Ecological Economics 86 (2013) 235–245

Contents lists available at SciVerse ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Classifying and valuing ecosystem services for urban planning

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ARTICLE INFO

Article history:
Received 9 January 2012
Received in revised form 28 August 2012
Accepted 31 August 2012
Available online 30 October 2012

Keywords:
Cities
Urban ecosystems
Ecosystem services
Ecosystem disservices
Resilience
Valuation
Green infrastructure
Urban planning

ABSTRACT

While technological progress has fostered the conception of an urban society that is increasingly decoupled from ecosystems, demands on natural capital and ecosystem services keep increasing steadily in our urbanized planet. Decoupling of cities from ecological systems can only occur locally and partially, thanks to the appropriation of vast areas of ecosystem services provision beyond the city boundaries. Conserving and restoring ecosystem services in urban areas can reduce the ecological footprints and the ecological debts of cities while enhancing resilience, health, and quality of life for their inhabitants. In this paper we synthesize knowledge and methods to classify and value ecosystem services for urban planning. First, we categorize important ecosystem services and disservices in urban areas. Second, we describe valuation languages (economic costs, socio-cultural values, resilience) that capture distinct value dimensions of urban ecosystem services. Third, we identify analytical challenges for valuation to inform urban planning in the face of high heterogeneity and fragmentation characterizing urban ecosystems. The paper discusses various ways through which urban ecosystems services can enhance resilience and quality of life in cities and identifies a range of economic costs and socio-cultural impacts that can derive from their loss. We conclude by identifying knowledge gaps and challenges for the research agenda on ecosystem services provided in urban areas.

1. Introduction

More than half of the world's population lives in cities (Dye, 2008) and more than two thirds are expected to live in cities by 2050 (UN, United Nations, 2010). Concentration of population in cityscapes dominated by technology and built infrastructure has fostered the conception of an urban society that is increasingly decoupled and independent from ecosystems (Ausubel, 1996). However, demands on natural capital and ecosystems services keep increasing steadily in our urbanized planet (Ayres and van den Bergh, 2005; Guo et al., 2010; Krausmann et al., 2009). Furthermore, extensive research has shown that decoupling of cities from ecological systems can only occur locally and partially, thanks to the appropriation of vast areas of ecosystem services provision beyond the city boundaries (Folke et al., 1997; Rees, 1992; Rees and Wackernagel, 1996). Just as any other social–ecological system, cities depend on ecosystems and their components to sustain long-term conditions for life (Odum, 1989), health (Maas et al., 2006; Tzoulas et al., 2007), security (Costanza et al., 2006a; Dixon et al., 2006), good social relations (EEA, European Environmental Agency, 2011) and other important aspects of human well-being (TEEB, The Economics of Ecosystems and Biodiversity, 2011).

Urban ecosystems are still an open frontier in ecosystem service research. Since the seminal article by Bolund and Hunhammar (1999) was published in this journal, a mounting body of literature has strived to advance our understanding of urban ecosystem services in their biophysical (Escobedo et al., 2011; Pataki et al., 2011), economic (Jim et al., 2009; Sander et al., 2010), and socio-cultural dimensions (Chiesura, 2004; Andersson et al., 2007; Barthel et al., 2010). Ecosystem services provided in urban areas were addressed by major initiatives like the Millennium Ecosystem Assessment (McGranahan et al., 2005) and The Economics of Ecosystems and Biodiversity (TEEB, The Economics of Ecosystems and Biodiversity, 2011), and have received increasing attention as part of the policy debate on green infrastructure (DG Environment, 2012). Yet, as compared to other ecosystems like wetlands or forests, the attention given to urban ecosystems is relatively modest. Most studies on the topic have focused on single ecosystem services and/or value dimensions. For example, whereas monetary values have been broadly examined in the literature, description or measurement of symbolic, cultural, identity and other non-economic values remain largely unexplored (Chan et al., 2012). This is also the case for the 'insurance value' stemming from the contribution of urban ecosystems and green infrastructure to the resilience of cities. To our knowledge there is also little understanding of the additional challenges to

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0921-8009/$ – see front matter
http://dx.doi.org/10.1016/j.ecolecon.2012.08.019

the valuation in urban ecosystems, characterized by high complexity, heterogeneity, and fragmentation (Pickett et al., 2001.

In an attempt to address these knowledge gaps, this paper draws on recent developments in ecosystems service research to synthesize knowledge to classify and value ecosystem services for urban planning. Specifically, we i) categorize the most relevant ecosystem services and disservices provided in urban and peri-urban areas, ii) identify economic and non-economic values associated to urban ecosystem services, and iii) examine challenges in measuring and articulating ecosystem service values in urban planning.

Ecosystem services are defined as benefits that humans obtain from ecosystem functions (de Groot et al., 2002; MA, Millennium Ecosystem Assessment, 2003), or as direct and indirect contributions from ecosystems to human well-being (TEEB, The Economics of Ecosystems and Biodiversity, 2010). The range of our inquiry is restricted to 'urban ecosystem services', defined here as those provided by urban ecosystems and their components. Urban ecosystems are those where the built infrastructure covers a large proportion of the land surface, or those in which people live at high densities (Pickett et al., 2001). They include all 'green and blue spaces' in urban areas, including parks, cemeteries, yards and gardens, urban allotments, urban forests, wetlands, rivers, lakes, and ponds. Definitions of urban areas and their boundaries vary between countries and regions, depending on land use type, total population, population density, distance between dwellings, and percentage employment outside the primary sector. Given that many ecological fluxes and interactions extend well beyond the urban boundaries defined by political or biophysical reasons, urban ecosystems are defined here in the broader sense that comprises the hinterlands directly managed or affected by the energy and material flows from the urban core and suburban lands, including city catchments, and peri-urban forests and cultivated fields (see Pickett et al., 2001, p.129). Because in the urban context ecosystems are by definition highly modified and fragmented, our analysis is not restricted to ecosystems as such, but also includes specific ecosystem components involved in the delivery of services such as individual trees, water surfaces, and soil surfaces (Nowak and Crane, 2002).

In public policy discourse, urban ecosystems are often portrayed as 'green infrastructure' (EEA, European Environmental Agency, 2011; DG Environment, 2012). This metaphor 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). Urban ecosystems may be seen as a broader concept in the sense that they can also include community-driven forest or river/lake areas close or within the city boundaries as well as private gardens not directly subjected to public urban planning.

The paper is structured in four main sections. Section 2 classifies and describes ecosystem services and disservices provided in urban areas. Section 3 discusses the range of economic and non-economic values associated to urban ecosystem services provided and identifies methods and tools by which such values may be elicited and quantified. Section 4 discusses the scope and limits of valuation methods in urban planning and identifies additional challenges for valuation in urban ecosystems. Section 5 synthesizes our main findings and points out priorities for the research agenda in urban ecosystem assessments.

2. Classifying Ecosystem Services Provided in Urban Areas

Building on previous categorizations of ecosystem services (Daily, 1997; de Groot et al., 2002; MA, Millennium Ecosystem Assessment, 2003) the TEEB report identifies 22 types of ecosystem services grouped in four categories: provisioning, regulating, habitat, and cultural and amenity services (TEEB, The Economics of Ecosystems and Biodiversity, 2010). Because different habitats provide different types of ecosystem services, general classifications need to be adapted to specific types of ecosystems (MA, Millennium Ecosystem Assessment, 2003). For example, if agroecosystems are critical for food production, wetlands for nutrient cycling, and forests for carbon sequestration, 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 (Bolund and Hunhammar, 1999). Which ecosystem services in a given city are most relevant varies greatly depending on the environmental and socio-economic characteristics of each site. For example, natural barriers to buffer environmental extremes are critical for cities located in or close to coastal areas (e.g. New Orleans); air quality regulation can be of significance in cities severely polluted due for instance to topography of heat inversions (e.g. Santiago de Chile), but may be of secondary importance in cities where atmospheric pollution is favored by topography, as well as policy (e.g. Helsinki). Similarly, while urban green areas will generally play a secondary role in tourism, emblematic city parks can be an important part of the portfolio of attractions valued by city tourists (e.g. the Central Park in New York). A classification of ecosystem functions and services in urban areas with examples of proxies and indicators for biophysical measurement is provided in Table 1. For a comprehensive framework for urban ecosystem services indicators see Dobbs and Escobedo (2011).

2.1. Food Supply

Urban farming takes place in peri-urban fields, rooftops, backyards, and in community vegetable and fruit gardens (Andersson et al., 2007). In general, cities only produce a small share of the total amount of food they consume. However 'for many of today's urban dwellers, urban agriculture provides an important source of food and supplementary income' (McGranahan et al., 2005: 810). Urban allotments also play a role in food security and resilience, especially in periods of crises (Barthel et al., 2010; Barthel and Isendahl, 2013). For example, Altieri et al. (1999) estimated that, in 1996, food production in urban gardens of Havana included 8500 tons of agricultural products, 7.5 million eggs and 3650 tons of meat.

2.2. Water Flow Regulation and Runoff Mitigation

Ecosystems play a fundamental role in providing 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 (Higgens et al., 1997). Increasing the impermeable surface area in cities reduces the capacity of water to percolate in soils, increasing the volume of surface water runoff and thus increasing the vulnerability to water flooding (Villarreal and Bengtsson, 2005). Interception of rainfall by tree canopies slows down flooding effects and green pavements/soft lanes reduce the pressure on urban drainage systems by percolating water (Bolund and Hunhammar, 1999; Pataki et al., 2011).

2.3. Urban Temperature Regulation

The so-called 'urban heat island effect' consists of local rises in the temperature of city areas caused by greenhouse gas emission from heating and traffic in combination with heat absorption by built surfaces (Moreno García, 1994). Urban blue and green space regulates local temperatures (Hardin and Jensen, 2007). Water areas absorb heat in summer time and release it in winter (Chaparro and Terradas, 2009) and vegetation absorbs heat from the air through evapotranspiration, particularly when humidity is low (Hardin and Jensen, 2007). Urban trees moderate local temperatures by providing humidity and shade (Bolund and Hunhammar, 1999).

2.4. Noise Reduction

Traffic, construction and other human activities make noise a major pollution problem in cities, affecting health through physiological and

Table 1
Classification of important ecosystem services in urban areas and underlying ecosystem functions and components.

Functions and components	*Ecosystem service*	*Examples*	*Examples of indicators/proxies*	*References*
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)	Villarreal 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 × 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)
Filtering and fixation of gases and particulate matter	Air purification	Removal and fixation of pollutants by urban vegetation in leaves, stems and roots	O_3, SO_2, NO_2, CO, and PM_{10} µm removal (tons yr^{-1}) multiplied by tree cover (m^2)	Chaparro and Terradas (2009)
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 (2011)
Carbon sequestration and fixation in photosynthesis	Climate regulation	Carbon sequestration and storage by the biomass of urban shrubs and threes	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 provide habitat for birds, insects, and pollinators	Species diversity and abundance of birds and bumble bees	Andersson et al. (2007)
Ecosystems with recreational and educational values	Recreation and cognitive development	Urban parks provide multiple opportunities for recreation, meditation, and pedagogy	Surface of green public spaces (ha)/inhabitant (or every 1000 inhabitants)	Chiesura (2004)
Habitat provision for animal species	Animal sighting	Urban green space 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.
Source: Own elaboration based on literature review.

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; Ishii, 1994; 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 (Chaparro and Terradas, 2009).

2.5. Air Purification

Air pollution from transport, industry, domestic heating, and waste incineration is responsible for increases in respiratory and cardiovascular diseases in cities (Sunyer et al., 2002). Vegetation in urban areas improves air quality by removing pollutants from the atmosphere, including ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and particulate matter less than 10 µm (PM_{10}) (Nowak, 1994a; Escobedo et al., 2008). Removal of pollutants operates through filtration of particulates through the leaves of trees and shrubs (Nowak, 1996). Removal rates follow both daily and seasonal variation; during the night the stomas are closed and do not absorb pollutants; deciduous forest shed leaves during the winter.

2.6. Moderation of Environmental Extremes

Ecosystems such as mangroves act as natural barriers that buffer cities from extreme climate events and hazards, including storms, waves, floods, hurricanes, and tsunamis (Farber, 1987; Danielsen et al., 2005; Costanza et al., 2006a; Kerr and Baird, 2007). Vegetation stabilizes the ground reducing the likelihood of landslides. Likewise, as discussed above, cooling effects by urban vegetation can buffer the impact of heat waves in cities (Hardin and Jensen, 2007).

2.7. Waste Treatment

Ecosystems filter out, retain and decompose nutrients and organic wastes for urban effluents through dilution, assimilation and chemical re-composition (TEEB, The Economics of Ecosystems and Biodiversity, 2011). Ponds, for example, filter wastes from human activities reducing the level of pollution in urban waste water (Karathanasis et al., 2003), and urban streams retain and fix nutrients from organic waste. Plant communities in urban soils can play an important role in the decomposition of many labile and recalcitrant litter types (Vauramo and Setälä, 2011).

2.8. Climate Regulation

Emissions of greenhouse gases in cities include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2), chlorofluorocarbons, and tropospheric ozone (O_3). Urban trees act as a sinks of CO_2 by storing excess carbon as biomass during photosynthesis (Birdsey, 1992; Nowak, 1994b; Jo and McPherson, 1995; McPherson, 1998; McPherson and Simpson, 1998). The amount of CO_2 stored is proportional to the biomass of the trees (Chaparro and Terradas, 2009).

2.9. Pollination and Seed Dispersal

Urban ecosystems are heterogeneous patchy mosaics of habitats where biodiversity in specific taxonomic groups can be surprisingly high (McKinney, 2008; Muller et al., 2010). For example, urban systems host important populations of birds (Melles et al., 2003), and bees (Saure, 1996; Tommasi et al., 2004), thereby maintaining processes of pollination and seed dispersal. Research has shown that management practices of biodiversity in allotment gardens, cemeteries, and city parks promote functional groups of insects and birds, also enhancing pollination and seed dispersal (Andersson et al., 2007).

Table 2
Examples of ecosystem disservices in urban areas.

Ecosystem functions	*Disservice*	*Examples*	Indicators	References
Photosynthesis	Air quality problems	City tree and bush species emit volatile organic compounds (VCOs)	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 Sipilä (2009)
Habitat provision for animal species	Habitat competition with humans	Animals/insects perceived as scary, unpleasant, disgusting	Abundance of insects, rats, etc.	Bixler and Floyd (1997)

Own elaboration based on literature review.

2.10. Recreation and Cognitive Development

People often choose where to spend their leisure time based on the characteristics of the natural landscapes in a particular area (Chiesura, 2004; Kaplan, 1983; Kaplan and Kaplan, 1989). Green spaces in urban areas provide multiple opportunities for physical exercise, improved mental health, and cognitive development. For example, allotment gardens are often used for environmental education (Groening, 1995; Tyrväinen et al., 2005), and important bodies of local ecological knowledge have been documented in cities (Andersson et al., 2007; Barthel et al., 2010). Because urban inhabitants develop affective links to the ecological sites of their cities, urban ecosystems also play an important role in sense of place (Altman and Low, 1992).

2.11. Animal Sighting

Some urban ecosystems include large numbers of birds (Melles et al., 2003), butterflies (Blair and Launer, 1997), amphibians (Beebee, 1979), and other species that many urban inhabitants like to see in streets, parks, and gardens. Diversity may peak at intermediate levels of urbanization, at which many native and nonnative species thrive, but it typically declines as urbanization intensifies (Blair, 1996).

2.12. Ecosystem Disservices

Urban ecosystems do not only produce services, but also 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 O_3 emissions (Geron et al., 1994; Chaparro and Terradas, 2009). Another important disservice from urban biodiversity is damage 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 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 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 ecosystem disservices in urban areas is provided in Table 2.

3. Valuing Ecosystem Services in Urban Areas

Classifications of ecosystem service values can vary greatly depending on the axiological, ontological, and epistemological positions adopted at the outset (Gómez-Baggethun and de Groot, 2010; TEEB, The Economics of Ecosystems and Biodiversity, 2010). Here we endorse a 'value pluralism' perspective, which maintains that valuation processes in social-ecological systems involve dealing with multiple and often conflicting valuation languages, whereby values may be combined to inform decisions but may not be reduced to single metrics (Martínez-Alier et al., 1998; Chan et al., 2012). Consequently, we analyze economic, socio-cultural, and insurance values of urban ecosystem services as distinct value dimensions. Defining conditions and contexts where different values may (or may not) be compressed into single units, and defining epistemological boundaries within which different valuation approaches can be consistently combined, are critical tasks for the ecological economics research agenda (Douai, 2009; Spash, 2012), but they are beyond the scope of this paper. Below, we examine how different values of ecosystem services provided in urban areas may be captured and measured, and how they can be used to inform urban planning.

3.1. Economic Values

Loss of ecosystem services in urban areas often involves economic costs in one form or another (TEEB, The Economics of Ecosystems and Biodiversity, 2010; Boyer and Polasky, 2004; Tyrväinen et al., 2005; EEA, European Environmental Agency, 2011; Escobedo et al., 2011). Avoided cost methods, for example, 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 demands the construction of costly water purification plants (Daily and Ellison, 2002).

Additional economic costs arise from health problems related to loss of ecosystem services like air purification (McPherson et al., 1997; Nowak and Crane, 2002; Escobedo and Nowak 2009), noise reduction by vegetation walls (Bolund and Hunhammar, 1999), carbon sequestration by urban trees (McPherson et al., 1999; Jim et al., 2009), buffering

Table 3
Biophysical and economic accounts for the ecosystem services air purification, urban cooling, and climate regulation. Examples from studies conducted in Europe and United States.

Ecosystem service	City	Biophysical accounts	Economic value estimates	Valuation model	Reference
Air purification	Barcelona, Spain	305.6 t/y	€1,115,908	Avoided costs/UFORE	Chaparro and Terradas (2009)
	Chicago, USA	5575 t/y	US$ 9.2 million	Avoided costs/C-BAT	McPherson et al. (1997)
	Modesto, USA	154 t/y; 3.7 lb/tree	US$1.48 million US$16/tree	Willingness to pay	McPherson et al. (1999)
	Sacramento, USA	1457 t/y	US$28.7 million US$1500/ha	Avoided costs	Scott et al. (1998)
	Philadelphia, USA	802 t/y	US$ 3.9 million/y	Avoided costs	Nowak et al. (2007)
Urban cooling /heating	Chicago, USA	0.5 GJ/tree (cooling) 2.1 GJ/tree (heating)	US$15/tree US$10/tree US$50–90 per dwelling unit	Avoided costs/C-BAT	McPherson et al. (1997)
	Modesto, USA	110,133 Mbtu/y; 122 kWh/tree	US$870,000 US$10/tree	Avoided costs	McPherson et al. 1999
	Sacramento, USA	157 GWh (cooling) 145 TJ (heating)	US$18.5 mill/y US$ 1.3 mill/y	Avoided costs	Simpson (1988)
Climate regulation (t of C/y)	Barcelona, Spain	Storage: 113,437 t Sequestration: 6187 t/y; 5422 t/y (net)	Not assessed	Avoided costs/UFORE	Chaparro and Terradas (2009)
	Modesto, USA	13,900 t 336 lb/tree	US$ 460,000 US$ 5/tree	Avoided costs	McPherson et al. (1999)
	Philadelphia, USA	Storage : 530,000 t Sequestration 16,100 t /y	US$ 9.8 million US$ 297,000	Avoided costs/UFORE	Nowak et al. (2007)
	Washington, USA	572 t/y 1.0 t/ha/y	US$ 13,156	Avoided costs/UFORE	Nowak and Crane (2002)
	Chicago, USA	Storage: 5.6 million t (14–18 t/ha)	Not assessed	Avoided costs/C-BAT	McPherson et al. (1997)

PM: particulate matter. UFORE: Urban Forest Effects model; C-BAT: Cost–Benefit Analysis of Trees. When pollutants are not specified, calculations include NO_2, SO_2, PM_{10}, O_3 and CO). Note: Figures were not converted to net present values and should be taken as illustration only.

of climate extremes by vegetation barriers (Costanza et al., 2006a), and water flow regulation (Xiao et al., 1998). It should be noted, however, that when playing the game of economic values, serious economic analysis should not only take into account benefits from ecosystem services, but also the economic costs from ecosystem disservices.

Yet, because at the margin ecosystem services can be largely substituted by economic services from built infrastructure and because traditional economic accounts neglect the costs of replacing ecosystems services once they are lost or degraded, costs from ecosystem service decline are often overseen in municipal budgets and planning.[1] The invisibility of these costs can result in incentives for undesirable conversion of urban ecosystems into built infrastructure, with associated loss of ecosystem services. Table 3 shows examples of economic measurement of urban ecosystems services values in both biophysical and pecunary terms.

Using combinations of valuation methods is necessary to address multiple ecosystem services (Boyer and Polasky, 2004; Costanza et al., 2006b; Escobedo et al., 2011). Avoided expenditure or replacement costs are often used to address values of regulating services of trees such as air purification and climate regulation (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 to value ecosystem services in cities (Boyer and Polasky, 2004; 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 (Tyrvänien, 2000); views and aesthetic benefits (Anderson and Cordell, 1985; Sander et al., 2010); noise reduction (McMillan et al., 1980; Day et al., 2003; Kim et al., 2007); air quality (Chattopadhyay, 1999; Bible et al., 2002; Bayer et al., 2009; Smith and Huang, 1995), 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 neighborhood scales had been assessed (open space, open space vegetation and trees, water and wetlands), whereas features at regional scales (property rights), streetscape (pavement type, temperature) and building level (energy efficiency, roofing type) were less common. In Table 4 we show valuation methods that have been and potentially could be applied to urban planning issues at the different scales. A few broad conclusions can be drawn from the literature. Stated preference methods are potentially applicable at all scales, although their main use has been at regional scale. Travel cost methods application seems limited by the large number of substitute sites and alternative modes of travel to urban recreation sites. All valuation methods are challenged by the costs of conducting representative, large scale, high spatial resolution studies in urban settings. This applies particularly to production function and damage function approaches. Methodological challenges to applying monetary valuation methods in urban settings at different scales are further discussed in Section 4.2.

3.2. Social and Cultural Values

People hold moral, spiritual, educational, aesthetic, place-based, and other values towards the urban environment, all of which can affect their attitudes and actions toward ecosystems and the services they provide (MA, Millennium Ecosystem Assessment, 2003). These values reflect emotional, affective, and symbolic views attached to urban nature that in most cases cannot be adequately captured by commodity metaphors or monetary metrics (Martínez-Alier et al., 1998; Norton and Hannon, 1997).

Social and cultural values are most directly associated to the category of cultural ecosystem services, and may include place values, sense of community and identity, physical and mental health, social cohesion, and educational values (Chiesura, 2004; Chan et al., 2012).

[1] The 'blindness' of traditional economic accounts to the costs of ecosystem service loss has been used to make a case for the internalization of ecosystem services in markets. In the view of the authors this response to the problem is in most cases misleading (see e.g. Gómez-Baggethun et al., 2010b; Gómez-Baggethun and Ruiz-Pérez, 2011). What the underestimation of ecosystem services reveals is not a 'zero price problem', but the way some 'value articulating institutions' allocate little or no weight to particular value types in decision-making and planning.

Table 4
Economic valuation of ecosystem services in urban planning at different scales.

Scale	Urban planning issue	Role of economic valuation	Economic valuation methods HP	TC	PF/DF	RC	SP	Selected methodological challenges
Region	Prioritising urban growth alternatives between different areas	Valuing benefits and costs of (i) urban revitalisation (ii) urban infill (iii) urban extension (iv) suburban retrofit (v) suburban extension (vi) new neighbourhoods, with (vii) existing infrastructure (ix) new infrastructure (x) in environmentally sensitive areas					potential	Comprehensive benefit-cost analysis at multiple scales and resolutions at multiple locations is expensive.Spatial multi-criteriaanalysis as alternative.
	Fair and rational location of undesirable landuses (LULUs)	Value of the disamenities of e.g. powerplants and landfills	potential		currently used		currently used	Using benefit-cost analysis to allocate 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	potential				currently used	Large import substitution possibilities for locally produced food
	Preservation of peri-urban forest, water bodies	Willingness to pay for preservation of recreational areas/sites	potential	currently used			currently used	Large substitution possibilities for alternative recreation alternatives
	Water availability to support urban growth	Valuation to support full cost pricing of water supply. Incentive effects of removing water subsidies.				currently used	currently used	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	potential				potential	Using real estate prices versus opportunity costs of foregone farm production versus landowner perceptions of opportunities
Neighbourhood	Preserving views, open spaces, parks and trees in public places	Willingness to pay of households for quality and proximity of recreational spaces	currently used				currently used	Accounting for substitute sites an.d recreational activities Spatial autocorrelation of neighbourhoodamenities
	Conserving soil drainage conditions and wetlands	Valuation of replacement costs of man-made drainage and storage infrastructure; floodand landslide damage			currently used	currently used	potential	Hydrological and hydraulic modeling required
	Conserving water and urban wetlands	Costs of household water harvesting, recycling and xeriscapes, constructed wetlands	currently used			currently used	potential	Cost-benefit evaluation requires comparison with full costs of water supply (see regional analysis)
	Natural corridors	Benefits of habitat conservation; opportunity costs to urbanisation	potential			potential	potential	Difficulty in specifying habitat connectivity requirements of corridors
	Local farm produce Edible gardens	WTP for local, fresh produce. Recreational value of home gardens			potential	potential	potential	Large import substitution possibilities for locally produced food
Street-scape	Street trees	Value pedestrian safety through slowing traffic; disamenities of heat islands; absorption of stormwater, and airborne pollutants, WTP for healthamenities			currently used	currently used	potential	Associating ecosystem service values at neighbourhood level to individual trees.
	Green pavements for stormwater management	Willingness to pay of households for green streetscape; additional costs of larger dimension stormwater			potential	potential	potential	Associating ecosystem service values at neighbourhood level to individual pavements
Building	Green roof tops Yard trees Lawns vs. xeriscapes	Additional costs of traditional stormwater manage-ment; mitigation of heat island			potential	potential	potential	Associating ecosystem service values at neighbourhood and street level to individual roofs, trees and lawns

currently used potential probably not relevant

Note: Valuation methods: HP: Hedonic pricing; TC: travel cost; AC avoided cost including production or damage function methods; RC: replacement cost; SP: stated preference methods.
Source: urban planning issues selected by the authors based on a listing by Duany et al. (2010). Evaluation of valuation methods based on literature review and authors own evaluation.

Sense of place emerges from the emotional and affective bonds between people and ecological sites (Altman and Low, 1992; Feldman, 1990; Williams et al., 1992, Norton and Hannon, 1997); place attachment is a source of social cohesion, shared interests, and neighborhood participation (Bennett, 1997; Gotham and Brumley, 2002); sense of community relates to the feelings towards a group and strength of attachment tocommunities (Chavis and Pretty, 1999). In many places, ecosystems and biodiversity are deeply intertwined with spiritual values (Stokols, 1990), but we would expect spiritual values associated with urban ecosystems to be less prevalent, in the sense that they are often substituted by spiritual values for religious buildings and monuments, rather than natural features.

Social and cultural values may be difficult to capture and measure, often demanding the use of qualitative assessments, constructed scales, or narrations (Patton, 2002; Chan et al., 2012). In some cases academics have developed methods to quantify some cultural values such as sense of place (Williams and Roggenbuck, 1989; Shamai, 1991) and traditional ecological knowledge (Gómez-Baggethun et al., 2010a) making use of scores and constructed scales. In other cases translating cultural values into quantitative metrics may be too difficult or simply senseless. Most often, elicitation of social and cultural values in urban areas may require some sort of deliberative process and the use of locally defined metrics, values, and guiding principles.

Articulation of social and cultural values into decision-making processes can be particularly challenging in urban areas because of the very high cultural and social heterogeneity. For this reason, we would also expect values of sense of place, community, and social cohesion to be more diverse in urban settings vis a vis rural and wild areas.

3.3. Insurance Value

With increased intensity and frequency of environment extremes affecting urban areas as a consequence of climate change (Meehl and

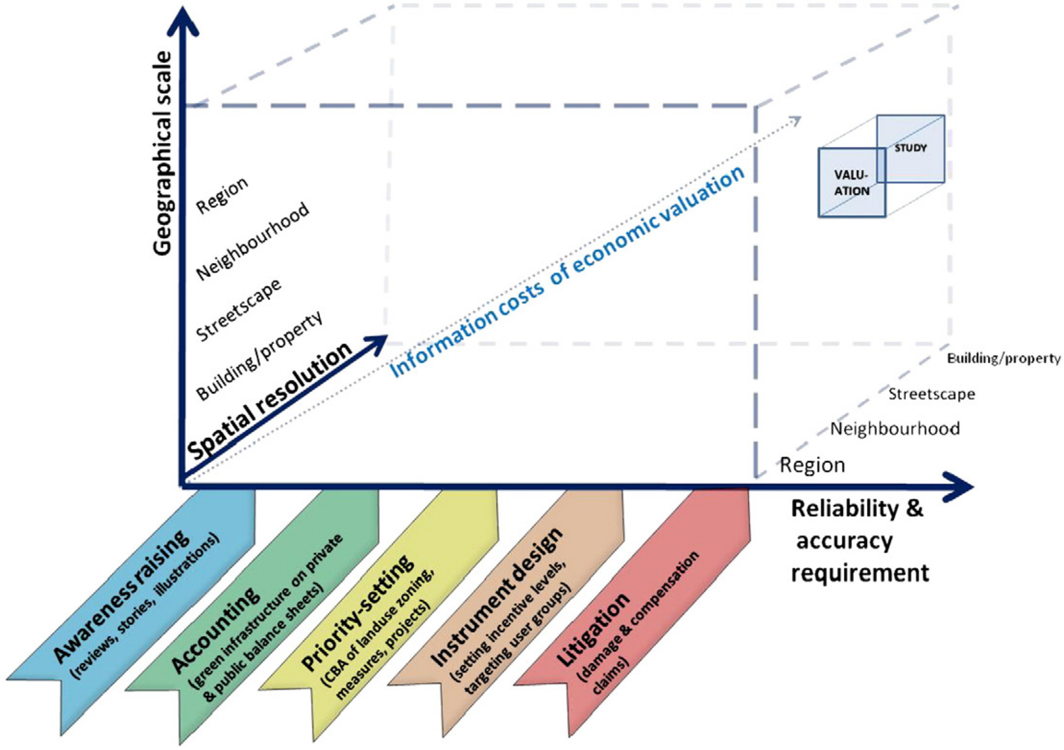

Fig. 1. Economic valuation of ecosystem services in different urban planning contexts.

Tebaldi, 2004), ecosystem services can play a major role in increasing resilience and adaptive capacity in cities. The contribution of ecosystem services to increase resilience to shocks can be referred to as a form of 'insurance value'.

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, runoff mitigation, and food production. For example, as discussed above, 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, cooling by urban ecosystems becomes an increasingly important buffer to health impacts (Lafortezza et al., 2009).

In some geographical areas and socio-economic contexts, food production in urban allotments can play an important role in increasing resilience to shocks, especially during crisis (Smit and Nasr, 1992; Moskow, 1999; Page, 2002; McGranahan et al., 2005; UNEP, United Nations Development Programme, 1996). In Cuba, for example, urban agriculture increased greatly in response to the decline of Soviet aid 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). Finally, recent contributions have noted the role of urban ecosystems in maintaining living bodies of local ecological knowledge (Andersson, 2006), as well as the importance of this knowledge for maintaining long-term resilience to shocks (Barthel et al., 2010; Gómez-Baggethun et al., 2012). Social movements associated to urban allotments are now emerging in Europe. This phenomenon gains special interest in the context on the economic crises and related uncertainties (Barthel and Isendahl, 2013).

Because changes caused by environmental or socio-economic shocks can be irreversible or costly to reverse, insurance value can also be seen as embedding an economic value (Walker et al., 2010). Yet, available knowledge to value resilience in monetary metrics is limited (Pascual et al., 2010). When systems are close to ecological thresholds, small changes can trigger abrupt shifts in ecosystem service supply (Scheffer et al., 2001; Walker and Meyers, 2004), and thus ecosystem service values can change drastically and in a non-linear way (Limburg et al., 2002). For example, value may increase exponentially as possibilities for substitution are lost as a consequence of crises. This may be the case of food supply by urban allotments. Under normal circumstances the economic importance of this service is small, but if conventional chains of food supply collapse during crises, market substitutes can become very expensive and allotments can make non negligible contributions to meet basic nutritional requirements (Barthel et al., 2010). However, urban food supply systems in general are vulnerable unless peri-urban areas can take on such a role.

4. Valuation and Urban Planning

4.1. Informing Urban Planning Through Ecosystem Services Valuation

Decision contexts in which valuation of ecosystem services can inform urban planning include awareness raising, economic accounting, priority-setting, incentive design, and litigation (TEEB, The Economics of Ecosystems and Biodiversity, 2010; Barton et al., 2012) (Fig. 1).

Economic valuation of ecosystem services increases in cost with increases in the spatial scale and resolution at which biophysical quantification is required, and with the policy requirements for accuracy and reliability. The demands on accuracy and reliability of valuation methods increase successively when moving from a policy setting requiring simply awareness raising (e.g. regarding costs of ecosystem service loss); to including green infrastructure in accounting of municipal assets; to priority-setting (e.g. for location of new neighborhoods); to instrument design (e.g. user fees to finance public utilities); or finally to calculation of claims for damage compensation in a litigation (e.g. sitting of locally undesirable land-uses (LULUs)).

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 in sampling particular assets at specific locations within heterogeneous urban landscapes. For example, a valuation study calculating damage compensation due to nuisances from the location of an airport, requires high data reliability (a regional scale sample) as well as a high level of accuracy to calculate e.g. noise nuisance reduction measures due to vegetation at building level resolution. Fig. 1 suggests that this is one of the costly valuation contexts.

4.2. Challenges to Ecosystem Services Valuation in Urban Planning

High heterogeneity in urban areas poses additional challenges that go beyond the generic trade-offs between scale, resolution, and accuracy which are common to all valuations. Below, we identify some of these challenges.

(i) *Population density*. Combined scarcity of urban ecosystems and high density of beneficiaries lead to increased willingness to pay for ecosystem services protection. 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 a meta-analysis of wetland valuation studies worldwide Brander et al. (2010) found a positive effect of population density within a 50 km radius of wetlands on willingness to pay.

(ii) *Non-linear distance decay of willingness to pay*. In urban settings, non-linear effects may also be extremely local depending on residents' perception of their neighborhood. Sander et al. (2010) observed an increase and then decline in the effect of tree cover on property values up to and then beyond 250 m in a hedonic pricing study in Minnesota. Hedonic pricing studies have also found housing markets and the value of ecological infrastructure derived from these studies to be very segmented (Costanza et al., 2006b).

(iii) *Recreational substitution possibilities*. Larger substitution possibilities generally reduce the value of the asset in question. 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.

(iv) *Substitution possibilities 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 maintaining or restoring extensive natural systems. The extent to which ecosystem regulating functions can be substituted for man-made technical processes, depends largely on health and safety standards and legislation (Barton et al., 2012).

(v) *Heterogeneity 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 urban ecosystems. For example, i) ecosystem services provided by urban green space 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 mitigated by urban ecosystems, and (iii) variation in densities and socio-demographics of populations (Tyrväinen et al., 2005; Escobedo et al., 2011).

(v) *Socio-economic and cultural diversity*. 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 studies have controlled for significant effects on house prices from differences in the presence of ethnic minorities (Costanza et al., 2006a,b), little is known about ethnic minorities preference for urban ecosystems (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).

(vi) *Connectivity/infrastructure value*. Hedonic pricing and contingent valuation studies of green infrastructure have demonstrated the importance of distance and substitutes, but few studies have addressed the economic value of connectivity—the 'infrastructure value'. Studies in the UK have shown that urban parks have a minimum attractive size for visitors of about two hectares and that their attractiveness increases when linked with footpaths (Coles and Bussey, 2000; Tyrväinen et al., 2005). In another example, urban forests effect on heat islands from buildings is limited to 200–400 m on the windward side, making a dense network of green spaces necessary to distribute heat mitigation services (Tyrväinen et al., 2005).

(vii) *Urban growth and time stability of values*. Rapid 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 also shape the economic value of green infrastructure (Costanza et al., 2006b; Brander et al., 2010; Sander et al., 2010; Brander and Koetse, 2011).

(viii) *Multiple environmental stressors*. With multiple stressors in urban environments comes the difficulty of attribution to proximal and underlying causes. For example, air pollution can trigger pollen-related allergies that might otherwise be latent in a person (D'Amato, 2000). Is the welfare loss due to pollen attributed to the trees in the neighborhood, to the air pollution activities, or to the choice of allergy-disposed people to live in urban rather than rural areas?

(ix) *Spatial scale of benefit–cost analysis*. Ecosystem disservices can be especially important in urban contexts (Lyytimäki et al., 2008; Lyytimäki and Sipilä, 2009; Escobedo et al., 2011).

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. 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.

5. Conclusions

We synthesized concepts, methods, and tools to classify and value ecosystem services delivered in urban areas to support decision-making, e.g. by reshaping municipal budgets and guiding land-use planning. Three main insights can be extracted from our review. First, in line with previous literature on the topic, our research shows that there is growing evidence on the positive impacts of urban ecosystem services on quality of life in cities. Regulating and cultural services, including air purification, noise reduction, urban cooling, runoff mitigation, recreation, and contributions to mental and physical heath, showed to be of special importance in urban contexts. Interestingly, even if urban ecosystems provide only a fraction of the total ecosystem services used in cities, high density of beneficiaries relative to existing green infrastructure implies that the social and economic value of services provided locally by urban ecosystems can be surprisingly high.

Second, loss of ecosystems in cities may involve high long-term economic costs and severe impacts on social, cultural, and insurance values associated to ecosystem services. 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. Further negative impacts derive from the effects in social and cultural values, including sense of place, identity and community, social cohesion, and local ecological knowledge. Loss of green infrastructure can also lead to decreases in resilience-related insurance values, increasing the vulnerability of cities to shocks such as heat waves, flooding events, storms, landslides, and even food crises. It should be noted, however, that urban ecosystems do not only provide ecosystem services but also disservices such as pollen causing allergies and breakup of pavements. Rigorous valuation exercises should not only take into account benefits from ecosystem services, but also costs from ecosystem disservices.

Finally, although our review revealed that evidence of the multiple values and benefits sustained by urban ecosystems is expanding rapidly, it also reveals knowledge asymmetries in our capacity to understand and capture specific types of values. A relative abundance of biophysical and economic studies contrasts with the scarcity of studies addressing non-economic values, including social, cultural, and insurance values. Although formally recognized in the ecosystem services literature, these values are rarely addressed at the operational level and little has been said on how the ecosystem services approach may contribute to better incorporate non-economic values in urban planning. Research on urban ecosystem services should broaden its present focus on biophysical and economic measurement so as to better capture and articulate non-economic values in decision making and planning. A further challenge for the research and policy agenda concerns the way different and often irreducible values of urban ecosystem services can be combined and consistently integrated to support decision-making processes at municipality and metropolitan levels.

Acknowledgments

We thank two anonymous reviewers for useful comments to a previous draft of this paper. This research was funded by the ERA-Net BiodivERsA through the Spanish Ministry of Science and Education project 'Urban Biodiversity and Ecosystem Services' (URBES) (PRI-PIMBDV-2011-1179).

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