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Comparing costs and supply of supporting and regulating services provided by urban parks at different spatial scales

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ABSTRACT

Researchers all over the world have been involved for some time in valuing and measuring ecosystem services. However, methods to value both costs and supply and to match them on the same scale are still under discussion. This study assesses costs and supply of a subset of supporting and regulating ecosystem service in urban parks and discusses the role and the value of these services under an environmental/economic point of view using emergy synthesis. A total of 73 parks in the city of São Paulo, Brazil, are used as a case study. Results show 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 wasted. The method can be applied in different locations and contexts to provide useful information to public managers and urban planners.

1. Introduction

The notion of urban park has been, for a long time, associated with aesthetics and recreational services. As the conditions and needs of the cities have changed, recreation now includes the provision of sport activities for all social classes, with the implementation of sport courts, jogging trails and fitness equipment in public green areas. Modern urban parks must, besides their leisure function, not only meet the demands for recreational activities, but also alleviate the negative effects of urban structures, compensating for built-up areas. Planning for an urban park is no more restricted to the perimeter of the park. The park borders are regularly crossed by individuals, by water flows into, out of, or underneath the park, and by the effects of the surrounding urban settlement and air quality conditions. In order to manage an urban park, urban planners must think about broader limits than the actual physical limits of the park, and this broader thinking must include the role and the value of ecosystem services (see Fig. 1).

Various authors relate green urban areas with aesthetics, noise reduction and habitat maintenance for wild animals (Chen and Jim, 2008; Xiao and McPherson, 2002; Nowak and Dwyer, 2000), recognizing the numerous social, environmental and economic services they provide (Buchel and Frantzeskaki, 2015; McPherson et al., 2005; Mellino and Ulgiati, 2013; Mellino et al., 2015). Benefits from the simple effect of a shadow to reduce heating of built and paved surfaces, to the reduction of heat islands that are intensified with cities growth are demonstrated empirically (Akbari et al., 2001; Rosenfeld et al., 1995). Xiao and McPherson (2002) and Xiao et al. (1998) emphasized the benefit provided by urban parks through reducing the volume of water runoff with consequent reduction of flood risk. In this context, concerns on preservation and implementation of urban parks are associated not only with leisure and aesthetics, but also with the supporting and regulating services they can provide to the whole city (Kaczorowska et al., 2016). Lin et al. (2011) associated urban green areas to double benefits of sequestration/storage of atmospheric carbon and high temperatures reduction in the vicinity of the park, concluding that: (1) the larger the amount of biomass in the park, the greater the energy savings and lower air pollution; (2) the implementation of several small green areas is more beneficial than the deployment of few units of larger green areas and (3) irregularly shaped green areas perform better than regularly shaped ones of the same size.

Methods for calculating the value of ecosystem services are attracting interest as instruments to express non-economic values of the environment into monetary terms (Claassen et al., 2008; Dobbs and Pretty, 2008; Pagiola, 2008; Wunder et al., 2008). The scientific discussion on methods to estimate those values is still ongoing. In several cases, the values of ecosystem services are derived by relying on economic-based instruments, such as the

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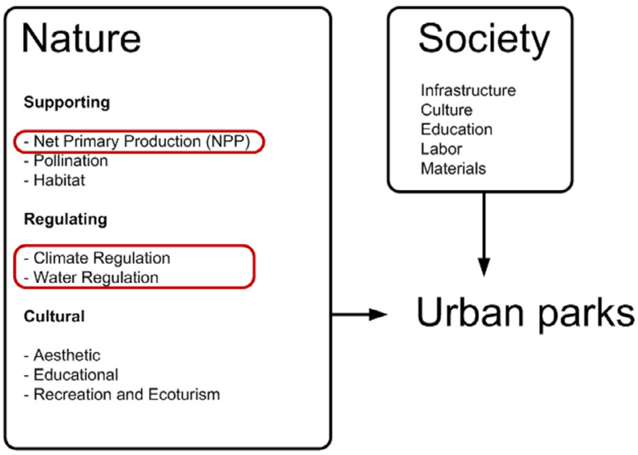

Fig. 1. Some of the main components integrated to urban parks from nature and society. The ecosystem services evaluated in this study are highlighted in red.

entry fees values to parks (Latinopoulos et al., 2016; Song et al., 2015), or the market value of the park as developable real estate (Sutton and Anderson, 2016).

There are methods in which value is given by observing ecosystem services' users/consumers preferences (Wunder and Albán, 2008; Asquith et al., 2008; Buchel and Frantzeskaki, 2015). Millward and Sabir (2011) investigated the value of services provided by the trees in a public park in Canada, estimating the monetary value of benefits related to energy savings, CO_2 sequestration, and increased property value. Their work showed that the money spent for planting and maintaining trees is justified by the benefits they brought to the city. McPherson et al. (2005) studied the relationships between urban forests and the local population considering benefits and costs. The benefits were accounted for by different methods: (i) benefits derived from climate regulation were evaluated by computer simulations and compared to the expenditure on electricity and natural gas; (ii) carbon dioxide sequestration was associated to the amount of biomass; flood risk reduction was compared to expenditures on flood control. These authors reported that for each dollar invested in the maintenance and deployment of urban forests, the benefits return approximately between $ 1.37 and $ 3.09 a year.

A different option for evaluating ecosystem services is the emergy synthesis (Odum, 1996). Emergy synthesis offers a complement (or a substitute) to market-based and monetary evaluations. It allows calculating biophysical values, also linking them with monetary flows. For these reasons, emergy synthesis is increasingly used for evaluating ecosystem services.

In this vein, most of the research focused on large scale territorial systems (Coscieme et al., 2014), including environmental, cultural and economic subsystems (Higgins, 2003), biomes (Campbell and Brown, 2012; Campbell and Tilley, 2014a; Coscieme et al., 2011) and natural reserves (Liu et al., 2009; Tilley and Swank, 2003; Pulselli et al., 2011). The ecological and economic benefits of an urban wetland park in China were evaluated by Duan et al. (2011) using emergy indices. Mariano et al. (2015) 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 the most dependable scientific measure to assess the provision of ecosystem services, since it is capable of assessing both the quantity and quality of contributions, providing a foundation for managing the economy/environment interface (Ulgiati et al., 2011). 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) (MA, 2005).

Starting from that, 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.

The city of São Paulo, Brazil is used as a case study. This approach is applicable in other geographical contexts, providing useful information for public managers.

2. Methods

2.1. System description

The total green area of the municipality of São Paulo is approximately 40 times larger than the green area of the 73 urban parks studied (SVMA, 2012), since it includes permanent protected areas, areas under State protection, and the afforestation of streets and avenues. Fig. 2 shows the distribution of the parks studied within the metropolitan area.

Table 1 shows the total area, the built area and the cost per square meter of the 73 parks assessed. A detailed cost report for each park was provided by the municipality and includes equipment, workers and auxiliary materials used for maintenance and use of each park.

2.2. Emergy synthesis

Emergy tracks the cumulative quantity of solar equivalent joules necessary to create a product or service through the network of energy transformations (Odum et al., 2000). It can be used to represent the work done by nature and humans to provide a service calculated in terms of equivalent solar energy processed and expressed in solar emergy Joules (seJ) (Odum, 1996; Pulselli et al., 2011; Coscieme et al., 2013). The factor that enables to express different forms of energy and materials in terms of solar equivalent is the Unit Emergy Value (UEV) that represents the quantity of solar energy directly or indirectly required to produce 1 unit (i.e. 1 J or 1 g) of a product, a different form of energy, or a service (Brown and Ulgiati, 2004).

Ecosystem services emerge from the interactions between Natural, Human, and Social capital (Costanza et al., 2014). The main advantage of using emergy for ecosystem services evaluation is that it is able to account for the different inputs to the final contribution coming from these different forms of Capital on a common unit.

To perform the emergy accounting, an energy diagram is used (Fig. 3) indicating the flows that make up the system investigated. The diagram also shows the interactions of the internal processes taking place in the urban park and the ecosystem service flows. For this reason, emergy is particularly suitable to understand the nexus between supporting services (such as NPP), and regulating services.

From the energy diagram, tables containing the emergy of renewable resources (R), local non-renewable resources (N) and

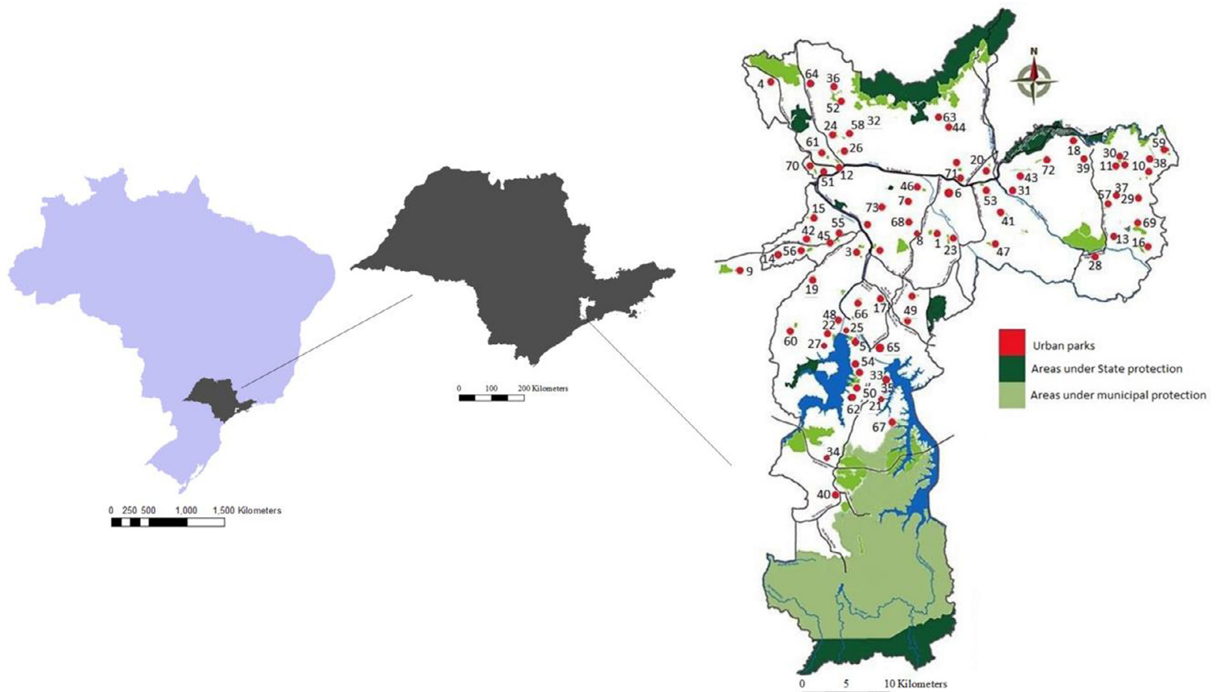

Fig. 2. Distribution of the urban parks evaluated in this study. From left to righ: Brazil, the State of Sao Paulo, the Municipality of Sao Paulo. 1 – Aclimação; 2 – Águas; 3 – Alfredo Volpi; 4 – Anhanguera; 5 – Barragem Guarapiranga; 6 – Benemérito Brás; 7 – Buenos Aires; 8 – Casa Modernista; 9 – Cemucam; 10 – Chácara das Flores; 11 – Chico Mendes; 12 – Cidade Toronto; 13 – Ciência; 14 – Cohab Raposo Tavares; 15 – Colina de São Francisco; 16 – Consciência Negra; 17 – Cordeiro; 18 – Ermelino Matarazzo; 19 – Eucaliptos; 20 – Faria Lima; 21 – Guanhembú; 22 – Guarapiranga; 23 – Independência; 24 – Jacinto Alberto; 25 – Jacques Cousteau; 26 – Jardim Felicidade; 27 – Jardim Herculano; 28 – Jardim Sapopemba; 29 – Lajeado; 30 – Linear Água Vermelha; 31 – Linear Aricanduva; 32 – Linear Canivete; 33 – Linear Castelo; 34 – Linear Caulim; 35 – Linear Cocaia; 36 – Linear do Fogo; 37 – Linear Guaratiba; 38 – Linear Itaim; 39 – Linear Mongaguá; 40 – Linear Parelheiros; 41 – Linear Rapadura; 42 – Linear – Sapé; 43 – Linear Tiquatira; 44 – Lions Club Tucuruvi; 45 – Luiz Carlos Prestes; 46 – Luz; Lydia Natalizio Vila Prudente; 48 – M Boi Mirim; 49 – Nabuco; 50 – Nove de Julho; 51 – Orlando Villas Boas; 52 – Pinheirinho D ' Água; 53 – Piqueri; 54 – Praia do Sol; 55 – Previdência; 56 – Raposo Tavares; 57 – Raul Seixas; 58 – Rodrigo Gásperi; 59 – Santa Amélia; 60 – Santo Dias; 61 – São Domingos; 62 – São José; 63 – Sena; 64 – Senhor do Vale; 65 – Sete Campos; 66 – Severo Gomes; 67 – Shangrilá; 68 – Trianon; 69 – Vila do Rodeio; 70 – Vila dos Remédios; 71 – Vila Guilherme; 72 – Vila Silvia; 73 – Zilda Natel.

Table 1
Summary of the São Paulo's urban parks considering the total area, the built area and the annual cost per square meter.

Parks*	Total area (m^2)	Built area (m^2)	Maintenance Cost (US\$/m^2 yr)
Small	823,758	9,5807	2.9
Medium	1,215,940	97,092	2.5
Large	15,633,018	231,666	0.7
All	17,672,716	424,564	1.0

* Parks are classified into small (area < 50,000 m^2), medium (50,000 m^2 < area < 100,000 m^2) and large (area > 100,000 m^2).

resources coming from the economic system (F) are built. All these flows contribute to the overall functioning of the urban park, including its provision of services. A full detailed emergy table of Tenente Siqueira Campos (Trianon) park is available in Appendix A, while the emergy-based calculation of its ecosystem services is available in Appendix B. A summary emergy table of the 73 parks is available in Appendix C, and the emergy of the ecosystem services provided by the 73 urban parks studied is available in Appendix D.

In this analysis, a subset of the ecosystem services shown in Fig. 3 has been assessed: i.e. Climate Regulation, through Evapotranspiration and CO_2 sequestration; Water Regulation through water retention in the soil. "Soil (occupied)" in Fig. 3 refers to the area occupied by facilities and equipment, visitors facilities, sport courts, jogging trails and fitness equipment. This element is important for providing recreational services, among others; it is however not relevant for the subset of supporting and regulating services evaluated in this study. Cultural services (and other ecosystem services) provided by urban parks in São Paulo will be the object of further research.

The green areas of the urban parks of the city of São Paulo are formed mainly by lawns, previously existing Atlantic forest in smaller proportion and planted trees (SVMA, 2012). The variation among the emergy of parks depends on the different proportion of both types of vegetation and the built area. The amount of biomass (NPP) has been considered as a supporting service, underlying all the other contributions assessed.

The amount of biomass (NPP) produced in each park was calculated according to Eq. (1), using the dry matter values of 2.16×10^7 J/m^2 year for trees and 7.60×10^6 J/m^2 year for grass (Lu et al., 2006). Values from Lu et al. (2006) were chosen being the most reliable available in peer-reviewed international literature. More specific values for Brazil are available in Parron et al. (2015). However, we avoid referring to the latter being it published only in Portuguese, being not published in a peer-reviewed journal, and being not indexed in international literature databases. In any case, NPP values calculated by Parron et al. (2015), i.e. 2.48×10^7 J/m^2 year for trees and 7.88×10^6 J/m^2 year for grass, are very similar to the values used in this study. The NPP is the difference between the amount of chemical energy created by primary producers (biomass) and the energy used for cellular respiration and maintenance of tissues in a given area and period. Eq. (2) expresses the energy of the NPP calculated for one year. The emergy of the NPP (Eq. (3)) is the product between the NPP_{energy} and the Unit Emergy Values (UEV) for trees (5.54×10^3 sej/J) and grass (4.26×10^3 sej/J) (Lu et al., 2007). These values were calculated without considering human services embodied in the purchased resources, as well as all the calculations presented in this paper.

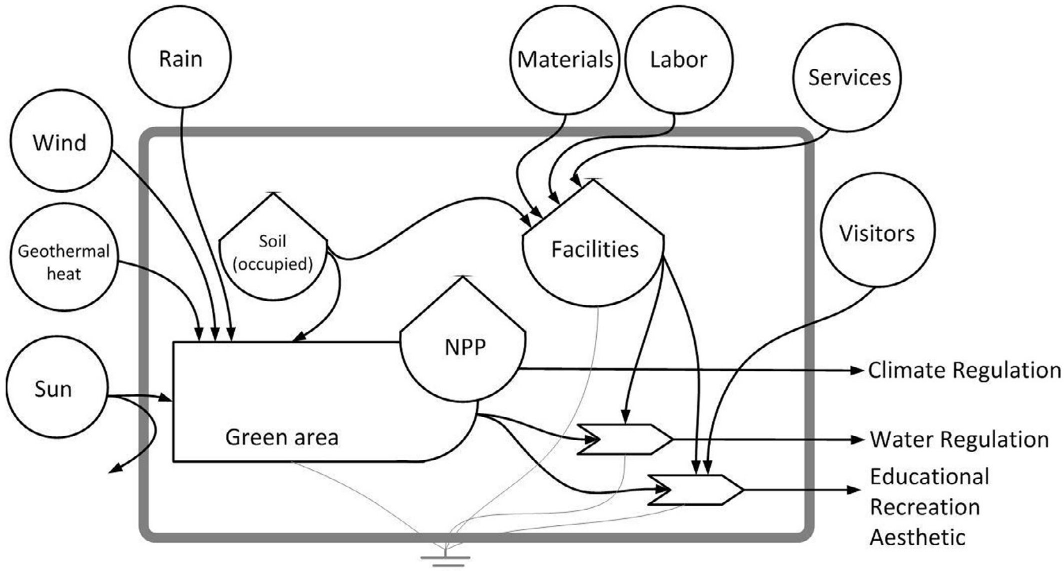

Fig. 3. Energy system diagram of an urban park. NPP – net primary production.

$$NPP_{mass} = greenarea(m^2) \times drymatter\left(\frac{g}{m^2 year}\right) \quad (1)$$

$$NPP_{energy} = greenarea(m^2) \times drymatterenergy\left(\frac{J}{m^2 year}\right) \quad (2)$$

$$NPP_{eMergy} = NPP_{eMergy,trees}\left(\frac{seJ}{year}\right) + NPP_{eMergy,grass}\left(\frac{seJ}{year}\right) \quad (3)$$

Transpiration is a metabolic process necessary for the growth and development of plants. It occurs simultaneously with evaporation, and both processes control the availability of energy and the water supply to the plants. The Evapotranspiration volume is the product between the evapotranspiration index and the green area. Separate calculations were made for trees with evapotranspiration index of 0.1006 m year (Cicco, 2009) and lawn areas (0.8321 m/year; Lu et al., 2006), and the emergy of evapotranspiration was calculated (Eq. (4)). The UEV value (2.69×10^4 sej/J) and the Gibbs free energy (4.940 J/kg) were taken from Odum (1996).

$$Evapo_{eMergy} = volume(m^3) \times Gibb's\ free\ energy\left(\frac{J}{m^3}\right) \times UEV \quad (4)$$

Water Retention is mainly influenced by the soil moisture and the vegetation cover. Eq. (5) includes the difference between the total volume of rainfall and the volume of evapotranspiration. The UEV of Water Retention (6.85×10^{11} sej/m^3) was taken from Buenfil (2001).

$$WatRet_{eMergy} = (precipitation - evapotranspiration)(m^3) \times UEV \quad (5)$$

As the purpose of this paper is to quantify a subset of ecosystem services of urban parks of São Paulo, comparing them with the maintenance costs of the parks, the emergy feedback of the economy (F) to each park was included in the calculation (Fig. 4) to assess the Global Productivity (GP) – defined as the lower emergy needed to provide one unit of service, or the inverse of the UEV (Bonilla et al., 2010; Almeida et al., 2010 and Almeida et al., 2012). The GP depends on the proportions of each type of vegetation and the built area, and the energy and matter (such as equipment and workers) invested by the municipality in maintaining the parks.

Eq. (6) shows the calculations to estimate the GP of CO_2 sequestration, also considering the emergy embodied in the maintenance of each park by the municipality (F). The same idea was applied to calculate the GP of Evapotranspiration and Water retention (Eqs. (7) and (8)). The amount of carbon sequestrated varies depending on the age of the species and the density of the forested areas (Melo and Durigan, 2006). 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 (Holtz, 2016), which is the average value for the region.

$$GP_{CO2Sequestration} = \frac{NPP_{energy}}{(NPP_{eMergy}) + F}\left(\frac{J}{seJ}\right) \quad (6)$$

$$GP_{Evapotranspiration} = \frac{Evapo_{energy}}{Evapo_{eMergy} + F}\left(\frac{J}{seJ}\right) \quad (7)$$

$$GP_{WaterRetention} = \frac{WatRet_{energy}}{WatRet_{eMergy} + F}\left(\frac{J}{seJ}\right) \quad (8)$$

3. Results and discussion

Emergy evaluation makes clear that the investments made by the municipality of São Paulo are proportional to the built area within the urban parks. The emergy coming from environmental flows supporting the production of NPP-related ecosystem services in the parks is the sum of rain and geothermic energy and represents 50% of the overall emergy supporting São Paulo's parks (Table 2). However, this support is unevenly distributed, being less significant for small (R/F = 0.12) and medium parks (R/F = 0.23). The share of the annual operation costs sustained by the municipality for preserving the parks' area show the high dependence of the urban parks on the municipality investment (Fig. 5).

According to the rules of emergy algebra (Odum, 1996), since CO_2 Sequestration and Evapotranspiration are related to the same biogeochemical processes, the total value of the ecosystem services accounted is the sum of the highest between them (i.e. CO_2 Sequestration) and Water Retention in the soil (14.5×10^{18} sej/year). We added here the emergy of Climate Regulation and Water Regulation services because these two flows are not co-products, but splits (Dong et al., 2014).

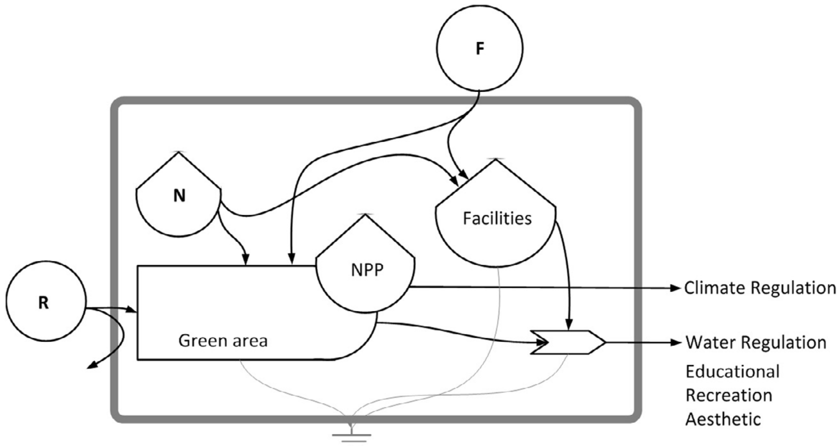

Fig. 4. A schematization of a subset of the ecosystem services provided by the 73 urban parks of Sao Paulo. Environmental (R + N) and purchased (F) flows supporting the urban parks are indicated. NPP – net primary production; R – renewable resources, N – local non-renewable resources; and F – purchased resources.

Table 2
Distribution of the environmental and municipal support for the 73 parks.

Parks*	Emergy Support		$Y/10^{17}$ (sej/year)	R/F
	Environment	*Municipality*		
	$R/10^{17}$ (sej/year)	$F/10^{17}$ (sej/year)		
Small parks	3.1	25.9	29.0	0.12
Medium parks	4.8	20.7	25.5	0.23
Large parks	46.7	62.8	109.0	0.74
73 parks	54.5	109.4	163.5	0.50

* Parks are classified into small (area < 50,000 m^2), medium (50,000 m^2 < area < 100,000 m^2) and Large (area > 100,000 m^2): R – renewable resources, N – local non-renewable resources; F – purchased resources; and Y the total emergy (Y = R + N + F).

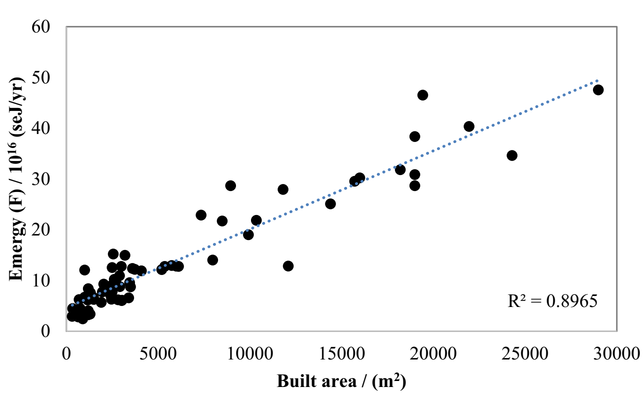

Fig. 5. The emergy support from the municipality (F) as a function of the built area of each park.

Accordingly, since these ecosystem services provide separate benefit streams, they were "double counted" as in (Dong et al., 2014; Campbell and Tilley, 2014a,b). The emergy of CO_2 Sequestration is higher than the emergy calculated for the other services, thus CO_2 Sequestration is the most valuable service provided by the parks (Table 3). However, Water Retention shows the highest emergy for Large parks (Table 3).

Evapotranspiration corresponds to 12% of the total emergy of the ecosystem services and it is plausible that this share would be higher during the raining season, possibly overcoming the emergy of CO_2 Sequestration.

The flows of ecosystem services produced by each park depend on the size of the built area and the overall costs sustained by the municipality. Fig. 6 shows the relationship between the GP of each environmental service and the built area of each park. The higher the proportion of built areas, the lower the space for green areas and the lower the production of supporting and regulating ecosystem services. On one hand, despite the great variation in GP values for parks with less than 10,000 m^2 of built area, it is clear in Fig. 6 that these parks are more likely to reach higher GP values and have a higher potential to produce ecosystem services efficiently. On the other hand, as the UEVs of the emergy flows supporting the built areas are significantly higher than those of the environmental flows, when the constructed area is greater than 10,000 m^2, the production of ecosystem services reaches a level of low efficiency.

In other words, parks with less than 10,000 m^2 of built area are associated with higher rates of Evapotranspiration, CO2 Sequestration, Water Retention and NPP per unit of equivalent solar energy used (Figs. 5 and 6). These results depend on the subset of ecosystem services evaluated. In fact, supporting and regulating services mostly derive from ecological processes that are independent from the built areas in the park. It is expected this relationship to be very different for other ecosystem services for which facilities and built areas play a more important role, like for example recreational and leisure services.

Emergy evaluation also offers the possibility to assess a currency emergy-based value of flows that support or are produced by a given system. Hence, flows that have no direct market value are allowed to be evaluated in terms of the equivalent currency monetary values (Em$). It expresses the emergy one receives through the service, for each dollar paid for the service. It was introduced by Odum (1996) to estimate the monetary value of the emergy content of a service. In this case, Em$ is the emergy that the municipality is saving due to the environmental flows feeding the parks (R). The Em$ value is calculated by dividing the emergy value of each flow by the emergy money ratio (EMR),

Table 3
Emergy values of supporting and regulating ecosystem services provided by the 73 parks of Sao Paulo. A summary table of the emergy of this subset of ecosystem services provided by the 73 parks is available on Appendix B.

Parks*	Climate Regulation		Water Regulation	Supporting	Total**
	Evapotranspiration/10^{10} (sej/m^2 year)	*CO_2 Sequestration*/10^{10} (sej/m^2 year)	*Water Retention*/ 10^{10}(sej/m^2 year)	*NPP*/10^{10} (sej/m^2 year)	/10^{10}(sej/m^2 year)
Small	11	95	38	7	133
Medium	12	108	39	9	147
Large	32	72	104	24	176
All	55	275	180	40	456

* Parks are classified into small (area < 50,000 m^2), medium (50,000 m^2<area < 100,000 m^2) and large (area > 100,000 m^2).
** According to emergy algebra, the total emergy of the urban parks is the sum between the highest emergy among Climate Regulation services and Water Retention. The net primary production (NPP) underlies all the other services and it is not included in the total value in order to avoid double counting. Climate Regulation and Water Retention are considered as splits (Dong et al., 2014).

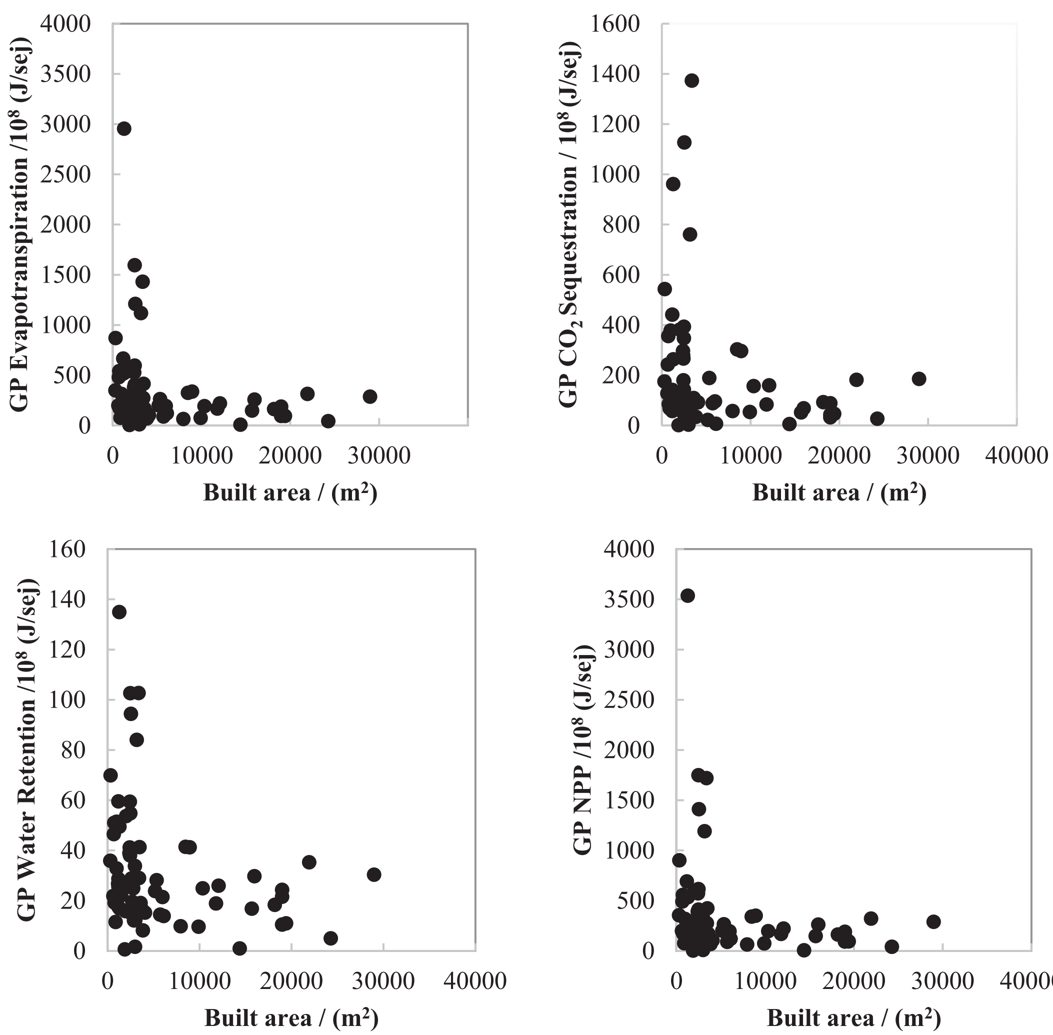

Fig. 6. Global Productivity (GP) of the ecosystem services considered in this study (Evapotranspiration, CO_2 Sequestration, Water Retention, Net Primary Production – NPP) as function of the size of the built area of each park.

which in turn is calculated by dividing the emergy of the State of São Paulo (1.7×10^{12} sej/year; Demétrio, 2011; Sevegnani et al., 2016a,b) by the Gross Domestic Product of the State in the same year. This value can be used to estimate the emergy spent in supporting of human activities to maintain the green and built areas of each park.

The fact that the EMR includes, and is partially affected by, local market dynamics, limits this analysis to the local system where the service is produced or provided.

The ecosystem service value is not accounted for by the municipality. In order to assess trade-offs between the costs and supply of ecosystem services in São Paulo's urban parks, the value of emergy inputs from the environment and the economy maintaining the urban park functions have been assessed in Em$ and compared (Table 4).

The natural renewable flows feeding the urban parks correspond to approximately 33% of the total cost of the 73 parks. Thus, if the costs to maintain these parks were calculated using the

Table 4
The emergy currency equivalent (Em$) of a subset of ecosystem services provided by the 73 parks; R – renewable resources, F – purchased resources, NPP – net primary production.

Support			Ecosystem services			
Environment		*Municipality*	Climate Regulation		Water Regulation	Supporting
Parks*	R (Em$/year)	F (Em$/year)	*Evapotranspiration* (Em$/year)	*CO_2 Sequestration* (Em$/year)	*Water Retention* (Em$/year)	*NPP* (Em$/year)
Small	181,860	1,521,453	53,435	948,113	183,737	36,979
Medium	281,837	1,217,092	83,301	970,327	276,600	61,094
Large	2,744,197	3,691,528	1,155,993	2,596,948	3,759,439	87,627
All	3,207,894	6,430,073	1,292,729	4,515,388	4,219,776	185,700

* Parks are classified into small (area < 50,000 m^2), medium (50,000 m^2 < area < 100,000 m^2) and Large (area > 100,000 m^2).

emergy currency equivalent, the total cost of the park should include the equivalent of Em$3,207,894 (currently received for free) in its accounting. The total value of supporting and regulating services (calculated as the value of Water Retention plus CO_2 Sequestration) add up to Em$8,735,164 and the total cost of the 73 parks sustained by the municipality is Em$6,430,073. In other words, each Em$ invested in the 73 urban parks of Sao Paulo, returns Em$1.36 to the municipality. This result is comparable with other cost-benefits analyses for urban ecosystems (e.g. McPherson et al., 2005). However, the returns calculated represent only a fraction of the total value of the whole set of ecosystem services provided by the parks of São Paulo, while the analysis of the costs sustained by the municipality is more complete. This means that the returns to the municipality calculated in this study represents at the best a minimum estimate.

Further analyses are needed in order to include a broader set of services and calculate a more comprehensive return value. This value could be compared with costs-benefits ratios of alternative uses of urban space, informing urban plans managing for well-being and cities livability. Emergy could be used as a common approach in order to be able to evaluate alternatives on the same basis.

4. Conclusions

The costs and supply of a subset of supporting and regulating ecosystem services of 73 urban parks were evaluated with the use of the emergy synthesis. By comparing costs and supply of urban parks ecosystem services, some conclusions can be drawn:

1) The 73 parks of Sao Paulo are using a total of 163.5×10^{17} sej/year producing a series of ecosystem services;
2) In biophysical terms, CO_2 Sequestration is the most important service provided by urban parks in São Paulo (among the services evaluated in this study);
3) The emergy invested by the municipality is proportional to the built area, and it is unevenly distributed among small, medium and large parks. The city invests more emergy on small and medium parks, and planning for implementation of new parks should consider balancing green areas and built areas within the urban parks.
4) Despite the great variation in the efficiency in providing services observed for parks with less than 10,000 m^2 of built area, these parks are more likely to produce ecosystem services efficiently;
5) When the built area is greater than 10,000 m^2, the provision of ecosystem services is characterized by low efficiency due to the high energy required to support built areas.
6) The total value of the ecosystem services considered for the 73 parks of Sao Paulo is equal to Em$8,535,164 while the total costs sustained by the municipality is Em$6,430,072;
7) The municipality investment, in emergy terms, is highly convenient, with a positive benefit/cost ratio of 1.36;
8) In addition to that, Natural Renewable flows are saving the municipality a total of Em$3,207,893;
9) Decisions on the implementation of new parks or the renovation of the existing ones should consider trade-offs between maintenance costs and the value of the main ecosystem services provided/desired.

The evaluation of ecosystem services allows urban planners, legislators, and the overall society to judge the costs, benefits, and trade-offs associated with the use of existent urban parks and plan the implementation of new ones. The approach presented to estimate the value of ecosystem services allows measuring trade-offs between developing green areas versus other forms of urban environments. Unlike more common monetary approaches to ecosystem services valuation, emergy synthesis is presented as an operative tool providing the means to calculate the cost of these contributions from a biophysical perspective. Emergy-based evaluations of ecosystem services help matching interests (environmental and economic) involved into decision making on how and if a new park could be installed.

Further studies are necessary to include and to account for other services, such as biodiversity conservation, and educational, recreational and aesthetic services. However, this analysis might be considered a first step towards fulfilling the need for a biophysical accounting method to value urban parks' services.

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Appendix A

Emergy table of Tenente Siqueira Campos (Trianon) park

Raw data and detailed calculations are available in Mariano (2017).

The park Tenente Siqueira Campos, known as Trianon, is situated in the center-west region of the city of São Paulo. It has 48,600 m^2 of total area, with 47,600 m^2 of green area. The park is equipped with fitness equipment, Cooper track and hiking, and playgrounds (SVMA, 2012).

Renewable resources and resources from the economy represent 18% and 62%, respectively, of the total resources required for the operation of the Trianon park. The contribution of local non-renewable resources is less than 1%. Chemical rain corresponds to 16% of the total emergy, being the most important natural resource. In this park, with 12 employees, the workforce represents 62% of total emergy. This percentage is higher than that of the contribution of renewable resources (18%), showing that the park depends more on resources coming from the economy than from free natural resources.

Emergy table of Tenente Siqueira Campos (Trianon).

	Unit.	Energy (unit/year)	UEV* (sej/unit)	Emergy (sej/year)	% total emergy
Implantation					
Concrete	g	7.73×10^6	$1{,}54 \times 10^9$	$1{,}19 \times 10^{16}$	15%
Steel	g	3.09×10^5	$2{,}77 \times 10^9$	$8{,}56 \times 10^{14}$	1%
Gravel	g	2.45×10^6	$1{,}68 \times 10^9$	$4{,}12 \times 10^{15}$	5%
Seedlings	J	2.00×10^8	$4{,}58 \times 10^3$	$9{,}16 \times 10^{11}$	<1%
Total (F)				**1,69 × 1016**	**21%**
Operation					
Sun**	J	1.97×10^{14}	1	$1{,}97 \times 10^{14}$	<1%
Wind**	J	3.18×10^{11}	$2{,}45 \times 10^3$	$7{,}79 \times 10^{14}$	1%
Rain (chemical)	J	4.18×10^{11}	$3{,}05 \times 10^4$	$1{,}27 \times 10^{16}$	16%
Rain(geopotencial)	J	7.46×10^9	$4{,}70 \times 10^4$	$3{,}51 \times 10^{14}$	<1%
Geothermic energy	J	7.66×10^{10}	$1{,}49 \times 10^4$	$1{,}14 \times 10^{15}$	1%
Total (R)				$\mathbf{1{,}42 \times 10^{16}}$	**18%**
Soil	J	4.52×10^6	$1{,}24 \times 10^5$	$5{,}60 \times 10^{11}$	<1%
Total (N)				$\mathbf{5.60 \times 10^{11}}$	**<1%**
Plastic	kg	419.56	$5{,}76 \times 10^9$	$2{,}42 \times 10^{12}$	<1%
Chemicals	kg	378.32	$6{,}38 \times 10^8$	$2{,}41 \times 10^{11}$	<1%
Cotton	kg	2.97	$1{,}44 \times 10^6$	$4{,}28 \times 10^6$	<1%
Paper	kg	206.33	$2{,}38 \times 10^9$	$4{,}91 \times 10^{11}$	<1%
Stell (equipament)	kg	2541.67	$4{,}15 \times 10^9$	$1{,}05 \times 10^{13}$	<1%
Labor	J	1.16×10^{10}	$4{,}30 \times 10^6$	$4{,}99 \times 10^{16}$	62%
Seedlings	J	2.53×10^9	$4{,}58 \times 10^3$	$1{,}16 \times 10^{13}$	<1%
Total (F)				**4,99E + 16**	**62%**
Total (R + N + F)				**8,10E + 16**	**100%**

Baseline 15.83×10^{24} sej/year; **not accounted.

Appendix B

Calculations of supporting and regulating services of park Tenente Siqueira Campos

Evapotranspiration

The volume of evapotranspiration and the correspondent energy were calculated for the trees (Eqs. (B1)–(B4)) and grass (Eqs. (B4)–(B6)) areas, and the total emergy (trees + grass) is shown in Eq. (5). Trees and grass correspond to 80% and 20% of the green area, respectively. A 10% runoff coefficient, defined as the ratio of the volume of water drained to the volume of precipitated water, was adopted, and the average precipitation of 145 mm/month (Center for Weather Forecasting and Climate Studies, *www.inpe.br*). The evapotranspiration index used for the trees was 1006.2 mm/month (Cicco, 2009) and for the grass was 8.321×10^{-1} m/year (Lu et al., 2006). The UEV of the evapotranspiration used was 2.69×10^4 sej/J (Odum, 1996).

$$\text{Volume}_{\text{Evap.trees}} = 1006.2\frac{L}{m^2.year} \times 38080m^2 \times \frac{m^3}{1000L} = 3.83 \times 10^4 \frac{m^3}{year} \quad (9)$$

$$Energy_{\text{Evap.trees}} = 3.83 \times 10^4 \frac{m^3}{year} \times 4.94\frac{J}{mL} \times 10^6 \frac{mL}{m^3} = 1.89 \times 10^{11} \frac{J}{year} \quad (10)$$

$$Volume_{\text{Evap.grass}} = 8.321 \times 10^{-1} \frac{m}{year} \times \frac{1000L}{m^2} \times 9520m^2 \times \frac{m^3}{1000L} = 7.92 \times 10^3 \frac{m^3}{year} \quad (11)$$

$$Energy_{\text{Evap.grass}} = 7.92 \times 10^3 \frac{m^3}{year} \times 4.94\frac{J}{mL} \times 10^6 \frac{mL}{m^3} = 3.91 \times 10^{10} \frac{J}{year} \quad (12)$$

$$Emergy_{Evap.trees+grass} = \left(1.89 \times 10^{11} \frac{J}{year} + 3.91 \times 10^{10} \frac{J}{year}\right) \times 2.69 \times 10^4 \frac{\text{seJ}}{\text{J}} = 6.14 \times 10^{15} \frac{sej}{year} \quad (13)$$

Water retention

Water retention was calculated as the difference between the total rain (Eqs. (B6) and (B7)) and evapotranspiration (Eqs. (B1) and (B3)). The volume of water retention (2.13×10^4 m^3/year (grass) + 6.98×10^3 m^3/year (trees)) was multiplied by the UEV = 6.85×10^{11} sej/m^3 (Buenfil, 2001) resulting in an emergy value of 1.93×10^{16} sej/year.

$$Volume_{Rain,trees} = 130.5\frac{mm}{month}\times\frac{L}{m^2}\times 38080m^2\times 12\frac{month}{year}\times\frac{m^3}{1000L} = 5.96\times 10^4\frac{m^3}{year} \quad (14)$$

$$Volume_{Rain,grass} = 130.5\frac{mm}{month}\times\frac{L}{m^2}\times 9520m^2\times 12\frac{month}{year}\times\frac{m^3}{1000L} = 1.49\times 10^4\frac{m^3}{year} \quad (15)$$

Net primary production (NPP)

The energy values for the NPP of trees (2.16×10^7 J/year.m^2) and grass (7.60×10^6 J/year.m^2) were taken from Lu et al., 2006, who obtained the values from a system located in lower subtropical China. The values are similar to those reported in Brazil for Atlantic forest (Parron et al., 2015, in Portuguese) – 2.48×10^7 J/m^2 year for trees, and 7.88×10^6 J/m^2 year for grass). The UEVs were also taken from Lu et al., 2006: 5.54×10^3 sej/J for trees and 4.26×10^3 sej/J for grass. Equations B8 and B9 show the calculations for emergy, which resulted in a total value of 4.87×10^{15} sej/year.

$$Emergy_{NPP,trees} = 38080m^2\times 2.16\times 10^7\frac{J}{year.m^2}\times 5.54\times 10^3\frac{seJ}{J} = 4.56\times 10^{15}\frac{seJ}{year} \quad (16)$$

$$Emergy_{NPP,grass} = 9520m^2\times 7.60\times 10^6\frac{J}{year.m^2}x4.26\times 10^3\frac{seJ}{J} = 3.08\times 10^{14}\frac{seJ}{year} \quad (17)$$

Appendix C

Emergy results for the 73 urban parks studied. R – renewable resources, N – local non-renewable resources, F – purchased resources

Park	Area (m^2)	Built area (m^2)	R (sej/yr)	N (sej/yr)	F (sej/yr)	Total emergy (sej/yr)	US$/$m^2$
Zilda Natel	2386	1908	6.54E + 14	1.07E + 12	5.64E + 16	5.71E + 16	14.04
Vila Silvia	4400	3020	1.25E + 15	1.70E + 12	6.02E + 16	6.14E + 16	7.40
Ermelino Matarazzo	5181	900	1.53E + 15	5.05E + 11	2.40E + 16	2.56E + 16	4.48
Casa Modernista	12710	650	3.80E + 15	3.65E + 11	2.78E + 16	3.16E + 16	2.53
Eucaliptos	15447	792	4.63E + 15	4.44E + 11	3.95E + 16	4.41E + 16	3.70
Linear Caulim	16000	1200	4.79E + 15	6.73E + 11	3.20E + 16	3.68E + 16	2.81
Linear Parelheiros	16000	3041	4.75E + 15	1.70E + 12	6.07E + 16	6.54E + 16	2.78
Praia do Sol	17900	14400	5.04E + 15	8.07E + 12	2.51E + 17	2.56E + 17	1.10
M Boi Mirim	19000	1200	5.67E + 15	6.73E + 11	6.56E + 16	7.13E + 16	3.35
Senhor do Vale	21000	1200	6.30E + 15	6.73E + 11	4.00E + 16	4.63E + 16	1.42
Sena	21661	1201	6.57E + 15	6.73E + 11	3.61E + 16	4.26E + 16	2.79
Benemerito Brás	22300	2500	6.49E + 15	1.40E + 12	8.13E + 16	8.78E + 16	5.22
Linear Sapé	23544	320	6.89E + 15	1.80E + 11	2.90E + 16	3.59E + 16	2.90
Lions Club – Tucuruvi	23700	1967	7.09E + 15	1.10E + 12	7.71E + 16	8.42E + 16	4.81
Buenos Aires	25000	1320	6.74E + 15	7.40E + 11	7.56E + 16	8.23E + 16	5.69
Luiz Carlos Prestes	27100	2900	7.36E + 16	1.62E + 12	1.09E + 17	1.83E + 17	4.17
Jardim Felicidade	28800	1497	8.63E + 15	8.39E + 11	6.23E + 16	7.09E + 16	3.93
Linear Guaratiba	29000	7981	8.52E + 15	4.48E + 12	1.40E + 17	1.48E + 17	2.16
Linear do Fogo	30000	2819	8.95E + 15	1.57E + 12	6.17E + 16	7.07E + 16	2.38
Nabuco	31300	1486	9.37E + 15	8.33E + 11	6.60E + 16	7.54E + 16	0.57
Raul Seixas	33000	4098	9.83E + 15	2.29E + 12	1.19E + 17	1.29E + 17	3.61
Cordeiro	34000	2921	1.01E + 16	1.64E + 12	8.77E + 16	9.78E + 16	3.62
Santa Amélia	34000	5746	1.01E + 16	3.22E + 12	1.29E + 17	1.39E + 17	1.13
Severo Gomes	34900	1168	1.05E + 16	6.55E + 11	6.12E + 16	7.17E + 16	1.21
Lajeado	36000	2460	1.07E + 16	1.38E + 12	6.28E + 16	7.35E + 16	2.21
Rodrigo Gásperi	39000	6121	1.16E + 16	3.43E + 12	1.27E + 17	1.39E + 17	3.88
Faria Lima	40131	3735	1.20E + 16	2.10E + 12	1.22E + 17	1.34E + 17	3.16
Jacinto Alberto	40910	9927	1.21E + 16	5.57E + 12	1.90E + 17	2.02E + 17	2.73
Chácara das Flores	41735	2720	1.25E + 16	1.53E + 12	1.03E + 17	1.15E + 17	3.93
Trianon	48600	1000	1.42E + 16	5.60E + 11	6.68E + 16	8.10E + 16	0.41
Colina de São Francisco	49053	3606	1.43E + 16	2.02E + 12	1.23E + 17	1.38E + 17	3.02
Cohab Raposo Tavares	54384	24300	1.54E + 16	1.36E + 13	3.46E + 17	3.61E + 17	0.26
Orlando Villas Boas	55000	2620	1.49E + 17	1.46E + 12	1.02E + 17	2.51E + 17	1.67
Linear Canivete	60000	2400	1.80E + 16	1.35E + 12	7.21E + 16	9.01E + 16	2.45
Linear Itaim	60000	750	1.80E + 16	4.20E + 11	4.50E + 16	6.30E + 16	1.22

Appendix C (*continued*)

Park	Area (m^2)	Built area (m^2)	R (sej/yr)	N (sej/yr)	F (sej/yr)	Total emergy (sej/yr)	US$/$m^2$
Linear Mongagua	60000	6000	1.79E + 16	3.36E + 12	1.28E + 17	1.46E + 17	1.63
Lydia Natalizio Vila Prudente	60000	5200	1.79E + 16	2.91E + 12	1.21E + 17	1.39E + 17	10.22
Chico Mendes	61600	3455	2.41E + 15	1.93E + 12	9.55E + 16	9.79E + 16	2.29
Linear Rapadura	70000	2460	2.10E + 16	1.38E + 12	8.96E + 16	1.11E + 17	0.84
Guanhembú	71920	700	2.16E + 16	3.92E + 11	6.21E + 16	8.37E + 16	2.67
Jardim Herculano	75277	2500	2.26E + 16	1.40E + 12	7.73E + 16	9.99E + 16	1.82
Shangrilá	75643	2426	2.27E + 16	1.36E + 12	8.03E + 16	1.03E + 17	3.04
Águas	76300	12098	2.26E + 16	6.78E + 12	1.28E + 17	1.51E + 17	3.15
São José	79115	19000	2.33E + 16	1.07E + 13	3.08E + 17	3.32E + 17	2.98
São Domingos	80000	5366	2.39E + 16	3.01E + 12	1.27E + 17	1.51E + 17	1.08
Barragem Guarapiranga	88000	3500	2.64E + 16	1.96E + 12	8.72E + 16	1.14E + 17	0.82
Previdência	91500	1316	2.68E + 16	7.38E + 11	7.16E + 16	9.84E + 16	0.09
Piqueri	97200	3000	2.91E + 16	1.69E + 12	1.27E + 17	1.57E + 17	6.51
Linear Castelo	103338	350	3.10E + 16	1.96E + 11	4.44E + 16	7.54E + 16	1.17
Cidade Toronto	109100	10362	3.26E + 16	5.80E + 12	2.18E + 17	2.51E + 17	1.81
Vila dos Remédios	109800	15716	3.18E + 16	8.82E + 12	2.95E + 17	3.27E + 17	1.48
Aclimação	112200	19431	3.24E + 16	1.09E + 13	4.65E + 17	4.97E + 17	3.13
Luz	113400	11813	3.30E + 16	6.62E + 12	2.79E + 17	3.12E + 17	2.69
Linear Aricanduva	120000	19000	3.56E + 16	1.07E + 13	2.86E + 17	3.22E + 17	0.69
Linear Água Vermelha	124207	2450	3.73E + 16	1.38E + 12	8.50E + 16	1.22E + 17	1.48
Consciência Negra	130135	18202	3.87E + 16	1.02E + 13	3.18E + 17	3.57E + 17	0.94
Santo Dias	134000	2044	4.02E + 16	1.15E + 12	9.25E + 16	1.33E + 17	1.86
Alfedro Volpi	142432	1200	4.17E + 16	1.10E + 11	8.36E + 16	1.25E + 17	0.93
Guarapiranga	152600	1005	4.58E + 16	5.64E + 11	1.20E + 17	1.66E + 17	2.01
Independência	161300	3870	4.83E + 16	2.17E + 12	1.08E + 18	1.13E + 18	2.07
Ciência	187000	2500	5.62E + 16	1.40E + 12	1.25E + 17	1.81E + 17	1.09
Vila Guilherme	187000	19000	5.58E + 16	1.07E + 13	3.83E + 17	4.39E + 17	2.22
Sete Campos	188000	8500	5.64E + 16	4.76E + 12	2.17E + 17	2.73E + 17	2.95
Raposo Tavares	195000	16000	5.69E + 16	8.97E + 12	3.02E + 17	3.59E + 17	4.97
Pinheirirnho D ' Água	250306	8958	7.50E + 16	5.02E + 12	2.86E + 17	3.61E + 17	2.88
Linear Tiquatira	320000	21952	9.56E + 16	1.23E + 13	4.03E + 17	4.99E + 17	0.94
Jacques Cousteau	335000	29000	1.00E + 17	1.62E + 13	4.75E + 17	5.75E + 17	0.61
Jardim Sapopemba	345000	3400	1.09E + 16	1.91E + 12	6.55E + 16	7.65E + 16	6.13
Cemucam	500000	3200	1.47E + 17	1.80E + 12	1.49E + 17	2.96E + 17	0.55
Nove de Julho	500000	2500	1.50E + 17	1.40E + 12	8.56E + 16	2.36E + 17	3.40
Vila do Rodeio	613200	2560	1.84E + 17	1.44E + 12	1.52E + 17	3.36E + 17	1.83
Linear Cocaia	1000000	1300	3.72E + 17	7.29E + 11	3.34E + 16	4.05E + 17	0.05
Anhanguera	9500000	7350	2.86E + 18	4.12E + 12	2.29E + 17	3.09E + 18	0.04

Appendix D

Emergy of supporting and regulating services provided by the 73 urban parks studied. NPP – net primary production.

	Emergy			
	Evapotranspiration sej/year	CO_2 Sequestration sej/year	Water Retention sej/year	NPP sej/year
Zilda Natel	0.00E + 00	3.47E + 16	2.40E + 14	1.54E + 13
Vila Silvia	1.52E + 14	3.70E + 16	6.93E + 14	4.45E + 13
Ermelino Matarazzo	4.93E + 14	1.48E + 16	2.05E + 15	2.13E + 14
Casa Modernista	1.56E + 15	1.76E + 16	4.91E + 15	1.23E + 15
Eucaliptos	1.89E + 15	2.48E + 16	5.97E + 15	1.50E + 15
Linear Caulim	1.91E + 15	2.02E + 16	6.03E + 15	1.51E + 15
Linear Parelheiros	1.61E + 15	3.77E + 16	5.59E + 15	1.10E + 15
Praia do Sol	4.03E + 14	1.54E + 17	1.68E + 15	1.74E + 14
M Boi Mirim	1.97E + 15	4.05E + 16	8.95E + 15	5.75E + 14
Senhor do Vale	2.46E + 15	2.52E + 16	8.54E + 15	1.68E + 15
Sena	2.55E + 15	2.28E + 16	8.82E + 15	1.73E + 15
Benemerito Brás	2.28E + 15	5.03E + 16	9.48E + 15	9.86E + 14
Linear Sapé	3.00E + 15	1.87E + 16	9.46E + 15	2.37E + 15

(*continued on next page*)

Appendix D (*continued*)

Emergy				
	Evapotranspiration sej/year	CO_2 Sequestration sej/year	Water Retention sej/year	NPP sej/year
Lions Club – Tucuruvi	2.70E + 15	4.81E + 16	9.37E + 15	1.84E + 15
Buenos Aires	3.00E + 15	4.72E + 16	9.93E + 15	2.21E + 15
Luiz Carlos Prestes	3.12E + 15	6.79E + 16	9.86E + 15	2.47E + 15
Jardim Felicidade	3.52E + 15	3.93E + 16	1.11E + 16	2.79E + 15
Linear Guaratiba	2.42E + 15	8.63E + 16	1.01E + 16	1.05E + 15
Linear do Fogo	3.19E + 15	3.85E + 16	1.27E + 16	1.59E + 15
Nabuco	3.85E + 15	4.17E + 16	1.21E + 16	3.05E + 15
Raul Seixas	3.33E + 15	7.34E + 16	1.38E + 16	1.44E + 15
Cordeiro	3.94E + 15	5.49E + 16	1.30E + 16	2.91E + 15
Santa Amélia	3.12E + 15	7.97E + 16	1.42E + 16	9.13E + 14
Severo Gomes	4.35E + 15	3.89E + 16	1.37E + 16	3.45E + 15
Lajeado	4.33E + 15	3.98E + 16	1.37E + 16	3.43E + 15
Rodrigo Gásperi	4.24E + 15	7.95E + 16	1.34E + 16	3.36E + 15
Faria Lima	4.53E + 15	7.58E + 16	1.57E + 16	3.09E + 15
Jacinto Alberto	3.86E + 15	1.18E + 17	1.34E + 16	2.63E + 15
Chácara das Flores	5.04E + 15	6.45E + 16	1.59E + 16	3.99E + 15
Triyearn	6.14E + 15	4.28E + 16	1.94E + 16	4.87E + 15
Colina de São Francisco	5.87E + 15	7.76E + 16	1.85E + 16	4.65E + 15
Cohab Raposo Tavares	3.88E + 15	2.14E + 17	1.23E + 16	3.08E + 15
Orlando Villas Boas	6.03E + 15	6.36E + 16	2.51E + 16	2.61E + 15
Linear Canivete	6.90E + 15	4.57E + 16	2.62E + 16	3.88E + 15
Linear Itaim	7.65E + 15	2.99E + 16	2.41E + 16	6.06E + 15
Linear Mongagua	6.97E + 15	8.06E + 16	2.20E + 16	5.52E + 15
Lydia Natalizio Vila Prudente	6.82E + 15	7.61E + 16	2.36E + 16	4.65E + 15
Chico Mendes	7.50E + 15	6.09E + 16	2.37E + 16	5.95E + 15
Linear Rapadura	7.94E + 15	5.65E + 16	3.15E + 16	3.95E + 15
Guanhembú	9.19E + 15	4.09E + 16	2.90E + 16	7.28E + 15
Jardim Herculyear	9.39E + 15	5.03E + 16	2.97E + 16	7.44E + 15
Shangrilá	9.11E + 15	5.17E + 16	3.16E + 16	6.21E + 15
Águas	7.99E + 15	8.07E + 16	2.77E + 16	5.44E + 15
São José	7.90E + 15	1.92E + 17	2.38E + 16	6.67E + 15
São Domingos	9.63E + 15	8.11E + 16	3.04E + 16	7.63E + 15
Barragem Guarapiranga	1.09E + 16	5.68E + 16	3.44E + 16	8.64E + 15
Previdência	1.16E + 16	4.75E + 16	3.67E + 16	9.22E + 15
Piqueri	1.22E + 16	8.19E + 16	3.84E + 16	9.63E + 15
Linear Castelo	1.35E + 16	3.16E + 16	4.07E + 16	1.14E + 16
Cidade Toronto	1.18E + 16	1.36E + 17	4.49E + 16	6.64E + 15
Vila dos Remédios	1.21E + 16	1.85E + 17	3.83E + 16	9.62E + 15
Aclimação	1.20E + 16	2.89E + 17	3.78E + 16	9.49E + 15
Luz	1.31E + 16	1.75E + 17	4.14E + 16	1.04E + 16
Linear Aricanduva	1.14E + 16	1.77E + 17	4.96E + 16	4.15E + 15
Linear Água Vermelha	1.40E + 16	5.45E + 16	5.83E + 16	6.06E + 15
Consciência Negra	1.44E + 16	2.00E + 17	4.56E + 16	1.14E + 16
Santo Dias	1.70E + 16	6.19E + 16	5.38E + 16	1.35E + 16
Alfedro Volpi	1.82E + 16	5.68E + 16	5.75E + 16	1.44E + 16
Guarapiranga	1.89E + 16	7.86E + 16	6.54E + 16	1.29E + 16
Independência	2.03E + 16	6.71E + 17	6.41E + 16	1.61E + 16
Ciência	2.38E + 16	8.39E + 16	7.52E + 16	1.89E + 16
Vila Guilherme	2.01E + 16	2.40E + 17	7.65E + 16	1.13E + 16
Sete Campos	2.07E + 16	1.37E + 17	8.60E + 16	8.94E + 15
Raposo Tavares	2.23E + 16	1.91E + 17	7.72E + 16	1.52E + 16
Pinheirirnho D ' Água	2.84E + 16	1.81E + 17	1.13E + 17	1.41E + 16
Linear Tiquatira	3.71E + 16	2.57E + 17	1.29E + 17	2.53E + 16
Jacques Cousteau	3.95E + 16	3.04E + 17	1.25E + 17	3.13E + 16
Jardim Sapopemba	4.09E + 16	4.89E + 16	1.55E + 17	2.30E + 16
Cemucam	6.41E + 16	1.11E + 17	2.02E + 17	5.08E + 16
Nove de Julho	6.42E + 16	7.17E + 16	2.03E + 17	5.09E + 16
Vila do Rodeio	7.32E + 16	1.09E + 17	2.78E + 17	4.11E + 16
Linear Cocaia	1.29E + 17	5.90E + 16	4.07E + 17	1.02E + 17
Anhanguera	1.23E + 18	5.06E + 17	3.87E + 18	9.71E + 17

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