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Current Opinion in
Environmental
Sustainability

Benefits of restoring ecosystem services in urban areas

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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.

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Current Opinion in Environmental Sustainability 2015, **14**:101–108

This review comes from a themed issue on **Open issue**

Edited by **Eduardo Brondizio, Rik Leemans and William Solecki**

For a complete overview see the [Issue](#) and the [Editorial](#)

Received 22 December 2014; Revised 28 April 2015;

Accepted 03 May 2015

Available online 22nd May 2015

<http://dx.doi.org/10.1016/j.cosust.2015.05.001>

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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 (m³/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 <i>et al.</i> [65]
Chicago, IL	13.5 (74.9)	0.38 (2.1)	10.9 (60.3)	–	317 (1760)	Nowak <i>et al.</i> [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 <i>et al.</i> [67]
Kansas (urban areas)	14.6 (104.6)	0.40 (2.8)	10.4 (74.2)	–	253 (1809)	Nowak <i>et al.</i> [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 <i>et al.</i> [69]
Minneapolis, MN	18.3 (53.8)	0.53 (1.6)	15 (44.1)	–	1111 (3258)	Nowak <i>et al.</i> [70]
Modesto, CA	210	18.4	–	390	16.8	McPherson <i>et al.</i> [71], McPherson and Simpson [72]
Morgantown, WV	23.4 (59.0)	1.2 (3.1)	34.6 (87.4)	–	1085 (2741)	Nowak <i>et al.</i> [73]
Nebraska (urban areas)	32.0 (213.6)	0.40 (2.7)	10 (66.7)	–	455 (3036)	Nowak <i>et al.</i> [68]
New York, NY	19.0 (91.0)	0.48 (2.3)	15.3 (73.3)	–	1014 (4851)	Nowak <i>et al.</i> [74]
North Dakota (urban areas)	1.3 (48.3)	0.08 (2.8)	2.1 (77.8)	–	129 (4768)	Nowak <i>et al.</i> [68]
Philadelphia, PA	15.3 (73.5)	0.43 (2.1)	14.1 (67.7)	–	836 (4020)	Nowak <i>et al.</i> [75]
Sacramento, CA	9.3	2.02	66.3	1000	9800	McPherson [76], Scott <i>et al.</i> [77], Xiao <i>et al.</i> [78], Simpson [79]
San Francisco, CA	10.7 (66.7)	0.39 (2.4)	14.7 (91.8)	–	–	Nowak <i>et al.</i> [80]
Scranton, PA	15.6 (70.9)	0.88 (4.0)	20.3 (92.4)	–	361 (1639)	Nowak <i>et al.</i> [81]
South Dakota (urban areas)	10.3 (60.8)	0.22 (1.3)	5.3 (31.4)	–	237 (1393)	Nowak <i>et al.</i> [68]
Syracuse, NY	15.2 (56.6)	0.77 (2.9)	23.1 (85.9)	–	372 (1383)	Nowak <i>et al.</i> [82*]
Tennessee (urban areas)	39.1 (103.6)	1.28 (3.4)	24.4 (64.7)	–	1843 (4888)	Nowak <i>et al.</i> [83]
Toronto, Canada	29.9 (112.4)	0.73 (2.8)	17.4 (65.3)	–	646 (2430)	Nowak <i>et al.</i> [84]
Washington, DC	23.8 (68.0)	0.92 (2.6)	29.8 (85.2)	–	1766 (5045)	Nowak <i>et al.</i> [85]
Wisconsin (urban areas)	17.6 (65.8)	1.0 (3.7)	15.3 (57.3)	–	409 (1530)	Buckelew Cumming <i>et al.</i> [86]

–: not available.

Table 2

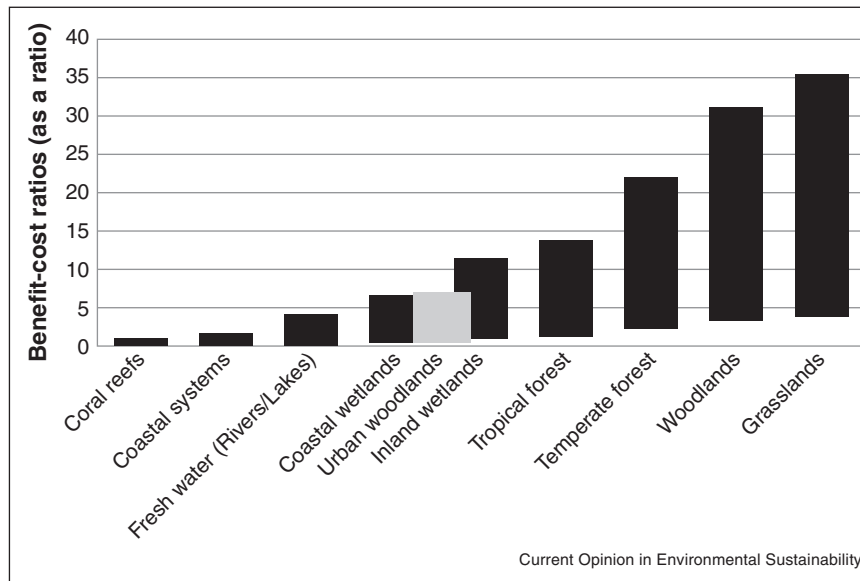
Average value in US\$/ha/y (2013) of selected services provided by green spaces in urban areas

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, Groenig 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.

Acknowledgments

We thank the TEEB team and team leader Pavan Sukhdev for inspiring discussions and crucial views. This study has been possible through support to T. Elmqvist from Formas and Biodiversa through the URBES project and to T. Elmqvist and J. Kronenberg by GREEN SURGE, EU FP7 collaborative project, FP7-ENV.2013.6.2-5-603567.

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>.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- of special interest
- of outstanding interest

1. Solecki W, Seto KC, Marcotullio PJ: **It's time for an urbanization science.** *Environ Sci Policy Sustain Dev* 2013, **55**:12-17.
 2. Hodson M, Marvin S: **Urbanism in the anthropocene: ecological urbanism or premium ecological enclaves?** *City* 2010, **14**:298-313.
 3. Elmqvist T, Fragkias M, Goodness J, Güneralp B, Marcotullio PJ, •• McDonald RI, Parnell S, Schewenius M, Sendstad M, Seto KC (Eds): *et al.: Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities.* Springer; 2013.
 4. Kates RW, Wilbanks TJ: **Making the global local responding to climate change concerns from the ground.** *Environ Sci Policy Sustain Dev* 2003, **45**:12-23.
- The most comprehensive monograph on urban ecosystem services, providing an overview of practical and theoretical aspects of the benefits that people derive from urban ecosystems and of their management.

5. Solecki W, Marcotullio PJ: **Climate change and urban biodiversity vulnerability.** In *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*. Edited by Elmqvist T, Fragkias M, Goodness J, Güneralp B, Marcotullio PJ, McDonald RI, Parnell S, Schewenius M, Sendstad M, Seto KC. et al.: Springer; 2013:485-504.
6. CBD: *Ways and means to support ecosystem restoration (UNEP/CBD/SBSTTA/15/4)*. Secretariat of the Convention on Biological Diversity; 2011.
7. UNEP: *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication – A Synthesis for Policy Makers*. UNEP; 2011.
8. Gómez-Baggethun E, Gren Å, Barton DN, Langemeyer J, McPhearson T, O'Farrell P, Andersson E, Hamstead Z, Kremer P: **Urban ecosystem services.** In *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*. Edited by Elmqvist T, Fragkias M, Goodness J, Güneralp B, Marcotullio PJ, McDonald RI, Parnell S, Schewenius M, Sendstad M, Seto KC. et al.: Springer; 2013:175-251.
9. Haase D, Frantzeskaki N, Elmqvist T: **Ecosystem services in urban landscapes: practical applications and governance implications.** *AMBIO* 2014, **43**:407-412.
- Introduction to a special issue on the governance of urban ecosystem services.
10. Dobbs C, Nitschke CR, Kendal D: **Global drivers and tradeoffs of three urban vegetation ecosystem services.** *PLoS ONE* 2014, **9**:e113000.
11. Kroeger T, Escobedo FJ, Hernandez JL, Varela S, Delphin S, Fisher JRB, Waldron J: **Reforestation as a novel abatement and compliance measure for ground-level ozone.** *PNAS* 2014, **111**:E4204-E4213.
12. Pataki DE, Carreiro MM, Cherrier J, Grulke NE, Jennings V, Pincetl S, Pouyat RV, Whitlow TH, Zipperer WC: **Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions.** *Front Ecol Environ* 2011, **9**:27-36.
13. Gómez-Baggethun E, Barton DN: **Classifying and valuing ecosystem services for urban planning.** *Ecol Econ* 2013, **86**:235-245.
- An overview of various valuation methods available for valuing urban ecosystem services.
14. Rey Benayas JM, Newton AC, Diaz A, Bullock JM: **Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis.** *Science* 2009, **325**:1121-1124.
15. Gill SE, Handley JF, Ennos AR, Pauleit S: **Adapting cities for climate change: the role of the green infrastructure.** *Built Environ* 2007, **33**:115-133.
16. Nicholson-Lord D: *Green Cities: And why We Need Them*. New Economics Foundation; 2003.
17. Akbari H: **Shade trees reduce building energy use and CO₂ emissions from power plants.** *Environ Pollut* 2002, **116**(Suppl. 1):S119-S126.
18. Kaye JP, Groffman PM, Grimm NB, Baker LA, Pouyat RV: **A distinct urban biogeochemistry?** *Trends Ecol Evol* 2006, **21**:192-199.
19. Escobedo FJ, Kroeger T, Wagner JE: **Urban forests and pollution mitigation: analyzing ecosystem services and disservices.** *Environ Pollut* 2011, **159**:2078-2087.
20. Escobedo FJ, Nowak DJ: **Spatial heterogeneity and air pollution removal by an urban forest.** *Landsc Urban Plan* 2009, **90**:102-110.
21. Vos PEJ, Maiheu B, Vankerkom J, Janssen S: **Improving local air quality in cities: to tree or not to tree?** *Environ Pollut* 2013, **183**:113-122.
22. Setälä H, Viippola V, Rantalainen A-L, Pennanen A, Yli-Pelkonen V: **Does urban vegetation mitigate air pollution in northern conditions?** *Environ Pollut* 2013, **183**:104-112.
23. Tzoulas K, Korpela K, Venn S, Yli-Pelkonen V, Kazmierczak A, Niemela J, James P: **Promoting ecosystem and human health in urban areas using green infrastructure: a literature review.** *Landsc Urban Plan* 2007, **81**:167-178.
24. Douglas I: **Urban ecology and urban ecosystems: understanding the links to human health and well-being.** *Curr Opin Environ Sustain* 2012, **4**:385-392.
25. Mitchell R, Popham F: **Effect of exposure to natural environment on health inequalities: an observational population study.** *Lancet* 2008, **372**:1655-1660.
26. Maas J, Verheij RA, Groenewegen PP, de Vries S, Spreeuwenberg P: **Green space, urbanity, and health: how strong is the relation?** *J Epidemiol Community Health* 2006, **60**:587-592.
27. Pickett STA, Cadenasso ML, Grove JM, Groffman PM, Band LE, Boone CG, Burch WR, Grimmold CSB, Hom J, Jenkins JC et al.: **Beyond urban legends: an emerging framework of urban ecology, as illustrated by the Baltimore Ecosystem Study.** *BioScience* 2008, **58**:139.
28. Ernstson H: **The social production of ecosystem services: a framework for studying environmental justice and ecological complexity in urbanized landscapes.** *Landsc Urban Plan* 2013, **109**:7-17.
- An important paper emphasizing the environmental justice aspects of the benefits that urban inhabitants derive from nature.
29. Bird W: *Natural Thinking: Investigating the Links between the Natural Environment, Biodiversity and Mental Health*. Royal Society for the Protection of Birds; 2007.
30. Mueller N, Werner P, Kelcey JG: *Urban Biodiversity and Design*. Wiley-Blackwell; 2010.
31. Melles S, Glenn S, Martin K: **Urban bird diversity and landscape complexity: species-environment associations along a multiscale habitat gradient.** *Conserv Ecol* 2003, **7**:5.
32. McKinney ML: **Effects of urbanization on species richness: a review of plants and animals.** *Urban Ecosyst* 2008, **11**:161-176.
33. Fuller RA, Irvine KN, Devine-Wright P, Warren PH, Gaston KJ: **Psychological benefits of greenspace increase with biodiversity.** *Biol Lett* 2007, **3**:390-394.
34. Lee J, Park B-J, Tsunetsugu Y, Kagawa T, Miyazaki Y: **Restorative effects of viewing real forest landscapes, based on a comparison with urban landscapes.** *Scand J Forest Res* 2009, **24**:227-234.
35. Brander LM, Koetse MJ: **The value of urban open space: meta-analyses of contingent valuation and hedonic pricing results.** *J Environ Manag* 2011, **92**:2763-2773.
36. Ninan KNN: *Conserving and Valuing Ecosystem Services and Biodiversity: Economic, Institutional and Social Challenges*. Earthscan; 2009.
37. Jim CY, Chen WY: **Ecosystem services and valuation of urban forests in China.** *Cities* 2009, **26**:187-194.
38. Society for Ecological Restoration: *SER International Primer on Ecological Restoration*. Society for Ecological Restoration; 2004.
39. Harris J: **Soil microbial communities and restoration ecology: facilitators or followers?** *Science* 2009, **325**:573-574.
40. Vauramo S, Setälä H: **Urban belowground food-web responses to plant community manipulation – impacts on nutrient dynamics.** *Landsc Urban Plan* 2010, **97**:1-10.
41. US EPA: *Ecological Revitalization: Turning Contaminated Properties Into Community Assets*. U.S. Environmental Protection Agency; 2009.
42. De Groot RS, Blignaut J, Van Der Ploeg S, Aronson J, Elmqvist T, Farley J: **Benefits of investing in ecosystem restoration.** *Conserv Biol* 2013, **27**:1286-1293.
43. Moreno-Mateos D, Power ME, Comín FA, Yockteng R: **Structural and functional loss in restored wetland ecosystems.** *PLoS Biol* 2012, **10**:e1001247.

44. Gómez-Baggethun E, Ruiz-Pérez M: **Economic valuation and the commodification of ecosystem services.** *Progr Phys Geogr* 2011, **35**:613-628.
45. Hubacek K, Kronenberg J: **Synthesizing different perspectives on the value of urban ecosystem services.** *Landsc Urban Plan* 2013, **109**:1-6.
- Introduction to a special issue on urban ecosystem services, emphasizing the plurality of value perceptions of the benefits provided by urban nature.
46. De Groot RS, Ramakrishnan PS, van den Berg A, Kulenthiran T, Muller S, Pitt D, Wascher D, Wijesuriya G, Amelung B, Eliezer N et al.: **Cultural and amenity services.** In *Ecosystems and Human Well-being: Current State and Trends*. Edited by Hassan R, Scholes R, Ash NJ. Island Press; 2005:455-476.
47. Casado-Arzuaga I, Onaindia M, Madariaga I, Verburg PH: **Mapping recreation and aesthetic value of ecosystems in the Bilbao Metropolitan Greenbelt (northern Spain) to support landscape planning.** *Landsc Ecol* 2014, **29**:1393-1405.
48. Takano T, Nakamura K, Watanabe M: **Urban residential environments and senior citizens' longevity in megacity areas: the importance of walkable green spaces.** *J Epidemiol Community Health* 2002, **56**:913-918.
49. Ulrich RS: **View through a window may influence recovery from surgery.** *Science* 1984, **224**:420-421.
50. Korpela KM, Ylén M: **Perceived health is associated with visiting natural favourite places in the vicinity.** *Health Place* 2007, **13**:138-151.
51. White MP, Alcock I, Wheeler BW, Depledge MH: **Would you be happier living in a greener urban area? A fixed-effects analysis of panel data.** *Psychol Sci* 2013, **24**:920-928.
52. Alcock I, White MP, Wheeler BW, Fleming LE, Depledge MH: **Longitudinal effects on mental health of moving to greener and less green urban areas.** *Environ Sci Technol* 2014, **48**:1247-1255.
53. Van den Berg AE, Maas J, Verheij RA, Groenewegen PP: **Green space as a buffer between stressful life events and health.** *Social Sci Med* 2010, **70**:1203-1210.
54. Maas J, Spreeuwenberg P, Winsum-Westra MV, Verheij RA, Vries Sde, Groenewegen PP: **Is green space in the living environment associated with people's feelings of social safety?** *Environ Plan A* 2009, **41**:1763-1777.
55. Kaźmierczak A: **The contribution of local parks to neighbourhood social ties.** *Landsc Urban Plan* 2013, **109**:31-44.
56. Andersson E, Barthel S, Ahrné K: **Measuring social-ecological dynamics behind the generation of ecosystem services.** *Ecol Appl* 2007, **17**:1267-1278.
57. Groening G: **School garden and kleingaerten: for education and enhancing life quality.** *Acta Hort* 1994, **391**:53-64.
58. Tidball KG, Krasny ME (Eds): *Greening in the Red Zone*. Springer; 2014.
- An important monograph highlighting linkages between urban ecosystems and community resilience in the face of external disturbances. Focusing on the restorative and place-making benefits of urban nature.
59. Baró F, Chaparro L, Gómez-Baggethun E, Langemeyer J, Nowak DJ, Terradas J: **Contribution of ecosystem services to air quality and climate change mitigation policies: the case of urban forests in Barcelona, Spain.** *AMBIO* 2014, **43**:466-479.
- One of the first applications of the adapted i-Tree Eco model to the European context.
60. Von Döhren P, Haase D: **Ecosystem disservices research: a review of the state of the art with a focus on cities.** *Ecol Ind* 2015, **52**:490-497.
- This paper, building upon a coherent literature, gives a nice balance between ecosystem services and disservices. It helps the reader to focus on essential services that urban greenspace can provide.
61. Kronenberg J: **Why not to green a city? Institutional barriers to preserving urban ecosystem services.** *Ecosystem Services* 2015 <http://dx.doi.org/10.1016/j.ecoser.2014.07.002>. forthcoming.
62. Maxwell D: **The political economy of urban food security in Sub-Saharan Africa.** *World Dev* 1999, **27**:1939-1953.
63. Altieri MA, Companioni N, Cañizares K, Murphy C, Rosset P, Bourque M, Nicholls CI: **The greening of the "barrios": urban agriculture for food security in Cuba.** *Agric Human Values* 1999, **16**:131-140.
64. McGranahan G, Marcotullio P, Bai X, Balk D, Braga T, Douglas I, Elmqvist T, Rees W, Satterthwaite D, Songsore J et al.: **Urban systems.** In *Ecosystems and Human Well-being: Current State and Trends*. Edited by Hassan R, Scholes R, Ash N. Island Press; 2005:795-825.
65. Nowak DJ, Hoehn REI, Crane DE, Stevens JC, Walton JT: *Assessing Urban Forest Effects and Values: Casper's Urban Forest*. USDA Forest Service, Northern Research Station; 2006.
66. Nowak DJ, Hoehn REI, Crane DE, Stevens JC, Fisher CL: *Assessing Urban Forest Effects and Values: Chicago's Urban Forest*. USDA Forest Service, Northern Research Station; 2010.
67. Nowak DJ, Buckelew Cumming A, Twardus DB, Hoehn R, Mielke M: *Monitoring Urban Forests in Indiana: Pilot Study 2002, Part 2: Statewide Estimates Using the UFORE Model*. USDA Forest Service, Northeastern Area State and Private Forestry; 2007.
68. Nowak DJ, Hoehn REI, Crane DE, Bodine AR: *Assessing Urban Forest Effects and Values of the Great Plains: Kansas, Nebraska, North Dakota, South Dakota*. USDA Forest Service, Northern Research Station; 2012.
69. Nowak DJ, Hoehn REI, Crane DE, Weller L, Davila A: *Assessing Urban Forest Effects and Values: Los Angeles' Urban Forest*. USDA Forest Service, Northern Research Station; 2011.
70. Nowak DJ, Hoehn REI, Crane DE, Stevens JC, Walton JT, Bond J, Ina G: *Assessing urban forest effects and values: Minneapolis' urban forest*. USDA Forest Service, Northern Research Station; 2006.
71. McPherson EG, Simpson JR, Peper PJ, Xiao Q: **Benefit-cost analysis of Modesto's municipal urban forest.** *J Arboric* 1999, **25**:235-248.
72. McPherson EG, Simpson JR: *Carbon Dioxide Reduction Through Urban Forestry*. US Department of Agriculture, Forest Service, Pacific Southwest Research Station; 1999.
73. Nowak DJ, Hoehn REI, Crane DE, Stevens JC, Cumming J, Mohen S, Cumming AB: *Assessing Urban Forest Effects and Values: Morgantown's Urban Forest*. USDA Forest Service, Northern Research Station; 2012.
74. Nowak DJ, Hoehn RE, Wang J, Lee A, Krishnamurthy V, Schwetz G: *Urban Forest Assessment in Northern Delaware*. USDA Forest Service, Northern Research Station; 2007.
75. Nowak DJ, Hoehn REI, Crane DE, Stevens JC, Walton JT: *Assessing Urban Forest Effects and Values: Philadelphia's Urban Forest*. USDA Forest Service, Northern Research Station; 2007.
76. McPherson EG: **Atmospheric carbon dioxide reduction by Sacramento's urban forest.** *J Arboric* 1998, **24**:215-223.
77. Scott KI, McPherson EG, Simpson JR: **Air pollutant uptake by Sacramento's urban forest.** *J Arboric* 1998, **24**:224-234.
78. Xiao Q, McPherson EG, Simpson JR, Ustin SL: **Rainfall interception by Sacramento's urban forest.** *J Arboric* 1998, **24**:235-244.
79. Simpson JR: **Urban forest impacts on regional cooling and heating energy use: Sacramento County case study.** *J Arboric* 1998, **24**:201-214.
80. Nowak DJ, Hoehn REI, Crane DE, Stevens JC, Walton JT: *Assessing Urban Forest Effects and Values: San Francisco's Urban Forest*. USDA Forest Service, Northern Research Station; 2007.
81. Nowak DJ, Hoehn REI, Crane DE, Stevens JC, Cotrone V: *Assessing Urban Forest Effects and Values: Scranton's Urban Forest*. USDA Forest Service, Northern Research Station; 2010.
82. Nowak DJ, Hoehn RE, Bodine AR, Greenfield EJ, O'Neil-Dunne J: **Urban forest structure, ecosystem services and change in**

Syracuse, NY. *Urban Ecosyst* 2013 <http://dx.doi.org/10.1007/s11252-013-0326-z>.

One of the recent applications of the i-Tree Eco model to value urban forests in US cities.

83. Nowak DJ, Cumming AB, Twardus D, Hoehn RE, Oswald CM, Brandeis TJ: *Urban Forests of Tennessee, 2009*. Department of Agriculture, Forest Service, Southern Research Station; 2012.
84. Nowak DJ, Hoehn REI, Bodine AR, Greenfield EJ, Ellis A, Endreny TA, Yang Y, Zhou T, Henry R: *Assessing Urban Forest*

Effects and Values: Toronto's Urban Forest. USDA Forest Service, Northern Research Station; 2013.

85. Nowak DJ, Hoehn REI, Crane DE, Stevens JC, Walton JT: *Assessing Urban Forest Effects and Values: Washington, D.C.'s Urban Forest*. USDA Forest Service, Northern Research Station; 2006.
86. Buckelew Cumming A, Nowak DJ, Twardus DB, Hoehn R, Mielke M, Rideout R: *Urban Forests of Wisconsin: Pilot Monitoring Project 2002*. USDA Forest Service, Northeastern Area State and Private Forestry; 2007.