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SUSTAINABLE FEATURES OF STREET TREE SPECIES

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Abstract: Services provided by green infrastructure are relevant to sustainability. This importance can be observed by the increase in quantitative approaches in the area recently developed. However, many available tools do not allow to evaluate the sustainability of urban floristic composition practically and efficiently. Hence, planning for urban trees in cities is usually not based on sustainable principles. And this is critical for encouraging sustainable mobility, given the importance of the trees growing in streets for walkability. From this context, the present study aimed to analyze the features of street trees species from the perspective of sustainability. For this, a census survey of tree specimens of height, above 1.0 meter, present along the sidewalks of a Brazilian town, was conducted. The inventoried species were evaluated based on sustainable principles, which were identified based on official documents resulting from UN-led conferences. From a total of 73 tree species surveyed (n=4,081 specimens), 23 showed no less sustainable features (n=3,072; f=75.3%). In the town, the peripheral areas are the ones that most demand interventions to promote more sustainable public spaces. From actions aligned with sustainable urban planning, it is possible to promote safer and more inclusive spaces for citizens.

Keywords: Sustainable principles; green infrastructure; floristic analysis; urban forestry

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INTRODUCTION

Green infrastructure is an essential element for sustainable development, liveability, and the promotion of a more equitable quality of life for urban populations (Roy *et al.*, 2012; Halpern *et al.*, 2013; Donovan, 2017; Artmann *et al.*, 2017).

As a part of this infrastructure, urban forestry and its ecosystem services have been the subject of different researchers in recent years. These services include carbon sequestration (Zheng *et al.*, 2013), reducing air pollution (Wang & Lin, 2012; Bottalico *et al.*, 2017), weather mitigation (Kirnbauer *et al.*, 2013), the improvement of thermal comfort (Tan *et al.*, 2016), and even its influence on the value of urban properties (Saphores & Li, 2012), and city aesthetics (Notaro & De Salvo, 2010).

However, it is essential to plan urban space sustainably, integrating biotic and abiotic infrastructure, for communities to achieve these benefits (Salas-Zapata *et al.*, 2011; Säynäjoki *et al.*, 2014; Capotorti *et al.*, 2015). And this is especially important in the case of trees planted in walking areas. Without adequate planning to select species, trees can cause damage to sidewalks and decrease urban mobility (North *et al.*, 2015; Silva & De Angelis Neto, 2019).

Since sustainable development is based on sustainability principles (Moldan *et al.*, 2012), researchers have proposed ways of quantitative assessments of public green spaces through indicator systems based on these principles (Arnberger, 2012; Gu *et al.*, 2019; Liu *et al.*, 2019). However, there is a lack of qualitative approaches to analyze street trees (Ostoić & Konijnendijk Van Den Bosch, 2015) and to highlight the intrinsic interdisciplinarity of this green infrastructure (Vogt *et al.*, 2016).

Exclusively quantitative analyzes of urban forestry are not able to identify the level of sustainability of each species. Only through technical floristic analysis is it possible to identify less sustainable botanical features and thus to determine the need for interventions at a specific level (Silva *et al.*, 2019). Also, a qualitative approach is required to assess the diversity of tree species (Sjöman *et al.*, 2016; Ren *et al.*, 2017).

Urban studies that aim to measure sustainability in its different dimensions are powerful decision support tools to promote sustainable development, which also corroborates the scientific literature (Waas *et al.*, 2014). Besides, means for sustainability assessment are relevant for their support for the implementation of the 2030 Agenda Sustainable Development Goals (Villeneuve *et al.*, 2017).

Thus, this study aimed to analyze the sustainability of botanical features of street tree species, based on the sustainable principles formally approved in different conferences coordinated by the United Nations (UN). From this information, possible actions can be taken to make the public space more sustainable, safer, and healthier for citizens.

MATERIAL AND METHODS

This section initially defines the sustainability principles that are appropriate to the street tree species. Then, information about the study area and the technical procedures for data collection and floristic analysis are provided.

Based on the principles for sustainable development as agreed in the Stockholm Declaration on the Human Environment (UN, 1972), Our Common Future Report, also known as the Brundtland Report (WCED, 1987), the Rio Declaration on Environment and Development (UN, 1992) and the Earth Charter (ECC, 2000), it is possible to identify the most sustainable attributes for street tree species, specifically those used on sidewalks.

Also, the list of source documents for sustainable attributes includes the Universal Declaration of Human Rights - UDHR (UN, 1948), given that the Earth Charter (ECC, 2000) provides the instruction that ensures that communities at all levels guarantee human rights and fundamental freedoms and provide each with the opportunity to realize their full potential for democratic societies to be just, participatory, sustainable and peaceful. All these documents are part of international law and should be understood as guiding instruments for the promotion of public policies for sustainable development.

The following principles associated with the sustainability of tree species for planting in walkable areas were identified:

(a) Right to life (elementary principle): every human being has the right to life, liberty and an environment suitable for his well-being and health (UN, 1948; 1972; WCED, 1987);
(b) Environmental protection: forms an integral part of the sustainable development process, and states should maintain essential ecosystems and ecological processes and preserve biodiversity (WCED, 1987; UN, 1992);
(c) Prevention: states should prevent or reduce any environmental interference beyond their borders that could cause or cause significant damage (WCED, 1987);
(d) Precaution: states should take all reasonable precautionary measures to limit the risk when conducting, or permitting, activities that are dangerous but beneficial (WCED, 1987; UN, 1992);
(e) Intergenerational equity: states must enable equitable development and environmental needs of present and future generations to be met (WCED, 1987; UN, 1992);
(f) Meeting accessibility and security needs: every human being has equal right of access to the public

service of his country, as well as to personal safety (UN, 1948);

(g) Cultural continuity: everyone, as a member of society, has the right to the realization of cultural rights indispensable to his dignity and the free development of his personality (UN, 1948).

Based on the principles linked to sustainability, different problems caused by species inadequately chosen for street planting can be associated. These species must provide safety and accessibility, as well as the environmental gains common to all plants.

Regarding origin, species must have no environmental restrictions, i.e. invasive behavior. Exotic species with invasive behavior, after introduced in places other than their natural occurrences, bring negative consequences to native species and many ecosystem services (Millennium Ecosystem Assessment, 2005).

The existence of environmental impediments (i.e. accidental or intentional invasive species on the streets) are related to the Right to Life, Environmental Protection, Prevention, and Precaution principles. If there is interference in the ecological processes of other species existing in streets or other locations near the urban area, biological diversity may be affected, which contributes to the promotion of an unsafe environment for people due to a possible imbalance between populations. This issue is also associated with Cultural Continuity, as native plants linked to local customs and practices, including the local fauna dependent on these plants, may lose their ability to recover naturally after being affected.

However, exotic but non-invasive species can be planted in the streets (Almas & Conway, 2016). Many of these species are used due to the convenience of often having better-known behavior in urban space, which facilitates maintenance practices by the local government.

Three other floristic features are related to Right to life and the Meeting accessibility and security needs principles. These include toxic principles, the existence of sharp structures, and the production of large or abundant fleshy fruits. In these cases, the usability of sidewalks may be limited by situations of pedestrian insecurity.

The contact of people with sharp structures can cause cuts and other superficial or even deeper injuries. Intoxications can occur through direct contact, ingestion or inhalation, and may cause dermatitis and poisoning (Ozturk *et al.*, 2008).

Regarding fruiting, the fall of this biomass can make the pavement slippery, which can lead to accidents and expenses if the fall occurs on vehicles in transit or parked under the treetops. Also, insects and other pathogen vectors can be attracted, which brings risks to the health of pedestrians (Hegedüs *et al.*, 2011).

In addition, the existence of roots that damage the pavement and natural architecture that obstructs the walking space can be mentioned as problems caused by inappropriate species (Mullaney *et al.*, 2015; Corazza *et al.*, 2016). These features are linked to Right to life, Meeting accessibility and security needs, and Intergenerational equity principles. Equity is relevant because people with disabilities are the most exposed to the adverse effects of reduced accessibility of urban space. **Table 1** shows the association of floristic features of sidewalk street tree species with sustainable principles.

Floristic features were determined based on the understanding that the absence of a sustainable factor necessarily implies a less sustainable feature to walks. Thus, the production of small fleshy fruits, however not excessively, for example, although it is an interesting aspect for birds, was not contemplated, given that the absence of these fruits does not constitute a species as less sustainable. The opposite is true for toxic principles, for example, since the presence of this factor limits people's use of sidewalks.

In this study, a species that does not have features that contradict the determined principles is considered a more sustainable street tree species. On the other hand, a species that has at least one inappropriate aspect is considered a less sustainable species. It is assumed that an inadequate factor is sufficient to restrict its use for the purpose analyzed, according to current regulations and legislation.

Study Area

The data collection was conducted in São Tomé, a town located in the state of Paraná, southern Brazil, which presents trees on 99.5% of its streets. The local population is estimated at approximately 5,700 inhabitants for the year 2019 (IBGE, 2020). Its urban grid comprises approximately 27 km of streets (**Fig. 1**). In Sao Tomé, there is the occurrence of the Semideciduous Seasonal Forest and humid subtropical climate (Cfa), according to the Köppen classification. The town has an average altitude of 465 m, with the occurrence of oxisols.

Table 1. Less sustainable floristic features related to sustainable principles

Features	Principles
Environmental impediment	Rl; Ep; Pv; Pc; Cc
Toxic principles	Rl; Mas
Sharp structures	Rl; Mas
Large or abundant fleshy fruits	Rl; Mas
Roots that damage the pavement	Rl; Ie; Mas
Plant architecture that obstructs the walking space	Rl; Ie; Mas

Rl: Right to life; Ep: Environmental Protection; Pv: Prevention; Pc: Precaution; Cc: Cultural continuity; Mas: Meeting accessibility and security needs; Ie: Intergenerational equity.

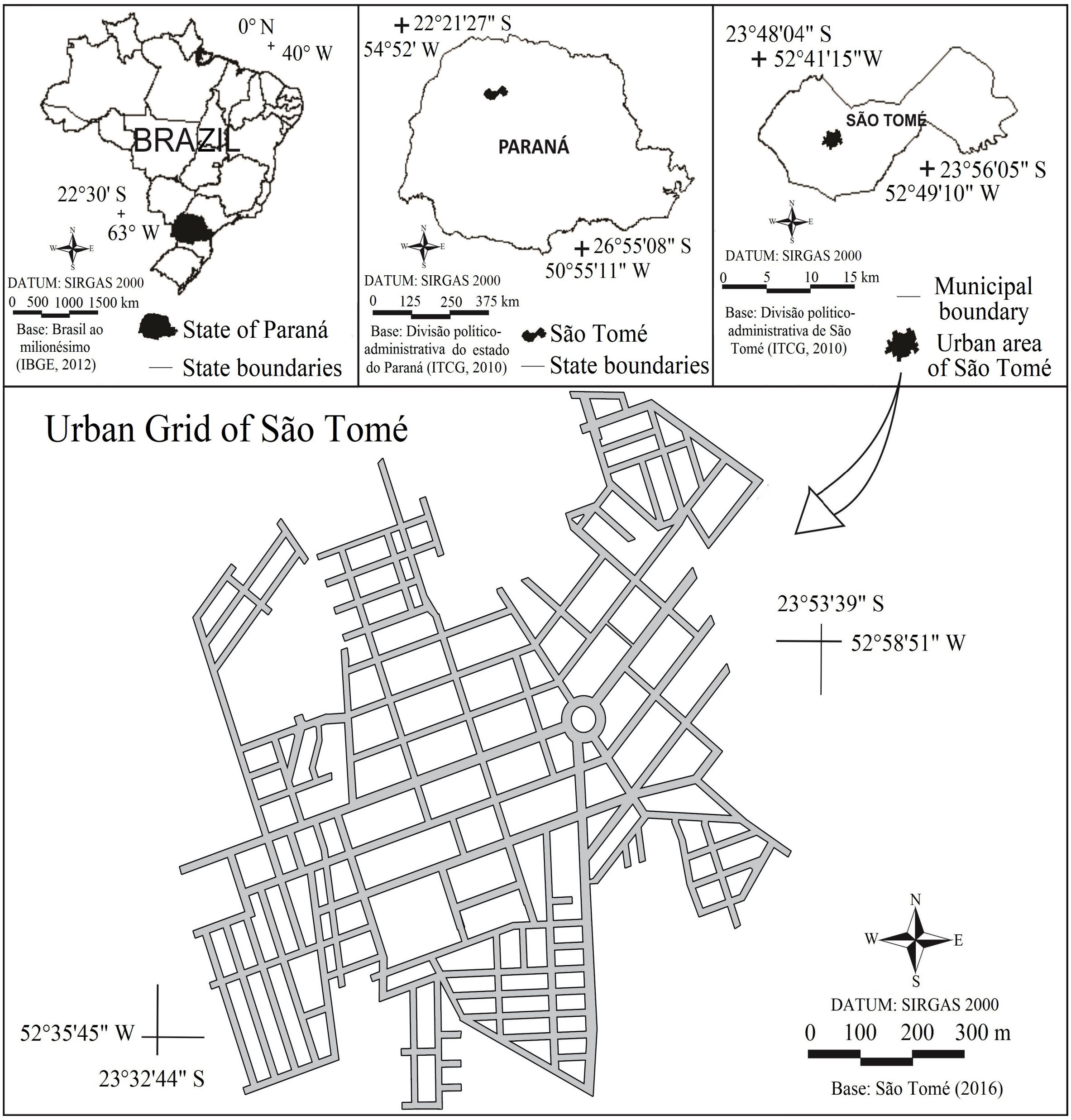

Fig. 1 Location of the urban grid of São Tomé, state of Paraná, Brazil.

Forest Inventory

A qualitative and quantitative survey of all plant specimens with a minimum height of 1.0-meter was conducted in São Tomé sidewalks. All tree-sized individuals, including bushes and palm trees (Arecaceae), were inventoried.

Regarding taxonomy, the specimens were identified based on the APG IV System (The Angiosperm Phylogeny Group *et al.*, 2016). The List of Species of the Brazilian Flora (Jardim Botânico do Rio de Janeiro, 2020) and the Tropicos database (Missouri Botanical Garden, 2020) were followed to determine the botanical families and specific epithets, respectively.

The botanical features of the identified species were obtained from the Herbarium of the Federal University of Technology – Paraná database, Campo Mourão Campus (HCF). Also, Ordinance n. 059 of April 15, 2015, published by the Paraná Environmental Institute (IAP, 2015), was consulted to determine the presence of invasive behavior. After knowing the species distribution in the São Tomé urban grid, the concentration of less and more sustainable species was determined along the stretches limited by street corners. Finally, some proposals were formulated to promote a more sustainable green infrastructure.

RESULTS AND DISCUSSION

The forest inventory was conducted between February 2 and May 31, 2016, and covered all 570 sections of the town, which correspond to 47,256 m of sidewalks. In total, 4,081 individuals belonging to 73 species and 29 families were registered. After identifying the floristic features of the species, those with inadequate sustainability features were determined (**Table 2**).

Table 2. Family, occurrence, frequency, origin and behavior, and less sustainable features of tree size species listed in São Tomé, Paraná, Brazil

Family	Species	n	f	O	Less sustainable features
Chrysobalanaceae	*Licania tomentosa* (Benth.) Fritsch	1,722	42.20%	N	-
Fabaceae	*Cenostigma pluviosum* var. *peltophoroides* (Benth.) E. Gagnon & G.P. Lewis	604	14.80%	N	-
Lauraceae	*Nectandra megapotamica* (Spreng.) Mez.	256	6.27%	N	-
Rutaceae	*Murraya paniculata* (L.) Jacq.	202	4.95%	I	Imp
Dilleniaceae	*Dillenia indica* L.	133	3.26%	E	Ft
Bignoniaceae	*Handroanthus chrysotrichus* (Mart. ex DC.) Mattos	117	2.87%	N	-
Malvaceae	*Pachira aquatica* Aubl.	108	2.65%	N	Ft
Magnoliaceae	*Magnolia champaca* (L.) Baill. ex Pierre	88	2.16%	I	Imp
Combretaceae	*Terminalia catappa L.*	84	2.06%	I	Imp
Bignoniaceae	*Handroanthus heptaphyllus* Mattos	76	1.86%	N	-
Sapindaceae	*Sapindus saponaria* L.	73	1.79%	N	-
Fabaceae	*Tipuana tipu* (Benth.) Kuntze	44	1.08%	E	R
Melastomataceae	*Pleroma granulosum* (Desr.) D. Don	42	1.03%	N	-
Rutaceae	*Citrus limon* (L.) Burm. f.	38	0.93%	I	Imp; S
Verbenaceae	*Duranta erecta* L.	35	0.86%	N	T
Fabaceae	*Bauhinia variegata* L.	34	0.83%	E	-
Anacardiaceae	*Mangifera indica* L.	31	0.76%	I	Imp; Ft
Fabaceae	*Libidibia ferrea* var. *leiostachya* (Benth.) L.P.Queiroz	28	0.69%	N	-
Bignoniaceae	*Tabebuia roseoalba* (Ridl.) Sandwith	26	0.64%	N	-
Anacardiaceae	*Schinus molle* L.	24	0.59%	N	T
Bignoniaceae	*Handroanthus impetiginosus* Mattos	23	0..56%	N	-
Fabaceae	*Paubrasilia echinata* (Lam.) Gagnon, H.C. Lima & G.P. Lewis	20	0.49%	N	S
Myrtaceae	*Eugenia uniflora* L.	17	0.42%	N	-
Apocynaceae	*Nerium oleander L.*	16	0.39%	E	T
Fabaceae	*Delonix regia* (Boojer ex Hook.) Raf.	16	0.39%	E	R
Malvaceae	*Pachira glabra* Pasquale	16	0.39%	N	Ft
Arecaceae	*Archontophoenix alexandrae* (F. Muell.) H. Wendl. & Drude	14	0.34%	E	-
Oleaceae	*Ligustrum lucidum* W. T. Aiton	14	0.34%	I	Imp; T
Rutaceae	*Citrus reticulata* Blanco	14	0.34%	E	S
Myrtaceae	*Psidium guajava* L.	13	0.32%	I	Imp; Ft
Fabaceae	*Holocalyx balansae* Micheli	10	0.25%	N	T
Anacardiaceae	*Schinus terebinthifolia* Raddi	9	0.22%	N	T
Bignoniaceae	*Spathodea campanulata* P. Beauv.	9	0.22%	I	Imp; T
Moraceae	*Morus nigra* L.	9	0.22%	I	Imp
Rosaceae	*Eriobotrya japonica* (Thunb.) Lindl.	9	0.22%	I	Imp
Malvaceae	*Hibiscus rosa-sinensis* L.	8	0.20%	E	-
Cupressaceae	*Cupressus lusitanica* Mill.	7	0.17%	E	T
Fabaceae	*Erythrina variegata* L.	7	0.17%	E	S
Myrtaceae	*Eugenia involucrata* DC.	7	0.17%	N	Ft
Arecaceae	*Phoenix roebellenii* O'Brien	6	0.15%	E	S
Malpighiaceae	*Malpighia emarginata* Sessé & Moc. ex DC.	5	0.12%	E	
Moraceae	*Ficus auriculata* Lour.	5	0.12%	E	Sr
Apocynaceae	*Plumeria rubra* L.	4	0.10%	E	T
Araliaceae	*Schefflera actinophylla* (Endl.) Harms	4	0.10%	E	-
Fabaceae	*Leucaena leucocephala* (Lam.) de Wit	4	0.10%	I	Imp
Malvaceae	*Dombeya wallichii* (Lindl.) K. Schum.	4	0.10%	E	-
Moraceae	*Ficus benjamina* L.	4	0.10%	E	T; R
Apocynaceae	*Aspidosperma parvifolium* A. DC.	3	0.07%	N	-
Bignoniaceae	*Jacaranda mimosifolia* D. Don.	3	0.07%	E	-
Fabaceae	*Anadenanthera colubrina* (Vell.) Brenan	3	0.07%	N	-
Fabaceae	*Peltophorum dubium* (Spreng.) Taub.	3	0.07%	N	-
Myrtaceae	*Syzygium cumini* (L.) Skeels	3	0.07%	I	Imp; Ft
Anacardiaceae	*Anacardium occidentale* L.	2	0.05%	N	Ft
Cycadaceae	*Cycas circinalis* L.	2	0.05%	E	T
Fabaceae	*Inga edulis* Mart.	2	0.05%	N	-
Moraceae	*Morus alba* L.	2	0.05%	E	-

Table 2. (Continued)

Family	Species	n	f	O	Less sustainable features
Myrtaceae	*Callistemon viminalis* (Sol. ex Gaertn.) G. Don.	2	0.05%	E	-
Rubiaceae	*Coffea arabica* L.	2	0.05%	E	P
Annonaceae	*Annona reticulata* L.	1	0.02%	N	F
Araucariaceae	*Araucaria angustifolia* (Bertol.) Kuntze	1	0.02%	N	S
Arecaceae	*Acrocomia totai Mart.*	1	0.02%	N	S
Arecaceae	*Caryota urens* L.	1	0.02%	E	T
Cycadaceae	*Cycas revoluta* Thumb.	1	0.02%	E	T
Fabaceae	*Erythrina speciosa* Andrews	1	0.02%	N	S
Fabaceae	*Senna macranthera* (DC. ex Collad.) H.S. Irwin & Barneby	1	0.02%	I	Imp
Fabaceae	*Tamarindus indica* L.	1	0.02%	E	-
Lythraceae	*Punica granatum* L.	1	0.02%	E	T; Ft
Meliaceae	*Melia azedarach* L.	1	0.02%	I	Imp; T
Moraceae	*Artocarpus heterophyllus* Lam.	1	0.02%	E	Ft
Myrtaceae	*Plinia cauliflora* (DC.) Kausel	1	0.02%	N	Ft
Nyctaginaceae	*Bougainvillea glabra* Choisy	1	0.02%	N	S
Rutaceae	*Citrus sinensis* L. Osbeck	1	0.02%	E	S; Ft
Sapindaceae	*Litchi chinensis* Sonn.	1	0.02%	E	Ft
Total		4,081	100%		

n: occurrence; f: relative frequency; O: origin and behavior; N: native from Brazil; E: exotic (non-invasive); I: invasive; Imp: environmental impediment; T: toxic principles; S: sharp structures, Ft: large or abundant fleshy fruits; R: Roots that damage the pavement; P: plant architecture that obstructs the walking space.

The inventory indicated the existence of 50 plant species (n=1,009; f=24.7%) with features unfavorable to sustainability and, therefore, undesirable for street planting. The remaining 23 species present a larger number of specimens that do not have less sustainable features (n=3,072; f=75.3%). Therefore, based on the specifications of this study, such specimens are understood as less sustainable.

Regarding origin and behavior, there are 30 native species (f=79.2%), 29 exotic (but non-invasive) species (f=8.4%) and 14 invasive species (f=12.4%). Considering the problems that invasive species bring to the environment, as well as the cultural issue, their insertion in the afforestation is prohibited (IAP, 2016).

Due to the proximity of trees to people, the existence of toxicity becomes incompatible with the promotion of a healthy environment. According to the inventory, 15 species (f=3.4%) presented toxic principles, whose contact may cause different adverse effects to the human organism. For example, the most frequently occurring toxic species, *Duranta erecta* (n=35), has a saponin capable of causing fever, edema of lips and eyelids, and convulsions (Nelson *et al.*, 2007).

Another six species presented allergic pollen to people: *Schinus molle* (n=24)*, Ligustrum. lucidum* (n=14), *Schinus terebinthifolia* (n=9), *Cupressus lusitanica* (n=7), *Cycas circinalis* (n=2), and *Cycas revoluta* (n=1) (Cariñanos & Casares-Porcel, 2011). The adverse effects of these plants can be potentiated when there is an interaction between pollen and air pollutants, or when there is an excess of species that produce specific pollen.

All parts of *Nerium oleander* (n=16) and *Plumeria rubra* (n=4) are toxic, which have cardiotoxic glycosides as the active principle (Biondi *et al.*, 2008). A person who comes into contact with or eats the latex of these plants is subject to symptoms related to cardiac disorders (Nelson *et al.*, 2007).

The *Holocalyx balansae* (n=10) and *Ficus benjamina* (n=4) species have cyanogenic glycosides as the active principle. Contact or ingestion of any part of these plants can cause tachycardia, spasms, irritation, and edema. Also, in the case of *Ficus benjamina*, latex has a purgative effect that can cause dermatitis (Brito *et al.*, 2000; Winters, 2000).

Popularly known as fishtail palm, *Caryota urens* (n=1) has calcium oxalate crystals in its fruits and roots. Ingestion and contact with these parts of the plant may cause a burning sensation, lip, mouth and tongue edema, nausea, vomiting, diarrhea, abundant salivation, difficulty in swallowing and asphyxiation. Eye contact may cause corneal irritation and injury (Winters, 2000; Srivastav *et al.*, 2015).

The *Punica granatum* (n=1) and *Melia azedarach* (n=1) species present toxicity in their barks and fruits, respectively, due to the presence of alkaloids. Ingestion results in increased salivation, nausea, vomiting, and abdominal cramps (Biondi *et al.*, 2008; Bhatia *et al.*, 2014). Individuals of the *Spathodea campanulata* (n=9) species have toxic flowers, especially for insects (Queiroz *et al.*, 2014).

Cases of human intoxication are recurrent in Brazil. In 2017, 27,322 cases occurred in the country, 239 associated with toxic plants (63% related to children up to 9 years old) (FIOCRUZ, 2020). This demonstrates the importance of the absence of these specimens in public spaces.

Regarding sharp structures, 9 species (f=2.2%) present this feature. This situation increases the possibility of pedestrian accidents. Specimens of *Citrus limon* (n=38), *Paubrasilia echinata* (n=20), *Citrus reticulata* (n=14), *Erythrina variegata* (n=7), *Phoenix roebellenii* (n=6), *Erythrina speciosa* (n=1), *Acrocomia totai* (n=1), *Bougainvillea glabra* (n=1), and *Citrus sinensis* (n=1) have thorns on trunk. The individual of *Araucaria angustifolia* (n=1) species presents sharped leaves.

Based on the floristic analysis, 9 species (f=7.5%) present large fruits: *Dillenia indica* (n=133), *Pachira aquatica* (n=108), *Mangifera indica* (n=31), *Pachira glabra* (n=16), *Psidium guajava* (n=13), *Anacardium occidentale* (n=2), *Annona reticulata* (n=1), *Artocarpus heterophyllus* (n=1), and *Citrus sinensis*. The fall of these fruits is a risk to pedestrians due to the possibility of accidents.

The production of abundant fleshy fruits is another possible problem. This aspect may reduce accessibility when the floor becomes slippery due to the fall. The attraction of insects is another undesirable consequence. This feature was attributed to 5 species (f=0.3%): *Eugenia involucrata* (n=7), *Syzygium cumini* (n=3), *Punica granatum, Plinia cauliflora* (n=1), and *Litchi chinensis* (n=1).

Species that produce large or abundant fleshy fruits, but do not have other inappropriate features, can be planted in places that are not intended for the constant transit of pedestrians, such as squares and parks. This strategy can contribute to the promotion of public spaces that are more attractive to citizens and, consequently, to the quality of urban space.

In total, 4 species (f=1.7%) have roots that can damage the pavement: *Tipuana tipu* (n=44), *Delonix regia* (n=16), *Ficus auriculata* (n=5), and *Ficus benjamina*. In the case of the first three species, considering that they do not have another less sustainable feature, their planting can be done as long as there is sufficient area for plant development. However, this is an unavailable condition in the study area.

The *Coffea arabica* (n=2) specimes are considered potentially conflicting with the walking space. The architecture of this plant makes it a less sustainable species for street planting. However, there is the possibility of use in other places not dedicated to pedestrian circulation.

Based on the floristic analysis of the species, *Citrus limon, Mangifera indica*, *Ligustrum lucidum, Psidium guajava*, *Spathodea campanulata, Ficus benjamina, Syzygium cumini, Punica granatum, Melia azedarach*, and *Citrus sinensis* presented two inappropriate aspects each. From a sustainable perspective, this makes the use of these species even more inappropriate.

Distribution of the street tree species in urban space

The proportion of more sustainable species was determined along the sidewalk stretches. **Table 3** shows the number of stretches, with respective length, for five species proportions, according to the level of sustainability. **Fig. 2** indicates the location of these stretches in the urban grid.

Based on **Table 2** and **Fig. 2**, the most sustainable species have more participation in tree composition than those with less sustainable features. If considered as an adequate condition, the case where there are most or all of the most sustainable species in a stretch, 79.1% of the sidewalks (37,389 m) can be considered appropriate. In contrast, 20.9% (7,867 m) of sidewalks have an equal number of more and less sustainable species or a preponderance of the less sustainable ones.

Species spatialization indicates greater sustainability in the central areas. Therefore, there is a higher incidence of less sustainable species in the more peripheral areas, especially in the south, northwest, and northeast of the town. The same pattern occurs for stretches without trees, which correspond to 4.0% of the total sidewalks.

São Tomé had its road system expanded, especially from the 2010s. Thus, the edges of the town present recently built environments, including areas to be occupied. Hence, these sites are in the consolidation phase of the infrastructure, which includes tree planting on the streets. Also, there is the usual behavior of some residents who plant trees on sidewalks without following technical criteria. Since there is no proper supervision by the local government, these trees may cause problems in the future. Inappropriate tree composition and damage to sidewalk pavement are examples of these consequences.

Regarding the local government, there are appropriate and inappropriate actions conducted by it. There are examples of more sustainable species that were recently planted in the streets by the Municipality: *Handroanthus chrysotrichus, Bauhinia variegata*, and *Tabebuia roseoalba.* However, the planting of less sustainable species is also promoted, such as *Magnolia champaca* and *Paubrasilia echinata.* This action can negatively influence the level of safety and comfort offered to citizens.

Table 3. Number and length of stretches according to the proportion of more sustainable species

Proportion of more sustainable species	Number of stretches	Total length
100%	229	16,875 m
Between 50% and 100%	201	20,514 m
50%	23	1,921 m
Between 0% and 50%	51	4,706 m
0%	30	1,333 m
Absence of street trees	36	1,907 m

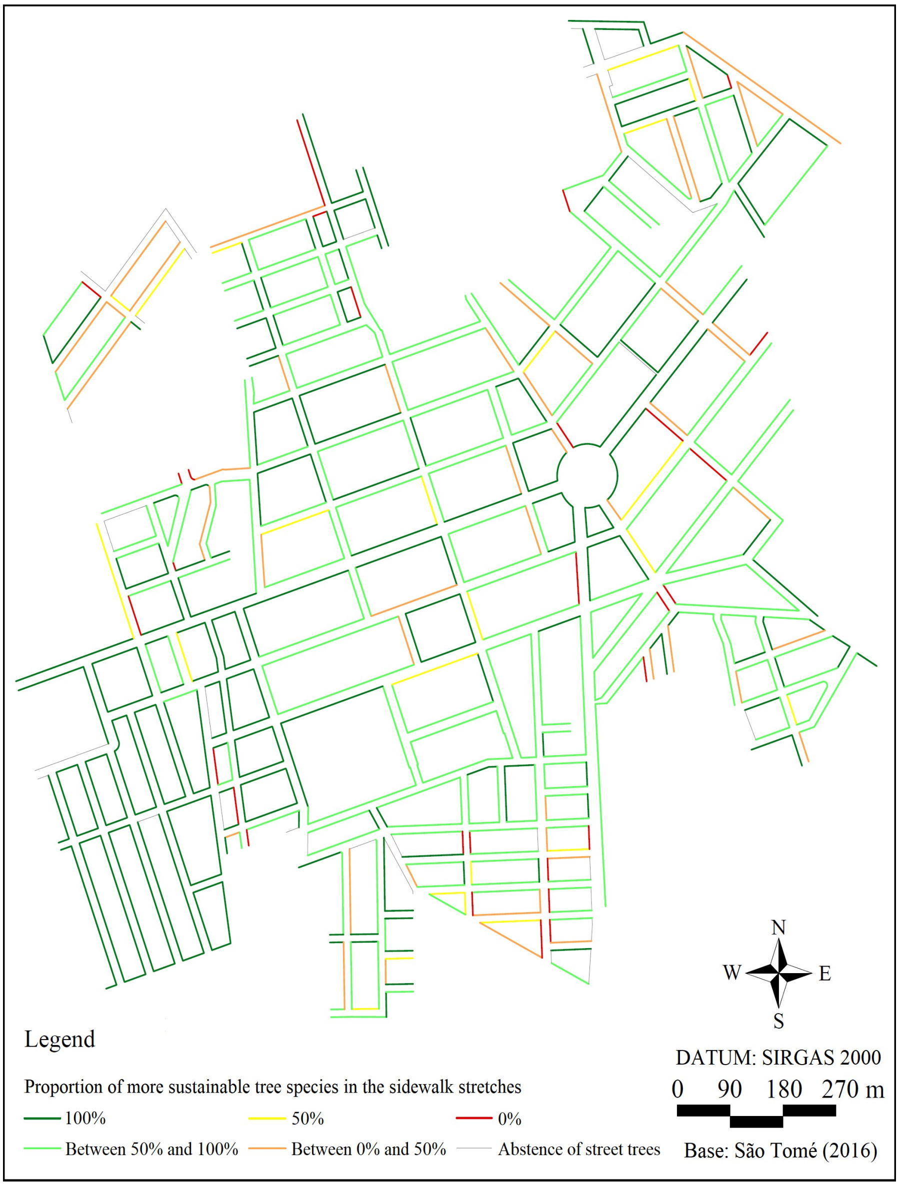

Fig. 2 Proportion of more sustainable tree species in the sidewalk stretches of São Tomé, Paraná, Brazil.

All urban areas need appropriate planning. But, the southwest area of the town needs special attention. In this case, the site was in the initial phase of occupation, with no residents at the time of inventory. However, specimens were already planted, which mostly belonged to the *Licania tomentosa* species, understood in this study as a more sustainable species. For this reason, the condition in which there are all more sustainable species prevails in the area. Thus, proper planning is essential to ensure the sustainability of tree composition.

Proposals for a more sustainable green infrastructure

Some strategies and actions can promote a safer, accessible, healthier and more sustainable environment for citizens. Initially, all specimens belonging to less sustainable species must be replaced by others of more sustainable species. The replacement of these inappropriate tree individuals is necessary for the legal and technical compliance of urban space. For example, this action supports the application of ISO 21542:2011 (ISO, 2011), which seeks for all people to use the built environment safely. Also, these species are suitable for planting on sidewalks that do not have trees.

However, based on the pattern proposed by (Grey & Deneke, 1978), where individual populations by species should not exceed 10 or 15% of the total population, the *Licania tomentosa* (f = 42.2%) and *Cenostigma pluviosum* (f = 14.8%) species should be avoided. This is essential to promote floristic diversity and to hinder the spread of disease (Yan & Yang, 2018).

This diversity is also favorable for attracting insects and birds to urban space. For this, street trees must produce flowers and fruits in different seasons of the year. However, the selection of these species must follow sustainable criteria for continuous improvement of walkability.

The choice of species should also consider the possibility of conflict between street trees and power lines. Under this infrastructure, smaller species are more appropriate (up to 8 meters in height), such as *Handroanthus chrysotrichus, Bauhinia variegata*, and *Pleroma mutabilis* (Vell.) Triana. Large and medium trees may be planted in the absence of power lines, such as *Tabebuia roseoalba*, *Jacaranda mimosifolia*, and *Ocotea odorifera* Rower (Lauraceae) species.

Finally, the Public Authority should adequately publicize information related to local green infrastructure. Thus, citizens can contribute to public decision-making, which is in line with the Public participation principle (UN, 1992; ECC, 2000).

CONCLUSIONS

Analyzing the total of 47,256 m of sidewalks of the Brazilian town of São Tomé from the perspective of sustainability, from a total of 73 tree species (n=4,081), 23 presented no less sustainable features (n=3,072; f=75.3%). The other 50 species (n=1,009; f=24.7%) presented at least one less sustainable feature. Therefore, species belonging to this second group are inappropriate for street planting, including from the perspective of legal and technical standards.

Investigating the pattern of distribution of species in the urban grid, according to its level of sustainability, the peripheral areas of the town are the ones that most demands attention. Interventions should consider sustainable principles, legislation, technical standards, and citizen participation. This approach is necessary for the selection of new species, as well for planting and subsequent street trees management.

The proposed evaluation system can be used as a tool to determine the level of sustainability of a local street tree composition and to base more sustainable public policies that promote the continuous improvement of the urban space. However, invasive species should be identified for each evaluation, as this aspect varies according to location.

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REFERENCES

Almas, A.D. & Conway, T. M. (2016) The role of native species in urban forest planning and practice: a case study of Carolinian Canada. *Urban For. Urban Green.* **17**(1), 54–62, doi: 10.1016/j.ufug.2016.01.015.

Arnberger, A. (2012) Urban densification and recreational quality of public urban green spaces - A Viennese case study. *Sustainability* **4**(4), 703–720, doi: 10.3390/su4040703.

Artmann, M., Chen, X., Iojă, C., Hof, A., Onose, D., Poniży, L., Lamovšek, A.Z. & Breuste, J. (2017) The role of urban green spaces in care facilities for elderly people across European cities. *Urban For. Urban Green.* **27**, 203–213, doi: 10.1016/j.ufug.2017.08.007.

Bhatia, H., Manhas, R.K., Kumar, K. & Magotra, R. (2014) Traditional knowledge on poisonous plants of Udhampur district of Jammu and Kashmir, India. *J. Ethnopharmacol.* **152**(1), 207–216, doi: 10.1016/j.jep.2013.12.058.

Biondi, D., Leal, L. & Schaffer, M. (2008) Aspectos importantes das plantas ornamentais em escolas públicas estaduais da cidade de Curitiba, PR. *Rev. Bras. Ciênc. Agrár.* **3**(3), 267–275, doi: 10.5039/agraria.v3i3a325.

Bottalico, F., Travaglini, D., Chirici, G., Garfì, V., Giannetti, F., De Marco, A., Fares, S., Marchetti, M., Nocentini, S., Paoletti, E., Salbitano, F. & Sanesi, G. (2017) A spatially-explicit method to assess the dry deposition of air pollution by urban forests in the city of Florence, Italy. *Urban For. Urban Green.* **27**, 221–234, doi: 10.1016/j.ufug.2017.08.013.

Brito, M.F., Franca, T.N., Oliveira, K.D. & Cerqueira, V.D. (2000) Estudos experimentais em coelhos com plantas cianogênicas. *Pesq. Vet. Bras.* **20**(2), 65–70, doi: 10.1590/S0100-736X2000000200002.

Capotorti, G., Mollo, B., Zavattero, L., Anzellotti, I. & Celesti-Grapow, L. (2015) Setting priorities for urban forest planning. A comprehensive response to ecological and social needs for the metropolitan area of Rome (Italy). *Sustainability* **7**(4), 3958–3976, doi: 10.3390/su7043958.

Cariñanos, P. & Casares-Porcel, M. (2011) Urban green zones and related pollen allergy: a review. Some guidelines for designing spaces with low allergy impact. *Landscape Urban Plan.* **101**(3), 205–214, doi: 10.1016/j.landurbplan.2011.03.006.

Corazza, M.V., Di Mascio, P. & Moretti, L. (2016) Managing sidewalk pavement maintenance: a case study to increase pedestrian safety. *J. Traffic Transp.* **3**(3), 203–214, doi: 10.1016/j.jtte.2016.04.001.

Donovan, G.H. (2017) Including public-health benefits of trees in urban-forestry decision making. *Urban For. Urban Green.* **22**, 120–123, doi: 10.1016/j.ufug.2017.02.010.

ECC, Earth Charter Commission. (2000) *The Earth Charter*. San Jose, Costa Rica.

FIOCRUZ, Fundação Oswaldo Cruz. (2020) *Sistema Nacional de Informações Toxico Farmacológicas: Dados Nacionais*. Available online: http://sinitox.icict.fiocruz.br/dados-nacionais (accessed on 14 January 2020).

Grey, G.M. & Deneke, F.J. (1978) *Urban Forestry*. John Wizey, New York, USA.

Gu, W., Chen, Y. & Dai, M. (2019) Measuring community greening merging multi-source geo-data. *Sustainability* **11**(4), 1104, doi: 10.3390/su11041104.

Halpern, B.S., Klein, C.J., Brown, C.J., Beger, M., Grantham, H.S., Mangubhai, S., Ruckelshaus, M., Tulloch, V.J., Watts, M., White, C. & Possingham, H.P. (2013) Achieving the triple bottom line in the face of inherent trade-offs among social equity, economic return, and conservation. *Proc. Natl. Acad. Sci. U.S.A.* **110**(15), 6229–6234, doi: 10.1073/pnas.1217689110.

Hegedüs, A, Gaál, M. & Bérces, R. (2011) Tree appraisal methods and their application – first results in one of Budapest's districts. *Appl. Ecol. Env. Res.* **9**(4), 411–423, doi: 10.15666/aeer/0904_411423.

IAP, Instituto Ambiental do Paraná. (2015) *Ordinance n. 059 of April 15, 2015*. Curitiba, Brazil.

IBGE, Instituto Brasileiro de Geografia e Estatística. (2012) *Base Cartográfica Digital Integrada ao Milionésimo – bCIMd*. Rio de Janeiro, Brazil.

IBGE, Instituto Brasileiro de Geografia e Estatística. (2020) *IBGE Cidades, São Tomé – PR*. Available online: https://cidades.ibge.gov.br/brasil/pr/sao-tome (accessed on 14 January 2020).

ISO, International Organization for Standardization. (2011) *ISO 21542: Building construction - Accessibility and usability of the built environment*. Geneva, Switzerland.
ITCG, Instituto de Terras, Cartografia e Geociências. (2010) *Divisão político-administrativa do Paraná*. Curitiba, Brazil.
Jardim Botânico do Rio de Janeiro. (2020) *Lista de espécies da Flora do Brasil*. Available online: http://floradobrasil.jbrj.gov.br (accessed on 14 January 2020).
Kirnbauer, M.C., Baetz, B.W. & Kenney, W.A. (2013) Estimating the stormwater attenuation benefits derived from planting four monoculture species of deciduous trees on vacant and underutilized urban land parcels. *Urban For. Urban Green.* **12**(3), 401–407, doi: 10.1016/j.ufug.2013.03.003.
Liu, T.-Y., Chen, P.-H. & Chou, N.N.S. (2019) Comparison of assessment systems for green building and green civil infrastructure. *Sustainability* **11**(7), 2117, doi: 10.3390/su11072117.
Millennium Ecosystem Assessment. (2005) *Ecosystems and Human Well-being*: Synthesis. Island Press, Washington, USA.
Missouri Botanical Garden. (2020) *Tropicos*. Available online: http://www.tropicos.org/ (accessed on 14 January 2020).
Moldan, B., Janouaková, S. & Hák, T. (2012) How to understand and measure environmental sustainability: Indicators and targets. *Ecol. Indic.* **17**, 4–13, doi: 10.1016/j.ecolind.2011.04.033.
Mullaney, J., Lucke, T. & Trueman, S.J. (2015) A review of benefits and challenges in growing street trees in paved urban environments. *Landscape Urban Plan.* **134**, 157–166, doi: 10.1016/j.landurbplan.2014.10.013.
Nelson, S.L., Shih, D.R. & Balik, J.M. (2007) *Handbook of Poisonous and Injurious Plants*, 2nd ed. The New York Botanical Garden, New York, USA.
North, E.A., Johnson, G.R. & Burk, T.E. (2015) Trunk flare diameter predictions as an infrastructure planning tool to reduce tree and sidewalk conflicts. *Urban For. Urban Green.* **14**(1), 65–71, doi: 10.1016/j.ufug.2014.11.009.
Notaro, S. & De Salvo, M. (2010) Estimating the economic benefits of the landscape function of ornamental trees in a sub-Mediterranean area. *Urban For. Urban Green.* **9**(2), 71–81, doi: 10.1016/j.ufug.2009.09.001.
Ostoić, S.K. & Konijnendijk Van Den Bosch, C.C. (2015) Exploring global scientific discourses on urban forestry. *Urban For. Urban Green.* **14**(1), 129–138, doi: 10.1016/j.ufug.2015.01.001.
Ozturk, M., Uysal, I., Gücel, S., Mert, T., Akcicek, E. & Celik, S. (2008) Ethnoecology of poisonous plants of Turkey and Northern Cyprus. *Pak. J. Bot.* **40**(4), 1359–1386.
Queiroz, A.C.M., Contrera, F.A.L. & Venturieri, G.C. (2014) The effect of toxic nectar and pollen from *Spathodea campanulata* on the worker survival of *Melipona fasciculata* Smith and *Melipona seminigra* Friese, two Amazonian stingless bees (Hymenoptera: Apidae: Meliponini). *Sociobiology* **61**, 536–540, doi: 10.13102/sociobiology.v61i4.536-540.
Ren, Y., Ge, Y., Ma, D., Song, X., Shi, Y., Pan, K., Qu, Z., Guo, P., Han, W. & Chang, J. (2017) Enhancing Plant Diversity and Mitigating BVOC Emissions of Urban Green Spaces through the Introduction of Ornamental Tree Species. *Urban For. Urban Green.* **27**, 305–313, doi: 10.1016/j.ufug.2017.08.011.
Roy, S., Byrne, J. & Pickering, C. (2012) A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. *Urban For. Urban Green.* **11**(4), 351–363, doi: 10.1016/j.ufug.2012.06.006.
Salas-Zapata, W., Ríos-Osorio, L. & Castillo, J.A.D. (2011) La Ciencia emergente de la sustentabilidad: de la práctica científica hacia la constitución de una ciencia. *Interciencia* **36**(9), 699–706.
São Tomé. (2016) *Planta Geral da Cidade*.
Saphores, J.D. & Li, W. (2012) Estimating the value of urban green areas: a hedonic pricing analysis of the single family housing market in Los Angeles, CA. *Landscape Urban Plan.* **104**(3–4), 373–387, doi: 10.1016/j.landurbplan.2011.11.012.
Säynäjoki, E., Heinonen, J. & Junnila, S. (2014) The power of urban planning on environmental sustainability: a focus group study in Finland. *Sustainability* **6**(10), 6622–6643, doi: 10.3390/su6106622.
Silva, O.H. & De Angelis Neto, G. (2019) Índice de Serviço das Calçadas (ISC). *Ambient. Constr.* **19**(1), 221–236, doi: 10.1590/s1678-86212019000100303.
Silva, O.H., Locastro, J.K., Sanches, S.P., De Angelis Neto, G., De Angelis, B.D. & Caxambu, M.G. (2019) Avaliação da arborização viária da cidade de São Tomé, Paraná. *Ci. Fl.* **29**(1), 371–384, doi: 10.5902/1980509824889.
Sjöman, H., Morgenroth, J., Sjöman, J. D., Sæbø, A. & Kowarik, L. (2016) Diversification of the Urban Forest - Can We Afford to Exclude Exotic Tree Species? *Urban For. Urban Green.* **18**(1), 237–241, doi: 10.1016/j.ufug.2016.06.011.
Srivastav, A.K., Singh, R., Manimegalai, S. & Rajeswari, V.D. (2015) Identification of flavonoids in methanolic extract of *Caryota urens* (fish tail palm): a phytochemical screening involving structure analysis by FTIR spectroscopy. *Res. J. Phytochemistry* **9**(3), 127–136, doi: 10.3923/rjphyto.2015.127.136.
Tan, Z., Lau, K.K.L. & Ng, E. (2016) Urban tree design approaches for mitigating daytime urban heat island effects in a high-density urban environment. *Energ. Buildings* **114**(15), 265–274, doi: 10.1016/j.enbuild.2015.06.031.
The Angiosperm Phylogeny Group, Chase, M.W., Christenhusz, M.J.M., Fay, M.F., Byng, J.W., Judd, W.S., Soltis, D.E., Mabberley, D.J., Sennikov, A.N., Soltis, P.S. & Stevens, P. F. (2016) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. *Bot. J. Linn. Soc.* **181**(1), 1–20, doi: 10.1111/boj.12385.
UN, United Nations. (1948) *Universal Declaration of Human Rights*. Paris, France.
UN, United Nations. (1972) *Declaration of the United Nations Conference on the Human Environment*. Stockholm, Sweden.
UN, United Nations. (1992) *Rio Declaration on Environment and Development*. Rio de Janeiro, Brazil.
Villeneuve, C., Tremblay, D., Riffon, O., Lanmafankpotin, G.Y. & Bouchard, S. (2017) A Systemic Tool and Process for Sustainability Assessment. *Sustainability* **9**(10), 1909, doi: 10.3390/su9101909.
Vogt, J., Fischer, B.C. & Hauer, R.J. (2016) Urban forestry and arboriculture as interdisciplinary environmental science: importance and incorporation of other disciplines. *J. Environ. Stud. Sci.* **6**(2), 371–386, doi: 10.1007/s13412-015-0309-x.
Waas, T., Hugé, J., Block, T., Wright, T., Benitez-Capistros, F. & Verbruggen, A. (2014) Sustainability assessment and indicators: Tools in a decision-making strategy for sustainable development. *Sustainability* **6**(9), 5512–5534, doi: 10.3390/su6095512.
Wang, Y.C. & Lin, J.C. (2012) Air quality enhancement zones in Taiwan: a carbon reduction benefit assessment. *Forest Policy Econ.* **23**, 40–45, doi: 10.1016/j.forpol.2012.07.009.
WCED, World Commission on Environment and Development. (1987) *Our Common Future*. Oxford, UK.
Winters, G.H.M. (2000) *Plantas ornamentais tóxicas*. Centro Paisagístico, Holambra, Brazil.
Yan, P.; Yang, J. (2018) Performances of Urban Tree Species under Disturbances in 120 Cities in China. *Forests* **9**(2), 50, doi: 10.3390/f9020050.
Zheng, D., Ducey, M.J. & Heath, L.S. (2013) Assessing net carbon sequestration on urban and community forests of northern New England, USA. *Urban For. Urban Green.* **12**(1), 61–68, doi: 10.1016/j.ufug.2012.10.003.