared data from preexisting to new inventories; 12 adopted streets as sample units and 4 choose blocks; 11 performed geoprocessing images; 10 filled field sheets with tree and site information; 3 used photographs and 5 collected branches for botanical identification. The authors of SBSTI obtained and analyzed data using ArcGis, WorldView-2, Google Street View, and XLStat® free trial, Excel, BioEstat 4.0 e The authors of the 27 analyzed articles, 24 informed the total number of trees, and 5 calculated the number of trees per kilometer of street or sidewalk. The number of species was mentioned in 74% of the articles. The articles that have not informed the number of species were normally based on remote sensing. The most abundant species was informed in 66.7% of the articles. The number of botanic families was informed by 37% of the SBSTI and the most abundant family was informed by 29% of the papers. The origin of the species was informed in 52% of the analyzed articles, 35.7% of which differentiated Brazilian species from local ones.

Three articles presented the available space for tree development. Conflicts between street trees and electric power wiring were observed in 5 studies, and conflicts with the urban equipment appeared in 8 studies. Finally, problems such as roots outgrowing were mentioned in 4 articles.

The most recommendations made by the authors of the SBSTI were: to arrange a tree management plan, cited in 12 articles; to construct a urban forest plan, by 11 studies; to prioritize the planting of native species, by 10 studies; and to conduct environmental education activities, by 6 studies. Other recommendations appeared only once in the set of this systematic review: invasive exotic species removal; systematic registration; systematic monitoring; resident listening; pruning supervision; forestation plan constitution; adequate species production saplings, use of geotechnology to data collecting; implementation of alternative power wiring and lightning; substitution of sick and dead individuals; use of canopy area and species performance index (SPI) as parameters to assess species relevance.

Table 2: Relevant content of the articles selected for analysis

Objective	Evaluation of tree sampling methods	Specific objectives:
	Biodiversity conservation	- Evaluate the influence of planting spacing under the diversity index
	Tree management	- Analysis of the species richness for the conservation of the biodiversity in urban flora
	Planning	- Understand the relation between trees and architecture
	Historical and cultural appreciation of the tree location	- Demonstrate the potential use of ornamental native species
		- Determine Landscape Ecology indices
		- Identify conflicts between trees and the surroundings
		- Investigate ecology services
		- Remeasurements of street trees to analyze the dynamics of the arboreal component
		- Provide support information for the preparation of the Master Plan
		- Verify the viability of census produced by aerial images
Material and Methods	Street sampling	- Calculation of phytosociological indices (botanical identification, allometric data, diversity, and frequency indices)
	Block Sampling	- Surrounding characterization
	Random sampling	- Study based on preexisting inventory
	Stratified sampling	- Georeferenced image
	Determination of sample intensity	- Physical map
	Census	- Spreadsheet with tree information
		- Survey
		- Remote sensing
Results and Discussion	Abundance and richness of tree species	
	Adequacy of the space for tree planting and development	
	Gini's coefficient	
	Growth performance and phytosanitary condition	
	Inadequate pruning	
	Number of trees per capita	
	Presence of fauna on urban trees	
	Presence of fruit trees	
	Presence of concrete pipe	
	Tree planting position in sidewalk	
Recommendations	Environmental Education Actions	
	Increase in species diversity	
	Phytosanitary care	
	Intervention and management	
	Tree monitoring	
	Planting planning	
	Replacement of the conventional electric power network per compact or underground wiring	
	Use of geotechnologies for tree registration	

Source: The authors, (2022).

3.2 Outstanding methods and findings

Alvarez et al. (2015) used two methods to accomplish the inventory in Campinas, São Paulo State. The first one used aerial images and the second, verification of that in the field. In both cases, the team was formed by 4 researchers. It took a total of 90 hours to complete both phases. Comparatively, it would take 1500 hours to survey the same area working strictly in the field. In addition, this was the only article to present the Gini's coefficient, an index that indicates the relation between canopy cover and socioeconomic population status. Similarly, Lima Neto et al. (2012) and Castro et al. (2016) also compared data obtained through the same two methods, fieldwork and geoprocessing images, in order to check the efficiency of the second one. Likewise, the results showed that there was no statistically relevant difference between the conventional and SIG (Geographic Information System) method.

Some challenges were faced by Lima Neto et al. (2012) when executing this tree inventory utilizing geoprocessing images. The authors reported that saplings and small trees were hard to detect, requiring a previous registration, avoiding misrepresentation of this kind of plant during the images processing. According to the authors, trees' canopy of private properties was confused with public ones, and the opposite also happened; the authors suggested accomplishing a conventional data collection and adding geographic coordinates to avoid this issue. They reported that the building's shadows and the phenological phase of the trees also interfered with the contour of the treetops.

Bobrowski et al. (2016) proposed two forms to describe species representation – expressed by the Importance Value Index (IVI) – in street trees composition. The first one used canopy instead of tree diameter, so that the importance of the species was a consequence of the shade area provided by it, that is, the forest service provided. The second one used Species Performance Index (SPI) – index based on abundance, canopy coverage and tree general condition – instead of species dominance. According to the authors, the SPI offered a more reliable expression of the Importance Value Index because the structural stability of the tree individuals representing each species also determined its significance.

The study of Bobroswski and Biondi (2012) was based on a tree inventory produced in 1984 in Curitiba, Paraná. The authors assessed species composition of the same sample plots of the previous inventory comparing trees reported in 1984 to trees existing in 2010. They verified relative similarity between sample units, i.e., the pattern of the species practically remained in the planting of trees in this period. In addition, they reported the occurrence of trees of different ages, that is, with the presence of young, mature, and adult individuals.

Lastly, Bobrowski and Biondi (2016) verified the influence of planting spacing on species richness and diversity index. The authors verified that the spacing between trees influenced the richness indices, since the reduction in the number of individuals emphasized the weight of the number of species in this value.

3.3 What do the inventories say about street trees

As for the structure of the street trees in the surveyed studies, Almeida et al. (Almeida and Rondon Neto 2010) found 47.7, 52.3, and 56 trees per sidewalk kilometer in 3 cities of Mato

Grosso State. Alvarez et al. (2015) obtained 24.8 trees/km for Campinas, São Paulo State; Locastro et al. (2015) found 172 and 145 per sidewalk kilometer for two avenues of Maringá, Paraná State. Maria et al. (2019) found 21 trees per sidewalk kilometer in Itanhaém, São Paulo State, and Rossetti et al. (2010) found 25.85 trees per street kilometer in São Paulo city. Castro et al. (2016) obtained 0.07 trees per capita for Macapá, Amapá State and Moro and Westerkamp (2011) obtained 10.8 and 13.4 trees per capita for Fortaleza, Ceará State. Some authors (Benatti et al. 2012; Zamproni et al. 2018; Edson-Chaves et al. 2019) found a predominance of small-stature trees.

The number of species ranged from 12 to 219. *Ficus benjamina*, *Cenostigma pluviosum* (sibipiruna) and *Licania tomentosa* (oiti) were the three most frequent species, and *Ficus benjamina* was cited as the most abundant species in 22% of the 18 articles that reported the frequency of the species. The number of botanic families ranged from 7 to 47. The most abundant family was Fabaceae (37.5%). Ceará State cities showed the highest percentage of exotics, i.e., 98% (Edson-Chaves et al. 2019) and 95% (Moro and Westerkamp 2011), as opposed to Palmas, with only 33.17% of exotics and 51.28% of local species (Pinheiro et al. 2020).

As for the development of the street trees, Castro et al. (2016) evaluated the phytosanitary condition and informed that 35% of the studied trees were dead or in bad and regular condition in Macapá; Bortoleto and Silva Filho (2008) and Benatti (2012) observed inadequate pruning. Bortoleto and Silva Filho (2008) observed *Ficus benjamina* and *Caesalpinia peltophoroides* (currently *Cenostigma pluviosum*) as great performing species in Estância Águas de São Pedro, São Paulo State. Still based on tree performance, native species such as *Astronium fraxinifolium*, *Tapirira guianensis*, *Himatanthus drasticus*, and *Andira surinamensis* were recommended as potentially appropriated for broader scale use on in urban treescapes (MORO; CASTRO, 2015).

Two of the three articles that measured the space available for tree development showed that most evaluated site were also inadequate (SILVA et al. 2008; Lobato et al. 2021). Two of 5 studies that mentioned conflicts between street trees and electric power wiring measured the conflict occurrence: 44.89% (Paula et al. 2014) and 14.4% (Bacelar et al. 2020). Two of 8 studies that mentioned conflicts with the urban equipment informed the occurring percentage: 29.82% (Bortoleto and Da Silva Filho 2008) and 34.71% (Paula et al. 2014). *Ficus benjamina* and *Poincianella pluviosa* (currently *Cenostigma pluviosum*) were often pointed as the main cause of damage to the sidewalks (Bortoleto and Da Silva Filho 2008; Benatti et al. 2012; Locastro and Angelis 2015).

4. DISCUSSION

The questions we sought to answer to understand the species composition of Brazilian street trees were: How have street tree inventories been carried out? Which results did they find? Would it be possible to suppose that the street trees currently reflect the characteristic species richness of the primary forests in Brazil? How do these inventories contribute to the management of urban trees?

Firstly, it is important to mention that it was necessary to consult several databases during the search because the number of records obtained in the first searches was lower than we expected. One explanation would be that the articles published in the Brazilian Society of

Urban Trees Journal – REVSBAU, considered relevant for Urban Forestry in Brazil, are not included in the records of the consulted databases. Santos et al. (2021), who presented a systematic review of technology-based studies for the characterization of urban trees, also observed that many Brazilian studies were not cataloged in the usual databases. This systematic review, despite covering 21 years of research, almost a generation in scientific content, included only 27 articles. However, there are currently 5570 Brazilian cities (IBGE 2022). We recognize the existence of numerous research based on urban trees inventory that was not comprised in this work because they were not published in journals cataloged in International Databases. Such Bases are constituted only by journals that implement a rigorous process for the publication of articles, and for this reason, we decided to prioritize the works that attained this rigor. The non-publication of SBSTI in recognized journals evidences the lack of knowledge about the arboreal heritage. Thus, we identified the need to expand the dissemination of knowledge about Brazilian street trees and publish national studies in recognized peer-reviewed journals, gaining scientific rigor and visibility in the content produced.

Moreover, the cost and time to carry out urban trees inventory might be another explanation for the small number of studies found in this systematic review (Alvarez et al. 2015). We believe that the cultural heritage of colonial Brazil influenced the way decision-makers spend resources for the urban trees inventory. In an exploration colony like Brazil was, the tropical forests – whose original characteristic is dense occupation by arboreal individuals and high biodiversity – were seen as a barrier to be overcome for the occupation and exploitation of the territory for economic purposes (Serrão 2002). Apparently, the current urban population and the public managers do not consider trees a legacy that must be well-known and preserved. Although the Federal Constitution of Brazil (Brasil 1988) proclaims the citizen's right to a healthy and balanced environment, we realized that the actions for the increment and maintenance of urban vegetation have not reflected this statement in most Brazilian municipalities. Therefore, we understand that the valuation of a service or product as an inventory depends on the relevance it is given.

In terms of geographic distribution, we observed that most SBSTI were carried out in cities in the Southeast and South regions of Brazil. This regionalization trend probably is due to the number of research institutions and the scientific productivity of those institutions in these regions (José et al. 2016; SEMESP 2020).

How were the surveys done? What results do we consider most important?

The studies based on remote sensing technologies included in this review confirmed the effectiveness of this tool for optimizing the time and cost of carrying out an inventory. Tait et al. (2009), Alvarez et al.(2015) and Jung (2016) proposed alternative methodologies using aerial images and open access software to obtain georeferenced images at a relatively lower cost compared to conventional methodologies for determining the urban forest structure. Despite this advantage, we consider that not all the information necessary to know and manage the arboreal heritage can be obtained exclusively through aerial images. We understand that fieldwork is essential but could be done in a more targeted and assertive way if used as a complement to remote sensing.

The most collected information in SBSTI were number of individuals and the frequency of species: some authors highlighted the most frequent species while others indicated the group of most frequent species and the percentage that this group represents in the total number of inventoried trees. This allows us to state that species composition was the main information in the articles.

We have observed that the term "census" was adopted in some articles even when this method was used just in part of the inventory. Locastro et al. (2015) chose to study just two avenues of Maringá, Paraná State, and yet, they considered it a census. On the other hand, Zamproni et al. (2018) adequately referred to census as the counting of all the trees in Bonito city and inventory when qualifying them by sampling. A variety of approaches and differences in the use of terminologies made it difficult for us to find content intersections, as well as to provide an overview of the "state of the art" of this topic.

We also noticed that, in some SBSTI, the methods were reported as the objective. Perhaps, for this reason, carrying out a qualitative or quantitative research has been the most listed "goals". We tried to scrutinize the real objectives for each of these cases and rethink how this information could be better understood. If we become aware of an existing tree cover from the quantitative survey and this assessment is carried out again, it is possible to build a timeline to know if there is a decrease or increase in the tree density of the streets, and then indicate the need for new planting to achieve the desired coverage goals. In qualitative research, we also have the quantity of trees, but it requires smaller samples in order to compensate for the time demanded in a more accurate survey. Most of the articles included in this systematic review carried out qualitative research. However, this finding does not mean there was a greater availability of resources and time for a type of task that provided more detailed information. The qualitative SBSTI, although carried out in small samples, provides some information that makes it possible to anticipate future accidents caused by falling trees, situations that cause bad publicity to the municipal administration.

Finally, none of the surveyed SBSTI detailed the carbon storage by Brazilian street trees. Considering urban forests sequester CO2 and affect the emission of CO2 from urban areas, this type of information could be used to help assess the actual and potential role of urban forests in reducing atmospheric CO2 (Nowak and Crane 2002).

The best practice to be adopted / New directives join old ones to be executed

To summarize, we note that the use of the SIG method was repeatedly recommended to gain practicability in carrying out continuous inventories. Despite having shown to be statistically efficient in all SBSTI in which it was adopted (Lima Neto et al. 2012; Neto and Biondi 2012; Alvarez et al. 2015; CASTRO, H. S.; DIAS, T. C. A. C.; AMANAJÁS 2016), the remote sensing method still seems not widespread in tree public inventories, considering it was not mentioned in articles published after 2016 included in this review.

We did not observe an increase or decrease in the number of surveys based on urban tree inventories for the period analyzed, which shows a disconnection with the growing concern with issues related to urban trees management and the sustainability of the urban forest biodiversity. The alternative path for this scenario would be for the public managers to prioritize long-term actions and public policies starting from inventories that generate information about the municipal tree heritage and the potential areas to receive new plantings. Knowing which environmental services trees offer to the population depends on the available information about them, such as: quantity; spatial distribution of trees; size; botanical species; and phytosanitary conditions. Based on this information, urban forest managers can make essential decisions to achieve a positive balance, since savings gained by the environmental services provided by the trees compensate for the investments in information and conservation.

A predominance of small-stature trees in the street trees population is the result of many factors such as specific phenotypic characteristics, environmental restrictions, crown-reduction pruning occurrence, the predilection by shrubs, or still indicates juvenile individuals originated from recent planting. Considering the necessity to maximize the ecosystem services offered by street trees, it is necessary to prioritize and ensure the survival and vigor of large trees because small-stature trees do not provide the same benefits as taller ones (Nowak 1994; Center for Urban Forest Research 2004).

Answering the last question, we found out that the tree species of the native flora are severely underrepresented in the roads in Brazilian cities. Examples with higher participation rates of exotics are 98.74% in two cities of Ceará State (Edson-Chaves et al. 2019), 95% in Fortaleza, Ceará (Moro and Westerkamp 2011), and 77% in a neighborhood of São Gabriel, Rio Grande do Sul (Teixeira 2015). Such data demonstrate that Brazilian urban landscaping is colonized by foreign species, provoking aesthetic and environmental effects, as the native fauna might not find a source of food among exotic species. Moreover, in more severe cases, we have examples of invasive species, such as *Leucaena leucocephala*, which spreads through the territory and impedes the growth of other species (Machado et al. 2020).

Finally, this systematic review was an opportunity to detect that, even among professionals who promote and generate knowledge about urban forests, the cultural value that trees are elements that generate conflicts in the urban environment persists. The use of terms such as "aggressive" roots, or statements that trees cause damage to the electrical network and to the surrounding buildings not only shows but also continues to reverberate such misconception. Reviewing speeches and proposing alternatives for better coexistence between trees and urban equipment are challenges to be faced by researchers, residents, public managers, and decision-makers. It is, therefore, necessary to rethink how research produced from inventories can direct the look to urban trees from a less hostile and more “ecosystemic” perspective.

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