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Research paper

Changes in the provision of ecosystem services based on sidewalk tree-composition scenarios

Modificações na oferta de serviços ecossistêmicos em função de cenários de composição da arborização de calçadas

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ABSTRACT: Cities have been experiencing environmental and social issues due to urban expansion processes, be them planned or not. However, several environmental solutions have been proposed and sidewalk tree planting stands out among them. The aim of the current research is to assess the process to estimate ecosystem services under different sidewalk tree composition scenarios in Irati and Curitiba cities, Paraná State. In order to do so, 10 street segments from neighborhoods sampled in city-wide inventories were selected. Information about sidewalk length, curb ramps' width, and number of utility poles was collected for each street segment. The number of trees to be fit in each segment and sampled neighborhood was determined based on safety recommendations for these urban structures. Tree dimensions (Diameter at Breast Height - DBH, total height and crown diameter) were projected for the 55th year post-planting, based on using minimum dimensions of seedlings from small, medium and large-sized species. It was done to estimate ecosystem services in i-Tree Eco software. Significant differences among floristic composition scenarios ($p<0.05$) were observed for all ecosystem services in both cities. Compositions featuring large-sized species have show higher ability to provide ecosystem services, as well as higher monetary valuation, despite fitting a smaller number of trees in the assessed street segments. The herein formulated scenarios have shown the potential to increase the number of planted trees and to select compositions capable of maximizing ecosystem services' provision and trees' monetary value.
Keywords: Urban trees; Environmental benefits; Urban Forest.

RESUMO: *As cidades têm apresentado problemas de ordem ambiental e social em função do processo de expansão urbana, planejado ou não. Entretanto, inúmeras soluções ambientais têm sido apresentadas, e dentre elas, a arborização de calçadas. O objetivo desta pesquisa foi testar a estimativa de serviços ecossistêmicos em diferentes cenários de composição da arborização de calçadas nas cidades de Irati e Curitiba, no estado do Paraná. Para isso, foram selecionados 10 segmentos de ruas em bairros amostrados em inventários realizados nas cidades. Em cada segmento de rua coletou-se informações sobre comprimento das calçadas, largura das guias rebaixadas e número de postes. A partir de recomendações de segurança para estas estruturas urbanas, determinou-se o número de árvores que caberia em cada segmento e cada bairro amostrado. A dimensão das árvores (diâmetro à altura do peito – DAP, altura total e diâmetro de copa) foi projetada para o 55° ano pós plantio, partindo-se de dimensões mínimas das mudas de espécies de pequeno, médio e grande porte, para estimativas de serviços ecossistêmicos no software i-Tree Eco. Houve diferença significativa entre os cenários de composição florística ($p<0,05$) para todos os serviços ecossistêmicos, nas duas cidades. A composição com espécie de grande porte demonstrou maior capacidade de oferta de serviços ecossistêmicos, com maior valoração destes (em reais), apesar do menor número de árvores cabíveis nos segmentos de rua avaliados. Os cenários elaborados demonstraram que há potencial para incrementar a quantidade de árvores plantadas e que se pode optar por composições que possam maximizar a oferta de serviços ecossistêmicos e os valores monetários das árvores.*
Palavras-chave: *Árvores urbanas; Benefícios ambientais; Floresta urbana.*

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INTRODUCTION

Increasing global urbanization and several changes in land use have significant impact on cities' environment. This expansion often takes place in a disorderly manner and without proper planning, a fact that leads to a series of social, economic and environmental conflicts. Unplanned growth can also lead to infrastructure issues, as well as make urban centers more vulnerable to natural disasters. Therefore, lack of proper planning is one of the main factors contributing to urban scenario degradation and to increasing loss of citizens' quality of life (YU; YANXU; BOJIE, 2019; BASU; DAS; DAS; PEREIRA, 2023; CALDERÓN-ARGELICH; ANGUELOVSKI; CONNOLLY; BARÓ, 2023).

Promoting tree planting is one of the visible ways to mitigate the negative effects of urban expansion, since trees are important components to protect biodiversity and individuals' quality of life. (ANANYEVA; EMMANUEL, 2023). Trees' different line, texture and color types of help standardizing landscapes formed by elements with different sizes, besides promoting dynamism and movement, as well as improving and valuing the environment by making it more attractive (BOBROWSKI, 2015). Therefore, vegetation spatialization must also be taken into consideration at the time to restructure cities, since landscapes' ecological, social and aesthetic functions are influenced by tree distribution (GRISE; BIONDI; ARAKI, 2016; SILVA; BIONDI, 2013; SILVA; DE CASTRO FONTES, 2018).

Another relevant factor associated with vegetation incidence in cities, besides its aesthetic function, lies on the fact that urban forests provide a series of benefits through ecosystem services, such as microclimatic regulation, reduced air pollution and rainfall water runoff, and promotion of physical activities. In addition, it has significant psychosocial effect on the population. Therefore, tree species composition is closely related to both the amount and quality of the provided services (MULLANEY; LUCKE; TRUEMAN, 2015; GERSTENBERG; HOFMANN, 2016; SELMI; WEBER; RIVIÈRE; BLOND *et al*, 2016; D LI; WANG, 2021; CIMBUROVA; PONT, 2021).

Accordingly, as cities face emerging challenges, such as extreme weather events and changing development patterns, it is essential creating scenarios to help better understanding urban vegetation-related benefits for urban adaptation and resilience purposes. This process can be a useful planning tool, since it enables developing flexible strategies capable of effectively responding to unexpected changes, besides enabling planners and managers to assess different approaches and to choose the ones that best meet community needs. (HILDE; PATERSON, 2014; ZHANG; HUANG; HE; YIN *et al.*, 2019; LUMENG; JIANGUO, 2022).

Likewise, trees' addition to the process aimed at creating intelligent scenarios is a fundamental approach to complex challenges faced by modern cities (YU; YANXU; BOJIE, 2019). Strategically managing urban trees as part of urban planning ensures ecosystem services' provision, as wel as contributes to environmental quality and social well-being. Prioritizing sustainable and adaptive urban planning enables ensuring more harmonious and resilient city development processes capable of benefiting both the present and future generations (LAWRENCE; DE VREESE; JOHNSTON; VAN DEN BOSCH *et al.*, 2013; LIVESLEY; MCPHERSON; CALFAPIETRA, 2016; RICHARDS; EDWARDS, 2017; SCHLAEPFER, M. A.; GUINAUDEAU, B. P.; MARTIN, P.; WYLER, N. *et al*, 2020).

However, studies focused on using differnt scenarios to investigate both the importance and contribution of urban trees (at different sizes) to ecosystem services' provision have been carried out in foreign cities (HILDE; PATERSON, 2014; NYELELE;

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KROLL; NOWAK, 2019). It is essential taking care of Brazilian cities to provide basic information to guide applied research, as well as to direct public policies focused on enhancing urban greenery. Therefore, the aim of the current research is to investigate the influence of variations in sidewalk tree composition on ecosystem services' provision in some neighborhoods in Curitiba and Irati cities, Paraná State.

MATERIAL AND METHODS

The current research used information on sidewalk afforestation in Irati and Curitiba cities, Paraná State. This information was collected from forest inventories carried out in 2019 and 2010, respectively. The inventories are available at the Urban Silviculture Laboratory database, Forestry Engineering Department, Unicentro. Although both herein investigated cities are inserted in the Mixed Ombrophylous Forest ecosystem, they differ from each other in several factors, such as in urban territorial area, and in urban planning and environmental policies focused on urban greenery.

Data collected from these inventories comprised information about tree species, diameter at breast height (DBH), total height, crown diameter and general condition classes, as well as information about urban structure, such as sidewalk width and street length. However, only information about urban structure was used to guide the process to create sidewalk tree composition scenarios.

Both cities were sampled based on using sampling units with different shapes, areas, and locations that fully, or partly, covered their streets. Therefore, ten full street segments were selected per sampled neighborhood, in each city. Each street segment, with varying area, corresponded to part of a given street in the space between two other cross streets including the roadway and two sidewalks, one on each side of the street. In total, 10 street segments in 19 neighborhoods were selected in Irati City, whereas 10 street segments in 15 neighborhoods were selected in Curitiba City. This procedure was adopted to enable repeting the elaborated composition planning**.**

Six sidewalk tree composition scenarios - depicting the landscape 55 years after planting - were created in each study site, based on information from each street segment. The composition scenarios were: Scenario 1, composition comprising small species, such as *Lagerstroemia indica L*., which is often planted in these cities; Scenario 2, composition comprising medium-sized species, such as *Handroanthus albus* (Cham.) Mattos, which is often found in these cities; Scenario 3, composition comprising large species, such as *Parapiptadenia rigida* (Benth.) Brenan; Scenario 4, composition comprising 50% of small species (side of the street with power lines) and 50% of medium-sized species (side of the street without power lines); Scenario 5, composition comprising 50% of small species (street side with power lines) and 50% of large species (street side without power lines); Scenario 6, composition comprising 50% of medium-sized species (side of the street with power lines) and 50% of large species (side of the street without power lines). The spacing adopted in each composition scenario was determined based on the methodology by Mata *et al.* (2020).

The number of trees to fit in each street segment, in the aforementioned tree composition scenarios, was estimated based on the total length of the street in a given segment, by subtracting the value of 5.0 m (corresponding to each corner) to find the total width of the lowered guides (lowered guide is understood as a change in the transverse slope of the sidewalk, whose floor is lowered to allow vehicles to both enter and exit the street towards a given property), as well as the sum of the safety distance of each lowered

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guide, and the sum of the safety distances from the posts, based on the size of the tree species to be planted (COPEL, 2009).

Ecosystem services provided by trees planned in the composition scenarios were estimated for the selected street segments in each city. The following ecosystem services were estimated in i-Tree Eco software (USDA Forest Service): carbon storage (ton), carbon sequestration (ton. $year^{-1}$), avoided surface runoff ($m^3.year^{-1}$) and atmospheric pollutants' retention (ton/year). Variables, such as DAP, total height, and crown diameter (according to the composition scenario), as well as tree condition (considered excellent for the composition scenarios) were used to calculate the estimates. All estimates calculated in i-Tree Eco software were adjusted to the reference base of microclimatic and environmental pollution information registered for Curitiba City, in 2018, at dollar exchange rate equal to R$5.2561.

Non-parametric analysis of variance (Friedman's test) was applied to values recorded for each ecosystem service in each city. It was done based on a randomized block design, according to which, each neighborhood featured a block to control the existing spatial variability, and treatments corresponded to the elaborated composition scenarios. This non-parametric test was used because data did not meet criteria set for normal distribution or homoscedasticity variance of residuals. Medians were compared to each other through Nemenyi-Wilcoxon-Wilcox post-hoc test, whenever significant difference between treatments was observed ($p<0.05$). All statistical and graphical analyses were performed in R software, based on using rstatix, PMCMRPlus, dplyr and ggplot2 packages.

RESULTS AND DISCUSSIONS

The total width of the lowered guides, the 5.0-m difference from each corner, the distance from the lowered guides and the distance from the posts (variables) were subtracted from the length of each selected street segment (depending on the size of the used tree species) to find the total number of trees that would fit the selected samples in an ideal composition context in Irati and Curitiba cities (**Table 1**).

Variations observed in the size of each species selected for each city were associated with the number of restrictions found in the selected segments, namely: number of posts, as well asnumber and width of lowered guides, in addition to segment length, which was different and not standardized among neighborhoods. Likewise, variations in the number of trees between composition scenarios were associated with variations in protection distances, depending on the selected species' size.

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Table 1. Number of suitable trees in the 10 street segments selected based on tree species size in floristic composition scenarios: small, medium, large, small and medium (S+M), small and large (S+L) and medium and large (M+L).

Number of trees in each scenario for Irati						
Neighborhood	Small	Medium	Large	S+M	S+L	M+L
Riozinho	203	120	75	161	139	97
Centro	627	382	248	504	437	315
São João	930	564	364	747	647	464
Eng. Gutierrez	402	245	159	323	281	202
Jardim Aeroporto	304	182	117	243	210	149
Vila Nova	81	48	30	64	55	39
Nhapindazal	162	97	62	130	112	80
Lagoa	565	342	220	453	393	281
Canisianas	261	157	101	209	181	129
Camacuã	205	124	80	165	143	102
DER	296	181	117	238	207	149
Jardim Virginia	237	143	92	190	165	118
Jardim Califórnia	421	257	167	339	294	212
Colina	229	137	88	183	159	113
Alto da Glória	415	253	164	334	290	208
Stroparo	394	239	155	316	274	197
Rio Bonito	784	476	307	630	546	392
Alto da Lagoa	456	278	181	367	318	229
Fosforo	415	252	163	334	289	208
Number of trees in each scenario for Curitiba						
Neighborhood	Small	Medium	Large	S+M	S+L	M+L
Água Verde	314	177	105	246	210	141
Alto da XV	383	208	118	296	251	163
Bacacheri 1	340	189	111	265	226	150
Bacacheri 2	318	184	113	251	216	149
Bacacheri 3	287	166	102	227	195	134
Bigorrilho	287	157	89	222	188	123
Boqueirão	370	211	127	291	249	169
Centro	401	241	154	321	278	198
Cristo Rei	374	214	130	294	252	172
Jardim Social	368	215	133	292	251	174
Mercês	378	201	123	290	251	162
Portão	346	193	114	270	230	154
Rebouças 1	308	171	99	240	204	135
Rebouças 2	365	208	125	287	245	167
Seminário	450	258	157	354	304	208

The growth projection planning applied to small-sized tree species *L. indica*, to medium-sized species *H. albus* and to large-sized species *P. rigida* was carried out based on a hypothetical tree life expectancy limit of 100 years (**Figure 1**), with sharp growth rate decline from the 75th year, onwards (NOWAK; AEVERMAN, 2019). It was done because of

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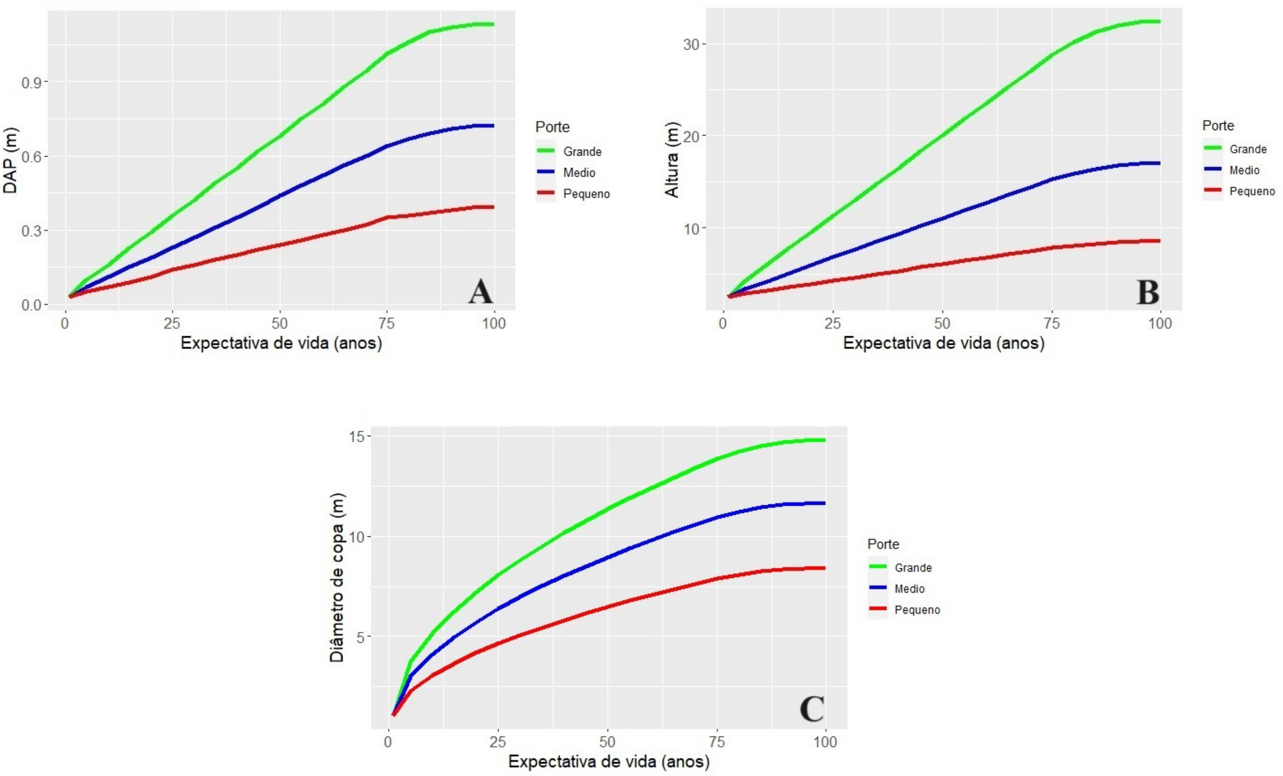
lack of information available in the literature about this subject, either under natural growth or urban stress conditions.

Figure 1. Growth curves plotted for variables DBH (A), total height (B) and crown diameter (C) for small-sized species *L. indica*, medium-sized species *H. albus* and for large-sized species *P. rigida*.



Results of growth projections carried out for small-, medium- and large-sized trees at the age of 55 years were used to create floristic composition scenarios. This growth projection time set for the composition scenarios was empirically determined, since there are no records of trees' maximum life expectancy in cities' afforestation processes that could be used as model in the current research. DAP values recorded for species *L. indica*, *H. albus* and *P. rigida* reached 0.26 m, 0.48 m and 0.75 m, respectively. Values recorded for total tree height reached 6.35 m, 11.85 m and 21.75 m, respectively. Values recorded for crown diameter reached 6.78 m, 9.38 m and 11.88 m, respectively. These values are like maximum tree size values recorded for these species in the literature (LORENZI, 2000; BIONDI; ALTHAUS, 2005; SAUERESSIG, 2014).

Results of ecosystem services' estimates calculated for the number of suitable trees on the sidewalks of sampled street segments (**Table 1**) have evidenced that the floristic composition comprising large-sized trees species (*P. rigida*) tends to provide the largest number of services to both cities (**Figure 2**), despite the smaller number of trees in the investigated compositions (**Table 1**) - 38% less trees in Irati and 34% less trees in Curitiba -, in comparison to the composition comprising small-sized species. There was significant difference in all assessed ecosystem services (**Table 2**) among the herein proposed composition scenarios ($p<0.05$).

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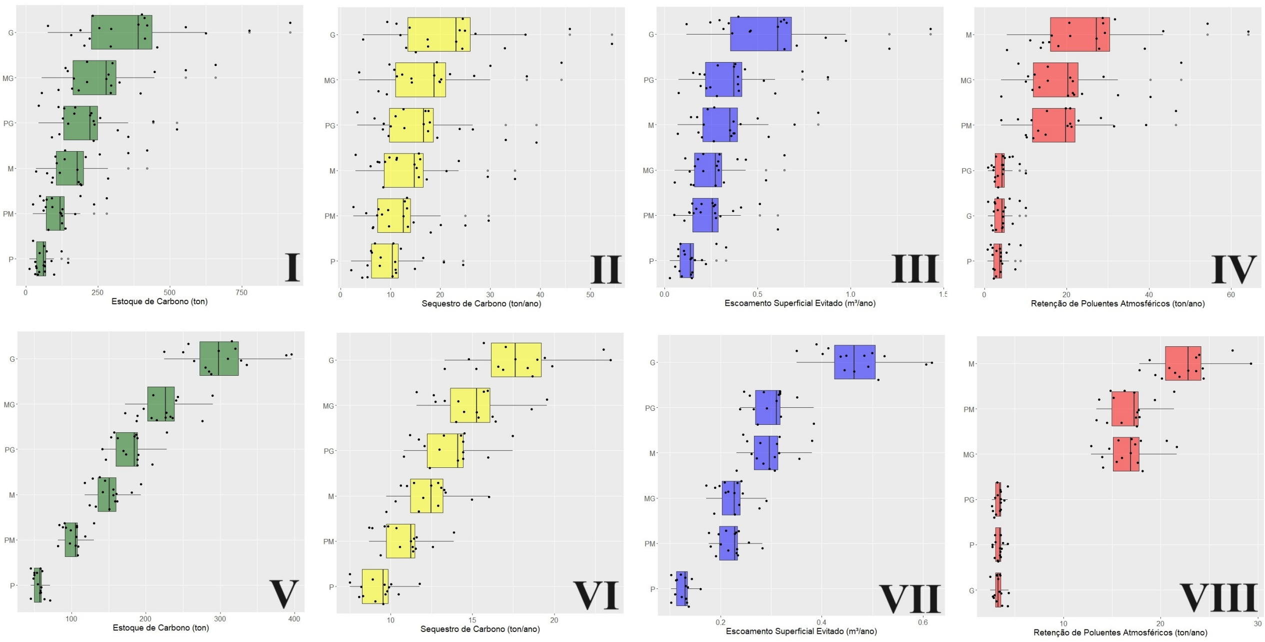
Figure 2. Variation range in ecosystem services, such as Carbon Storage and Sequestration, Avoided surface runoff and Atmospheric pollutants' retention, estimated for Irati (I, II, III and IV) and Curitiba (V, VI, VII and VIII) cities, for six floristic composition scenarios: only small-sized species, *Largestroemia indica* (P); only medium-sized species, *Handroanthus albus* (M); only large-sized species, *Parapiptadenia rigida* (G); composition comprising both small- and medium-sized species (PM); composition comprising both small- and large-sized species (PG); composition comprising both medium- and large-sized species (MG).



Scenarios planned for ecosystem services, such as carbon storage and sequestration, did not significantly differ (p>0.05) from the scenario that only comprised medium-sized species, both in Irati and Curitiba cities. Ecosystem services estimated for the composition scenario comprising both small- and large-sized species did not significantly differ (p>0.05) from those estimated for the scenario comprising large-sized species (**Table 2**). Altough power supply companies (COPEL, 2009) recommend using small-sized species under power lines and large-sized species on the sidewalk without power lines, small and medium-sized species are the ones mostly subjected to frequent and intense pruning by these companies (BOBROWSKI; BIONDI, 2012). It is done to prevent them from exceeding the high voltage line, which is oftentimes 10.0 m above the ground.

The different pattern observed for ecosystem service "atmospheric pollutants' retention", based on the highest values observed for medium-sized species, may be associated with internal flaw in the estimation model, in i-Tree Eco software, since, although the used species (*H. albus*) presented compound leaf with leaflets significantly larger than those of large-sized species (*P. rigida*), its mean crown diameter was significantly smaller. In other words, its crown volume has lower potential to retain atmospheric pollutants. However, according to Wu et al. (2019), atmospheric pollutant retention estimates, such as PM2.5, carried out in i-Tree Eco software, essentially depend on species' leaf area index (LAI) values.

Although it does not represent a real sidewalk afforestation composition, since there is no uniform planting of the same species and all trees have the same size, this planning

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type helps better understanding what could be obtained through a technically conducted planting aimed at maximizing the provided ecosystem services.

Table 2. Likely difference between median values observed for ecosystem services compared through Nemenyi-Wilcoxon-Wilcox post-hoc test, for projected data.

Comparisons for Irati										
	Carbon Storage					Carbon Sequestration				
	G	M	MG	P	PG	G	M	MG	P	PG
M	1.1^{-5}					1.1^{-5}				
ML	0.57	0.01				0.57	0.01			
S	7.1^{-14}	0.01	6.6^{-10}			7.1^{-14}	0.01	6.6^{-10}		
SL	0.01	0.57	0.57	1.1^{-5}		0.01	0.57	0.57	1.1^{-5}	
SM	6.6^{-10}	0.57	1.1^{-5}	0.57	0.01	6.6^{-10}	0.57	1.1^{-5}	0.57	0.01
	Surface runoff avoided					Retention of atmospheric pollutants				
	L	M	ML	S	SL	L	M	ML	S	SL
M	0.01					1.6^{-7}				
ML	1.1^{-5}	0.57				9.4^{-4}	0.51			
S	7.1^{-14}	1.1^{-5}	0.01			0.12	7.1^{-14}	1.2^{-9}		
SL	0.57	0.57	0.01	6.6^{-10}		1.00	9.4^{-8}	6.5^{-4}	0.15	
SM	6.6^{-10}	0.01	0.57	0.57	1.1^{-5}	0.12	0.02	0.68	7.3^{-6}	0.09
Comparisons for Curitiba										
	Carbon Storage					Carbon Sequestration				
	L	M	ML	S	SL	L	M	ML	S	SL
M	1.6^{-4}					1.6^{-4}				
ML	0.69	0.04				0.69	0.04			
S	3.8^{-12}	0.04	7.1^{-8}			3.8^{-12}	0.04	7.1^{-8}		
SL	0.04	0.69	0.69	1.6^{-4}		0.04	0.69	0.69	1.6^{-4}	
SM	7.1^{-8}	0.69	1.6^{-4}	0.69	0.04	7.1^{-8}	0.69	1.6^{-4}	0.69	0.04
	Surface runoff avoided					Retention of atmospheric pollutants				
	L	M	ML	S	SL	L	M	ML	S	SL
M	0.05					1.3^{-7}				
ML	9.6^{-6}	0.26				4.1^{-3}	0.26			
S	3.8^{-12}	1.0^{-4}	0.18			1.00	3.9^{-8}	2.0^{-3}		
SL	0.62	0.80	8.4^{-3}	1.3^{-7}		1.00	7.1^{-8}	2.9^{-3}	1.00	
SM	2.0^{-6}	0.14	0.99	0.31	2.9^{-3}	5.9^{-3}	0.22	1.00	2.9^{-3}	4.1^{-3}

Monetary values of ecosystem services provided by trees, in different floristic composition scenarios (**Table 3**), are influenced by both number of trees and selected species' size. These values are important to show the benefits provided by trees to both public managers and the overall population, as well as their potential as public assets to help promoting quality of life, rather than just implementation and maintenance costs (CHEN; WANG; NI; ZHANG *et al*, 2020; PISTÓN; SILVA FILHO; DIAS, 2022; SUCHOCKA; HECIAK; BLASZCZYK; ADAMCZYK et al., 2023).

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Table 3. Values of ecosystem services provided by trees in different floristic composition scenarios of sidewalk afforestation processes implemented in street segments sampled in Irati and Curitiba cities.

Composition scenarios	Number of trees	Carbon storage (R$)	Carbon sequestration (R$/year)	Avoided Runoff (R$/year)	Pollutant retention (R$/year)
Ecosystem service values for Irati					
Small	7387	1,147,578.99	192,497.36	49,976.42	16,028.31
Medium	4467	3,309,151.46	274,057.89	81,426.58	28,758.17
Large	2890	7,205,170.19	426,592.78	93,615.24	31,444.48
S+M	5940	2,205,763.16	232,782.24	59,925.58	20,421.64
S+L	5144	4,120,322.14	307,911.48	70,333.48	23,739.56
M+L	3684	5,165,870.71	346,856.30	63,540.83	21,342.76
Ecosystem service values for Curitiba					
Small	5289	821,652.03	137,825.67	33,473.68	11,354.47
Medium	2993	2,217,242.79	183,625.54	54,730.43	19,330.68
Large	1800	4,487,647.49	265,697.82	59,860.96	20,225.58
S+M	4148	1,504,346.76	160,376.90	40,975.91	13,899.28
S+L	3552	2,633,775.63	201,571.97	46,849.42	15,851.57
M+L	2406	3,308,098.49	223,276.50	41,630.60	14,065.98

Like what was observed for estimates on the number of ecosystem services, their monetary values tend to be more significant in compositions comprising large-sized species, even with fewer trees. This factor is following the statement by Widney et al. (2016), according to whom, benefits provided by urban trees may be higher than implementation and maintenance costs over the years. It must be highlighted to help promoting the value of trees.

CONCLUSIONS

Although there is no basic information in the literature about both the growth and life expectancy of forest species planted in sidewalks, the herein calculated estimates were consistent with data on species' maximum size.

The herein developed scenarios have evidenced the potential to increase the number of trees planted in the assessed cities. They have also shown that compositions can be selected to help maximizing ecosystem services' supply, as well as the monetary value of trees, by treating them as public assets to be used in quality-of-life promotion.

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