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Benefits of restoring ecosystem services in urban areas

T Elmqvist[1], H Setälä[2], SN Handel[3], S van der Ploeg[4], J Aronson[5,6], JN Blignaut[7], E Gómez-Baggethun[8,9], DJ Nowak[10], J Kronenberg[11] and R de Groot[4]

Cities are a key nexus of the relationship between people and nature and are huge centers of demand for ecosystem services and also generate extremely large environmental impacts. Current projections of rapid expansion of urban areas present fundamental challenges and also opportunities to design more livable, healthy and resilient cities (e.g. adaptation to climate change effects). We present the results of an analysis of benefits of ecosystem services in urban areas. Empirical analyses included estimates of monetary benefits from urban ecosystem services based on data from 25 urban areas in the USA, Canada, and China. Our results show that investing in ecological infrastructure in cities, and the ecological restoration and rehabilitation of ecosystems such as rivers, lakes, and woodlands occurring in urban areas, may not only be ecologically and socially desirable, but also quite often, economically advantageous, even based on the most traditional economic approaches.

Addresses
[1] Stockholm Resilience Center, Stockholm University, SE-10691 Stockholm, Sweden
[2] Department of Environmental Sciences, University of Helsinki, FIN-15140 Lahti, Finland
[3] Department of Ecology, Evolution, & Natural Resources, Rutgers University, New Brunswick, NJ 08901-1582, USA
[4] Environmental Systems Analysis Group, Wageningen University, 6700 AA Wageningen, The Netherlands
[5] CEFE (UMR 5175_Campus du CNRS) 34293, Montpellier, France
[6] Missouri Botanical Garden, St. Louis, MO 63110, USA
[7] Department of Economics, University of Pretoria, Pretoria, South Africa
[8] Norwegian Institute for Nature Research (NINA), 0349 Oslo, Norway
[9] Institute of Environmental Science and Technology (ICTA), Autonomous University of Barcelona (UAB), Campus UAB, Barcelona, Spain
[10] USDA Forest Service, SUNY-ESF, Syracuse, NY 13210, USA
[11] Faculty of Economics and Sociology, University of Lodz, POW 3/5, 90-255 Lodz, Poland

Corresponding author: Elmqvist, T (thomas.elmqvist@su.se)

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Introduction

We are entering a new urban era in which the ecology of the planet as a whole is increasingly influenced by human activities, with cities as crucial centers of demand for ecosystem services and sources of environmental impacts [1,2]. Approximately 60% of the urban land expected to exist 2030 is forecast to be built in 2000–2030 [3••]. Urbanization therefore presents fundamental challenges but also unprecedented opportunities to enhance the resilience and ecological functioning of urban systems. For example, urban ecosystems, that is, the urban 'green and blue infrastructure', may have a crucial role in increasing the adaptive capacity to cope with climate change [4,5]. Analyses of urban investments in green infrastructure and ecosystem-based adaptation to climate change are gaining interest, particularly since such investments simultaneously generate many other services enhancing human well-being [e.g. [3]].

Furthermore, there is a growing interest in restoring urban ecosystems, spurred in part by commitments made by the parties to the Convention on Biological Diversity to restore at least 15% of degraded ecosystems by 2020 [6]. Investing in urban green and blue infrastructure constitutes a tangible contribution that cities can make to the United Nations' agenda on a Green Economy for the 21st century [7] and the Sustainable Development Goals (SDGs). Although several recent studies highlight the importance of urban ecosystem services [e.g. [8,9•,10,11]] still, ecosystem dynamics in urban landscapes are poorly understood [12,13•], especially when it comes to designing, creating and restoring ecological processes, functions, and services in urban areas [12,14].

Here, we analyze to what extent investments in green infrastructure in urban landscapes can bring multiple monetary and non-monetary benefits to society and human well-being, contributing to maintenance of biodiversity, and development of more resilient urban areas.

Urban ecosystem services

Urban ecosystem services are generated in a diverse set of habitats, including: *green spaces*, such as parks, urban forests, cemeteries, vacant lots, gardens and yards, campus areas, landfills; and *blue spaces*, including streams, lakes, ponds, artificial swales, and storm water retention ponds. Urban ecosystem services are generally characterized by a high intensity of demand/use due to a very large number of immediate local beneficiaries, compared for

Box 1 Examples of services provided by green and blue infrastructure in urban areas

Microclimate regulation: Urban parks and vegetation, including green roofs and green walls, reduce the urban heat island effect [12]. Data from Manchester (United Kingdom) show that a 10% increase in tree canopy cover may result in a 3–4 °C decrease in ambient temperature [15] and save large amounts of energy used in air conditioning [16]. The cooling effect of trees in cities may contribute significantly to reduce energy needs from fossil fuels and cut carbon emissions [17].

Water regulation: Interception of rainfall by trees, other vegetation, and permeable soils in urban areas can also be crucial in reducing the pressure on the drainage system and in lowering the risk of surface water flooding [12]. Urban landscapes with 50–90% impervious ground cover can lose 40–83% of incoming rainfall to surface runoff whereas forested landscapes only lose ca. 13% of rainfall input from similar precipitation events [12,18].

Pollution reduction and health effects: Urban vegetation is widely reported to improve air quality [19,20] although this effect can be context dependent due to the high spatial and temporal variability in and among cities [21,22]. Many other potentially positive public health benefits have been identified [23,24]. Green area accessibility has been linked to reduced mortality [25] and improved perceived and actual general health [26]. The distribution and accessibility of green space to different socio-economic groups, however, often reveals large asymmetries in cities [27,28•], contributing to inequity in both physical and mental health among socio-economic groups [29].

Habitat: An important characteristic of urban areas is their mosaic of habitats and a surprisingly high diversity of plant and animal species [30–32]. In addition to the innate, or inherent value of species and biodiversity, this service also provides deeply important benefits for many citizens or many or all cultures, and also for national and local governments trying to implement their commitments to reduce biodiversity loss and restoring 15% of all degraded ecosystems (including 10% of the oceans).

Cultural services: Many cultural services are associated with urban ecosystems and there is evidence that biodiversity in urban areas plays a positive role in enhancing human well-being. For example, Fuller *et al.* [33] have shown that the psychological benefits of green space increase with biodiversity, whereas a 'green view' from a window increases job satisfaction and reduces job stress [34]. Many studies have shown an increased value of property with greater proximity to green areas [35]. Diverse ecosystems in urban areas may also be important in providing design features that can be utilized in the context of eco-design and bio-mimicry in architecture and urban planning [36].

example to ecosystem services generated in rural areas distant from densely populated areas. Box 1 contains examples of important services provided by green and blue infrastructure in urban areas.

Monetary benefits of urban green spaces

We present an analysis of monetary benefits of ecosystem services provided by urban forests/woodlands based on 25 studies done in urban regions (20 in the USA, 4 in China and 1 in Canada) (Table 1). We restricted the literature search to include only studies in which estimates of monetary values of benefits were calculated, based on a quantification in biophysical terms (e.g. amounts of C stored/sequestered by trees per hectare per year). The estimates of ecosystem services given in Table 1 are comparable except for the estimates given for Beijing, Guangzhou, Hangzhou and Lanzhou China. The estimate for these Chinese cities are derived from a literature review that is comprised of varying methods used to estimate the ecosystem services. The estimates for the remaining cities are based on a standardized data collection and analyses procedure using local field and environmental data. Thus some differences between estimates for Chinese cities and the remaining cities could be due to differences in methodologies used. Moreover the analyzed studies included only five out of many more potentially relevant services generated by urban forest/woodland ecosystems.

The Electronic Supplementary Material (ESM) provides a detailed description of the estimates of five ecosystem services in selected case study cities: (1) local pollution removal, (2) carbon sequestration and storage, (3) regulating water flows, (4) climate regulation/cooling effects, and (5) aesthetics, recreation and other amenities. The details given in ESM include a description of ecosystem service indicators and the methods used for monetary valuation in each of the studies. To standardize values, they were first calculated as Local Currency Unit/ha/year using available information in the articles or finding additional information (by communication with the authors of the original or review publication). Subsequently values were converted into 2013 prices. Finally — when applicable — these latter values were converted into USD using the purchasing power parity-conversion factors. All conversion factors used are based on the World Bank's World Development Indicators database of 2014.

Table 1 represents quantification of five services generated in urban woodlands (with variable tree cover): (1) pollution removal (kg/ha/y), (2) C-sequestration (tons/ha/y), (3) C-storage (tons/ha/y), (3) storm water reduction (m^3/ha/y), and (4) energy savings (kWh/ha/y).

In Table 2, the benefits provided by green space in urban areas are summarized and the monetary estimates are given as US$/ha/year.[12]

[12] In practically all the studies selected for our article, the monetary values were expressed as economic benefits for the entire city per year. To make the economic benefits comparable between cities, we first calculated the proportion of the green area in the total city area (often given as % canopy cover). To get the value per ha of urban green area per year, we divided the total ecosystem benefit a city derives by the amount (in hectares) of urban green area. In a few cases where the proportion of green area in a given city was not indicated, we approached the authors of the respective studies to provide the missing information (EG McPherson and WY Chen, personal communication). In the case of Chinese cities, all the data (originally given in publications written in Chinese) were obtained from the review by Jim and Chen [37]. Due to the scarcity of data on ecosystem services in urbanized settings it is also possible that benefits of some ecosystem services are overestimated.

Table 1

Quantification of urban ecosystem services in biophysical units. Amounts presented are averages per hectare of land area with tree cover (amounts given in parentheses are in units per hectare with high tree cover). For details, see ESM.

City or state	Pollution removal (kg/ha/y)	C sequestration (tons/ha/y)	C storage (tons/ha/y)	Stormwater reduction (m^3/ha/y)	Energy savings (kWh/ha/y)	Reference
Beijing	132	–	–	–	1400	Jim and Chen [37]
Casper, WY	6.2 (69.9)	0.20 (2.2)	6.2 (69.7)	–	72 (808)	Nowak *et al*. [65]
Chicago, IL	13.5 (74.9)	0.38 (2.1)	10.9 (60.3)	–	317 (1760)	Nowak *et al*. [66]
Guangzhou	42.4	4.0	25.0	–	14.1	Jim and Chen [37]
Hangzhou	–	–	–	167	–	Jim and Chen [37]
Indiana (urban areas)	13.6 (67.6)	0.59 (2.9)	17.7 (88.0)	–	377 (1875)	Nowak *et al*. [67]
Kansas (urban areas)	14.6 (104.6)	0.40 (2.8)	10.4 (74.2)	–	253 (1809)	Nowak *et al*. [68]
Lanzhou	4.1	–	–	–	22.7	Jim and Chen [37]
Los Angeles, CA	14.7 (71.4)	0.36 (1.8)	9.4 (45.9)	–	653 (3168)	Nowak *et al*. [69]
Minneapolis, MN	18.3 (53.8)	0.53 (1.6)	15 (44.1)	–	1111 (3258)	Nowak *et al*. [70]
Modesto, CA	210	18.4	-	390	16.8	McPherson *et al*. [71], McPherson and Simpson [72]
Morgantown, WV	23.4 (59.0)	1.2 (3.1)	34.6 (87.4)	–	1085 (2741)	Nowak *et al*. [73]
Nebraska (urban areas)	32.0 (213.6)	0.40 (2.7)	10 (66.7)	–	455 (3036)	Nowak *et al*. [68]
New York, NY	19.0 (91.0)	0.48 (2.3)	15.3 (73.3)	–	1014 (4851)	Nowak *et al*. [74]
North Dakota (urban areas)	1.3 (48.3)	0.08 (2.8)	2.1 (77.8)	–	129 (4768)	Nowak *et al*. [68]
Philadelphia, PA	15.3 (73.5)	0.43 (2.1)	14.1 (67.7)	–	836 (4020)	Nowak *et al*. [75]
Sacramento, CA	9.3	2.02	66.3	1000	9800	McPherson [76], Scott *et al*. [77], Xiao *et al*. [78], Simpson [79]
San Francisco, CA	10.7 (66.7)	0.39 (2.4)	14.7 (91.8)	–	–	Nowak *et al*. [80]
Scranton, PA	15.6 (70.9)	0.88 (4.0)	20.3 (92.4)	–	361 (1639)	Nowak *et al*. [81]
South Dakota (urban areas)	10.3 (60.8)	0.22 (1.3)	5.3 (31.4)	–	237 (1393)	Nowak *et al*. [68]
Syracuse, NY	15.2 (56.6)	0.77 (2.9)	23.1 (85.9)	–	372 (1383)	Nowak *et al*. [82•]
Tennessee (urban areas)	39.1 (103.6)	1.28 (3.4)	24.4 (64.7)	–	1843 (4888)	Nowak *et al*. [83]
Toronto, Canada	29.9 (112.4)	0.73 (2.8)	17.4 (65.3)	–	646 (2430)	Nowak *et al*. [84]
Washington, DC	23.8 (68.0)	0.92 (2.6)	29.8 (85.2)	–	1766 (5045)	Nowak *et al*. [85]
Wisconsin (urban areas)	17.6 (65.8)	1.0 (3.7)	15.3 (57.3)	–	409 (1530)	Buckelew Cumming *et al*. [86]

–: not available.

Table 2

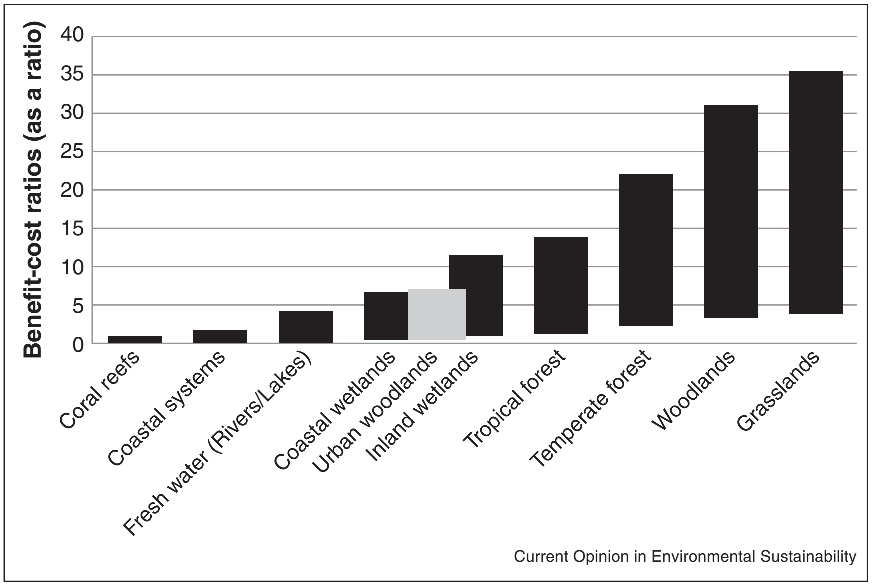
Average value in US$/ha/y (2013) of selected services provided by green spaces in urban areas

Service	Average value (US$/ha/y*)	Range
1. Pollution and air quality regulation	647 (*n* = 9)	*60–2106*
2. Carbon sequestration (annual flow)	395 (*n* = 5)	*58–702*
Carbon storage (stock value)	3125 (*n* = 3)	*1917–5178*
3. Storm water reduction	922 (*n* = 6)	*615–2540*
4. Energy savings/ temperature regulation	1412 (*n* = 4)	*34–1908*
5. Recreation and other amenity services	6325 (*n* = 2)	*2133–10 517*
6. Positive health effects	18 870 (*n* = 1)	*N/A*
Total (excl. health effects and carbon storage)	9701 US$/ha/year	3212–17 772

* See ESM for details.

The data from the above-cited studies support the finding that the analyzed ecosystems provide between US$ 3212 and 17 772 of benefits per ha per year. These estimates exclude some very important benefits, such as positive health effects and social welfare related to non-use values, and consequently should be treated as very conservative estimates. To put the values of the above-mentioned monetary benefits in perspective, we present data on costs of urban ecological restoration interventions, which includes costs for planning, preparation, soil restoration, plant propagation, planting, and management. Even in highly degraded urban areas, restoring ecological structure and functionality is — perhaps surprisingly — often possible [38]. Urban soils almost by definition are most often profoundly modified, depleted and often chemically stressful to organisms. Indeed, they are often polluted, compacted, sealed, and lacking in microbial organisms important for plant growth. In a restoration context, they must be cleaned up, decontaminated (where possible and cost-effective), and ameliorated in broad terms, biophysically, chemically, and aesthetically [39]. Such biochemo-physical

Figure 1



Benefit–cost ratios of restoring urban woodlands (grey) in relation to ratios calculated for nine different ecosystem types [42].

remediation or recuperation can however often be highly successful, and organic matter content in particular can be increased through links to urban composting initiatives and through manipulation of vegetation and plant community structure [40]. Thanks in part to innovative uses of organic urban wastes and advances in ecotoxicology and phytoremediation, there are many successful examples of urban ecological restoration and rehabilitation projects, including sites of former landfills, former industrial areas, vacant lots, and other 'brown' areas [41].

In our analyses we used the following estimates of restoration costs of urban public land in the USA in US$ per hectare (including costs for planning, preparation, modest soil restoration, plant propagation, and planting): meadow/grassland $26 000, and woodland $49 000.[13]

Given that these restoration efforts took place in urban areas, and involved more infrastructure and more sophisticated techniques than might be needed in extra-urban areas, they tend to be more expensive than most of their rural counterparts. De Groot *et al.* scrutinized over 200 peer-reviewed scientific papers from which they identified 94 restoration case studies with meaningful cost data [42]. The benefit–cost (BC) ratios calculated here for urban woodland restoration,[14] the minimum benefit and maximum cost combination yields a BC ratio of 1.21 and the maximum benefit and minimum cost combination yields a BC ratio of 6.57. These values compare favorably to the range of BC ratios calculated by de Groot *et al.* [42] for nine non-urban ecosystem types, including wetlands, lakes/rivers, tropical forests, woodland/shrubland, coral reefs and grasslands. As shown in Figure 1, those ratios ranged from about 0.05 to 35, with the bulk of ratios falling between 5 and 20.

It is important to note that when any ecosystem undergoes restoration, there is often a time lag of a decade or more before the values as expressed in Table 2 are realized and that a 100% habitat restoration effect is unlikely based on present technology and knowledge base. We therefore assumed a maximum of 75% success

[13] Data estimates are means by current landscape architecture workers in New York City (Marcha Johnson, NYC Parks Department), Baltimore (Keith Bowers, Biohabitats, Inc.), Boston (Nina Chase, Sasaki Associates), Los Angeles (M. Sullivan, Mia Lehrer + Associates) and Philadelphia (David Robertson, Pennypack Ecological Restoration Trust).

[14] We used a term of 20 years and a social discount rate of 8%. We consider this as very conservative as the benefits of restoration can, potentially, last for much longer. The discount rate is also high, adding more weight to the cost than to the benefits. We used these parameters in conjunction with a minimum cost of restoration of US$26 000/ha and a maximum value of US$49 000/ha. We furthermore made provision for an annual operating cost from year 2 onwards of 5% of the cost of restoration. With respect to benefits, we assumed a minimum value of US$14 418/ha and a maximum value of US$231,925/ha. This we took from Table 2 adding 25% of the health benefit to the stated minimum value and 75% of the health benefit to the maximum. The benefits were phased in at a rate of 10% (year 2), 20%, (year 3), 40% (year 4), 60% (year 5), and 75% (year 6 and beyond) of the aforementioned levels to respect the fact (1) it takes time for ecosystem values to be restored, and (2) restoring to a 100% level is unlikely. The maximum cost and minimum benefit combination yields a BC ratio of 1.21 and the minimum cost and maximum benefit combination yields a BC ratio of 6.57.

rate for all our calculations, based on meta-analysis data for wetland restorations reported by Moreno-Mateos *et al.* [43].

Non-monetary benefits of urban ecosystem services

Because many benefits produced by ecosystem services cannot be readily or adequately captured by monetary metrics, growing attention is being paid to the non-monetary benefits of ecosystem services [13•,44,45•] such as health, aesthetics and education for all ages. A range of additional, more subtle benefits can accrue from restored urban ecosystems such as enhanced social cohesion and trust, human well-being, sharpened sense of place and space-specific — values called sense of identity [46,47] (Box 1).

Many such non-monetary benefits have now been empirically defined or even mapped and measured in cities worldwide, especially those related to physical and psychological health [24]. For example, access to green space in cities was shown to correlate with longevity [48], recovery from surgeries [49], reduced stress [50,51], mental health [52] and self-reported perception of health [26,53], all of which translate into higher well-being.

Green spaces in urban areas have also been shown to influence social cohesion by providing a meeting place where users develop and maintain neighborhood ties [54,55]. Research conducted in Stockholm found sense of place to be a major driver for environmental stewardship, with interviewees showing strong emotional bonds to their plots and the surrounding garden areas [56]. Urban ecosystems also provide opportunities for cognitive development and education of young children [57]. Based on a large sample of case studies in different countries, Groening documented the important role that school gardens played in education and enhancement of urban life quality within the last century. Cognitive development in urban green areas includes the development and transmission of local ecological knowledge [52,54,55]. Many examples also demonstrate how local greening practices become a source of resilience in chaotic post-disaster and post-conflict contexts as diverse as post-Katrina New Orleans and in Monrovia after the Liberian civil war [58•]. There is also a growing literature on 'ecosystem disservices' [59•,60•,61], which are important to include in the future analyses, but so far there are limited quantifications of these due to methodological challenges.

Finally, additional benefits stems from the 'insurance value' related to the contribution of urban green infrastructure to enhancing the capacity of cities to respond and adapt in the face of disturbance and change and reduce risks of, for example, flooding [62–64]. With climate change and sea level rise already occurring in many coastal cities, the capacity of ecosystems of reducing risks will play an essential role in mitigating new physical stresses.

Conclusion

Investing in restoring, protecting, and enhancing green infrastructure and ecosystem services in cities is not only ecologically and socially desirable. It is also very often economically viable, even under prevailing economic models, provided that the multiple services and all their associated benefits for the large number of beneficiaries in cities are properly quantified and recognized. Such information is essential to include in decision-making processes related to land use and management in urban landscapes, and to help guide urban and landscape planners, architects, restoration practitioners, and public policy makers, as well as private and institutional stakeholders.

Even though economic calculations provide useful arguments for environmental improvements, they are insufficient to fully capture, measure or monitor the scope of benefits related to restoring ecosystem services in cities. Indeed, many important ecosystem services were not taken into account in the few published studies featuring economic assessments of urban green infrastructure benefits considered here, including multiple health effects, provisioning services, and social well-being related to non-use values. Much further works is needed to adequately capture and visualize these values.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cosust.2015.05.001.

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