

Chapter 4: Urban ecosystem services

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4.1. Reconnecting cities to the biosphere

Cities are interconnected globally through political, economic, and technical systems, and also through the Earth's biophysical life-support systems. Cities also have significant disproportionate environmental impacts at the local, regional, and global scale well beyond their borders (Grimm et al. 2000, 2008; Seto et al. 2012), yet they provide critical leadership in the global sustainability agenda (Folke et al. 2011). Although urbanized areas cover only a tiny proportion of the surface of the planet, their impact, through their vast human populations, are significant. Still, the impacts of urbanization on biodiversity and ecosystems remain insufficiently understood (see e.g. McDonald and Marcotullio 2011).

In this chapter we explore the potential of the ecosystem services concept for deepening our understanding of urban area connections to the biosphere. Ecosystem services are “the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life” (Daily 1997). They are often defined as the benefits human populations derive, directly or indirectly from ecosystems (TEEB 2010) and have proven useful in illuminating and describing the connections between the work of nature and human welfare and survival (see e.g. MA 2005). However, there is considerable lack of knowledge of *urban* ecosystem services (see e.g. MA 2005 and World Bank 2009), perhaps because the concept of urban areas as integrated with ecosystems, has not been widely accepted. For a discussion and a review on this subject see Elmqvist 2011.

4.1.1. Ecology of vs. ecology in cities

Cities appropriate vast areas of functioning ecosystems for their consumption and waste

assimilation (see Chapter 1 and 9). Most of the ecosystem services consumed in cities are generated by ecosystems located outside of the cities themselves, not seldom half a world away (Rees 1992; Folke et al. 1996; Rees and Wackernagel 1996; Deutsch and Folke 2005, see Chapter 1). Folke et al. (1997) estimated that that the 29 largest cities in the Baltic Sea Drainage Basin, taking into account only the most basic ecosystem services such as food production and assimilation of nitrogen and carbon, appropriate ecosystem areas equivalent to the size of the entire drainage basin, several hundred times the area of the cities themselves (Chapter 1 and Chapter 9). Thus, we need to be concerned not only with what is sometimes referred to as “the ecology *in* cities”, which is characterized by studies typically single discipline in nature, small scale and located within a city (Niemelä et al. 2011), and which often focuses on designing energy efficient building, sustainable logistics, restoration, and providing inhabitants with functioning green urban environments, but also focus on “the ecology *of* cities” characterized by interdisciplinary and multiscale studies with a social-ecological systems approach (Grimm et al. 2000; Pickett et al. 2001, see also Chapter 2). This framework acknowledges the total dependence of cities on the surrounding landscape and the links between urban and rural, viewing the city as an ecosystem (Grimm et al. 2008). We need to be concerned with the generation potential, not only to uphold and safeguard the welfare of city inhabitants, but also to effectively manage the potential of cities as arenas for learning (this aspect is discussed in detail in Chapter 11), development, and transformation.

4.1.2. Urban ecosystems and green infrastructure

Pickett et al. (2001) define urban ecosystems as those where the built infrastructure covers a large proportion of the land surface, or those in which people live at high densities. Definitions of urban areas and their boundaries vary between countries and regions. European countries define urbanized areas on the basis of urban-type land use; in the United States, the term urbanized area denotes an urban area of 50,000 or more people; and in China, an urban area is defined by having a population density higher than 1,500/km². In less developed countries, besides land use and density, a requirement is that a majority of the population (typically 75%) is not engaged in the primary sector (Gómez-Baggethun and Barton 2012, in press). Because many fluxes and interactions extend beyond the urban boundaries defined by political or biophysical reasons, urban

ecosystems are defined here in the broader sense that comprise the hinterlands directly managed or affected by the energy and material flows from the urban core and suburban lands (Pickett et al. 2001, p. 129) including city catchments, and peri-urban forests and cultivated fields.

Urban ecosystems can be portrayed as a form of ecological infrastructure, often called “green infrastructure”, providing a variety of ecosystem services for humans. The term ecological infrastructure captures the role that water and vegetation in or near the built environment play in delivering ecosystem services at different spatial scales (building, street, neighborhood, region). It includes all ‘green and blue spaces’ (urban ecosystems) that may be found in urban and peri-urban areas, including parks, cemeteries, gardens and yards, urban allotments, urban forests, single trees, wetlands, streams, rivers, lakes, and ponds (EEA 2011).

4.2. Classifying urban ecosystem services

Building on previous categorizations of ecosystem services (Daily 1997; de Groot et al. 2002; MA 2005) the TEEB report identifies 22 types of ecosystem services grouped in four categories: provisioning, regulating, habitat, and cultural and amenity services (TEEB 2010) (Figure 1).

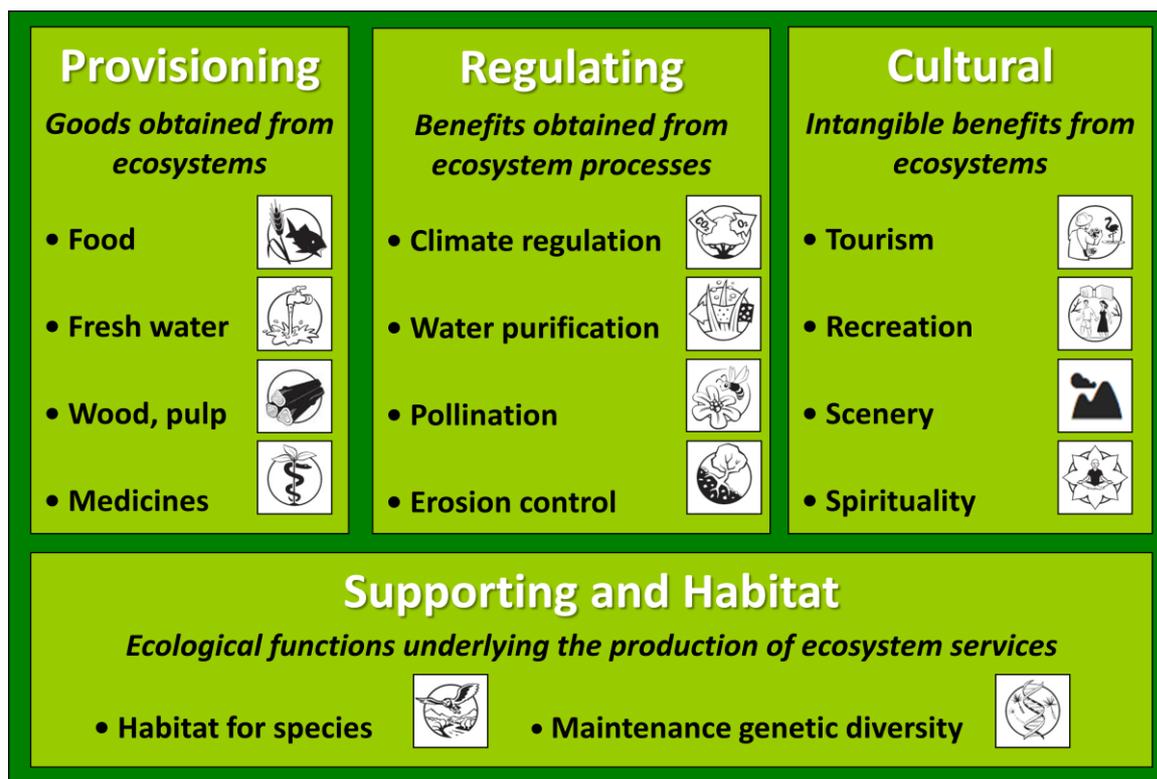


Figure 1. Classification of ecosystem services by the TEEB initiative. (Sources: Millennium Ecosystem Assessment 2005; TEEB for Local and Regional Policy 2010; Icons by Jan Sasse, TEEB)

Provisioning services include all the products obtained from ecosystems, including, for example, genetic resources, food and fiber, and fresh water. Regulating services include all the benefits obtained from the regulation of ecosystem processes, including, for example, the regulation of climate, water, and some human diseases. Cultural services are the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience as well as knowledge systems, social relations, and aesthetic values. Finally, supporting or habitat services are those that are necessary for the production of all other ecosystem services. Examples include biomass production, atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling, and provisioning of habitat.

Because different habitats provide different types of ecosystem services, general classifications need to be adapted to specific types of ecosystems (MA 2005). Urban ecosystems are especially important in providing services with direct impact on health

and security such as air purification, noise reduction, urban cooling, and runoff mitigation. Yet, which ecosystem services in a given place are most relevant varies greatly depending on the environmental and socio-economic characteristics of each site. Below we provide a classification and description of important ecosystem services provided in urban areas using the Millennium Ecosystem Assessment and the TEEB initiative as major classification frameworks, and drawing on previous research on the topic (e.g. Bolund and Hunhammar 1999; Gómez-Baggethun and Barton 2012)..

4.2.1. Provisioning services

4.2.1.1. Food supply

Urban food production takes place in peri-urban farm fields, on rooftops, in backyards, and in community vegetable and fruit gardens (Andersson et al. 2007; Barthel et al. 2010). In most geographical contexts, cities normally only produce a small share of the food they consume, depending largely on other areas to meet their demands (Folke et al. 1997; Ernstson et al. 2010). In some geographical areas and in particular periods, however, food production from urban agriculture can play an important role for food security, especially during economic crises (Smit and Nasr 1992; Moskow 1999; Page 2002; Buchmann 2009; Barthel et al. 2011; Barthel and Isendahl 2012). Altieri et al. (1999) estimated that in 1996 food production in urban gardens of Havana included 8.500 tons of agricultural products, 7.5 million eggs and 3,650 tons of meat.

Moustier (2007) provides an extensive summary of the importance of urban agriculture in 14 African and Asian cities. Among the results are e.g. that 90% of all vegetables consumed in Dar es Salaam originate from urban agriculture (Jacobi et al. 2000) and 60% in Dakar (Mbaye and Moustier 2000). As regards to staple food such as rice, plantain banana, and maize, the situation is highly variable according to the cities. In Asia, the share of rice supplied by the city to urban residents ranges from 7% (in Phnom Penh) to 100% (in Vientiane, where pressure on land is low), Hanoi being an intermediary case with 58% (Anh 2004; Ali et al. 2005).

4.2.1.2. Water supply

Ecosystems provide cities with fresh water for drinking and other human uses and by

securing storage and controlled release of water flows. Vegetation cover and forests in the city catchment influences the quantity of available water. One of the most striking examples of the importance of functioning ecosystems for city water supply is the New York City Watershed. This watershed is one of New York State's most important natural resources, providing approximately 1.3 billion gallons of clean drinking water to roughly nine million people every day. This is the largest unfiltered water supply in the United States (Chichilnisky and Heal 1998). Another example is the Omerli Watershed outside Istanbul, Turkey. The Omerli Watershed (OW) is the most important among the seven Mediterranean watersheds that provide drinking water to Istanbul, a megacity with over 10 million people. The OW is threatened by urban development in, and around of, its drinking water sources. It faces acute, unplanned pressures of urbanization with potentially serious impacts on water quality and biodiversity (Wagner et al. 2007).

4.2.2. Regulating

4.2.2.1. Urban temperature regulation

Urban blue and green infrastructure regulates local temperatures and buffers the effects of urban heat islands (Moreno-Garcia 1994). For example, water areas buffer temperature extremes by absorbing heat in summer time and by releasing it in wintertime (Chaparro and Terradas 2009). Vegetation reduces temperature in the hottest months through shading and absorbs heat from the air through the evapotranspiration process, particularly when humidity is low (Bolund and Hunhammar 1999; Nowak and Crane 2000).

Evaporated water leaves the plant as water vapor; absorbing heat as it evaporates and rises, thus cooling the air in the process. Trees can also regulate local surface and air temperatures by reflecting solar radiation and shading surfaces, such as streets and sidewalks that would otherwise absorb heat. Decreasing the heat loading of the city and thereby mitigating the urban heat island effect may be the most important ecological service trees provide to cities (McPhearson 2011).

4.2.2.2. Noise reduction

Traffic, construction, and other human activities make noise a major pollution problem in cities, affecting health through physiological and psychological damages. Urban soil and

plants and trees can attenuate noise pollution through absorption, deviation, reflection, and refraction of sound waves (Aylor 1972; Kragh 1981; Fang and Ling 2003). In belt trees, for example, the sound waves are reflected and refracted, dispersing the sound energy through the branches and trees. It has also been shown that different plant species mitigate noise differently (see e.g. Pathak et al. 2007).

4.2.2.3. Air purification

Air pollution from transport, industry, domestic heating, and solid urban waste incineration is a major problem for environmental quality and human health in the urban environment, leading to increases in respiratory and cardiovascular diseases. Vegetation in urban systems can improve air quality by removing pollutants from the atmosphere, including ozone (O₃), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO) and particulate matter less than 10µm (PM₁₀) (Nowak 1994a; Escobedo et al. 2008). Especially urban trees have been shown to intercept the transport of air pollutants (Aylor et al. 2003). However, significant differences have been found between different plant species of urban trees and shrubs, e.g. between deciduous and evergreen species. The distribution of different particle size fractions can differ both between and within species and also between leaf surfaces and in waxes (Dzierzanowski et al. 2011). Removal of pollutants by vegetation operates through filtration of particulates from the air through the leaves of trees and shrubs (Nowak 1996). Performance of pollution removal follows daily variation because during the night the plant stomas are closed and do not absorb pollutants, and monthly variation because of the changes in light hours and because of the shedding of the leaves by deciduous forest during the winter.

4.2.2.4. Moderation of climate extremes

Ecosystems act as natural barriers that buffer cities from extreme climate events and hazards, including storms, waves, floods, hurricanes, and tsunamis (Danielsen et al. 2005; Kerr and Baird 2007). Vegetation stabilize the ground reducing the likelihood of landslides, and coastal ecosystems such as mangroves and coral reefs can dramatically reduce the damage caused by hurricanes or large waves to coastal cities (Costanza et al.

2006a).

4.2.2.5. Runoff mitigation

Increasing the impermeable surface area in cities reduces the capacity of water to percolate in soils, increasing the volumes of surface water run-off and thus increasing the vulnerability to water flooding. Urban landscapes with 50–90% impervious cover can lose 40–83% of rainfall to surface runoff compared to 13% in forested landscapes (Bonan 2002). Interception of rainfall by tree canopies slows down flooding effects and green soft lanes reduce the pressure on urban drainage systems by percolating water (Bolund and Hunhammar 1999; Pataki et al. 2011). Street trees in New York e.g. intercept 890 million gallons of stormwater annually (Peper et al. 2007). Other means of reducing both the amount of urban stormwater runoff and pollution load are e.g. linear features (bioswales), green roofs, and rain gardens (Clausen 2007; Shuster et al. 2008). For example, green roofs can retain 25–100% of rainfall, depending on rooting depth, roof slope, and the amount of rainfall (Oberndorfer et al. 2007). Also, green roofs may delay the timing of peak runoff, thus lessening the stress on storm-sewer systems and rain gardens and bioretention filters can reduce the volume of surface runoff (Clausen 2007; Shuster et al. 2008).

4.2.2.6. Waste treatment

Ecosystems filter out and decompose organic wastes for urban effluents by storing and recycling waste through dilution, assimilation and chemical re-composition (TEEB 2011). Wetlands and other aquatic systems, for example, filter wastes from human activities reducing the level of nutrients and pollution in urban wastewater, and plant communities in urban soils can play an important role in the decomposition of many labile and recalcitrant litter types (Vauramo and Setälä 2010). In urban streams, nutrient retention can be increased by adding coarse woody debris, constructing in-channel gravel beds, and increasing the width of vegetation buffer zones and tree cover (Booth 2005).

4.2.2.7. Pollination, pest regulation and seed dispersal

Pollinators, pest regulators and seed dispersers are potentially threatened by habitat loss and fragmentation due to urban development and expansion. In this context allotment gardens and private gardens have been shown to be important source areas (Andersson et al. 2007; Ahrné et al. 2009). Also, research in urban ecosystem services shows that a number of formal and informal management practices in allotment gardens, cemeteries and city parks promote functional groups of insects enhancing pollination and bird communities enhancing seed dispersal (Andersson et al. 2007). To manage these services sustainably over time spatially explicit, quantitative assessments are crucial (Nelson et al. 2009) and the role of biodiversity has to be recognized. Jansson and Polasky (2010) have developed a method for quantifying the impact of change in pollination potential in the regional urban landscape. Their results indicate that while the impact of urban development on the pollination service can be modest, the erosion of the resilience of the service, measured through change in response diversity (see Elmqvist et al. 2003), could be potentially substantial. Such spatially explicit and quantitative methods could aid in identifying appropriate scales and land use patterns for securing e.g. the pollination service over time in urban landscapes.

4.2.2.8. Climate regulation

There is an increasing concern in cities about climate change and its effects on residents because of direct threats such as coastal flooding and extreme heat events (Zahran et al. 2008). Emissions of greenhouse gases in cities include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (NO₂), chlorofluorocarbons, and tropospheric ozone (O₃). Urban trees act as a sink of CO₂ by storing excess carbon as biomass during photosynthesis (Birdsey 1992; Jo and McPherson 1995; McPherson and Simpson 1999). The amount of CO₂ stored is proportional to the biomass of the trees. Urban soils also act as carbon pools (Nowak and Crane 2000; Pouyat et al. 2006) and urban trees and soils as well as other urban C pools, has been estimated for several cities in the US (Churkina et al. 2010). An attractive option for climate change mitigation in cities is tree-planting programs as trees, apart from contributing to C sequestration also provide local cooling and shading effects, provision of habitat for native and rare species, and cultural ecosystem services. A good

example is the MillionTreesNYC Program, a public-private partnership between the New York City Department of Parks & Recreation and the non-profit New York Restoration Project, with the goal of planting and caring for one million trees across the City's five boroughs by 2017 (McPhearson et al. 2010). By planting one million trees, New York City can increase its urban forest by 20%. Since MillionTreesNYC began in 2007, 590,000 trees have been planted to date on city streets, private land, and public parkland. The maintenance of a suitable climate in cities beyond microclimatic effects, however, depends on the maintenance of global forests and other carbon sinks located worldwide.

4.2.3. Cultural services

4.2.3.1. Outdoor recreation

People often choose where to spend their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area (Kaplan and Kaplan 1989; Chiesura 2004).

4.2.3.2. Education and knowledge preservation

Green spaces in urban areas provide multiple opportunities for cognitive development. For example, urban forests and allotment gardens are often used for environmental education purposes (Groening 1995; Tyrväinen et al. 2005), and important bodies of local ecological knowledge have been documented in cities (Barthel et al. 2010).

4.2.3.3. Amenity and aesthetic

Also, several studies have shown an increased value of properties (as measured by hedonic pricing) with greater proximity to green areas (Tyrväinen 1997; Cho et al. 2008; Troy and Grove 2008) and natural elements 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 (Ninan 2009).

Across these cultural services urban inhabitants develop affective links to the ecological

sites of their cities, urban ecosystems also play an important role in place attachment and community cohesion (Altman and Low 1992).

4.2.4. Habitat services

4.2.4.1. Habitat for biodiversity

Urban systems can play a non-negligible role as refuge for many species of birds, amphibians, bees, and butterflies (Melles et al. 2003; Müller et al. 2010). Well-designed green roofs can provide habitat compensation e.g. for species affected by urban land-use changes (Brenneisen 2003). Also, golf courses, providing appropriate climatic conditions, can have the potential to contribute to wetland fauna support, particularly in urban settings where they may significantly contribute to wetland creation (Colding and Folke 2009; Colding et al. 2009). Diversity may peak at intermediate levels of urbanization, at which many native and non-native species thrive, but it typically declines as urbanization intensifies (Blair 1996). Also, certain habitats can be perceived as key habitats for certain species but not for others, depending on the dispersal capacity. For example old hardwood deciduous trees in the National City Park of Stockholm, Sweden is seen as an important resource for the whole region for species with high dispersal capacity, while for species with lower dispersal capacity the habitat were considered to be very isolated and not very accessible (Zetterberg 2011).

A synthesis of the above classification of ecosystem services along with examples of proxies and indicators to quantify them in biophysical terms is provided in Table 1 (based on Gómez-Baggethun and Barton 2012, in press).

<i>Ecosystem functions</i>	<i>Ecosystem service type</i>	<i>Examples</i>	<i>Examples of indicators proxies</i>	<i>Key references</i>
Energy conversion into edible plants through photosynthesis	Food supply	Vegetables produced by urban allotments and peri-urban areas	Production of food (tons yr ⁻¹)	Altieri et al. (1999)
Percolation and regulation of runoff and river discharge	Water flow regulation and runoff mitigation	Soil and vegetation percolate water during heavy and/or prolonged precipitation events	Soil infiltration capacity; % sealed relative to permeable surface (ha)	Villareal and Bengtsson (2005)
Photosynthesis, shading, and evapotranspiration	Urban temperature regulation	Trees and other urban vegetation provide shade, create humidity and block wind	Leaf Area Index; Temperature decrease by tree cover x m ² of plot trees cover (°C)	Bolund and Hunhammar (1999)
Absorption of sound waves by vegetation and water	Noise reduction	Absorption of sound waves by vegetation barriers, specially thick vegetation	Leaf area (m ²) and distance to roads (m); noise reduction dB(A)/vegetation unit (m)	Aylor (1972); Ishii (1994); Kragh (1981)
Dry deposition of gases and particulate matter	Air purification	Absorption of pollutants by urban vegetation in leaves, stems and roots	O ₃ , SO ₂ , NO ₂ , CO, and PM ₁₀ µm pollutant flux (g/cm ² /s) multiplied by tree cover (m ²)	Escobedo and Nowak (2009); Jim and Chen (2009); Chaparro and Terradas (2009); Escobedo et al. (2011)

Physical barrier and absorption on kinetic energy	Moderation of environmental extremes	Storm, floods, and wave buffering by vegetation barriers; heat absorption during severe heat waves	Cover density of vegetation barriers separating built areas from the sea	Danielsen et al., (2005); Costanza et al. (2006b)
Removal or breakdown of xenic nutrients	Waste treatment	Effluent filtering and nutrient fixation by urban wetlands	P, K, Mg and Ca in mgkg^{-1} compared to given soil/water quality standards	Vauramo and Setälä (2010)
Carbon sequestration and storage by fixation in photosynthesis	Climate regulation	Carbon sequestration and storage by the biomass of urban shrubs and trees	CO_2 sequestration by trees (carbon multiplied by 3.67 to convert to CO_2)	Nowak (1994b); McPherson (1998)
Movement of floral gametes by biota	Pollination and seed dispersal	Urban ecosystem provided habitat for birds, insects, and pollinators	Species diversity and abundance of birds and bumble bees	Hougner et al. (2006); Andersson et al. (2007)
Ecosystems with recreational values	Outdoor recreation	Urban parks provide multiple opportunities for recreation, meditation, and pedagogy	Surface of green public spaces (ha) /inhabitant (or every 1000 inhabitants)	Chiesura (2004)
Human shaping of socio-ecological systems	Education and knowledge preservation	Allotment gardening as preservation of socio-ecological knowledge	Participation, reification, and external sources of social-ecological memory	Barthel et al. (2010)
Ecosystems with estetical	Amenity and aesthetic	Urban parks in sight from houses	Monetary property values	Tyrväinen (1997);

values				Cho et al. (2008); Troy and Grove (2008)
Habitat provision for animal species	Animal sighting	Urban green spaces provide habitat for birds and other animals people like watching	Abundance of birds, butterflies and other animals valued for their aesthetic attributes	Blair (1996); Blair and Launer (1997)

Note: The suitability of indicators for biophysical measurement is scale dependent. Most indicators and proxies provided here correspond to assessment at the plot level.

Table 1. Classification of important ecosystem services in urban areas and underlying ecosystem functions and components. (Source: Gómez-Baggethun and Barton 2012, based on existing literature.)

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4.2.5. Ecosystem disservices

Urban ecosystems do not only produce ecosystem services, but also ecosystem disservices. Ecosystem disservices have been defined as ‘functions of ecosystems that are perceived as negative for human well-being’ (Lyytimäki and Sipilä, 2009, p. 311). For example, some common city tree and bush species emit volatile organic compounds (VOCs) such as isoprene, monoterpenes, ethane, propene, butane, acetaldehyde, formaldehyde, acetic acid and formic acid, all of which can indirectly contribute to urban smog and ozone problems through CO and O₃ emissions (Geron, 1994; Chaparro and Terradas, 2009). Other examples are damages to physical infrastructures by e.g. microbial activity decomposing wood constructions, corrosion of stone buildings and statues by bird excrements, breaking up of pavements by root systems, or animals digging nesting holes (de Stefano and Deblinger, 2005; Lyytimäki and Sipilä, 2009).

Other important disservices from urban ecosystems include health problems from wind-pollinated plants causing allergic reactions (D’Amato, 2000), fear from dark green areas that are perceived as unsafe, especially by women in night-time (Bixler and Floyd, 1997; Koskela and Pain, 2000; Jorgensen and Anthopoulos, 2007), diseases transmitted by domestic animals (e.g. migratory birds carrying avian influenza, dogs carrying rabies), and blockage of views by trees (Lyytimäki et al., 2008). Likewise, just as some plants and animals are perceived by people as services, as discussed above, animals such as rats, wasps and mosquitoes, and plants such as stinging nettles, are perceived by many as disservices. A summary of disservices from urban ecosystem disservices is provided in Table 2.

<i>Ecosystem functions</i>	<i>Disservice</i>	<i>Examples</i>	<i>Indicators</i>	<i>References</i>
Photosynthesis	Air quality problems	City tree and bush species emit volatile organic compounds (VOCs)	Emission of VOCs (tons yr ⁻¹) / vegetation unit	Chaparro and Terradas (2009); Geron et al (1994)
Tree growth through biomass fixation	View blockage	Blockage of views by trees standing close to buildings	Tall trees close to buildings	Lyytimäki et al. (2008)

Movement of floral gametes	Allergies	wind-pollinated plants causing allergic reactions	Allergenicity (e.g. OPALS ranking)	D'Amato (2000)
Aging of vegetation	Accidents	Break up of branches falling in roads and trees	Number of aged trees	Lyytimäki et al. (2008)
Dense vegetation development	Fear and stress	Dark green areas perceived as unsafe in night-time	Area of non-illuminated parks	Bixler and Floyd (1997)
Biomass fixation in roots; decomposition	Damages on infrastructure	Breaking up of pavements by roots; microbial activity	Affected pavement (m ²) wood (m ³)	Lyytimäki and Sipila (2009)
Habitat provision for animal species	Habitat competition with humans	Animals / insects felt as scary, unpleasant, disgusting	Abundance of insects, rats, etc	Bixler and Floyd (1997)

Table 2. Ecosystem disservices in cities (Source: Gómez-Baggethun and Barton 2012 based on various sources)

4.3. Valuing urban ecosystem services

4.3.1. Ecosystem services values

Valuation of ecosystem services involves dealing with multiple, and often conflicting value dimensions (Martinez-Alier et al. 1998; Chan et al. 2012). In this section, we broaden the traditional focus on biophysical measurement and monetary values to explore a range of monetary, socio-cultural, health, and insurance (i.e. resilience-related) values of urban ecosystem services, how they can be captured and measured.

4.3.1.1. Economic values

Because most ecosystem services escape the money economy and because at the margin ecosystem services can be largely substituted by economic services from built infrastructure, many ecosystem services and related values tend to be taken for granted or downplayed in urban planning . This can often result in incentives for undesirable

conversion of urban ecological infrastructure into built infrastructure, with associated loss of ecosystem services. There is mounting evidence that loss of ecosystem services involves economic costs in one form or another (Boyer and Polasky 2004; Tyrväinen et al. 2005; TEEB 2010; EEA 2011; Escobedo et al. 2011; Elmqvist et al. forthcoming). These include costs related to health damage from air pollution (Escobedo et al. 2008, 2011; Escobedo and Nowak 2009) and to property damage from loss of natural barriers to environmental extremes (Costanza et al. 2006a).

Avoided cost methods show that loss of urban vegetation leads to increased energy costs in cooling in the summer season (McPherson et al. 1997; Chaparro and Terradas 2009). Likewise, loss of water regulation services from land-use change in the city catchments sometimes demands the construction of additional costly water purification technologies (Daily and Ellison 2003). The same occurs with the loss of ecosystem services such as air purification (McPherson et al. 1997; Nowak and Crane 2002), noise reduction by vegetation walls (Bolund and Hunhammar 1999), carbon sequestration by urban trees (McPherson et al. 1999; Jim and Chen 2009), buffering of climate extremes by natural barriers (Costanza et al. 2006a), and regulation of water flows (Xiao et al. 1998). In most cases these are real economic costs derived from the partial substitution of green infrastructure and ecosystem services by built infrastructure and economic services. The literature often classifies economic values of ecosystem services as direct use values (stemming from provisioning services), indirect use values (stemming mostly from regulating services), and non use values, which include so called existence and option values (reviewed in TEEB 2010). Table 3 shows examples of quantitative measures of ecosystems services in the urban context in both biophysical and monetary terms.

Ecosystem service	City	Ecological infrastructure	Biophysical accounts (t/y)	Economic valuation (\$/y)	Reference
Air purification	Barcelona, Spain	Urban forest	305,6 t/y	€1,115,908	Chaparro and Terradas (2009)
	Chicago, USA	Urban trees	5500 t/y	US\$ 9 million	McPherson et al. (1997)
	Washington,	Urban trees	540 t/y	-	Nowak and

	USA		0,12 t /ha/y		Crane (2000)
	Modesto, USA	Urban forest	154 t/y;	US\$1.48 million	McPherson et al. (1999)
	Sacramento, USA	Urban forest	3.7 lb/tree	US\$16/tree	al. (1999)
			189 t/y	US\$28.7 million	Scott et al. (1998)
	Lanzhou, China	Urban plants	28890 t pm /y	US\$102	Jim and Chen (2009)
			0,17 t pm /ha/y	US\$ 6,3 /ha	
			1,8 million tSO ₂ /y	-	
			10,9 t SO ₂ /ha/y		
	Beijing, China	Urban forest	2192 t SO ₂ /y	US\$ 4,7 million	Jim and Chen (2009)
			1518 t pm/y	US\$ 283 /ha	
			2192 t SO ₂ /y		Elmqvist et al. (Forthcoming)
			(132 t SO ₂ /ha/y)		
Microclimate regulation	Chicago	City trees	Saved heating 2.1 GJ /tree	US\$ 10 /tree	McPherson et al. (1997)
			Saved cooling 0,48 GJ/tree	US\$ 15/tree	McPherson et al. (1992)
	Modesto, USA	Street and park trees	Saved 110,133 Mbtu / y	US\$870,000	McPherson et al. (1999)
				122kWh/tree	
				US\$10/tree)	
	Sacramento, USA	Urban vegetation	Saved 9,8MW/ha/y	US\$1774/ha/y	Simpson (1998)
	Beijing, China	Urban forest	1,4kWH/ha/day	US\$12,3 million	Jim and Chen (2009)
				1352\$/ha/y	
Carbon sequestration	Barcelona, Spain	Urban forest	113,437t (gross)		Chaparro and Terradas (2009)
			5,422 t (net)		
	Modesto, USA	Urban forest	13,900 t or 336 lb/tree	US\$ 460,000 or US\$ 5/tree	McPherson et al. (1999)
	Washington DC, USA	Urban forest	16,200 tons	US\$ 299,000/y	Elmqvist et al. (Forthcoming)
			3,5 t/h/y	US\$ 653/ha/y	
	Philadelphia, USA	Urban forest	530,000t (gross)	US\$ 9.8 million	Nowak et al. (2007)
			96 ton /ha	(gross)	
			16,100 t (net)	US\$ 297,000	
			2,9 /ha /y	(net)	
	Beijing, China	Urban forest	4,2 million tons	US\$	Jim and Chen (2009)
			256t/ha/y	20,827/ha/y	
Regulation of water	Modesto, USA	Urban forest	Reduced runoff	US\$ 616,000 or US\$ 7/tree	McPherson et al. (1999)
			292,000 m ³ or 845		

flows			gal/ tree		
	Sacramento	Urban trees	Annual rainfall reduced by 10% 822 mm, 850m ³ /ha	US\$ 572/ha	Xiao et al. (1998)
Aesthetic information	Modesto, USA	Urban forest	88235 trees	US\$ 1,5 million US\$ US\$ 17/ tree)	McPherson et al. (1999)
	Guangzou, China	Urban green space	7360ha	US\$ 17,822/ha/y	Jim and Chen (2009)

PM = particulate matter. When pollutants are not specified, calculations include NO₂, SO₂, PM₁₀, O₃ and CO). Results from Jim and Chen converted from RMB to \$US after Elmqvist et al. Not all figures were normalized to net present values and should only be taken as illustration.

Table 3. Examples of economic valuations of five urban ecosystem services. Examples from empirical studies conducted in Europe, US, and China.

Using combinations of valuation methods is necessary to address multiple ecosystem services (Boyer and Polasky 2004; Costanza et al. 2006b; Escobedo et al. 2011). As much as the type of ecosystem service benefits of interest, the choice of valuation methods is determined by a combination of factors including the scale and resolution of the policy to be evaluated, the constituencies that can be contacted to obtain data, as well as supporting data constraints (e.g. GIS layers), all subject to a study budget (Table 4).

Scale	Urban planning issue	Role of economic valuation	Methodological challenges
Region	Prioritizing urban growth alternatives between different areas	Valuing benefits and costs to of (i) urban revitalization (ii) urban infill (iii) urban extension (iv) suburban retrofit (v) suburban extension (vi) new neighborhoods with (vii) existing infrastructure (ix) new infrastructure (x) in environmentally sensitive areas	Comprehensive benefit-cost analysis at multiple scales and resolutions at multiple locations is expensive
	Fair and rational location of	Value of the disamenities of e.g. power plants and landfills and foregone	Using benefit-cost analysis to allocate infrastructure

	undesirable land uses (LULUs)	ecosystem service values of green infrastructure	with local costs versus regional benefits may not achieve fair outcomes
	Preservation of productive peri-urban farm belt	Willingness to pay for preservation of open space and ‘short distance’ food	Large import substitution possibilities for locally produced food
	Water availability to support urban growth	Valuation to support full cost pricing of water supply. Incentive effects of removing water subsidies.	Can require inter-regional geographical scope of valuation
	Using transferable development rights (TDR) to concentrate growth and achieve zoning	Determine farmer opportunity costs and benefits of foregoing urban development as a basis for predicting the size of a TDR market	
Neighborhood	Preserving views, open spaces, and parks in neighborhoods	Willingness to pay of households for quality and proximity of recreational spaces	Accounting for substitute sites and recreational activities
	Conserving soil drainage conditions and wetlands	Valuation of replacement costs of man-made drainage and storage infrastructure	Hydrological and hydraulic modeling required
	Conserving water.	Costs of household water harvesting, recycling and xeriscapes	Cost-benefit evaluation requires comparison with full costs of water supply (see regional analysis)
	Natural corridors	Quantify opportunity costs of preserving corridors	Difficulty in specifying habitat connectivity requirements of corridors
	Local farm produce	WTP for local, fresh produce.	Large import substitution possibilities for locally produced food
	Edible gardens	Recreational value of home gardens	
Streetscape	Street trees	Value pedestrian safety through slowing traffic; disamenities of heat islands; absorption of storm water, and airborne pollutants	Associating ecosystem service values at neighborhood and street level to individual trees
	Green pavements for storm water management	Willingness to pay of households for green streetscape; additional costs of larger dimension storm water	

Building	Green rooftops Yard trees Lawns vs. xeriscapes	Additional costs of traditional storm water management; mitigation of heat island	Associating ecosystem service values at neighborhood and street level to individual roofs, trees and lawns
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Table 4. Economic valuation of ecosystem services in urban planning. (Source: selected by the authors based on a listing by Duany et al. 2010)

Avoided expenditure or replacement costs are often used to address values of regulating services of trees (air pollution mitigation, carbon sequestration) (Sander et al. 2010). However, meta-analyses conducted by other authors, show that hedonic pricing (HP) and stated preference methods (SP), in particular contingent valuation have been the methods most frequently used in the valuation of urban ecosystem services (Boyer and Polasky 2004b; Tyrväinen et al. 2005; Costanza et al. 2006b; Kroll and Cray 2010; Sander et al. 2010; Brander and Koetse 2011). A wide array of ecosystem service benefits have been valued using hedonic pricing, including recreational and amenity benefits (Tyrväinen and Miettinen 2000); views and aesthetic benefits (Anderson and Cordell 1985; Sander et al. 2010); noise reduction (Kim et al. 2007); air quality (Smith and Huang 1995; Bible et al. 2002; Chattopadhyay 1999), and water quality (Leggett and Bockstael 2000). Kroll and Cray's (2010) review of property features valued in hedonic pricing studies, showed that mainly property features at neighbourhood scales had been assessed (open space, open space vegetation & trees, water & wetlands), whereas features at other scales were less common; regional (property rights), streetscape(pavement type, temperature) and building(energy efficiency, roofing type) (Table 5).

Scale	Property feature	# of studies
National /regional	Policies affecting property rights	5
Regional / neighborhood	Open space	28
	Water & wetlands	24
Neighborhood / streetscape	Open space vegetation & trees	20
Streetscape	Pavement type	7
Streetscape / property	Climate & temperature	5

Building	Energy efficiency	7
	Roofing type	0

Table 5. Overview on hedonic pricing studies in cities. (Source: adapted from Kroll and Cray 2010)

Based on our literature review and personal judgment, we suggest potential valuation methods that have hitherto not been applied to urban planning issues at the different scales (Table 6). In section 4.2 we discuss the methodological challenges to applying monetary valuation methods in urban settings at different scales.

Valuation method	Types of value, ecosystem services	Scale	Constituencies	Constraints
Hedonic pricing (RP)	Use values (option value) Cultural services (amenities)	Building, streetscape and neighbourhood characteristics	Home and property owners	Observable quality variables. Spatially explicit Autocorrelation and latent variables
Travel cost (RP)	Use values Cultural services (amenities)	Regional park/recreational destinations	Recreational visitors	No/low travel costs to neighbourhood open spaces. Spatially explicit. Locational self-selection.
Contingent valuation (SP)	Use and non-use values All ecosystem services, but often amenities Service bundles	All infrastructure scales, easier for location specific policy scenario	Households or individuals, often as voters	Hypothetical, question framing issues, information burden Usually not spatially explicit
Choice experiments (SP)	Use and non-use values All ecosystem services, but often amenities. Incremental service levels, controlling for bundles	All infrastructure scales, but easier for location specific policy choice alternatives	Households or individuals, often as consumers	Hypothetical, question framing issues, Information burden Usually not spatially explicit
Production	Use values	Neighbourhood	Natural	Requires spatially explicit

Function / Damage cost	Regulating services	and regional scale.	scientists, experts	biophysical modelling.
Replacement cost	Use values All services, but often regulating services	Building, streetscape, neighbourhood level municipal infrastructure	Engineers, experts	Determining service equivalence for man-made replacement; depends on health and safety standards
Multi-criteria	Use values All services	All infrastructure scales, but easier for location specific policy choice alternatives	Often representatives of special interests; experts	Not representative of population Usually not spatially explicit. Deliberation, iteration

Table 6. Potential valuation methods for urban ecosystem service valuation.

4.3.1.2. *Socio-cultural values*

People hold material, moral, spiritual, aesthetic, and other values towards the (urban) environment, all of which can affect their attitudes and actions toward ecosystems and the services they provide. These include emotional, affective and symbolic views attached to urban nature that in most cases cannot be adequately captured by commodity metaphors and monetary metrics (Norton and Hannon 1997; Martinez-Alier et al. 1998; Daniel et al. 2012). Social and cultural values, associated mostly to cultural services, may be difficult to capture and measure, often demanding the use of holistic approaches and valuation methods that may include qualitative measures, constructed scales, and narration (Patton 2001; Chan et al. 2012). In some cases translating these values into quantitative metrics is difficult or senseless while in others, scientists have developed toolsets to measure values such as sense of place (Williams and Roggenbuck 1989; Shamai 1991) and traditional ecological knowledge (Gómez-Baggethun et al. 2010) using constructed scales.

Articulation of social and values into decision-making processes may require, in most cases, some sort of deliberative process, locally defined metrics, and broader valuation methods based on qualitative description and narration (Chan et al. 2012). A set of values

that may be labeled as socio-cultural and associated descriptions is provided in Table 7.

Socio-cultural values	Explanation	References
Spiritual values	In many places, especially among peoples with animistic religions, ecosystems and biodiversity are deeply intertwined with spiritual values	Stokols (1990)
Sense of place	Emotional and affective bonds between people and ecological sites	Altman and Low (1992), Feldman (1990), Williams et al. (1992), Norton and Hannon (1997)
Sense of community	Feelings towards a group and strength of attachment to communities	Doolittle and McDonald (1978), Chavis and Pretty (1999)
Social cohesion	Attachment as source of social cohesion, shared interests, and neighborhood participation	Bennett (1997), Gotham and Brumley (2002)

Table 7. Sociocultural values of urban ecosystems and biodiversity.

4.3.1.3. Health values

There are multiple connections between urban vegetation and human health (Tzoulas et al. 2007; Bowler et al. 2010a). Especially the links between green areas, human health and recovery rates is a rapidly expanding field of research (see.e.g. Grahn and Stigsdotter 2003). Access to green space was shown to have a positive relationship with longevity (Takano et al. 2002), as well as with self-reported health perception (Maas 2006; van den Berg et al. 2010). Furthermore, closeness to green space reduced stress in individuals (Korpela and Ylén 2007), and children with attention deficit disorder have showed improve alertness (Taylor and Kuo 2009). Other studies express regulating urban ecosystem services, for example air pollution reduction (Lovasi et al. 2008; Pérez et al. 2009) and urban cooling (Bowler et al. 2010b), in terms of health benefits.

4.3.1.4. Insurance values

Urban green infrastructure and ecosystem services can play a major role in increasing resilience and adaptive capacity in cities in the context of growing uncertainty from global change. The contribution of green infrastructure and ecosystem services to increased resilience and reduced vulnerability to shocks has been referred to as a form of ‘insurance value’ (TEEB 2010).

At the outset it should be recognized that urban areas have surpassed many local ecosystem thresholds of the pre-urban natural and agricultural landscape. Critical ecosystem services to the resilience of cities nevertheless include urban cooling, water supply, and runoff mitigation, and food production. For example, as discussed earlier, urban vegetation reduces surface runoff and binds soil following storm events by intercepting water through leaves and stems, thereby reducing the likelihood of damages by flooding and landslides. Likewise, with more intense frequent and longer lasting heat waves affecting cities worldwide (Meehl and Tebaldi 2004) urban cooling by green infrastructure becomes increasingly important (Lafortezza et al. 2009).

In some geographical areas and socio-economic contexts food production in urban allotments can play a critical role in increasing resilience to shocks and food security, especially in times of crisis (Smit and Nasr 1992; Moskow 1999; Page 2002; MA 2005; UNEP 1996). The MA notes that ‘for many of today’s urban dwellers, urban agriculture provides an important source of food and supplementary income’ (MA 2005, p.810). In Cuba urban agriculture emerged in response to the decline of Soviet aid and trade and the persistence of the trade embargo, playing a major role in food security (Altieri et al. 1999; Moskow 1999). Likewise, urban agriculture has provided an important safety net for landless peoples in sub-Saharan Africa (Maxwell 1999). At present, urban social movements associated to allotments gardens are emerging around all around Europe, a phenomenon that can gain special interest in the context on the ongoing economic crises and related uncertainties for food security (Barthel et al. 2010). A number of examples showing how urban allotments can contribute to increase resilience and store social-ecological memory to deal with shocks is provided in Table 8.

Category	Examples found in allotment gardens
Habits/rituals (<i>participation</i>)	Imitation of practices, exchange of seeds, embodied habits
Oral tradition (<i>participation</i>)	Ongoing negotiations, mentor programs, daily small talk
Rules-in-use (<i>reification</i>)	Norms of social conduct, norms towards the environment, property rights
Physical forms/artifacts (<i>reification</i>)	Written material, pictures, the gardens, tools, stories
External memory sources	Media and organizations external to individual allotment gardens

Table 8. Sources of resilience and carriers of social-ecological memory to deal with disturbance and change in urban allotments.

In summary, a number of recent contributions have noted the role of urban ecosystems in maintaining living bodies of local ecological knowledge (Andersson et al. 2007), as well as the importance of this knowledge for maintaining resilience to shocks (Barthel et al. 2010; Gómez-Baggethun et al. 2012). Measuring the insurance value of resilience remains a challenging task. For example, whereas there is growing evidence that increased resilience can bring direct and indirect economic benefits (Walker et al. 2010), available scientific knowledge to translate the value of resilience into monetary metrics is yet limited. In fact, because the economic value of ecosystem services is affected by the distance to ecological thresholds, trying to capture the value of resilience with traditional monetary valuation methods at the margin can be risky and even misleading (Limburg et al. 2002). When thresholds are close, small changes can trigger abrupt shifts in ecosystem services and related values (Scheffer et al. 2001; Walker and Meyers 2004). Since estimations of economic values are based on marginal changes over some non-critical range, when a system is close to a threshold, standard valuation techniques are likely to provide misleading information because of uncertainty or even ignorance about the potential consequences of non-linear change (Pascual et al. 2010).

Consequently, a critical insight when conducting valuations under complex systems conditions is that the value of particular ecosystem services can change drastically over time and in a non-linear way. An important implication of non-linear change for valuation is that ecosystem services that may have low economic value under normal circumstances may suddenly attain high values as possibilities for substitution are lost as a consequence of crises. For example, under normal circumstances the importance of food supply by urban allotments is generally modest. Urban and peri-urban allotments, however, can play a critical role in maintaining adaptive capacity and self-sufficiency in cities when conventional chains of food supply collapse as a consequence of crises or social unrest.

4.3.2. Issues in UES valuation

A review of the literature suggests that urban settings present particular challenges to valuation that go beyond the generic trade-offs between scale, resolution, and accuracy which are common to all valuation approaches. In the process of urbanization, as local ecological thresholds are crossed and on-site ecosystem services are lost, they are substituted by imported services from peri-urban areas and then more distant markets. New substitution possibilities arise from the fact that technology, transportation and markets 'resolve' successive local ecosystem 'crises'. This makes monetary valuation of localized ecosystem services for the purposes of planning long term changes in landscapes undergoing urban development a complicated task. Following Gómez-Baggethun and Barton (2012) below we identify aspects that make valuation in cities especially challenging:

4.3.2.1. Intensity of demand

Combined scarcity of ecological infrastructure and high population density leads to increased willingness to pay for ecosystem conservation. Brander and Koetse (2011) found a significant positive effect of population density per square km in the region where the studies were conducted, both for contingent valuation and hedonic pricing studies. In another meta-analysis of wetland valuation studies worldwide found a significant positive effect of population density within a 50 km radius of wetlands on willingness to pay (Brander et al. 2010).

4.3.2.2. Substitution possibilities

Larger substitution possibilities generally reduce the economic value of the ecosystem asset in question. One type of substitution acting this way is that of recreational demand. Willingness to pay for lake and river quality in peri-urban areas in the United Kingdom, Belgium, Lithuania, Denmark, and Norway have found significant positive effect of the distance to the nearest substitute wetland site on willingness to pay for ones respondents' favorite wetland site (Bateman et al. 2011). Valuation of ecological infrastructure in urban areas must also account for substitutes being differentiated by more alternative modes of transport than in rural settings.

A second important type of substitution concerns the possibility of substituting between ecosystem services and man-made services. In densely populated urban areas space is scarce and technologies that provide municipal services in a compact way are often more cost-effective than extensive natural systems. The extent to which natural ecosystem regulating functions can be substituted for man-made technical processes, depends in large part on health and safety standards and legislation (Barton et al. 2012).

4.3.2.3. High heterogeneity

Urban ecosystems show high diversity of inhabitant spatial 'perspectives'. Higher density of population is expected to be associated with a larger number of perspectives, i.e., inhabitants literally experience more sides to the same 'green infrastructure'. For example, i) urban ecosystem services are more likely to exhibit larger spatial variation because of larger fragmentation of vegetation and water bodies, (ii) multiple overlapping disservices such as air pollution and noise are mitigated by green infrastructure, and (iii) there are variation in densities and socio-demographics of populations (Tyrväinen et al. 2005; Escobedo et al. 2011).

Socio-economic and cultural diversity in cities constitute an additional challenge for sound valuation. Housing markets in urban areas can be highly segmented and diversified (DCLG 2007) - socio-cultural diversity varies more over smaller spaces in urban areas

with clustering of similar populations in specific neighborhoods or even streets. A rapidly growing segment of urban populations are ethnic minorities. While a few hedonic property pricing studies have controlled for significant effects on house prices from differences in the presence of ethnic minorities (Costanza et al. 2006a), little is known about ethnic minorities preference for ecological infrastructure (Tyrväinen et al. 2005). Urban green spaces are also likely to have a greater diversity of the age of inhabitants thanks to proximity. Different generations, elderly and young have different mobility and large difference in preferences for e.g. forest structure (Tyrväinen et al. 2005).

4.3.2.4. Dynamism and change

Rapid urban growth raises questions about time-stability of valuation estimates. Trial-retrial studies of contingent valuation of flood control and wetland conservation have found willingness to pay estimates to be statistically similar over a period of five years (Brouwer and Bateman 2005). Urban growth in many cities implies that population density, respondent heterogeneity, substitution options for ecosystem services, incomes, and the scarcity of space change more rapidly than in rural areas and relative to the national average. These factors have also been shown to significantly shape the economic value of green infrastructure (Costanza et al. 2006b; Brander et al. 2010; Sander et al. 2010; Brander and Koetse 2011).

4.3.2.5. Ecosystem disservices

Urban ecosystems do not only produce ecosystem services, but also ecosystem disservices. Ecosystem disservices have been defined as ‘functions of ecosystems that are perceived as negative for human well-being’ (Lyytimäki and Sipilä 2009, p. 311). For example, some common city tree and bush species emit volatile organic compounds (VOCs) such as isoprene, monoterpenes, ethane, propene, butane, acetaldehyde, formaldehyde, acetic acid and formic acid, all of which can indirectly contribute to urban smog and ozone problems through CO and O₃ emissions (Geron et al. 1994; Bolund and Hunhammar 1999; Chaparro and Terradas 2009). Another example are damages to physical infrastructures by e.g. microbial activity decomposing wood constructions, corrosion of stone buildings and statues by bird excrements, breaking up of pavements by

vegetation root systems, or animals digging nesting holes (Lyytimäki and Sipilä 2009). Other important disservices from urban ecosystems include health problems from wind-pollinated plants causing allergic reactions, fear from dark green areas that are perceived as unsafe, especially by women in night-time (Bixler and Floyd 1997; Koskela and Pain 2000; Jorgensen and Anthopoulou 2007), diseases transmitted by domestic animals (e.g. migratory birds carrying so-called avian influenza, cats carrying rabies or tick-borne diseases), and blockage of views by trees standing close to buildings (Lyytimäki et al. 2008; Lyytimäki and Sipilä 2009).

Just as economic benefits may be attributed to ecosystem services, explicit economic costs could be also attributed to economic disservices using similar valuation methods. For example, the avoided cost method could be used to measure health costs from treating pollen-related allergies, restoration costs methods could be used to assess costs from damages by ecosystems and biodiversity in physical infrastructures, and contingent valuation methods could be used to assess willingness to pay by people to avoid physiological stress from green areas in night time, or to remove the trees that are blocking the views of their windows. Just as economic valuation of ecosystem services is used today by environmental scientists and nature lovers to make a case for biodiversity conservation, economic valuation of ecosystem disservices can be used by developers to make a case for the removal of green infrastructure in urban areas.

In some cities it is reasonable to expect that ecosystem disservices are mainly on-site due to congestion (e.g. allergies due to coincidental air pollution and pollen) and competition for habitat space with humans and built infrastructure (e.g. bird droppings, root damage to pavements). On the other hand, regulating ecosystem services are provided by off-site systems at neighborhood and regional scale. We suspect that where this spatial clustering of ecosystem services and disservices is present, a cost benefit analysis of excessively limited spatial scope would have a higher likelihood of showing that costs of green infrastructure exceed benefits.

4.4. Ecosystem services and urban planning

4.4.1. Connecting ecosystem service values to urban policy

Ways in which valuation can inform urban planning include awareness raising, economic accounting, priority-setting, incentive design and litigation broadly reflecting the objectives of ‘recognizing, demonstrating, and capturing value’ as suggested in the TEEB report (TEEB 2010; Barton et al. 2012) (Figure 2).

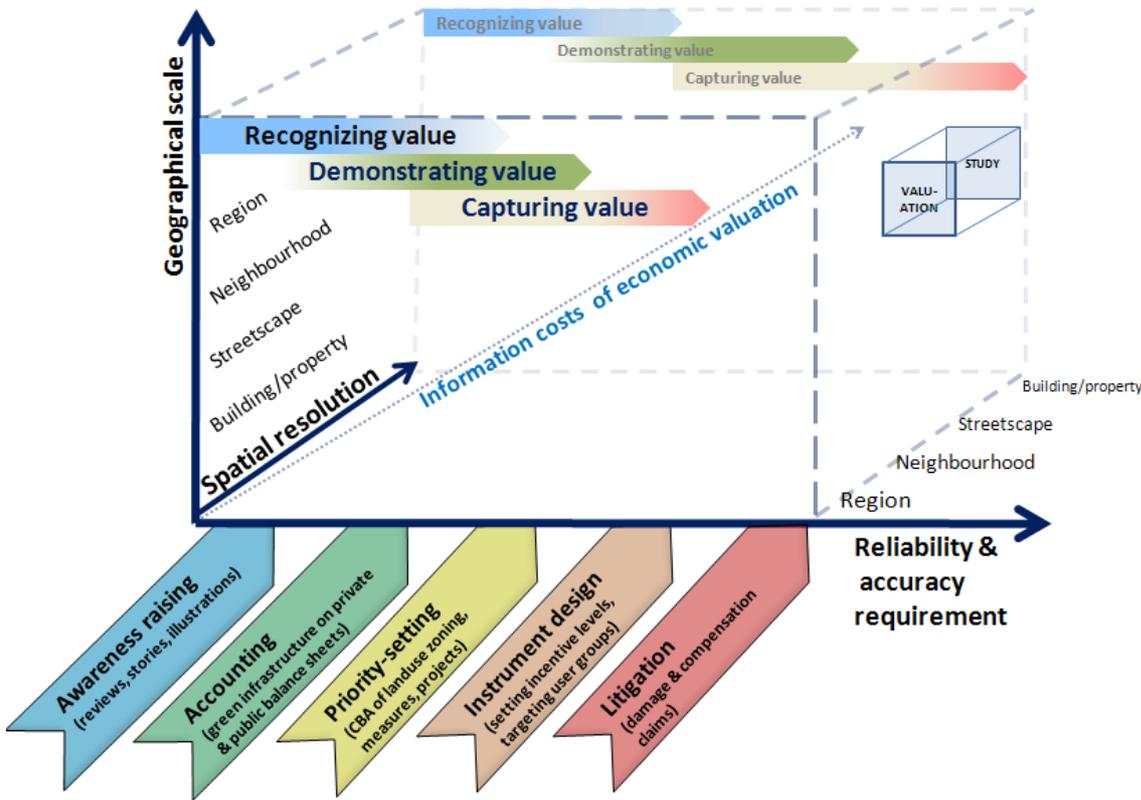


Figure 2. Trade-offs between scale, resolution, reliability and accuracy in recognizing, demonstrating and capturing values in different decision-support contexts of valuation. (Source: Gómez-Baggethun and Barton 2012)

The demands on accuracy and reliability of valuation methods increase when moving from a policy setting requiring simply awareness rising regarding ‘large’ values of green infrastructure, to including green infrastructure in accounting of a municipal governments assets, to priority-setting and location of urbanization, to instrument design - for example

of user fees to finance public utilities, or property taxes to finance urban public goods, to calculation of claims for damage compensation in a litigation setting. While several monetary valuation methods are potentially applicable at different spatial scales (Table 3), valuation studies in urban areas for any given decision-support context are more demanding because of requirements for higher spatial resolution and multiple scales of analysis.

Using valuation of urban ecosystem services for decision about ecological infrastructure requires attributing service values to the particular assets at specific locations. For regulating services this requires some form of spatially explicit biophysical modeling which increases valuation costs with increasing geographical scale and resolution. For example, litigation regarding compensation due to disamenities from the location of undesirable land use such as an airport, requires a high level of accuracy and reliability, a regional scale sample, while calculating e.g. noise nuisance reduction measures due to vegetation at building level resolution. Figure 3 suggests that this is one of the most costly valuation contexts.

4.4.2. Ecosystem services in urban planning and design

A better understanding of ecosystem services, their spatial characteristics and interrelations is very much needed to move ecosystem services from an assessment tool to an instrument for planning and design (e.g. Troy and Wilson 2006). A first step is taken now that ecosystem service research is merging with landscape ecology and spatial planning to address the issue of the scales and structures related to the generation and utilization of ecosystem services (see e.g. Fisher et al. 2009). There are several possible spatial relationships between where an ecosystem service is generated and where and how people may benefit from it. Some services can only be enjoyed at the source, e.g. shading from vegetation or many recreational uses of green areas, others spill over into adjacent areas, e.g. noise reduction, wind breaks and pollination. Such spill-over may be omnidirectional or directional, the latter partly due to the physical geography (waterways, topography, location of roads) and partly dependent on the location of the beneficiaries. The connection between ecosystem service source areas and end-users is mediated by social structures such as infrastructure and access to land. There are a wide range of

solutions for providing the people in different cities with similar ecosystem services and city specific scales of relevance for addressing each ecosystem service.

Spatial scales and landscape structure affect the possibilities and constraints for ecosystem service planning. Efforts to address several services, as seen for example in the desire to create or maintain multifunctional landscapes, at the same time in the same area have seen considerable progress in the last decade. On larger scales access to multiple ecosystem services can be achieved by ensuring generation of different ecosystem services in different parts of the landscape – as long as they are accessible to the users (see Brandt and Vejre 2003). However, the scale in these studies is often coarse and not well suited to pick up the small-scale heterogeneity of the urban landscape. When the potential service providing areas are few and situated in a matrix of many and diverse users the number of services expected from each of these areas is likely to increase. Multiple interests coupled with limited size will highlight trade-offs between services and potentially lead to conflicts.

The urban mosaic is often complex and characterized by long and diverse boundaries between different land-uses. With such heterogeneity relative location and context can be expected to be especially important. Some ecosystem services will rely on species that require easy access to two or more habitat types (e.g. Andersson et al. 2007; Lundberg et al. 2008). For example, Lundberg and others (2008) described how long-term maintenance of an oak dominated landscape with highly valued cultural and aesthetical qualities in Sweden depends also on patches of coniferous forest, the latter providing the main seed disperser, Eurasian Jay (*Garrulus glandarius*), with breeding habitat. Other ecosystem services such as pest control or pollination rely on close proximity to a source area (e.g. Blitzer et al. 2012).

Many ecosystem services are directly mediated or provided by different organisms (Kremen 2005) and can thus be addressed through a focus on these organisms. From a temporal perspective, long-term provisioning of ecosystem services within cities raises concerns about population dynamics including the risks of extinction, at least local, and potential for re-colonization. For many species habitat within cities may be perceived as quite fragmented, suggesting not only that future urban development should try to avoid

further fragmentation but also that increased connectivity should be one of the prime objectives for restoration efforts (Hanski and Mononen 2011). It seems reasonable that the general character of urban green structures should be as close to that of the hinterlands to benefit the most from potential near-city source areas of ecosystem service providing organisms. To draw on these source areas cities need a connected green structure that reaches all the way through urban and peri-urban areas into the rural.

From a spatial perspective at least two distinct strategies for ensuring ecosystem service generation can be identified (see Forman 1995). The first draws on traditional conservation planning and is foremost concerned with enhancing and securing internal values within a bounded area, for example biodiversity or recreational opportunities within a protected area. This approach advocates large areas, and if spatial issues are considered at all it is usually in terms of green area networks where “green areas” are not necessarily the same as ecosystem service generating areas. The second strategy adopts more of a landscape management perspective where the focus is on enhancing the performance of all parts of the landscape (see Fahrig et al. 2011). Instead of the few large areas suggested above this perspective highlights the potential in smaller units interspersed throughout an area, e.g. small clumps of trees mixed with residential development may enhance overall biodiversity or aesthetic values, perhaps especially in the habitats often dismissed as “matrix”. The two approaches are by no means incompatible or always opposing, but their focus, prioritizations and trade-offs differ. Both are needed and address different aspects of conservation and availability of ecosystem services.

4.5. Conclusions

Just as any other social-ecological system, cities depend on ecosystems and their components to sustain long-term conditions for life, health, good social relations and other important aspects of human well-being. In the last years a mounting body of literature has strived to advance our understanding of urban ecosystem services in their biophysical, economic, and socio-cultural dimensions. Furthermore, ecosystem services provided in urban areas were addressed by major initiatives like the Millennium Ecosystem Assessment and The Economics of Ecosystem and Biodiversity, and also have

received increasing attention as part of the policy debate on green infrastructure. Yet, as compared to other ecosystems like wetlands or forests, the attention given to urban ecosystem services has yet been relatively modest and their understanding still constitute an open frontier in ecosystem service research. This chapter has synthesised concepts, methods, and tools to advance the understanding of ecosystem services delivered by urban green infrastructure.

Several aspects can be highlighted from the information synthesised in this chapter. First, there is increasing understanding of the multiple ecosystem services provided by urban ecosystems and green infrastructure. Urban ecosystem services and associated benefits can play a major role improving the quality of life in cities, and include, most notably, regulating services such as air purification, noise reduction, urban temperature regulation, and moderation of climate extremes, and cultural services such as outdoor recreation, environmental learning and cognitive development, social cohesion and sense of place. While provisioning services generally play a secondary role, quality food provided locally by urban allotments is becoming an increasingly important service in some cities.

Although our understanding of the links between urban ecosystems and quality of life in cities is increasing rapidly, important knowledge gaps remain. For example, it has been clearly shown that biodiversity does indeed have positive effects on many ecosystem services (Balnavera et al. 2006) but there is still a large gap in our knowledge on exactly which and how different species contribute to specific ecosystem services in urban environments (see e.g. Pathak et al. 2007; Dzierżanowski et al. 2011). Useful classification and evaluation schemes of urban ecosystem services need to take into account the complex nature of social-ecological systems, including the recognition of ecological thresholds, interdependencies, synergies and trade-offs between different ecosystem functions and services, multiple spatial-temporal characteristics, as well as the variety of beneficiaries and decision contexts in which ecosystems services are evaluated.

Second, urban ecosystem services embody a variety of important social, cultural, and economic values. Consequently, loss of ecosystems and biodiversity in cities may involve important economic and sociocultural impacts. Economic costs from the loss of urban ecosystems derive from the need to restore and maintain public services and supplies

through built infrastructure as similar services provided by urban green infrastructure are lost or degraded. For example, avoided cost methods, show that loss of urban vegetation leads to increased energy costs in cooling in the summer season and loss of water regulation services from land-use change in the city catchments demands the construction of costly water purification plants. It should be also noted, however, that when playing the game of measuring economic values underlying urban ecosystem services, serious economic analysis should not only take into account benefits from ecosystem services, but also the economic costs from ecosystem disservices.

Further negative impacts from the loss of urban ecosystems and biodiversity derive from the effects in social and cultural values, including sense of place, identity and community, social cohesion, and local ecological knowledge. Urban green spaces provide multiple opportunities for social interaction, socialization and outdoor activities. They allow people to benefit collectively from ecosystem services and, in some cities, they are amongst the few remaining urban spaces offering opportunities for enjoyment, recreation, and socialization non based on consumptive activities.

Eliciting and integrating the multiple values of ecosystem services in urban decision-making and planning is essential to secure the sustainability of cities. Whereas the bulk of the literature on ecosystems services valuation has been traditionally focused on biophysical and monetary values, recent contributions have stressed the need to extend the scope of ecosystem services valuation to better include social, cultural and symbolic values (Gómez-Baggethun and Ruiz-Perez 2011; Chan et al. 2012).

Third, urban ecosystem services can play a major role as sources of social-ecological resilience in cities and thereby improving the capacity of urban social-ecological systems to deal with environmental and socio-economic shocks. For example, temperature regulation by urban vegetation can reduce the sometimes severe health impacts of heat waves in cities, natural barriers (such as mangroves, coral reefs and marshlands) can reduce the destructive impacts of storms and waves in coastal areas, and urban allotments can improve food security in times of crises. The fundamental role that biodiversity plays in building resilience needs to be recognized as well as operationalized (Elmqvist et al. 2003; Rockström et al. 2009). Translating the work of biodiversity into ecosystem service

generation and the quantification of resilience e.g. through the mapping of functional- and response diversity, is one of many necessary steps towards operationalizing this knowledge (Jansson and Polasky 2010).

In summary, this chapter suggests that urban green areas should play a major role in the design and development of sustainable cities. Successful implementations of large-scale urban green infrastructure programs, however, requires new knowledge about urban biogeochemical cycles, extended information on the nature of the connections between biodiversity and ecosystem service generation in cities (Jansson 2012), as well as modified and new urban spatial planning tools to meet the numerous challenges posed by the infrastructure for ecosystem services (Gómez-Baggethun and Barton 2012).

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4.6. References

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