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Implementing and managing urban forests: A much needed conservation strategy to increase ecosystem services and urban wellbeing

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ABSTRACT

Megacities contain at least 10 million people whose wellbeing largely depends on ecosystem services provided by remote natural areas. What is, however, most often disregarded is that nature conservation in the city can also contribute to human wellbeing benefits. The most common mind set separates cities from the rest of nature, as if they were not special kinds of natural habitats. Instead, awareness that urban systems are also nature and do host biodiversity and ecosystem services opportunities, should push urban people towards increased urban forest conservation and implementation strategies. This research estimated existing and potential, tree cover, and its contribution to ecosystem services in 10 megacity metropolitan areas, across 5 different continents and biomes. We developed estimates for each megacity using local data to transform i-Tree Eco estimates of tree cover benefits to reductions in air pollution, stormwater, building energy, and carbon emissions for London, UK. The transformation used biophysical scaling equations based on local megacity tree cover, human population, air pollution, climate, energy use, and purchasing power parity. The megacity metropolitan areas ranged from 1173 to 18,720 sq km (median value 2530 sq km), with median tree cover 21%, and potential tree cover another 19% of the city. Megacities had a median tree cover density of 39 m^2/capita, much smaller than the global average value of 7800 m^2/capita, with density lower in desert and tropical biomes, and higher in temperate biomes. The present median benefit value from urban trees in all 10 megacities can be estimated as $482 million/yr due to reductions in CO, NO_2, SO_2, PM10, and PM2.5, $11 million/yr due to avoided stormwater processing by wastewater facilities, $0.5 million/yr due to building energy heating and cooling savings, and $8 million/yr due to CO_2 sequestration. Planting more trees in potential tree cover areas could nearly double the benefits provided by the urban forest. In 2016 there were 40 megacities, totaling 722 million residents, nearly 10% of the human population, who would benefit from nature conservation plans where they work and live. Nature conservation strategies in megacities should work to sustain and grow the benefits of the urban forest, and improve accounting methods to include additional ecosystem services provided by the urban forest.

1. Introduction

Megacities are densely populated, containing at least 10 million people, yet these urban systems still contain parts of nature that deserve an accounting of their benefits and nature conservation strategies. The human livelihoods in these megacities, unfortunately, are adversely impacted by urban pollution (Gurjar et al., 2008), climate change (Dasgupta et al., 2013; Mourshed, 2011), and constrained budgets that prohibit needed investments in education (Bunar, 2010; Maitra and Rao, 2015; Ngware et al., 2011) and healthcare (Loganathan et al., 2015; Vuong, 2015). Conserving and enhancing natural systems to solve or reduce pollution problems is one of the main functional applications of the field of ecological engineering. As such, ecological engineering recognizes the strategic importance of coupling urban areas and natural areas in order to convert urban pollution into ecosystem resources, in such a way that benefits human wellbeing and biodiversity (Mitsch and Jorgensen, 2003). Efforts to improve the condition of human livelihoods are the focus of the United Nations Sustainability Development Goals (Chin and Jacobsson, 2016; United Nations, 2016a),

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Table 1
Megacity name, area, human population (N_{Pop}), purchasing power parity conversion (PPP), annual average air pollutant concentration (C_{TSP} is total suspended particles, C_{SO2} sulfur dioxide, C_{NO2} nitrous dioxide), growing season ($N_{GrowDay}$), precipitation depth (D_{Ppt}), electricity use ($W_{Electricity}$), energy use (J_{Energy}), and inversion potential (F*Inversion*). Superscript [a] denotes data from Gurjar et al. (2008), except for Istanbul and Mumbai, which were estimated based on the Gurjar data, [b] is from Kennedy et al. (2015).

City	Area (sq km)	N_{Pop} (–)	PPP L£/$	C_{TSP}[a] (ug/m3)	C_{SO2}[a] (ug/m3)	C_{NO2}[a] (ug/m3)	$N_{GrowDay}$ (day)	D_{Ppt}[b] (mm)	$W_{Electricity}$[b] (GWh)	J_{Energy}[b] (TJ)	$F_{Inversion}$ (–)
Beijing	2742	2.1E+7	3.52	377	90	122	251	721	80686	652343	1.1
Buenos Aires	2941	1.4E+7	2.66	185	20	20	273	1195	34170	449961	1.0
Cairo	1173	1.6E+7	2.22	593	37	59	365	26	30897	250964	1.0
Istanbul	1990	1.3E+7	1.16	668	13	30	350	852	38249	286315	1.0
London	2906	1.0E+7	0.70	34	19	71	246	601	39946	386643	1.0
Los Angeles	6612	1.5E+7	1.00	39	9	66	365	379	63898	508755	1.1
Mexico City	2219	2.0E+7	7.93	201	47	56	365	697	13667	119262	1.1
Moscow	2318	1.6E+7	21.26	150	15	170	166	698	51954	1236353	1.0
Mumbai	1358	1.8E+7	17.00	405	18	36	365	3225	12952	29005	1.1
Tokyo	18720	3.8E+7	104.72	40	19	55	312	1480	240783	1047599	1.0

which call for additional tree cover in cities in order to provide needed environmental, economic, and social ecosystem services (Bolund and Hunhammar, 1999; Gauthier, 2003; United Nations, 2016b). The objective of this work is to advance these UN goals by applying accounting models of urban tree benefits, and thereby establish a rationale for the development of more advanced nature conservation strategies for megacities.

Urban tree cover delivers an array of ecosystem services, including: air pollutant reduction (Baró et al., 2014; Jim and Chen, 2008); stormwater runoff reduction (Coutts et al., 2013; Inkilainen et al., 2013; Soares et al., 2011); building energy savings from reduced heating and cooling costs, and the associated avoided carbon emissions from reduced energy use (Akbari, 2002; Kulak et al., 2013; Sawka et al., 2013; Wang et al., 2016); and carbon dioxide sequestration (Lwasa et al., 2015; Nowak et al., 2013). A benefit of providing these services with trees is the low energy cost due to solar radiation, via the process of photosynthesis, powering tree structure and function. The additional energy inputs needed for tree management is a real cost, but something that can be incorporated into green jobs, education, and outreach programs (Beck and Villarroel Walker, 2013; Gauthier, 2003).

Estimates of tree cover are used by some ecological models when accounting for the ecosystem services provided from trees. A set of widely applied, tested, and free models are collectively known as i-Tree tools (www.itreetools.org), which include computer programs that were been developed to help communities inventory their tree cover and estimate the associated ecosystem services. The i-Tree Eco tool uses input data of tree structure, air pollution, weather, buildings, and economic pricing to estimate the tree-based ecosystem services of air pollutant reduction, stormwater runoff reduction, building energy savings and avoided carbon emissions, and carbon dioxide sequestration (i-Tree, 2016b). To estimate ecosystem services for an entire city, the tree structure input data are typically obtained from a survey of 200 or more plots, each 0.04 ha in area, which requires approximately 5 person-hours per plot for trained staff (i-Tree, 2016a). While 10 s of cities have invested in these tree structure surveys and the subsequent i-Tree Eco analyses, surveys in megacities have been limited to London, Los Angeles, and New York City, and these analyses did not include their entire metropolitan areas. The preparation, implementation, and post-processing of field surveys for megacities can take months to years and 10 s to 100 s of thousands of dollars, limiting the implementation of such surveys for the 40 megacities known to exist worldwide.

A more rapid, lower cost approach is needed to obtain estimates of tree cover and associated ecosystem services in megacities. One approach is to start with the i-Tree Canopy tool, which provides a relatively rapid estimate of canopy cover without the need for field based plot surveys (i-Tree, 2011). The i-Tree Canopy tool uses human photo-interpretation of land cover captured in Google Earth aerial photography to determine percent tree canopy cover, which is the projected area of canopy on the surface, and is typically larger than the tree stem area. The accuracy of tree canopy estimates by human photo-interpretation have been shown to be higher than multi-spectral auto-classification, which tends to underestimate urban tree cover (Greenfield et al., 2009). The i-Tree Canopy tool can use tree canopy cover to generate estimates of ecosystem services, based on accessing a database of per canopy cover benefits generated by prior i-Tree Eco simulations in representative cities; the cities are representative based on vegetation, air pollution levels, weather, building energy usage, and human population. The i-Tree Canopy database of ecosystem services is only provided for US cities. In this manuscript we develop scaling equations that convert i-Tree Canopy estimates of canopy cover in international megacities to access i-Tree Eco estimates of ecosystem services.

Inherent in an accounting of nature across a set of megacities is that the investigated cities are located in very different geographical and climatic areas, with different characteristics spanning from concentration and typology of pollutants, tree species and growth rate, population density, season cycling, among others. Further, such a wide study will encounter data that are applicable to some cities but may not fully fit other ones. However, the methods used for such a study of ecosystem service benefits are able to provide at least a reliable estimate of the extent managing urban forests may provide wellbeing and economic benefits; moreover, the methods are such that they can easily be improved when new data become available. As stated above, implementing detailed ecosystem inventories and modeling is costly and urban administrations are reluctant to invest in something that does not seem to be directly linked to the urban daily life. This study aims to contribute to the awareness that managing urban forests is a way to provide wellbeing and economic benefits, as other kinds of investments in productive sectors do. New and more accurate estimates may emerge as a follow up of this study.

2. Methods

We selected ten megacities for the inventory of tree cover and estimation of the associated value in ecosystem services. The megacities were: Beijing, China; Buenos Aires, Argentina; Cairo, Egypt; Istanbul, Turkey; London; Great Britain; Los Angeles, United States; Mexico City, Mexico; Moscow, Russia; Mumbai, India; Tokyo, Japan. These megacities are distributed across five continents, and represent five different biomes. The biomes were defined by megacity annual average precipitation, maximum and minimum average temperatures, and their native vegetation density and types. The human population and area of each megacity (Table 1) was defined based on a combination of functional and physical definitions of the city, extending beyond the core area and political boundary to include the greater or metropolitan area, using