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Exploring the potential of urban park size for the provision of ecosystem services to urban centres: A case study in São Paulo, Brazil

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ABSTRACT

Urban parks include different infrastructures - green areas, fitness equipment, jogging tracks and sport courts – and are key suppliers of ecosystem services in cities. Given the importance of ecosystem services to the vigor of urban ecosystems, there is a developing awareness that ecosystem services concerns ought to be integrated into urban park design. Nonetheless this integration is incomplete due to the scarcity of applicable or available tools and criteria for implementation. To address this scarcity, the present study assesses costs and supply of a subgroup of supportive and regulative ecosystem services in urban parks and examines the significance of these services under an environmental/economic perspective using emergy synthesis. Seventy-three parks in São Paulo, Brazil, are used as a case study. Results show that green areas in urban parks provide valuable services to the municipality, and that parks can be designed according to the needs of the surrounding areas. The method may be useful for different localities and environments providing practical information to urban planners and policy makers. This study provides a basis for the incorporation of ecosystem service concerns into urban park design to boost their benefits in urban centers.

1. Introduction

Urban parks are critical components within the metabolism of cities as well as the core scenes for open-air leisure communal activities. Historically, the functions of urban parks have been connected to leisure and aesthetics, but with the change of the surroundings and necessities of urban centers, leisure now includes sport activities, with the consequent implementation of fitness equipment, jogging tracks and sport courts. In addition, contemporary urban parks also relieve the adverse effects of urban metabolism, compensating for densely built areas. Thus, the concerns for designing a contemporary urban park go beyond the park's borders. The design of producers of ecosystems services must consider water inflows and outflows, underground water, and the size and quality of the green areas aiming to improve the air quality conditions of the nearby urban settlement. Ecosystems services are public goods without a market price frequently overlooked or undervalued by urban policymakers, who must now to consider a broader perspective taking into account the provision of ecosystem services. In this perspective, projects for implementation or renovation of urban parks are connected not only with aesthetics and leisure, but also with the ecosystems services they may deliver to the entire city [1].

Several authors connected the benefits of green urban areas with aesthetics [2], noise reduction [3] and habitat for small animals and insects [4], identifying the many social, environmental and economic services they are responsible for [5,6]. Benefits are listed from the simple shadow effect to diminish the temperature within the parks, to the decreasing of heat islands using geographic information system [7] or by direct measurements in and out the parks [8,9]. The reduction of flood risk was studied by Xiao and McPherson [10] and Xiao et al. [11,12], who found that for each dollar spent in urban forests, the benefits return roughly between USD 1.37 and USD 3.09 per year.

Lin et al. [13] related green urban areas to the sequestration/storage of atmospheric carbon and the reduction temperature in the neighborhood of the park. According to Lin's results, the larger the amount of vegetation, the larger will be the energy savings, and the lower will be the pollution around the park. They concluded that several small green areas are more advantageous than a small number of large green areas, and that irregular borders perform better than regular ones of the same size. Su et al. [14] evaluated the cooling effect of seventeen parks in Guangzhou, using thermal infrared remote sensing techniques. They found a positive relationship between the temperature decrease and the size of the green areas, cooling distances from 14 to 432 m and

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temperature decrease from about 1.9 to 4.3 K. The cooling effects of urban parks was also studied using Landsat-5 Thematic Mapper data [15]. The results showed that the cooling effect varies along the year and depends on the size of urban parks, in agreement with the findings of Bilgili et al. [16], who reported that the contribution of urban parks is dynamic, and the result of the combination of spatial, structural and temporal characteristics of the surrounding area. Jaganmohan et al. [17] measured air temperature in 62 urban parks in Leipzig. The relationship of the change in temperature with park-distance was examined in multiple regression models revealing that cooling effects increased with increasing park size.

In regard to climate change, Othman et al. [18] assessed the impacts of the CO_2 sequestration, and estimated the carbon stored by urban parks by biomass equations, using field inventory and analysis survey data. Their study showed that distinct landscape design resulted in different quantities in stored carbon, providing understanding and new insights of the role of urban parks as carbon sinks. Recognizing that urban parks provide valuable ecosystem services for the well-being of city residents, Mexia et al. [19] stated that knowing the quantity of ecosystem services delivered by different types of vegetation may assist managing selections built on ecosystem services trade-offs.

Approaches for valuing the ecosystem services are being developed as instruments for communicating non-tangible values into currency [20–22]. Sutton and Anderson [23] used the developable real estate market value of Central Park to estimate the value of the park's natural capital. The estimated value of about $70 million per hectare per year of ecosystem services provided intends to represent the interaction of social, natural, human, and built capital. There are also approaches in which value is given by discerning the preferences for ecosystem services disclosed by users/consumers [4,24,25]. Despite the main reason to use the park was physical activities, most of the visitors acknowledged the park's cooling effect, and the authors recognized that additional research was required to evaluate people's perceptions about ecosystems services, such as flood security, air quality and biodiversity protection [25].

The discussion on procedures to evaluate those services rely on economic-based tools, such as the value of entry fees [26,27], or the real estate value of the park location [23]. The investment for planting and maintaining trees was defended by Millward and Sabir [28] considering the benefits related to increased energy savings and CO_2 sequestration. McPherson et al. [9] accounted for different benefits: (i) climate regulation – accounted by the costs of electricity and natural gas; (ii) carbon dioxide sequestration – accounted by the amount of biomass; (iii) reduction flood risks – accounted by expenditures on flood control.

A different option for evaluating ecosystem services is the emergy synthesis that offers a complement (or a substitute) to market-based and monetary evaluations [29]. Emergy assessment allows calculating biophysical values, also linking them with monetary flows. For these reasons, emergy synthesis is increasingly used for evaluating ecosystem services. Up till this moment, most of emergy-related research focused on large scale territorial systems [30], including environmental, cultural and economic subsystems [31], biomes [32–34] and natural reserves [35–37]. Mariano et al. [38] proposed emergy as a management tool for urban parks. A stimulating debate on the value of natural capital and ecosystem services suggests that emergy synthesis is one of the most dependable scientific measures to assess the provision of ecosystem services [39]. Due to its very own nature, emergy is suitable to assess the role and value of supporting (i.e. services that are the basis for further services and are not often considered as final services or direct benefits) and regulating services (i.e. benefits obtained from the regulation of ecosystem processes) [40].

In previous studies, an integrative methodology for the environmental assessment of urban parks was proposed [38,41]. The results showed that green areas in urban parks provide valuable services to the city's community through transformation processes of natural renewable inputs that would be otherwise worthless. This paper presents an emergy-based evaluation of the supply and indirect use of net primary production (NPP) and of a subset of regulating services directly connected with NPP in urban parks, and aims to:

- evaluate how these ecosystem services are provided and used in urban parks at different spatial scales,
- evaluate the environmental costs, as well as the costs sustained by the municipality, maintaining the supply of these ecosystem services in urban parks at different spatial scales,
- contribute to the effective implementation of new parks based on the costs and supply of ecosystem services,
- contribute to the effectual implementation of new parks based on the need of ecosystem services by the neighborhood.

The city of São Paulo, Brazil is used as a case study. Parks have several benefits for the society which have economic value and play a critical role during the decision-making process of city governors/professionals. For the case of São Paulo, three ecosystem services (infiltration, CO_2 sequestration and evapotranspiration) were considered, since these particular services are little (or not) considered by the city public administrators. However, this approach is applicable not only in other geographical contexts, but also to evaluate other benefits, providing useful information for public managers and urban planners.

2. Method

Emergy synthesis is especially suitable to evaluate ecosystem's services because it assesses the environmental performance of systems on global scale and takes into account the free environmental incomes such as sun, wind, rain and soil, which are indirectly embodied in human activities. The method goes back in time including the work required for resource formation. This aspect makes emergy synthesis a robust tool for assessing efficiency under a system's view that is not usually included in traditional analysis. Energy is degraded in every transformation, but its ability to produce work increases after each transformation. The method application starts with an energy system diagram that represents the system (Fig. 1) using the symbols recommended by Odum [29]. Next, all the quantities of energy and mass flowing into the system are multiplied by their respective unit emergy value (UEV), resulting in flows with a common unit, solar energy joules (sej). These flows are then combined to estimate the total emergy composed by indigenous fluxes (I) – free renewable and non-renewable inputs – and inputs provided by the human systems (F, such as labor, fuel and materials). The total solar emergy of a resource flow can be calculated using equation (1).

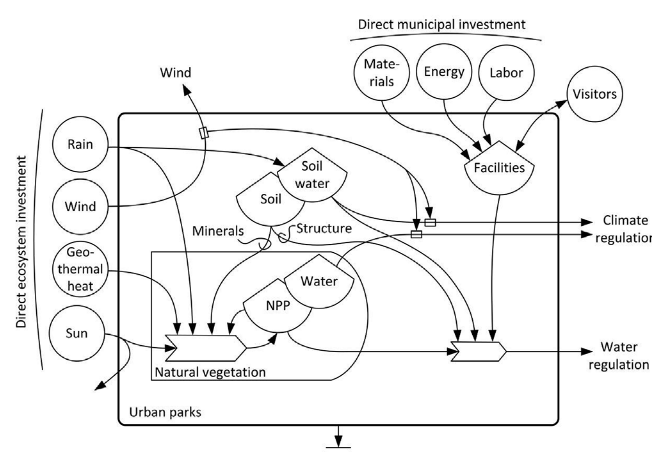

Fig. 1. Energy system diagram of an urban park, where free environmental incomes are represented on the right. NPP – net primary production.

Energy flow (unit) x UEV (sej/uni) = Emergy (sej) (1)

To facilitate the dialogue with decision-makers, the emergy-based currency equivalent (Em$) integrates economic and environmental evaluations and provides recognizable units. To calculate the Em$ value of any emergy flow, the emergy is divided by the emergy money ratio (EMR) of the local economy [29]. The EMR quotes the monetary value produced within an economy as the outcome of an emergy flow. The EMR and Em$ were calculated using American dollars to simplify comparison with values in the literature [42]. For São Paulo, the Em$ was 1.7×10^{12} sej/year [43–45].

Further information on emergy synthesis procedures and implications can be found in Refs. [29,46]. Appendix A shows the calculations for the emergy values of the ecosystem's services.

The evaluation procedure was accomplished by means of data collected through the Municipal Secretary of Green and Environment [47] formal documents through the following steps:

- Delineation of the system under study including its limits for investigation
- Assembly of the energy flows diagrams (Fig. 1)
- Construction of the emergy tables created upon the data collected
- Discussion based on the emergy ternary diagram.

Ternary diagrams portray information and assist the decision-making processes, and can be useful to compare different arrangements or highlight the main (and the hidden) characteristics of a system. The emergy triangular diagram encompasses three variables [48,49] constrained to a sum (1 or 100%), and allows to represent three variables in two dimensions. The assistance of ternary diagrams improves the evaluation of natural and anthropogenic production systems [49] and their interactions with the environment [50]. In this study, the ternary diagrams were used in two different ways. The first uses the ternary diagram as shown in Fig. 2 A. In this diagram, the upper apex of the diagram denotes the emergy city's investment for the park maintenance and operation, while the bottom apexes represent the emergy corresponding to climate regulation (left) and to water regulation (right). In this way, the emergy invested by the municipality can be compared to that obtained in the form of ecosystems services, making possible for decision-makers to assess the contribution of the park to the city in emergy terms.

The line, which crosses the diagram of Fig. 2 horizontally at 50%, shows the situation where the ecosystems' services produced are equal to the municipality investment (labor, fuel, goods and services). When

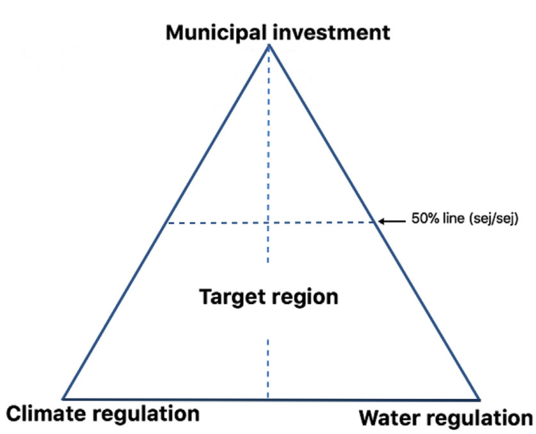

Fig. 2. Emergy ternary diagrams where the diagram to compare the municipal investment with the production of ecosystems' services. Climate regulation includes CO_2 sequestration and evapotranspiration). The target region indicates that the provision of ecosystem's services is higher than the municipal investment in emergy terms.

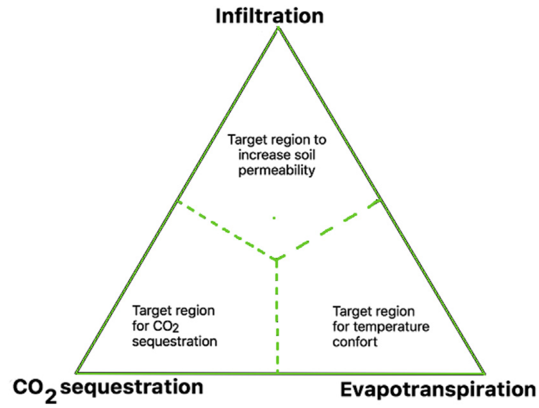

Fig. 3. Emergy ternary diagrams where the diagram to assess the combination the three considered ecosystem's services for each park. The three regions highlight which service is more significant for a given park.

the resources invested by the city to maintain and operate the park are lower than the ecosystems services emergy, the park will be represented by a point below the 50% line, and a net benefit can be identified (Eq. (2)).

Net benefit = Ecosystems services emergy – Emergy invested (2)

The second diagram (Fig. 3) compares the emergy values of the three ecosystems services placed in each axis, to aid decision-makers to identify which kind of park would be suitable for a given region requirement. For example, if a park is going to be implemented in a region subjected to floods, a park with characteristics (quantity of trees, grass, built area) to those placed in the upper part of the diagram should be chosen.

It is worthy noting that different methods also provide different results. Shade from trees, for example, has been shown to be important for lowering temperatures; however, temperatures have also been shown to be lower in unshaded green sites or above short vegetation, which suggests evaporative cooling may also play a role [51]. However, from an energy perspective (based on the energy balance of urban parks, but not considering the quality of each flux), the amount of energy exerted on the physical system through evapotranspiration and through shading depends on the park itself and it cannot be concluded that evapotranspiration is the larger portion. Then, under this perspective, there are various studies on urban parks establishing that cooling by evapotranspiration can be negligible compared to the cooling through the tree shading - being evapotranspiration and tree shading considered as separate benefit streams. According to the rules of emergy synthesis, when from the same renewable emergy base (shading and evapotranspiration derive from biomass production), only the largest flux must be accounted - evapotranspiration, in this case – to avoid double counting. Moreover, emergy accounts for fluxes that cross the system's boundaries, while shading (besides being derived from NPP), provides a cooling effect within the parks, and then is not considered.

3. Results and discussion

In order to compare the investment of society and nature in the operation and assessment of the environmental services produced by the group of parks, the ratio I/F is confronted with the emergy-based currency equivalent (Em$) of the city's investment (Fig. 4). Twenty-six percent of the parks have I/F less than 0.1 and 36% of the parks have $0.1 < I/F < 0.2$, which shows that the municipality should invest 5 to 10 times more emergy (F) for their maintenance than that provided by nature. This investment is directly proportional to the ratio between the green area and the built area of each park and there is no correlation

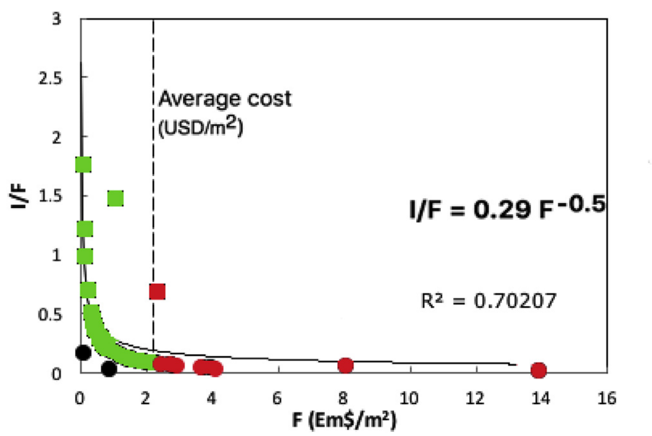

Fig. 4. Cost in Em$/m2 and the I/F ratio of the municipal parks of São Paulo. The vertical line shows the average cost in dollars (2.11 USD/m2), where (■) relates to parks with I/F > 0.2) and (●)to parks with I/F < 0.2).

with the amount of labor employed. The average Em$ values per square meter of the 73 parks is 1.03 Em$/m2 and corresponds to about 50% of the actual cost provided by the Secretary of the Green and Environment, 2.11 USD/m2 [47].

The ratio between the resources of nature and resources from the economy establishes an indicator for the management of existing urban parks that relates this ratio with the economic cost of one square meter of park, allowing to determine the best configuration for each park, to prioritize actions for new projects and to optimize the maintenance of old ones. Small parks receive little investment from nature and high investment from the municipality (Vila Silvia 8.04 Em$/m^2 and Zilda Natel 13.91 Em$/m^2, Table 1). In spite of most of the parks have an emergy investment of less than 2.00 Em$/m^2, it is clear that emergy is unevenly distributed among small, medium and large parks (Tables 1–3).

Small and medium parks receive more emergy investments, and projections for new parks should contemplate not only balancing green and built areas [41], but also establish a minimum green area for a new project. The use of the ternary diagram may help to identify the desirable balance between the municipal investment and the provision of ecosystem's services (Fig. 5).

Forty-six parks are above the 50%-line indicating that their production of ecosystem's is low (or the proportion of built area is too high, Fig. 5A). Tables 4–6 show net emergy benefit for the municipality investment for the small parks of Greater São Paulo. Among the small parks there are only two exceptions, Trianon (I/F = 0.21) and Linear Sapé (Table 4), which has I/F = 0.24 comparable to those of larger parks. The whole set of small parks is not able to provide enough ecosystems' services to cross the 50%-line. A negative emergy value indicates that the parks are actually a burden for the municipalities/cities, in terms of the trade-off between the emergy invested by the city and the emergy of produced ecosystems services.

About 50% of the medium parks show net emergy benefit (Table 5), but the position of the whole set is just below the 50% line (Fig. 4A). Finally, the representation in the ternary diagram makes clear that only the São Paulo's parks with more than 250,000 m^2 show a significant contribution to climate regulation, especially through evapotranspiration.

Since is not always feasible the availability of large areas in most of urban centers, the possibility for implementing several small parks was explored. For São Paulo, it would be necessary to implement 82 new small parks to make the whole set to reach the 50%-line. Moreover, the parks should be designed taking as models the Triannon park – with 48,600 m^2 of total area, 1000 m^2 of built area and a tree/grass relationship of 80:20. An other option would be the Linear Sapé park with 23,544 m^2 in total and the same tree/grass relationship. It is worth to

Table 1
Emergy values for indigenous flows (I), feedback flows (F) and the emergy-based currency equivalent for the small parks in Greater São Paulo. Area < 50,000 m^2.

Small parks	I (sej/year)	F (sej/year)	Emergy-based currency equivalent Em$ (F)/m^2
Zilda Natel	6.55E+14	5.64E+16	**13,91**
Praia do Sol	5,05E+15	2,51E+17	**8,24**
Vila Silvia	1,25E+15	6,02E+16	**8,04**
Linear Guaratiba	8,52E+15	1,40E+17	2,84
Ermelino Matarazzo	1,54E+15	2,40E+16	2,73
Jacinto Alberto	1,21E+16	1,90E+17	2,73
Luiz Carlos Prestes	7,36E+16	1,09E+17	2,37
Santa Amélia	1,01E+16	1,29E+17	2,24
Linear Parelheiros	4,75E+15	6,07E+16	2,23
Benemerito Brás	6,49E+15	8,13E+16	2,14
Raul Seixas	9,83E+15	1,19E+17	2,12
M Boi Mirim	5,67E+15	6,56E+16	2,03
Rodrigo Gásperi	1,16E+16	1,27E+17	1,92
Lions Club - Tucuruvi	7,09E+15	7,71E+16	1,91
Buenos Aires	6,74E+15	7,56E+16	1,78
Faria Lima	1,20E+16	1,22E+17	1,78
Cordeiro	1,01E+16	8,77E+16	1,52
Eucaliptos	4,63E+15	3,95E+16	1,50
Colina de São Francisco	1,43E+16	1,23E+17	1,48
Chácara das Flores	1,25E+16	1,03E+17	1,45
Casa Modernista	3,80E+15	2,78E+16	1,29
Jardim Felicidade	8,63E+15	6,23E+16	1,27
Nabuco	9,37E+15	6,60E+16	1,24
Linear do Fogo	8,95E+15	6,17E+16	1,21
Linear Caulim	4,80E+15	3,20E+16	1,18
Senhor do Vale	6,30E+15	4,00E+16	1,12
Severo Gomes	1,05E+16	6,12E+16	1,03
Lajeado	1,07E+16	6,28E+16	1,03
Sena	6,57E+15	3,61E+16	0,98
Trianon	1,42E+16	6,68E+16	0,81
Linear Sapé	6,89E+15	2,90E+16	0,73

Table 2
Emergy values for indigenous flows (I), feedback flows (F) and the emergy-based currency equivalent for the medium parks in Greater São Paulo. 50,000 m^2 < Area < 100,000 m^2.

Medium parks	I (sej/year)	F (sej/year)	Emergy-based currency equivalent Em$ (F)/m^2
Cohab Raposo Tavares	1,54E+16	3,46E+17	3,74
São José	2,33E+16	3,08E+17	2,29
Linear Mongagua	1,79E+16	1,28E+17	1,25
Lydia Natalizio Vila Prudente	1,79E+16	1,21E+17	1,19
Orlando Villas Boas	1,49E+17	1,02E+17	1,09
Águas	2,26E+16	1,28E+17	0,99
São Domingos	2,39E+16	1,27E+17	0,94
Chico Mendes	2,42E+15	9,55E+16	0,91
Piqueri	2,91E+16	1,27E+17	0,77
Linear Rapadura	2,10E+16	8,96E+16	0,75
Linear Canivete	1,80E+16	7,21E+16	0,71
Shangrilá	2,27E+16	8,03E+16	0,62
Jardim Herculano	2,26E+16	7,73E+16	0,60
Barragem Guarapiranga	2,64E+16	8,72E+16	0,58
Guanhembú	2,16E+16	6,21E+16	0,51
Previdência	2,68E+16	7,16E+16	0,46
Linear Itaim	1,80E+16	4,50E+16	0,44

highlight that this second option also offers a covered multi-sports court, playground, trails, and fitness equipment.

In addition to the cost of each park to the municipality, decision making can take into account the requirements of the region in which a park will be built (Fig. 6). To improve the design of an urban park in regard to a given regional need, the ecosystem services trade-offs must be observed (Fig. 6).

In regard to CO_2 sequestration, only the large parks with more than

Table 3
Emergy values for indigenous flows (I), feedback flows (F) and the emergy-based currency equivalent for the large parks in Greater São Paulo. Area > 100,000 m^2.

Large parks	I (sej/year)	F (sej/year)	Emergy-based currency equivalent Em$ (F)/m^2
Independência	4,83E+16	1,08E+18	3,95
Aclimação	3,24E+16	4,65E+17	2,44
Vila dos Remédios	3,18E+16	2,95E+17	1,58
Luz	3,30E+16	2,79E+17	1,45
Consciência Negra	3,87E+16	3,18E+17	1,44
Linear Aricanduva	3,56E+16	2,86E+17	1,40
Vila Guilherme	5,58E+16	3,83E+17	1,21
Cidade Toronto	3,26E+16	2,18E+17	1,18
Raposo Tavares	5,69E+16	3,02E+17	0,91
Jacques Cousteau	1,00E+17	4,75E+17	0,83
Linear Tiquatira	9,56E+16	4,03E+17	0,74
Sete Campos	5,64E+16	2,17E+17	0,68
Pinheirirnho D ′ Água	7,50E+16	2,86E+17	0,67
Guarapiranga	4,58E+16	1,20E+17	0,46
Santo Dias	4,02E+16	9,25E+16	0,41
Linear Água Vermelha	3,73E+16	8,50E+16	0,40
Ciência	5,62E+16	1,25E+17	0,39
Alfedro Volpi	4,17E+16	8,36E+16	0,35
Linear Castelo	3,10E+16	4,44E+16	0,25
Cemucam	1,47E+17	1,49E+17	0,18
Vila do Rodeio	1,84E+17	1,52E+17	0,15
Jardim Sapopemba	1,09E+16	6,55E+16	0,11
Nove de Julho	1,50E+17	8,56E+16	0,10
Linear Cocaia	3,72E+17	3,34E+16	0,02
Anhanguera	2,86E+18	2,29E+17	0,01

250,000 m^2 seem to be effective, and Fig. 6 also shows that most of the parks contribute more to water regulation than to climate regulation. The grey interval in Fig. 6 shows that among the city's parks, the infiltration and CO_2 sequestration are the ecosystems services with highest percent contribution.

4. Discussion

The literature review showed that the studies on the benefits of urban parks are mostly concentrated to analyze the problem partially – such as cooling or CO_2 sequestration. Most describe and/or quantify social, environmental and economic services, together or separately, but none combines the assessment of both the quantity and quality of environmental with a tool for managing the economy/environment interface.

The results obtained by comparing the investment of society and nature in the parks' operation indicate that the maintenance of the installed infrastructure for leisure and sports and, in some cases, education consumes more emergy than that employed to produce environmental services. The ratio between natural and economic resources provides an indicator for the management of existing urban parks permitting to prescript the best design for each park, to highlight actions for new developments and to adjust the housekeeping of old ones. Small and medium parks receive more economic investments, and plans for new parks would anticipate the balance between green and built areas [41]. For São Paulo, the total of small parks do not to deliver sufficient ecosystems' services to match the economic investment challenging studies that report that implementing several small parks would be more beneficial than the implementation of few of larger areas [13]. However, the results confirm those of Jaganmohan et al. [17] who found that the cooling effects increased with increasing park size.

A net emergy benefit was found to nearly half of the medium parks show (Table 5), but the complete group was positioned underneath the 50% line (Fig. 4A). This result indicates that a rearrangement in the layout of the parks in deficit could improve the provision of ecosystems' services to the city. The same reasoning may be applied to nine of the large parks, although the whole set shows net emergy benefit. The reorganization should include changes in layout and/or management. For the city of São Paulo, the representation in the ternary diagram makes clear that only the parks with more than 250,000 m^2 show a significant contribution to climate regulation, especially through evapotranspiration. This result is in agreement with those that reported that green areas smaller than 10,000 m^2 do not have cooling effects on surrounding environments, and parks with larger green areas (> 37,000 m^2) will have more significant outcomes, similar to the values were reported by Su et al. [14,52].

The option for implementing numerous small parks was also explored because large areas are not always available in most urban centers. For São Paulo, 82 new small parks would be required to make the whole set to reach the natural/economic balance. Additionally, the parks should be planned considering a tree/grass relationship of 80:20. These results corroborate that CO_2 sequestration ability is correlated with leaf area [53]. The tree/grass relationship of 80:20 found provides a raw estimative for the design of small urban parks with the objective to contribute to climate regulation, in agreement with the results of Mexia et al. [19] who considered considering different units of vegetation structure and composition, and showed carbon sequestration was positively influenced by tree density, independently of species composition. In this way, this study contributed to the discussion promoted by Bowler et al. [51] whose review showed that several studies indicate

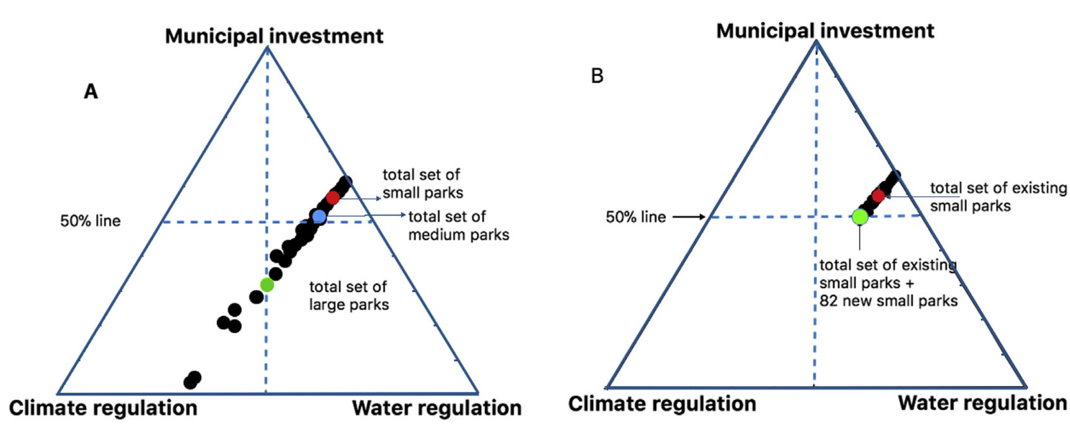

Fig. 5. Emergy ternary diagram of the 73 parks of Greater São Paulo (A), where each (●) represents one particular park, and (△) the total for the set of small, medium and large parks. B: Emergy ternary diagram of the small parks of Greater São Paulo, where each (●) represents one particular park, (△) the total for the set of small and the orange circle the results of adding 82 new parks (*) with area between 40,000 and 50,000 m^2 and green area with 80% of trees. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Values of area, ecosystem's services and the net emergy benefit for the municipality investment for the small parks of Greater São Paulo. The parks with Net Emergy benefit are highlighted in the last column. Area < 50,000 m^2.

Small Parks	Area (m^2)	CO_2 Sequestration (sej/year)	Evapo-transpiration (sej/year)	Climate regulation (sej/year)	Water regulation (sej/year)	Net Emergy Benefit (sej/year)
Linear Sapé	23544	1,87E+16	3,00E+15	2,17E+16	9,46E+15	**2,15E+15**
Trianon	48600	4,28E+16	6,14E+15	4,90E+16	1,94E+16	**1,59E+15**
Sena	21661	2,28E+16	2,55E+15	2,53E+16	8,82E+15	−1,90E+15
Casa Modernista	12710	1,76E+16	1,56E+15	1,91E+16	4,91E+15	−3,81E+15
Senhor do Vale	21000	2,52E+16	2,46E+15	2,77E+16	8,54E+15	−3,82E+15
Linear Caulim	16000	2,02E+16	1,91E+15	2,22E+16	6,03E+15	−3,86E+15
Severo Gomes	34900	3,89E+16	4,35E+15	4,32E+16	1,37E+16	−4,24E+15
Lajeado	36000	3,98E+16	4,33E+15	4,42E+16	1,37E+16	−4,95E+15
Ermelino Matarazzo	5181	1,48E+16	4,93E+14	1,53E+16	2,05E+15	−6,65E+15
Eucaliptos	15447	2,48E+16	1,89E+15	2,67E+16	5,97E+15	−6,80E+15
Linear do Fogo	30000	3,85E+16	3,19E+15	4,17E+16	1,27E+16	−7,35E+15
Jardim Felicidade	28800	3,93E+16	3,52E+15	4,28E+16	1,11E+16	−8,34E+15
Nabuco	31300	4,17E+16	3,85E+15	4,55E+16	1,21E+16	−8,35E+15
M Boi Mirim	19000	4,05E+16	1,97E+15	4,25E+16	8,95E+15	−1,42E+16
Buenos Aires	25000	4,72E+16	3,00E+15	5,02E+16	9,93E+15	−1,54E+16
Linear Parelheiros	16000	3,77E+16	1,61E+15	3,93E+16	5,59E+15	−1,58E+16
Cordeiro	34000	5,49E+16	3,94E+15	5,89E+16	1,30E+16	−1,58E+16
Lions Club - Tucuruvi	23700	4,81E+16	2,70E+15	5,08E+16	9,37E+15	−1,70E+16
Chácara das Flores	41735	6,45E+16	5,04E+15	6,96E+16	1,59E+16	−1,72E+16
Benemerito Brás	22300	5,03E+16	2,28E+15	5,26E+16	9,48E+15	−1,92E+16
Zilda Natel	2386	3,47E+16	5,29E+13	3,47E+16	2,40E+14	−2,15E+16
Colina de São Francisco	49053	7,76E+16	5,87E+15	8,34E+16	1,85E+16	−2,15E+16
Vila Silvia	4400	3,70E+16	1,52E+14	3,71E+16	6,93E+14	−2,24E+16
Faria Lima	40131	7,58E+16	4,53E+15	8,03E+16	1,57E+16	−2,55E+16
Raul Seixas	33000	7,34E+16	3,33E+15	7,67E+16	1,38E+16	−2,81E+16
Luiz Carlos Prestes	27100	6,79E+16	3,12E+15	7,10E+16	9,86E+15	−2,82E+16
Rodrigo Gásperi	39000	7,95E+16	4,24E+15	8,37E+16	1,34E+16	−3,03E+16
Santa Amélia	34000	7,97E+16	3,12E+15	8,28E+16	1,42E+16	−3,22E+16
Linear Guaratiba	29000	8,63E+16	2,42E+15	8,87E+16	1,01E+16	−4,11E+16
Jacinto Alberto	40910	1,18E+17	3,86E+15	1,21E+17	1,34E+16	−5,51E+16
Praia do Sol	17900	1,54E+17	4,03E+14	1,54E+17	1,68E+15	−9,46E+16

the effects of different types of vegetation, particularly the difference between short vegetation, such as grass, and tree cover.

For decision making taking into account the necessities of the district in which a park will be constructed, the trade-offs among ecosystem services were explored (Fig. 6) revealing that tree planting will increase carbon sequestration regardless of species [19]. In regard to CO_2 sequestration, only the large parks with more than 250,000 m^2 seem to be effective for the city of São Paulo. Regions susceptible to floods would receive parks with a layout that favor water regulation. In this case, all sizes of parks can be recommended, and especially small parks with high percentage of grass areas, distributed in such regions, would help avoid inundations. This particular aspect would justify a higher investment from the municipality.

The results obtained from the emergy analysis are in contrast with the studies by Ca et al. [54] who studied the potentials of reduction in air conditioning energy. Field measurements determined that during summer a park on the urban with a size of about 60,000 m^2 can reduce by up to 1.5 °C the air temperature in a busy commercial area 1 km downwind at noon. In the same way, Saito et al. [55] that small green areas like showed a cooling effect extends about 20 m from the green

Table 5
Values of area, ecosystem's services and the net emergy benefit for the municipality investment for the medium parks of Greater São Paulo. The parks with Net Emergy benefit are highlighted in the last column. 50,000 m^2 < Area < 100,000 m^2.

Medium Parks	Area (m^2)	CO_2 Sequestration (sej/year)	Evapo-transpiration (sej/year)	Climate regulation (sej/year)	Water regulation (sej/year)	Net Emergy Benefit (sej/year)
Previdência	91500	4,75E+16	1,16E+16	5,91E+16	3,67E+16	**2,42E+16**
Guanhembú	71920	4,09E+16	9,19E+15	5,01E+16	2,90E+16	**1,70E+16**
Linear Itaim	60000	2,99E+16	7,65E+15	3,75E+16	2,41E+16	**1,67E+16**
Barragem Guarapiranga	88000	5,68E+16	1,09E+16	6,77E+16	3,44E+16	**1,49E+16**
Jardim Herculano	75277	5,03E+16	9,39E+15	5,97E+16	2,97E+16	**1,20E+16**
Shangrilá	75643	5,17E+16	9,11E+15	6,08E+16	3,16E+16	**1,20E+16**
Linear Canivete	60000	4,57E+16	6,90E+15	5,26E+16	2,62E+16	**6,75E+15**
Linear Rapadura	70000	5,65E+16	7,94E+15	6,45E+16	3,15E+16	**6,37E+15**
Piqueri	97200	8,19E+16	1,22E+16	9,40E+16	3,83E+16	**4,97E+15**
Chico Mendes	61600	6,09E+16	7,50E+15	6,84E+16	2,37E+16	−3,41E+15
São Domingos	80000	8,11E+16	9,63E+15	9,07E+16	3,04E+16	−6,25E+15
Orlando Villas Boas	55000	6,36E+16	6,03E+15	6,97E+16	2,51E+16	−7,27E+15
Águas	76300	8,07E+16	7,99E+15	8,86E+16	2,77E+16	−1,17E+16
Lydia Natalizio Vila Prudente	60000	7,61E+16	6,82E+15	8,29E+16	2,36E+16	−1,45E+16
Linear Mongagua	60000	8,06E+16	6,97E+15	8,76E+16	2,20E+16	−1,83E+16
São José	79115	1,92E+17	7,90E+15	2,00E+17	2,38E+16	−8,48E+16
Cohab Raposo Tavares	54384	2,14E+17	3,88E+15	2,17E+17	1,23E+16	−1,16E+17

Table 6
Values of area, ecosystem's services and the net emergy benefit for the municipality investment for the large parks of Greater São Paulo. The parks with Net Emergy benefit are highlighted in the last column. Area > 100,000 m^2.

Large Parks	Area (m^2)	CO_2 Sequestration (sej/year)	Evapo-transpiration (sej/year)	Climate regulation (sej/year)	Water regulation (sej/year)	Net Emergy Benefit (sej/year)
Anhanguera	9500000	5,06E+17	1,23E+18	1,73E+18	3,87E+18	**5,37E+18**
Linear Cocaia	1000000	5,90E+16	1,29E+17	1,88E+17	4,07E+17	**5,61E+17**
Jacques Cousteau	335000	3,04E+17	3,95E+17	3,43E+17	1,25E+17	**3,48E+17**
Vila do Rodeio	613200	1,09E+17	7,32E+16	1,82E+17	2,78E+17	**3,08E+17**
Nove de Julho	500000	7,17E+16	6,42E+16	1,36E+17	2,03E+17	**2,53E+17**
Cemucam	500000	1,11E+17	6,41E+16	1,75E+17	2,02E+17	**2,28E+17**
Jardim Sapopemba	345000	4,89E+16	4,09E+16	8,98E+16	1,55E+17	**1,80E+17**
Ciência	187000	8,39E+16	2,38E+16	1,08E+17	7,52E+16	**5,78E+16**
Alfredo Volpi	142432	5,68E+16	1,82E+16	7,50E+16	5,75E+16	**4,89E+16**
Guarapiranga	152600	7,86E+16	1,89E+16	9,75E+16	6,54E+16	**4,27E+16**
Linear Água Vermelha	124207	5,45E+16	1,40E+16	6,85E+16	5,83E+16	**4,18E+16**
Linear Castelo	103338	3,16E+16	1,35E+16	4,51E+16	4,07E+16	**4,14E+16**
Santo Dias	134000	6,19E+16	1,70E+16	7,89E+16	5,38E+16	**4,02E+16**
Pinheirirnho D ′ Água	250306	1,81E+17	2,84E+16	2,09E+17	1,13E+17	**3,59E+16**
Sete Campos	188000	1,37E+17	2,07E+16	1,57E+17	8,60E+16	**2,63E+16**
Linear Tiquatira	320000	2,57E+17	3,71E+16	2,94E+17	1,29E+17	**1,95E+16**
Raposo Tavares	195000	1,91E+17	2,23E+16	2,13E+17	7,72E+16	−1,13E+16
Cidade Toronto	109100	1,36E+17	1,18E+16	1,48E+17	4,49E+16	−2,49E+16
Vila Guilherme	187000	2,40E+17	2,01E+16	2,60E+17	7,65E+16	−4,71E+16
Linear Aricanduva	120000	1,77E+17	1,14E+16	1,89E+17	4,96E+16	−4,80E+16
Luz	113400	1,75E+17	1,31E+16	1,88E+17	4,14E+16	−4,93E+16
Consciência Negra	130135	2,00E+17	1,44E+16	2,14E+17	4,56E+16	−5,84E+16
Vila dos Remédios	109800	1,85E+17	1,21E+16	1,97E+17	3,83E+16	−5,98E+16
Aclimação	112200	2,89E+17	1,20E+16	3,01E+17	3,78E+16	−1,26E+17
Independência	161300	6,71E+17	2,03E+16	6,91E+17	6,41E+16	−3,27E+17

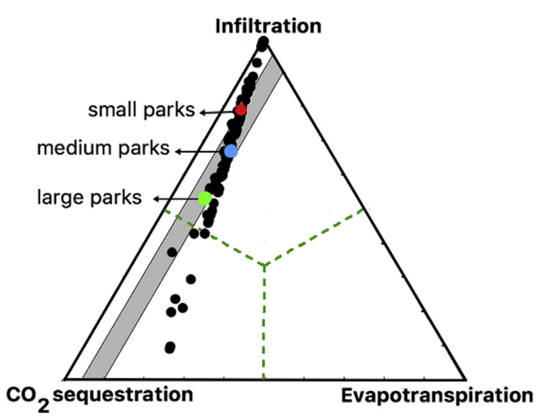

Fig. 6. Emergy ternary diagram of the 73 parks of Greater São Paulo, where each (●) represents one particular park, and the total for the set of small (red), medium (blue) and large parks (green). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

area. However, Toparlar et al. [56], in a comprehensive review, endeavored to classify and relate different types of greening but found a lack of more specific information on the revised articles, such as a defined area of grass and/or tree cover, vegetation age, height, species, and specially climate and atmospheric stability conditions. These authors found evidence that the cooling effect of a green area increases with its size, though it is not clear if there is a minimum size threshold or if there is a simple linear relationship.

The results of this study have important implications for the distribution of parks in an urban area in regard to water and climate regulation, but further empirical studies could help to test some of the predictions to provide a tighter coupling between the theory and empirical research, which should include collection of temperature, infiltration and CO2 sequestration data before and after implementation along with comparable 'control' non-green sites.

5. Conclusions

It is well known that the benefits of urban parks extend to their surroundings, in mitigating urban heat problems and helping water and climate regulation. The objectives of this study were to quantify and compare the strengths and weaknesses of urban parks in providing ecosystem services the surrounding environment, and to better understand the trade-off between the environmental costs and the costs provided by the municipality.

The findings emphasize the importance of public green spaces in the urban tissue and justify investment in these spaces in terms of sustainable development.

A scientific assessment of the environmental service provided by urban parks can assist to achieve better public services that consider the relationship between environmental and economic input and output of planned urban ecosystem. A set of recommendations may be put forward to help São Paulo's public administrators to manage the existing parks and the design of new ones:

- to establish a balance (I/F > 0.2) between the emergy invested for the maintenance of the installed infrastructure for leisure, sports and education and that to produce environmental services;
- to prioritize actions to optimize the maintenance of parks with I/F < 0.2 improving their green/built relationship. Actions may include changes in layout and/or management;
- to establish a minimum green area for new projects;
- to plan new parks with area between 20,000 and 50,000 m^2 in locations where water regulation and reduce floods are required;
- to contribute to climate regulation considering a tree/grass area relationship of 80:20.

The assessment method used can offer an applicable tool for urban planners for the design and implementation of new green spaces. Urban planners can use this method not only to improve the management of the existing green infrastructure – considering the trade-off between municipal and environmental investment, but also to encourage the implementation of urban parks as a nature-based provider of numerous ecosystem services according to the neighborhood needs. Further research is needed on how the benefits of green space change with the particular context, such as local urban environment, climate and type of greening; and although the emergy analysis and is able to demonstrate how green infrastructure should be designed in terms of the abundance, type and distribution of greening providing the quantity of ecosystems' services produced by each green area, further review is required to explicitly investigate the distance and size-dependence of the effects of green areas, allowing explicit bottom-up predictions of the effect of particular amounts and spatial arrangements of greening.

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Appendix A. Calculations ecosystems' services of urban parks of Greater Sáo Paulo.

Evapotranspiration for each park

The volume of evapotranspiration and the correspondent energy were calculated for the trees and grass (Eq. A1) areas, and the total emergy (trees + grass) is shown in Eq. A2, considering the proportion of tree and grass for each park. The average precipitation was taken from Center for Weather Forecasting and Climate Studies (www.inpe.br). The evapotranspiration index used for the trees was 1006.2 mm/month [57] and for the grass was 8.321×10^{-1} m/year [58]. The UEV of the evapotranspiration used was 2.69×10^{4} sej/J [29]. All values were calculated for an area of 1 m^2, and for total emergy, multiplied by the park area.

$$Energy_{Evap,\ trees\ or\ grass}\left(\frac{J}{year}\right) = Precipitation\left(\frac{m^3}{year}\right) x\ 4940\left(\frac{J}{L}\right) x\ 10^3\left(\frac{L}{m^3}\right)\Bigg) \qquad \text{A1}$$

$$Emergy_{Evap,\ trees+\ grass}\left(\frac{sej}{year}\right) = Energy_{Evap,\ trees+\ grass}\left(\frac{J}{year}\right) xUEV\left(\frac{sej}{J}\right) \qquad \text{A2}$$

Water retention for each park

Water retention was calculated as the difference between the total rain and evapotranspiration (Eq. A2). The volume of water retention (m^3/year) was multiplied by the UEV = 6.85×10^{11} sej/m^3 [59]. A 10% runoff coefficient, defined as the ratio of the volume of water drained to the volume of precipitated water, was adopted (https://www.waterboards.ca.gov/water_issues/programs/swamp/docs/cwt/guidance/513.pdf).

$$Water\ retention = Precipitation\left(\frac{m^3}{m^2 year}\right) x\ area\left(\frac{m^2}{park}\right) - Volume_{Evap,\ trees\ or\ grass}\left(\frac{m^3}{park}\right) \qquad \text{A3}$$

CO_2 sequestration

The amount of carbon sequestrated varies depending on the age of the species and the density of the forested areas [60]. In the studied urban parks, there is a great variation in the quality and distribution of biomass that is not explained only by age or density. The amount of CO_2 sequestered per hectare of green areas in the region was estimated in 10 t/ha year [61], which is the average value for the region.

Raw data and detailed calculations are available at: http://www.advancesincleanerproduction.net/papers/dissertations/mariano_mv.pdf (in Portuguese).

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