Nature Based Strategies for Urban Environment

Short title: Ecosystem Services in Urban Environments

Chapter 1.2

Ecosystem Services in Urban Environments

Sarah Milliken

University of Greenwich, London, United Kingdom

Introduction

Ecosystem services are the benefits provided by nature to society and the economy. They can be classified into four broad categories: (1) provisioning services, such as the supply of food and other raw materials; (2) regulating services, such as the mitigation of air pollution and the regulation of local and global climate; (3) cultural services, such as social relations, health and well-being; and (4) supporting services, such as water cycling and biodiversity (Millennium Ecosystem Assessment, 2005). Urban ecosystem services are generated in a diverse set of habitats, including street trees, parks, cemeteries, and private gardens. They are also generated by engineered green infrastructure, such as sustainable urban drainage systems, green roofs, and vertical greening systems.

Since the seminal article by Bolund and Hunhammar (1999), there has been a growing body of literature on the biophysical, economic, and sociocultural dimensions of ecosystem services in urban areas, and major initiatives such as the Millennium Ecosystem Assessment (2005) and The Economics of Ecosystems and Biodiversity (2011) have sparked increasing attention in public policy discourse around the world. The benefits of urban ecosystem services should be easily understood by policy makers and planners. For example, street trees contribute toward urban cooling, reducing air conditioning costs, and greenhouse gas emissions; they contribute to climate

change mitigation by sequestering and storing carbon; they improve air quality by filtering particulates and other airborne pollutants, thereby lowering health costs; they intercept stormwater, reducing the need for flood infrastructure; and they enhance the quality of place. While some benefits are directly measurable and have hard values, such as the energy savings due to the insulation provided by vertical greening systems, others are not so readily measurable and these soft values are difficult to estimate, such as the health benefits of a rooftop garden.

It is important to bear in mind that urban ecosystems do not only produce services, but also disservices, which have been defined as “functions of ecosystems that are perceived as negative for human well-being” (Lyytimäki and Sipilä, 2009: 311). For example, some species of trees and shrubs commonly planted in cities emit volatile organic compounds that can lead to secondary formation of ground-level ozone and indirectly contribute to urban smog, while some wind-pollinated plants can cause allergic reactions. The costs of disservices such as these can also be measured and valued.

Ecosystem services and disservices are coproduced by people and nature, and a social-ecological approach to planning and policies will become increasingly necessary in order to enhance human well-being in urban areas in the face of new and complex challenges such as climate change and migration (Kremer et al., 2015). Understanding and addressing resilience through urban ecosystem services should enable urban planning to become more adaptive and reflexive, but in order to improve resilience we need to understand the complex, interactive nature of urban social-ecological systems (McPhearson et al., 2015).

Provisioning Services

Provisioning services are the material or energy outputs from ecosystems. The high proportion of impermeable surfaces in urban areas restricts the production of goods, such as food, raw materials, and medicinal resources. Nevertheless, there is some food production by community farms, domestic gardens and allotments and, in recent years, a growing number of urban farming projects have been set up in and on buildings, including open rooftop farms, rooftop greenhouses, and indoor farms, largely driven by the desire to reconnect food production and consumption. Urban farming practices range from community-based to commercial flagship projects, and present innovative opportunities for recycling resources, especially those derived from synergies between agriculture and buildings, such as the reuse of residential or industrial wastewater, waste heat, and organic waste (Ackerman et al., 2014; Buehler and Junge, 2016; Specht et al., 2014; Thomaier et al., 2014).

Regulating Services

In urban contexts regulating services include the regulation of air quality, noise, climate, and stormwater. Air pollution caused by motor vehicle exhaust emissions, such as nitrogen dioxide and particulate matter, is a major health issue in cities around the world. Urban transport infrastructure often results in the funnelling of pedestrians along major roads, where the concentration of air pollution is highest. Green corridors across cities can reduce pedestrian exposure to pollution by providing alternative routes. Vegetation removes pollutants in several ways. Plants take up gaseous pollutants through their stomata, intercept particulate matter with their leaves, and are capable of breaking down certain organic compounds such as polyaromatic hydrocarbons in their plant tissues or in the soil. In addition, they indirectly reduce air pollutants by lowering surface temperatures through transpirational cooling and by providing shade, which in turn decreases the photochemical reactions that form pollutants such as ozone in the atmosphere (Rowe, 2011).

There is a growing corpus of studies from around the world which suggest that street trees can improve air quality by trapping particulates (Baró et al., 2014; McPherson et al., 2016; Pugh et al., 2012; Russo et al., 2016; Soares et al., 2011; Tallis et al., 2011). Such studies tend to be based on modeling, leading to claims that “the removal of atmospheric pollutants by vegetation is one of the most commonly cited ecosystem services, yet it is one of the least supported empirically” (Pataki et al., 2011: 32). However, recent empirical studies have shown that roadside vegetation can indeed play an important role in the reduction of traffic induced air pollution (Islam et al., 2012; Vailshery et al., 2013). The potential of urban vegetation to remove airborne pollutants is in fact context dependent due to the high spatial variability in and among cities, and depends on multiple factors such as the weather, the pollution concentration, and the type and quality of vegetation (Setälä et al., 2013). In some instances, however, roadside planting can lead to increased concentrations of pollutants because the trees and other types of vegetation reduce the ventilation that is needed for diluting them (Vos et al., 2013; Wania et al., 2012), while landscape and tree management practices can also be polluting (Escobedo et al., 2011; Roy et al., 2012).

In contrast to trees, the filtration potential of herbaceous vegetation is comparatively understudied. Herbaceous vegetation that is diversely structured in terms of plant height, branching pattern, or leaf traits is more effective at binding particulate matter than monotonously structured vegetation (Säumel et al., 2016; Weber et al., 2014). Modeling and empirical research both suggest that green roofs and vertical greening systems can reduce air pollution both directly as well as indirectly through reduced energy consumption resulting from their insulating properties (Berardi et al., 2014; Ottelé et al., 2010; Pérez-Urrestarazu et al., 2016; Rowe, 2011; Vijayaraghavan, 2016).

One particular ecosystem service that has become a high-profile feature of climate change mitigation efforts is carbon storage. The vast majority of urban vegetation carbon stocks are attributable to trees, rather than herbaceous and woody material. Urban trees act as sinks of carbon dioxide by storing excess carbon as biomass during photosynthesis. Sequestration rates vary locally based on tree size and health, and the growth rates associated with different species and particular site conditions (Davies et al., 2013; Nowak et al., 2013; Strohbach and Haase, 2012). Green roofs and vertical greening systems can also play a small part in reducing carbon dioxide in the atmosphere, by sequestering it in the plant tissues and the soil substrate via plant litter and root exudate, and by reducing energy consumption by insulating individual buildings (Rowe, 2011).

Noise is a major pollution problem in cities and can affect human health through physiological and psychological damage. Urban soil and vegetation can attenuate noise pollution through absorption, deviation, reflection, and refraction of sound waves (Gómez-Baggethun and Barton, 2013). Green roofs can reduce noise pollution by providing increased insulation and by absorbing sound waves diffracting over roofs (Rowe, 2011; Vijayaraghavan, 2016). The vegetated surfaces of vertical greening systems can block high frequency sounds, and when constructed with a substrate or growing medium, they can also block low-frequency noises (Azkorra et al., 2015; Pérez et al., 2016).

Urban vegetation can lower air temperatures through the evaporation of water and by providing shading. Urban areas often experience elevated temperatures compared with the surrounding countryside, because of extensive heat absorbing surfaces, such as concrete and tarmac, concentrated heat production, and impeded airflow. This is known as the urban heat island effect (Taha, 1997). Heat waves during the summer pose significant health risks to urban populations either directly from the heat or from increased air pollution. The problem of the urban heat island effect is likely to get worse with climate change, as mean temperatures are predicted to rise, as are the frequencies of heat waves. Street trees can help to reduce the urban heat island effect. Their three dimensional nature means that as well as having a cool canopy, they also shade adjacent areas, which lowers the surface temperature of the shaded area and reduces the storage and convection of heat (Armson et al., 2012).

Green roofs also have the potential to reduce the urban heat island effect. Empirical and simulation studies show that green roofs increase the evapotranspiration rate through the addition of soil and plants, and reduce the proportion of infrared radiation returned to the air (Santamouris, 2014; Speak et al., 2013a; Susca et al., 2011); different types of low-growing plants have been shown to vary in their ability to cool air temperatures (Blanusa et al., 2013). While the contribution of green roofs to mitigating heat stress at the pedestrian level is negligible (Alcazar et al., 2016; Zölch et al., 2016), vertical greening systems intercept both light and heat radiation which would otherwise be largely absorbed and converted to heat by the building surfaces and then radiated back into the surrounding streetscape (Pérez et al., 2014; Perini et al., 2011). The effectiveness of this cooling effect is related primarily to the total area shaded and evapotranspiration effects of the vegetation, rather than the thickness of the vertical greening system. Other potential benefits of vertical greening systems include bioshading—reducing sunlight penetration through windows. With strategic placement, the plants in vertical greening systems can also create enough turbulence to break vertical airflow, which slows and cools down the air (Pérez-Urrestarazu et al., 2016).

Ecosystem services-based approaches can be used both to regulate the urban water cycle by reducing the amount of stormwater runoff, and to improve water quality by removing pollutants from runoff; e.g., vegetated streetscapes designed to absorb water, such as bioswales and rain gardens, have been shown to be effective (Pataki et al., 2011). Street trees intercept rainfall in their canopies and store water on their leaves and stems until it is subsequently evaporated. However, the gross interception rate varies greatly with species and tree size. Trees planted in tree pits considerably increase the infiltration rate and thereby reduce surface water runoff (Armson et al., 2013). Green roofs may also delay the timing of peak runoff, thereby alleviating stress on storm-sewer systems, by storing water in the growing medium and to a lesser extent in the vegetation canopy. A roof's ability to retain stormwater depends on factors such as the intensity and duration of the rain event as well as substrate depth, substrate moisture content at the start of the rain event, and the type, health, and density of the vegetation (Sims et al., 2016; Speak et al., 2013b; Whittinghill et al., 2015). There is still debate as to whether green roofs act as a source or sink of pollutants (Berardi et al., 2014). The specific nature of runoff quality from green roofs is highly dependent on the green roof components; and nutrient concentrations in runoff decrease over time after installation (Vijayaraghavan et al., 2012). Extensive green roofs would appear to be better than intensive systems in terms of pollutant removal, which may be related to the reduced volume of soil that can leach pollutants (Carpenter et al., 2011; Razzaghmanesh et al., 2014).

Cultural Services

The Millennium Ecosystem Assessment defined cultural ecosystem services as “the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences” (Millennium Ecosystem Assessment, 2005: 40). Urban green infrastructure provides diverse social, psychological, and aesthetic benefits. Green spaces can improve mental health and the quality of community life, and researchers have observed a link between increasing urbanization and psychosis or depression (Annerstedt et al., 2012). Experimental evidence suggests that simply having views of nature can improve mood, self-esteem and concentration, increase job satisfaction, and help to treat stress and mental health disorders (Depledge et al., 2011; Douglas, 2012; Peckham et al., 2013).

While cultural ecosystem services are often neglected because they are challenging to assess, their valuation should be at the top of urban ecosystem services research priorities. Developing better understanding of urban dwellers' perceptions and the multilayered benefits and values they derive from urban cultural ecosystem services can help ensure that urban planning and decision making is grounded in and suitable for the particular social-ecological systems they serve (Kremer et al., 2015). Andersson et al. (2015) proposed that cultural ecosystem services and urban nature experiences can be used as a gateway to more informed discussions about what kind of urban green infrastructure is desirable, and can guide efforts to build support for all urban ecosystem services. Cultural ecosystem services can be especially important in cities since they are intimately known and acknowledged by most urban residents. People often notice changes in these services and can be motivated to engage in their protection or promotion. Since these are often bundled with other ecosystem services, engaging in their stewardship will implicitly include these as well (Ernstson, 2013).

Supporting Services

Supporting services are those that are necessary for the production of all other ecosystem services. They differ from provisioning, regulating, and cultural services in that their impacts on people are either indirect or occur over a very long time, whereas changes in the other categories can have relatively direct and short-term impacts (Millennium Ecosystem Assessment, 2005). In urban ecosystems, the most important supporting service is the provisioning of the habitat. Towns and cities are characterized by scattered habitat patches that form a network of nodes and links. The spaces between green areas are not completely blank but contribute to ecological connectivity in different ways. Theory predicts thresholds in several parameters such as patch size and connectivity below which ecological traits such as biodiversity or ecological functions decrease rapidly or even disappear completely. The planning and management of urban green areas should therefore adopt a spatially explicit approach that considers landscape connectivity, the scale of movement of different organisms, and how they use the many different habitats offered by cities. Indeed, for some species in urban environments, the configuration of the local habitat within the landscape may be as critical as the composition of the local habitat itself (Andersson and Bodin, 2008; Braaker et al., 2014).

The importance of biodiversity in underpinning the delivery of ecosystem services and the ecosystem processes that underlie them is well recognized. For example, the dynamics of soil nutrient cycles are determined by the composition of biological communities in the soil. Resilience to pests and environmental change is increased in more diverse biological communities and, in many contexts, higher biodiversity is associated with increased ecosystem functions (Mace et al., 2012). Urban biodiversity can be very high, indeed often much higher than in the surrounding agricultural landscapes, because of the high degree of heterogeneity of urban ecosystems which are characterized by a mosaic of different habitats (Andersson et al., 2014).

Increasing plant species diversity and increasing the range of vegetation types in cities can significantly increase other forms of biodiversity. Street trees enhance biodiversity by providing food, habitat, and landscape connectivity for urban fauna and, together with green roofs and vertical greening systems, should be part of an overall urban greening strategy linking different ground-level habitat patches.

The Value of Ecosystem Services

Presenting the economic benefits of urban ecosystem services in monetary terms allows them to be easily understood by policy and decision makers. The green infrastructure valuation toolkit (http://www.greeninfrastructurenw.co.uk) provides a flexible framework for identifying and assessing the potential economic and wider returns from investment in landscape schemes by valuing a range of ecosystem services including climate change adaptation and mitigation, water and flood management, quality of place, health, and well-being, and biodiversity (Milliken, 2013). The i-Tree software (http://www.itreetools.org/(remove forward slash)) is widely used to calculate the value of urban trees in North America and, increasingly, in Europe. The tool quantifies pollution removal, carbon storage, and stormwater reduction, in order to calculate the economic value of these ecosystem services (Baró et al., 2014; Elmqvist et al., 2015; Mullaney et al., 2015; Soares et al., 2011). Other types of modeling have been used to measure and value ozone uptake by urban trees (Manes et al., 2012), while the presence of street trees has been found to add value to the price of residential property (Donovan and Butry, 2010; Escobedo et al., 2015; Pandit et al., 2013).

Conclusion

Multiple benefits and both material and nonmaterial values can be produced simultaneously by the same system components. For example, community-based food production on a rooftop farm has added benefits such as regulating stormwater, enhancing biodiversity, improving human health and well-being, and fostering social cohesion. Conceiving of the multiple kinds

of services—provisioning, regulating, cultural and supporting—associated with a particular place enables a more holistic understanding of the ways that humans benefit from ecosystem services and how they can be synergistically managed (Andersson et al., 2015).

Urban morphology is an important factor influencing the provision of multiple ecosystem services. Connectivity adds complexity to ecological systems, and even small patches in a fragmented urban landscape can be of disproportionally high importance in terms of the generation of ecosystem services. The widespread trend to reduce urban sprawl by developing dense, compact cities is likely to lead to a deterioration in ecosystem service provision with consequent declines in both urban biodiversity and the quality of life of the human population (Holt et al., 2015). Engineered green infrastructure, such as green roofs, vertical greening systems, and rain gardens, present opportunities for providing that all important connectivity, even in the densest of cities. Urban planners need to use them in order to create networks of green space based on key ecological processes, such as the movement patterns of pollinators or seed dispersers, in order to realize the potential of those benefits which are dependent on ecological network structures.

References

Ackerman K., Conard M., Culligan P., Plunz R., Sutto M.P. and Whittinghill L., Sustainable food systems for future cities: the potential of urban agriculture, *Econ. Soc. Rev.* **45**, 2014, 189–206.

Alcazar S.S., Olivieri F. and Neila J., Green roofs: experimental and analytical study of its potential for urban microclimate regulation in Mediterranean-continental climates, *Urban Clim.* **17**, 2016, 304–317.

Andersson E. and Bodin O., Practical tool for landscape planning? An empirical investigation of network based models of habitat fragmentation, *Ecography* **32**, 2008, 123–132.

Andersson E., Barthel S., Borgström S., Colding J., Elmqvist T., Folke C., et al., Reconnecting cities to the biosphere: stewardship of green infrastructure and urban ecosystem services, *Ambio* **43**, 2014, 445–453.

Andersson E., Tengö M., McPhearson T. and Kremer P., Cultural ecosystem services as a gateway for improving urban sustainability, *Ecosyst. Serv.* **12**, 2015, 165–168.

Annerstedt M., Östergren P.O., Björk J., Grahn P., Skärbäck E. and Währborg P., Green qualities in the neighbourhood and mental health – results from a longitudinal cohort study in Southern Sweden, *BMC Public Health* **12**, 2012, 337. https://doi.org/10.1186/1471-2458-12-337.

Armson D., Stringer P. and Ennos A.R., The effect of tree shade and grass on surface and globe temperatures in an urban area, *Urban For. Urban Gree.* **11**, 2012, 245–255.

Armson D., Stringer P. and Ennos A.R., The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK, *Urban For. Urban Gree.* **12**, 2013, 282–286.

Azkorra Z., Pérez G., Coma J., Cabeza L.F., Bures S. and Álvaro J.E., Evaluation of green walls as a passive acoustic insulation system for buildings, *Appl. Acoust.* **89**, 2015, 46–56.

Baró F., Chaparro L., Gómez-Baggethun E., Langemeyer J., Nowak D.J. and Terradas J., Contribution of ecosystem services to air quality and climate change mitigation policies: the case of urban forests in Barcelona, Spain, *Ambio* **43**, 2014, 466–479.

Berardi U., GhaffarianHoseini A.H. and GhaffarianHoseini A., State-of-the-art analysis of the environmental benefits of green roofs, *Appl. Energy* **115**, 2014, 411–428.

Blanusa T., Vaz Monteiro M.M., Fantozzi F., Vysini E., Li Y. and Cameron R.W.F., Alternatives to Sedum on green roofs: can broad leaf perennial plants offer better ‘cooling service’?, *Buil. Environ.* **59**, 2013, 99–106.

Bolund P. and Hunhammar S., Ecosystem services in urban areas, *Ecol. Econ.* **29**, 1999, 293–301.

Braaker S., Ghazoul J., Obrist M.M. and Moretti M., Habitat connectivity shapes urban arthropod communities: the key role of green roofs, *Ecology* **95**, 2014, 1010–1021.

Buehler D. and Junge R., Global trends and current status of commercial urban rooftop farming, *Sustainability* **8**, 2016, 1108. https://doi.org/10.3390/su8111108.

Carpenter D.D. and Kaluvakolanu P., Effect of roof surface type on stormwater run-off from full-scale roofs in a temperate climate, *J. Irrigat. Drain. Eng.* **137**, 2011, 161–169.

Davies Z.G., Dallimer M., Edmondson J.L., Leake J.R. and Gaston K.J., Identifying potential sources of variability between vegetation carbon storage estimates for urban areas, *Environ. Pollut.* **183**, 2013, 133–142.

Depledge M.H., Stone R.J. and Bird W.J., Can natural and virtual environments be used to promote improved human health and wellbeing?, *Environ. Sci. Technol.* **45**, 2011, 4660–4665.

Donovan G.H. and Butry D.T., Trees in the city: valuing street trees in Portland, Oregon, *Landscape Urban Plan.* **94**, 2010, 77–83.

Douglas I., Urban ecology and urban ecosystems: understanding the links to human health and well-being, *Curr. Opin. Environ. Sustain.* **4**, 2012, 385–392.

Elmqvist T., Setälä H., Handel S.N., van der Ploeg S., Aronson J., Blignaut J.N., et al., Benefits of restoring ecosystem services in urban areas, *Curr. Opin. Environ. Sustain.* **14**, 2015, 101–108.

Ernstson H., The social production of ecosystem services: a framework for studying environmental justice and ecological complexity in urbanized landscapes, *Landscape Urban Plan.* **109**, 2013, 7–17.

Escobedo F.J., Kroeger T. and Wagner J.E., Urban forests and pollution mitigation: analyzing ecosystem services and disservices, *Environ. Poll.* **159**, 2011, 2078–2087.

Escobedo F.J., Adams D.C. and Timilsina N., Urban forest structure effects on property value, *Ecosyst. Serv.* **12**, 2015, 209–217.

Gómez-Baggethun E. and Barton D.N., Classifying and valuing ecosystem services for urban planning, *Ecol. Econ.* **86**, 2013, 235–245.

Holt A.R., Mears M., Maltby M. and Warren P., Understanding spatial patterns in the production of multiple urban ecosystem services, *Ecosyst. Serv.* **16**, 2015, 33–46.

Islam M.N., Rahman K.S., Bahar M.M., Habib M.A., Ando K. and Hattori N., Pollution attenuation by roadside greenbelt in and around urban areas, *Urban For. Urban Gree.* **11**, 2012, 460–464.

Kremer P., Andersson E., Elmqvist T. and McPhearson T., Advancing the frontier of urban ecosystem services research, *Ecosyst. Serv.* **12**, 2015, 149–151.

Lyytimäki J. and Sipilä M., Hopping on one leg – the challenge of ecosystem disservices for urban green management, *Urban For. Urban Gree.* **8**, 2009, 309–315.

Mace G.M., Norris K. and Fitter A.H., Biodiversity and ecosystem services: a multilayered relationship, *Trends Ecol. Evolut.* **27**, 2012, 19–26.

Manes F., Incerti G., Salvatori E., Vitale M., Ricotta C. and Costanza R., Urban ecosystem services: tree diversity and stability of tropospheric ozone removal, *Ecol. Applicat.* **22**, 2012, 349–360.

McPhearson T., Andersson E., Elmqvist T. and Frantzeskaki N., Resilience of and through urban ecosystem services, *Ecosyst. Serv.* **12**, 2015, 152–156.

McPherson G., van Doorn N. and de Goede J., Structure, function and value of street trees in California, USA, *Urban For. Urban Gree.* **17**, 2016, 104–115.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-Being: Synthesis. Washington, DC: Island Press.

Milliken S., The value of green infrastructure in urban design, *Urban Des. J.* **126**, 2013, 18–20.

Mullaney J., Lucke T. and Trueman S.J., A review of benefits and challenges in growing street trees in paved urban environments, *Landscape Urban Plan.* **134**, 2015, 157–166.

Nowak D.J., Greenfield E.J., Hoehn R.E. and Lapoint E., Carbon storage and sequestration by trees in urban and community areas of the United States, *Environ. Poll.* **178**, 2013, 229–236.

Ottelé M., van Bohemen H.D. and Fraaij A.L.A., Quantifying the deposition of particulate matter on climber vegetation on living walls, *Ecol. Eng.* **36**, 2010, 154–162.

Pandit R., Polyakov M., Tapsuwan S. and Moran T., The effect of street trees on property value in Perth, Western Australia, *Landscape Urban Plan.* **110**, 2013, 134–142.

Pataki D.E., Carreiro M.M., Cherrier J., Grulke N.E., Jennings V., Pincetl S., et al., Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions, *Front. Ecol. Environ.* **9**, 2011, 27–36.

Peckham S.C., Duinker P.N. and Ordóñez C., Urban forest values in Canada: views of citizens in Calgary and Halifax, *Urban For. Urban Gree.* **12**, 2013, 154–162.

Pérez G., Coma J., Martorell I. and Cabeza L., Vertical Greenery Systems (VGS) for energy saving in buildings: a review, *Renew. Sustain. Energy Rev.* **39**, 2014, 139–165.

Pérez G., Coma J., Barrenche C., de Gracia A., Urrestarazu M., Burés S., et al., Acoustic insulation capacity of Vertical Greenery Systems for buildings, *Appl. Acoust.* **110**, 2016, 218–226.

Pérez-Urrestarazu L., Fernández-Cañero R., Franco-Salas A. and Egea G., Vertical greening systems and sustainable cities, *J. Urban Technol.* **22** (4), 2016, 1–21.

Perini K., Ottelé M., Fraaij A.L.A., Haas E.M. and Raiteri R., Vertical greening systems and the effect on air flow and temperature on the building envelope, *Buil. Environ.* **46**, 2011, 2287–2294.

Pugh T.A.M., Mackenzie A.R., Whyatt J.D. and Hewitt C.N., Effectiveness of green infrastructure for improvement of air quality in urban street canyons, *Environ. Sci. Technol.* **46**, 2012, 7692–7699.

Razzaghmanesh M., Beecham S. and Kazemi F., Impact of green roofs on stormwater quality in a South Australian urban environment, *Sci. Total Environ.* **470–471**, 2014, 651–659.

Rowe D.B., Green roofs as a means of pollution abatement, *Environ. Poll.* **159**, 2011, 2100–2110.

Roy S., Byrne J. and Pickering C., A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones, *Urban For. Urban Gree.* **11**, 2012, 351–363.

Russo A., Escobedo F.J. and Zerbe S., Quantifying the local-scale ecosystem services provided by urban treed streetscapes in Bolzano, Italy, *AIMS Environ. Sci.* **3**, 2016, 58–76.

Santamouris M., Cooling the cities – a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments, *Solar Energy* **103**, 2014, 682–703.

Säumel I., Weber F. and Kowarik I., Toward livable and healthy urban streets: roadside vegetation provides ecosystem services where people live and move, *Environ. Sci. Policy* **62**, 2016, 24–33.

Setälä H., Viippola V., Rantalainen A.L., Pennanen A. and Yli-Pelkonen V., Does urban vegetation mitigate air pollution in northern conditions?, *Environ. Poll.* **183**, 2013, 104–112.

Sims A.W., Robinson C.E., Smart C.C., Voogt J.A., Hay G.J., Lundholm J.T., et al., Retention performance of green roofs in three different climate regions, *J. Hydrol.* **542**, 2016, 115–124.

Soares A.L., Rego F.C., McPherson E.G., Simpson J.R., Peper P.J. and Xiao Q., Benefits and costs of street trees in Lisbon, Portugal, *Urban For. Urban Gree.* **10**, 2011, 69–78.

Speak A., Rothwell J., Lindley S. and Smith C., Reduction of the urban cooling effects of an intensive green roof due to vegetation damage, *Urban Clim.* **3**, 2013a, 40–55.

Speak A.F., Rothwell J.J., Lindley S.J. and Smith C.L., Rainwater runoff retention on an aged intensive green roof, *Sci. Total Environ.* **461**, 2013b, 28–38.

Specht K., Siebert R., Hartmann I., Freisinger U.B., Sawicka M., Werner A., et al., Urban agriculture of the future: an overview of sustainability aspects of food production in and on buildings, *Agri. Human Values* **31**, 2014, 33–51.

Strohbach M.W. and Haase D., Above-ground carbon storage by urban trees in Leipzig, Germany: analysis of patterns in a European city, *Landscape Urban Plan.* **104**, 2012, 95–104.

Susca T., Gaffin S.R. and Dell'Osso G.R., Positive effects of vegetation: urban heat island and green roofs, *Environ. Poll.* **159**, 2011, 2119–2126.

Taha H., Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat, *Energy Buil.* **25**, 1997, 99–103.

Tallis M., Taylor G., Sinnett D. and Freer-Smith P., Estimating the removal of atmospheric particulate pollution by the urban tree canopy of London, under current and future environments, *Landscape Urban Plan.* **103**, 2011, 129–138.

The Economics of Ecosystems and Biodiversity, 2011. TEEB Manual for Cities: Ecosystem Services in Urban Management. <www.teebweb.org>

Thomaier S., Specht K., Henckel D., Dierich A., Siebert S., Freisinger U.B., et al., Farming in and on urban buildings: present practice and specific novelties of Zero-Acreage Farming (ZFarming), *Renew. Agri. Food Syst.* **30**, 2014, 43–54.

Vailshery L.S., Jaganmohan M. and Nagendra H., Effect of street trees on microclimate and air pollution in a tropical city, *Urban For. Urban Gree.* **12**, 2013, 408–415.

Vijayaraghavan K., Greenroofs: a critical review on the role of components, benefits, limitations and trends, *Renew. Sustain. Energy Rev.* **57**, 2016, 740–753.

Vijayaraghavan K.U., Joshi M. and Balasubramanian R., A field study to evaluate runoff quality from green roofs, *Water Res.* **46**, 2012, 1337–1345.

Vos P.E.J., Maiheu B., Vankerkom J. and Janssen S., Improving local air quality in cities: to tree or not to tree?, *Environ. Poll.* **183**, 2013, 113–122.

Wania A., Bruse M., Blond N. and Weber C., Analysing the influence of different street vegetation on traffic-induced particle dispersion using microscale simulations, *J. Environ. Manage.* **94**, 2012, 91–101.

Weber F., Kowarik I. and Säumel I., Herbaceous plants as filters: immobilization of particulates along urban street corridors, *Environ. Poll.* **186**, 2014, 234–240.

Whittinghill L.J., Rowe D.B., Andresen J.A. and Cregg B.M., Comparison of stormwater runoff from sedum, native prairie, and vegetable producing green roofs, *Urban Ecosyst.* **18**, 2015, 13–29.

Zölch T., Maderspacher J., Wamsler C. and Pauleit S., Using green infrastructure for urban climate-proofing: an evaluation of heat mitigation measures at the micro-scale, *Urban For. Urban Gree.* **20**, 2016, 305–316.

Abstract

This chapter presents a brief synthesis of recent literature on ecosystem services in urban environments. Different types of urban habitats generate different types of ecosystem service, including the supply food, mitigation of air pollution, human health and well-being, and biodiversity. These services can play an important role in enhancing the resilience of cities to climate change, but only if urban planners and polic makers take into account the connectivity required by key ecological processes in order for their potential to be optimized. The economic valuation of urban ecosystem services is a useful tool for communicating wit these stakeholders.

Keywords: Ecosystem services; ecosystem disservices; urban environments; social-ecological approach; economic valuation; multiple benefits