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Research article

A framework for assessing urban greenery's effects and valuing its ecosystem services

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ABSTRACT

Ongoing urban exploitation is increasing pressure to transform urban green spaces, while there is increasing awareness that greenery provides a range of important benefits to city residents. In efforts to help resolve associated problems we have developed a framework for integrated assessments of ecosystem service (ES) benefits and values provided by urban greenery, based on the ecosystem service cascade model. The aim is to provide a method for assessing the contribution to, and valuing, multiple ES provided by urban greenery that can be readily applied in routine planning processes. The framework is unique as it recognizes that an urban greenery comprises several components and functions that can contribute to multiple ecosystem services in one or more ways via different functional traits (e.g. foliage characteristics) for which readily measured indicators have been identified. The framework consists of five steps including compilation of an inventory of indicator; application of effectivity factors to rate indicators' effectiveness; estimation of effects; estimation of benefits for each ES; estimation of the total ES value of the ecosystem. The framework was applied to assess ecosystem services provided by trees, shrubs, herbs, birds, and bees, in green areas spanning an urban gradient in Gothenburg, Sweden. Estimates of perceived values of ecosystem services were obtained from interviews with the public and workshop activities with civil servants. The framework is systematic and transparent at all stages and appears to have potential utility in the existing spatial planning processes.

1. Introduction

Urbanization has become one of the most extensive and permanent land-use changes globally, causing increasing pressure to transform green spaces in or near cities (UN, 2014; World Bank, 2015). However, urban greenery provides a range of social and environmental services that benefit city residents and visitors (Kabisch et al., 2015). The potential synergies and conflicts arising from the benefits of urban green areas and demand for their exploitation pose challenges for sustainable urban development and initiatives to maintain or improve human well-being. A concept that has received increasing attention and can help efforts to address these challenges is ecosystem services (ES) (Haase et al., 2014; Kabisch et al., 2015; Luederitz et al., 2015). The ES concept

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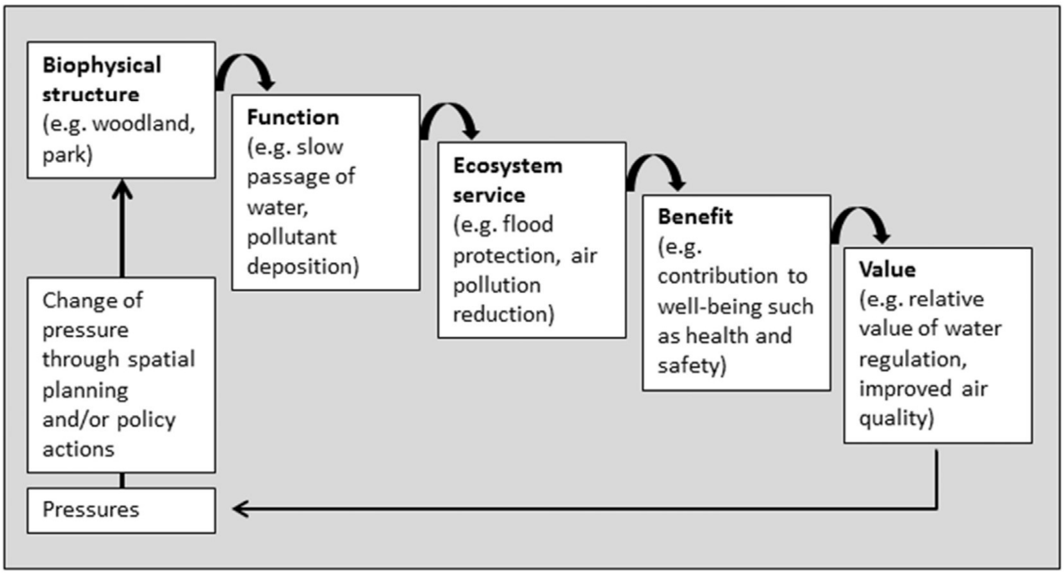

Fig. 1. The cascade model framework for ecosystem valuation modified from TEEB (2010) and Potschin and Haines-Young (2011).**.

embraces all the interlinked aspects of ecological structures with functions that are advantageous to humans (services), and thus contribute to human well-being (benefits) (MEA, 2005; Potschin and Haines-Young, 2011; TEEB, 2010). The ES cascade model may also be helpful. This captures the view that a "production chain" links biophysical structures and processes to the benefits and values of the services a considered system provides (Fig. 1). For example, an ecosystem such as urban woodland may have the capacity (function) of slowing the passage of surface water, thereby reducing flooding in cities (service), which provides benefits to humans. The value of these benefits (and, thus, preceding links in the chain) depends on time- and place-related factors that can be summarised as supply and demand. The cascade model also includes feedback loops, based on assumptions that services' values will impact the ecosystem, e.g. high demand for provisional services will result in high pressure on them. However, the pressure imposed on ecosystems can be modified through policy actions (Potschin and Haines-Young, 2011).

The aims of ES valuation are to unravel the complexities of socio-ecological relationships, recognize how human decisions impact perceived values of services, and express them in units that allow incorporation in planning and decision-making (Mooney et al., 2005; TEEB, 2010). Various methods can be used to estimate the value of ES, all of which have limitations because of the difficulties in quantifying most ES. Their values can be determined in monetary terms, such as current market prices, e.g. market prices for biofuel and timber, or estimates of costs that would be incurred if the services had to be created by artificial means (TEEB, 2010). This direct approach cannot be applied to various other ES (such as well-being and aesthetic appreciation) that do not have any market prices, but their monetary values can be estimated using proxies, e.g. travel costs, or hedonic pricing methods (TEEB, 2010; Goulder and Kennedy, 2011). Alternatively, non-monetary choice preference methods can be used to estimate most non-market ES values. These methods include perception ranking analysis and attitude rating, which are regarded as useful for probing perceived values and preferences regarding possible planning options (e.g. García-Llorente et al., 2008; TEEB, 2010).

In addition, multi-criteria methods for assessing ES based on Corine (Coordination of information on the environment) Land Cover (CLC) have been recently developed. They have been applied, for example, to estimate a region's contribution to provisioning services as well as climate regulation, air quality, water regulation, recreational facilities, aesthetic appeal and biodiversity, based on stakeholder-based weighting to reflect the relative importance of the investigated ES (Koschke et al., 2012). CLC data have also been applied to estimate gradients of cooling potential, carbon sequestration and available recreational area in four European cities (Larondelle and Haase, 2013).

Few studies have covered all the sequential steps related to urban ES, including links between ecological structures, their functions, performance and values to humans (Luederitz et al., 2015). However, during the last decade various models have been developed to quantify and value urban ES. One example is the i-Tree urban forest management tool[2] (developed from the UFORE model, Nowak et al., 2008) for assessing integrated benefits of services provided by urban trees (such as removal of atmospheric carbon dioxide and storm-water reduction), valuing the services in monetary terms. The results have been applied for several purposes, such as assessing and visualizing the benefits of trees and the impact of land use changes (e.g. Nowak et al., 2014a; Hilde and Paterson, 2014).

Despite the availability of models such as the i-Tree model, further development of appropriate methods for integrated quantification of benefits and valuation, including additional potential services and urban biophysical structure components other than trees, is still required (Haase et al., 2014; Luederitz et al., 2015). Further, both CLC- and i-Tree-based analyses require detailed modelling, which may hinder their use in local urban management. To address the requirement for methods that can be more readily applied, we present a method to integrate regulating ES (pollination, local climate regulation, air pollution control, noise reduction, storm water management) and cultural ES, allowing inclusion of additional ES not considered here. The method is a systematic process involving description of urban green structure components (trees, bushes, herbs, bees, birds) contributing to ES through functional trait indicators and a sequence of subsequent steps

[2] www.itreetools.org.

described in the following section.

Our aim is to provide a method for valuing multiple ES provided by urban greenery. The method is intended to be practically applicable in routine planning processes to enable planners to make well-informed trade-offs. It aims, for example, to be used to make rough assessments of effects of potential land use changes and designs in comprehensive plans and detailed land use plans or as a tool to increase the communication between municipal civil servants from different disciplines and units involved in the spatial planning process or to identify gradients and lack of ecosystem services in urban areas.

2. Framework of the method

The method involves several "steps" designed to link measured abundances of urban green structure components to functions delivering ES, by means of functional traits, i.e. phenotypic characteristics of groups of organisms that are considered relevant to such organisms' responses to the environment and/or their effects on ecosystem properties (e.g. Dıaz et al., 2013; Duncan et al., 2015). It should be noted here that mechanistic understanding of various species' contributions to ecosystem functions is crucial for robust assessments of multiple ES (see e.g. Lavorel et al., 2011).

To estimate abundances of functional traits, a number of relevant indicators have been identified. Some of the indicators are directly related to functional traits (e.g. canopy cover), but others are indirect indicators linked to the species' variation. The ES and functional trait indicators were selected according to identified needs for better understanding of relations between functional traits, ES effect and ES values, and the ease of obtaining relevant empirical information.

The framework of the method is based on the cascade model presented by TEEB (2010) and Potschin and Haines-Young (2011), taking into account the effectiveness of indicators' contributions to considered ES. The method is intended to be generically applicable and easy to use in planning processes, environmental impact assessments (EIA), and any other cases where understanding of ecosystems' current or potential services and values is required. It can be applied both for individual sites and estimates of gradients of services or values over a city or other urban area. It involves the following five steps (Fig. 2):

1) Compilation of an inventory of indicator abundances at the site(s)
2) Application of effectivity factors to rate indicators' effectiveness
3) Estimation of the effects for each ES
4) Estimation of the benefits for each ES
5) Estimation of the total ES value at the site(s)

2.1. Steps 1–3 - estimation of effects

To estimate a site's potential contribution to (investigated) ES the abundance of each indicator, e.g. leaf area or the abundance of birds or bee species, and their ability to contribute to the considered service(s) must be estimated. An indicator's ability to contribute to a service is here referred to as the indicator effectivity factor (f(i,j)). The resulting effect, E(i,j) is, calculated using the following equation:

$$E(i,j) = A(i)*f(i,j) \quad (1)$$

where

E(i,j) is the effect (the resulting contribution) to ES j provided by indicator i
A(i) is the abundance of indicator i, and
f(i,j) is the effectivity factor, describing the ability of indicator i to contribute to ES j

2.2. Step 4 – benefit estimation

The benefit $B(i,j)$, of a certain indicator, i, depends both on the estimated effect $E(i,j)$ and the value of the specific ES:

$$B(i,\ j) = \mathrm{E}(i,j)*\ v(j) \quad (2)$$

where v(j) is the perceived value of ES(j).

2.3. Step 5 – total value

The total ES value, V, of ecosystem services assessed at a site is then the sum of the benefits of the considered services:

$$V = \sum B(i,j) \quad (3)$$

Thus, a stepwise process based on the abundance and effectivity of individual functional trait indicators provides a generic framework that can be applied to estimate the total benefit and value of an ecosystem (Fig. 2).

3. Framework application

3.1. Study sites

To test the framework's applicability, it was used to assess the benefit and value of seven green sites in the Swedish city Gothenburg (57°42′N, 11°58′E), which has approximately 540 000 inhabitants. It is a green city, where there is a green area covering ≥10 ha within 300 m of homes of 58% of the population (SCB, 2010). However, there is strong urban densification pressure on the city's green areas (SCB, 2010). The seven study sites (Fig. 3) span a large gradient of urban green spaces, including a suburban forest, old central park, allotment gardens, green yards in a residential area and a small green area surrounded by busy roads and industrial estates (hereafter called infrastructural green space). Detailed information about the study sites is presented in Supplementary Table S1, and the five steps of the analysis are presented in the following sections.

3.1.1. Step 1- compilation of an inventory of indicator abundances

In the first step, the abundance of each selected indicator is estimated. Here, we first describe how the indicators were identified (from the literature) and selected, then how their abundances A(i,j) were empirically estimated at each study site. Both the indicators and empirical methods have been selected for applicability to any urban biophysical structure.

3.1.1.1. Identified regulating ES indicators. Leaf area is an important plant canopy characteristic that is widely applied in ecological analyses and has proven importance for predicting several regulating ES (Dobbs et al., 2011; Gomez-Baggethun and Barton, 2013). These include removal of air pollutants via deposition (e.g. Burkhard et al., 2012), wind reduction and cooling by both shading and transpiration (e.g. Hardin and Jensen, 2007; Konarska et al., 2014). It is also a robust predictor of water storage during and after rainfall events (Keim et al., 2006).

The amount of foliage of a vegetated surface is conventionally

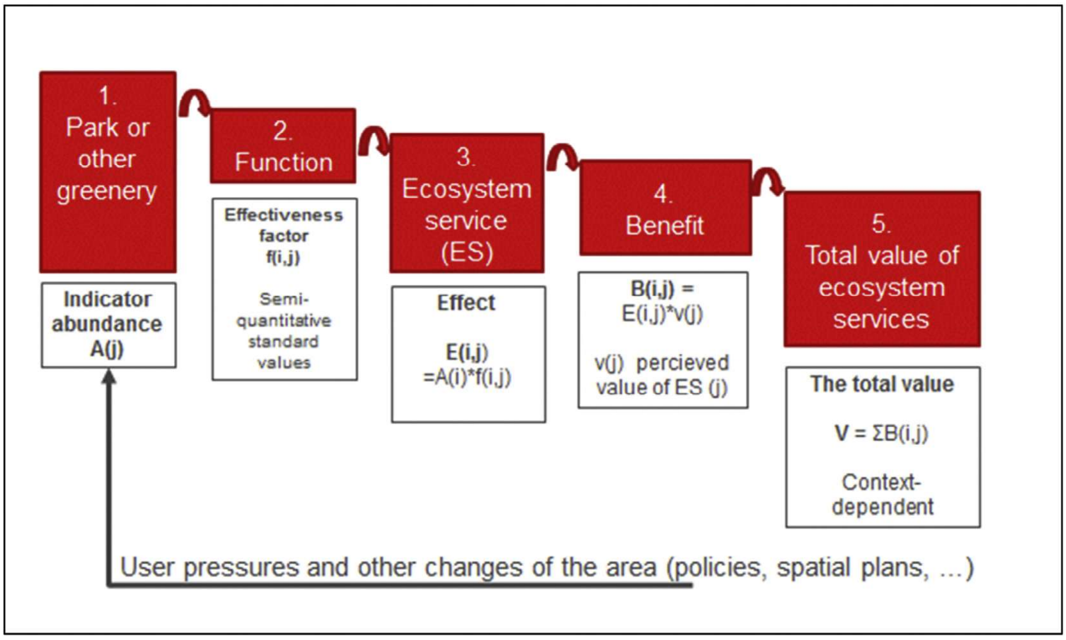

Fig. 2. Framework for benefit assessment and valuation of ES.

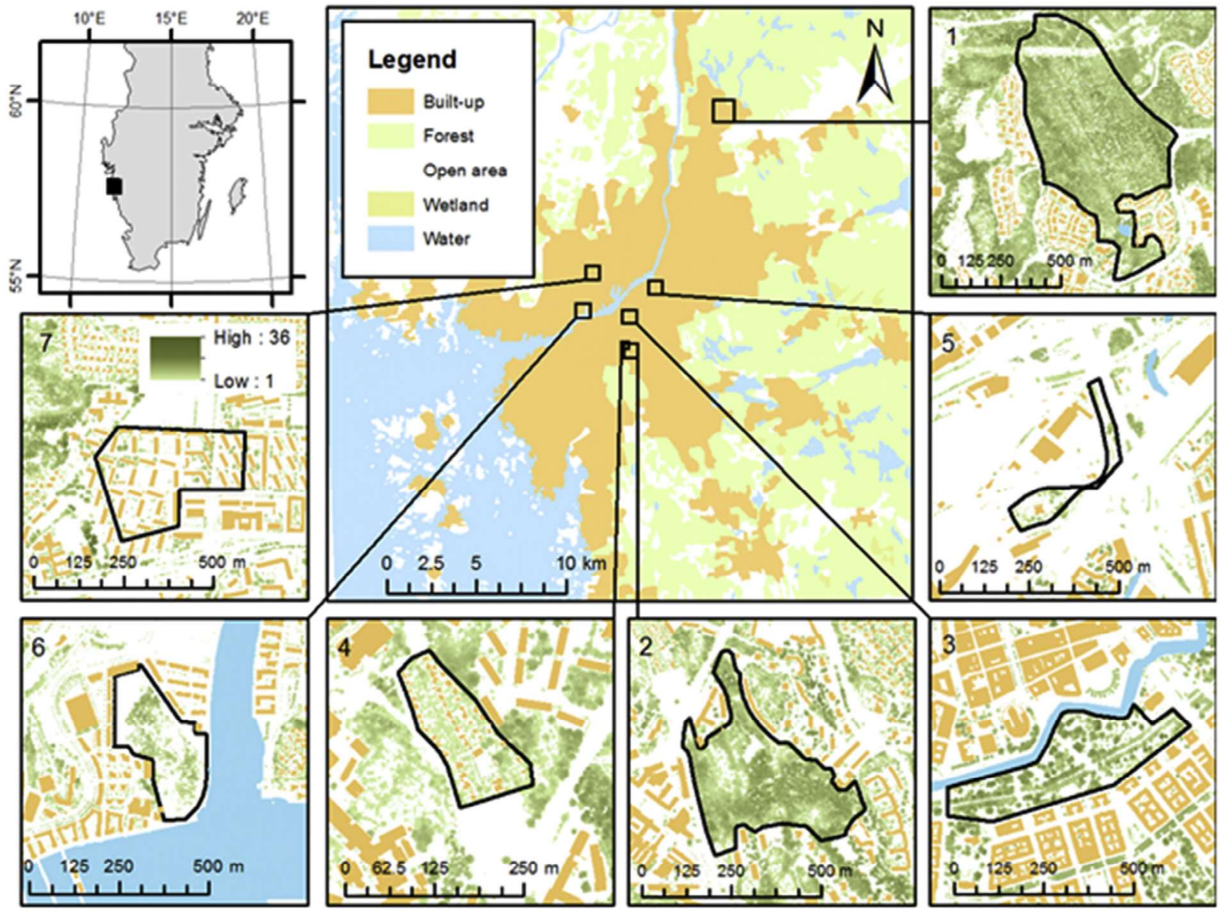

Fig. 3. Location of Gothenburg and the seven green areas selected for the study. Spatial characteristics of the study sites in terms of nearby buildings and tree canopy height are shown. The study sites are numbered according to their ID numbers in Table S1: 1) Suburban woodland, 2) Urban woodland, 3) Urban park, 4) Allotment area, 5) Infrastructural green space, 6) Urban park and woodland, 7) Residential area. Adapted from Klingberg et al. (2017a). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

described by the leaf area index (LAI), the projected (one-sided) leaf area per unit ground area (Monteith and Unsworth, 2008). LAI can be an appropriate indicator of the area of foliage available for photosynthesis, transpiration and deposition of air pollutants. However, LAI data can be time-consuming and costly to obtain compared to accurate, high-resolution canopy cover datasets (Klingberg et al., 2017a), which may be acceptable substitutes in some cases.

Water retardation through storage and soil evaporation is related to the surface permeability (EEA, 2015; Olsson et al., 2013; Peng et al., 2016), and leaf area through transpiration (Benyon and Doody, 2015; Zhang et al., 1999, 2001). The pollination of plants in urban and rural areas is highly dependent on the presence of insect pollinators, both honeybees and wild insects (Matteson and Langellotto, 2009; Garibaldi et al., 2013). Thus, a pertinent indicator is the total abundance of honeybees, bumblebees and solitary bees. The identified regulating indicators (i) are presented in Table 1.

3.1.1.2. Identified cultural ES indicators. Natural environments are known to have positive health effects and stimulate physical activities (Bell et al., 2008), but few quantitative correlations between these effects and specific biophysical structures (trees, shrubs etc.) have been published. In addition, physical places (e.g. urban green spaces) and time spent in such places can anchor people's reminiscences by forming psychological person-place ties (Blicharska et al., 2017; Knez, 2014). These ties are emotional and cognitive bonds that ground our personal memories and thus our life-stories (who we are) (Merleau-Ponty, 1945).

Recent findings, of studies focusing on the sites considered here (Ode Sang et al., 2016) and other settings (e.g. Sandifer et al., 2015), have shown that perceived naturalness is positively correlated with recreational and aesthetical values including physical activities, visual aesthetic values and self-reported well-being. Well-being is here defined broadly, including a state of physical, mental and social comfort and happiness (WHO, 1946 in Sandifer et al., 2015) and cultural identity (MEA, 2005; Sandifer et al., 2015).

Diversity of habitats and species is known to promote abilities to reflect and strengthen place-identification (Sandifer et al., 2015; Knez et al., submitted). Accordingly, recent studies focused on the sites considered here have also shown that people's valuation of green spaces is significantly correlated with estimates of biodiversity based on surveys of trees, bushes, herbs, birds and bees (Gunnarsson et al., 2017). Moreover, the perceived aesthetic and auditory appeal of urban greenery reportedly correlates with subcategories of “high, medium and low” diversity of these components (Gunnarsson et al., 2017). In addition, urban settings are appreciated more if bird songs are heard, especially if multiple species are heard (Hedblom et al., 2014). It was also recently shown that bird song and trees rustling make people feel calm, and that visible and audible experiences of urban greenery are connected (Hedblom et al., 2017).

3.1.1.3. Empirical measurements of indicator abundance

3.1.1.3.1. Regulating indicators. At each study site the leaf area index (LAI) and canopy cover were estimated from aerial LiDAR (light detection and ranging) data covering Gothenburg municipality acquired in 2010. Using laser penetration metrics, high resolution maps of canopy cover (1 m) and LAI (10 m) were produced following Klingberg et al. (2017a). Permeable surface (%) estimates were acquired from map information, and soil types were estimated using wet sieved soil samples collected at the study sites, following procedures presented by Van Kleef (2017). Densities of bees were estimated from point counts at each site (three points, three times in each site), as detailed by Gunnarsson et al. (2017).

3.1.1.3.2. Cultural indicators. At each study site, the diversity of birds and densities of tree, shrub and herb species were estimated, as follows. Numbers of songbirds observed in point counts at each site were recorded, and their diversities were estimated using Simpson's index (1/D), as recommended by Magurran (2004). Trees, shrubs and herbs were surveyed in circular plots with radii of 20, 10 and 0.28 m, in accordance with the National Inventory of Landscapes in Sweden monitoring program (Ståhl et al., 2011).

Data pertaining to trees and shrubs were collected in 2–4 plots, and data pertaining to herbs in 6–12 plots per site, depending on the size and heterogeneity of the sites. Songbirds were counted at two points three times in each site, as further described by Gunnarsson et al. (2017).

We would prefer, ‘The measured abundances are shown in supplementary material (Table S2). To allow analyses of the indicator abundances with a common scale, applicable for all types of indicators, we normalised the results by dividing the indicator abundance (or species density) recorded at each site by the maximum recorded across the seven sites. Thus, the possible range of values for each indicator was 0–1.0.’

3.1.2. Step 2 – application of effectivity factors to rate indicators' effectivity

Contributions of the function associated with a given indicator (functional trait indicator) to a given ES depend on the abundance of the indicator and its effectivity, here expressed by effectivity factors (f(i,j)) on a 3-point scale: 1 (weak), 2 (moderate) and 3 (strong). The rating is based on published evaluations. For example, trees are well known to block solar radiation at street level (creating shade) and to cool nearby surroundings through transpiration, thereby providing effective cooling during the warmer seasons (e.g. Ali-Toudert and Mayer, 2007; Mayer et al., 2009; Hamada and Ohta, 2010; Lindberg and Grimmond, 2011; Konarska et al., 2014, 2015a, 2015b). They also provide effective wind protection (Shashua-Bar et al., 2009; Buccolieri et al., 2009), and their leaves contribute area-dependently to removal of air pollutants via deposition (Manes et al., 2012; Nowak et al., 2006, 2014b; Grundström and Pleijel, 2014). However, the effectivity is pollutant-dependent; leaf area has no detectable impact on the quality of nearby air with respect to ground-level ozone (O3), weak effect on nitrogen dioxide (NO_2), and stronger effect on particulate matter particles with <10 μm diameter (PM10) (Janhäll, 2015; Nowak et al., 2006; Grundström and Pleijel, 2014; Klingberg et al., 2017b).

Quantification of cultural ES effectivity factors (f(i,j)) is less straightforward, since it involves both generic and rather complex context-dependent components (Knez, 2014). Thus, to our knowledge, ratings that can be applied are only available in the literature for the regulative ES investigated here. Here, the effectivity factor for cultural ES is arbitrarily set to medium (class 2). Further in-depth analyses and method development to improve understanding of the generic and context-dependent components are needed to enable more refined estimates.

The effectivity factors (f(i,j)) are summarised together with the reasoning and citations for published evaluations in Table 1. It should be noted that the effectivity factor ratings presented in the table are the maximum positive contributions that the indicator can provide. In some situations, and environments, their effects may be negative. For example, under some conditions increasing light availability is more widely desired than cooling, or a dense canopy with high LAI may reduce the air quality by reducing ventilation, thereby increasing rather than reducing local air pollutant concentrations (Andersson-Sköld et al., 2015; Gómez-Baggethun and Barton, 2013).

Table 1
Biophysical structure components contributing to the ES included in this study, related functions, indicators (*i*) included in this study and effectivity factors (*f*) (see next section).

Biophysical structure component	Function	Functional trait indicator (*i*)	Effectivity factor (*f*)	ES
Bees	Pollination: Bees are highly important for pollination (Matteson and Langellotto 2009; Garibaldi et al., 2013).	Bees' abundance	+3	Success of urban vegetation
Urban trees	Wind reduction: Leaves are effective wind reducers (Shashua-Bar et al., 2009; Buccolieri et al., 2009).	LAI (m^2/m^2)	+3	Local climate regulation
	Cooling[a]: Leaves contribute to cooling through provision of shade and transpiration during the warmer seasons (Ali-Toudert and Mayer, 2007, Hardin and Jensen, 2007; Konarska et al., 2014; Gillner et al., 2015) and the combined cooling effect is very high (Mayer et al., 2009; Hamada and Ohta, 2010; Konarska et al., 2015a, 2015b).	LAI (m^2/m^2) (For transpiratory cooling an alternative is permeable surface surrounding the tree (m^2/tree number of trees/ha))[b]	+3	
	Air pollution mitigation[a]: Leaves contribute to air pollution mitigation through deposition on leaves (Burkhard et al., 2012; Kandziora et al., 2013; Hirabayashi et al., 2012).	LAI (m^2/m^2)	Undetectable for O_3, low for NO_2 (+1) (Grundström and Pleijel, 2014; Klingberg et al., 2017b), stronger for PM10 (+2)[a] (Andersson-Sköld et al., 2015; Janhäll, 2015).	Air quality regulation
	Noise scattering and absorption: Leaves contribute, but have weaker effects than distances from sources (Kang et al., 2011; Kim et al., 2014).	Leaf area density (LAD) (m^2/m^3) and tree canopy volume (m^3/ha)	+1	Noise reduction
	Water retention: Transpiration and interception (EEA, 2015; Konarska et al., 2015b; Peng et al., 2016; Zhang et al., 1999, 2001) are highly effective during long precipitation periods, and less effective for extreme precipitation. Also less effective than high amounts of highly permeable surfaces (e.g. Peng et al., 2016; Zhang et al., 2001; Van Kleef, 2017; Abda Amin, 2017).	LAI (m^2/m^2) or the permeable surface surrounding the tree (m^2/tree[a]number of trees/ha) [b]	+2 during long precipitation periods, +1 for extreme precipitation.	Water regulation
	Audial contribution to wellbeing. Rustling trees calms people (Hedblom et al., 2017). The rustling depends on the amount (and type of) leaves, here assumed to be correlated to the canopy cover.	Canopy cover (m^2)	+2	Recreation and mental and physical health
Diversity of species	Audial contribution to wellbeing: Bird song by different species contributes to calmness (Hedblom et al., 2017) and appreciation of the urban setting (Hedblom et al., 2014).	Diversity of songbirds (1/D)	+2	
	Visual contribution to health and mental well-being (e.g. relaxation, calmness, ability to reflect, self-reported well-being and place identification): Species diversity (Sandifer et al., 2015; Ode Sang et al., 2016; Knez et al., submitted, Gunnarsson et al., 2017). Here based on diversity of trees, shrubs and herbs.	Number of tree species Number of shrub species Number of herb species	+2	
	Contribution to aesthetic value: Based here on subdivision by Gunnarsson et al. (2017) of measured high, medium and low species diversity of trees, shrubs and herbs.	Number of tree species Number of shrub species Number of herb species	+2	Aesthetic appreciation and inspiration for culture, art and design
Ground cover and surface	Water storage and soil evaporation through permeable **surfaces and highly** permeable soil (EEA, 2015; Olsson et al., 2013; Peng et al., 2016). The effectiveness depends on the amount of permeable surface. For large areas, it is more effective than evaporation and transpiration, but less effective than retardation ponds or steep slopes (Peng et al., 2016; Van Kleef, 2017; Abda Amin, 2017).	Permeable surface (%)	+2	Water regulation

[a] Note that in some situations and environments the effectivity can be negative for this indicator.
[b] The transpiratory cooling associated with stomatal conductance (and hence transpiration rates) is highly correlated to the permeable surface surrounding the tree, Konarska et al., 2015b.

3.1.3. Step 3 - estimation of effects

Effects of the indicators, E(i,j), are calculated using Eq. (1) in conjunction with the normalised abundances and effectivity factors. The results obtained in our study (using effectivity factors listed in Table 1) for effects of regulating ES, cultural ES (related to the diversity of birds, trees, shrubs and herbs), and total effects are shown in Fig. 4. The results indicate that at all sites, apart from the residential area, regulating ES have the highest effect, both reflecting the importance of LAI at these sites (Table 1) and that more regulating than cultural ES currently are included in the framework.

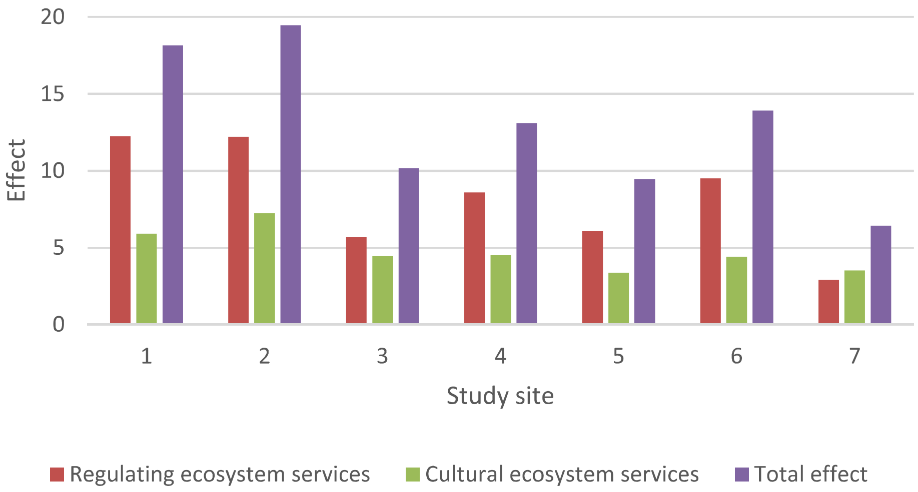

Fig. 4. Estimated effects of regulating and cultural ES, at each study site based on normalised abundances (Table S2) and the effectivity factors listed in Table 1 (assuming that every indicator contributing to cultural ES has a medium effectivity factor). The study sites are ordered as in Fig. 2 (1 = suburban woodland, 2 = urban woodland, 3 = urban park, 4 = allotment area, 5 = infrastructural green space, 6 = urban park & woodland, 7 = residential area).

However, the other indicators also contribute to the effects. For example, effects of regulating ES are similar at sites 1 and 2, but the diversity of trees, shrubs and herbs is higher at site 2 than at site 1, resulting in more cultural ES and a higher total effect at site 2.

3.1.4. Step 4 - estimation of benefits

A benefit is something that can 'change people's well-being', like health or the kinds of choices they can make. Its extent, or importance, is expressed by the value people assign to it (Potschin and Haines-Young, 2011), expressed here as in eq. (2), i.e. B(i,j) = E(i,j) *v(j), where B(i,j) is the benefit and v(j) the perceived value of ecosystem service (j).

The perceived values of the benefits considered here were obtained based on both the perceptions of civil servants and the public. The aim was twofold:

1) To achieve perceived importance of individual ES
2) To compare the perceived importance of ES to other important services in a developing city.

The perceived value of individual ES among the civil servants was done by ranking the investigated ES at a workshop (January 2016). Eight civil servants who daily dealt with green infrastructure and landscape planning issues in Gothenburg participated in the workshop. Of the participants, 3 were environmental analysts (marine, acoustics, terrestrial biology) at the Environmental administration, 2 were project engineers at the Gothenburg Management Recycling and Water, 2 were from the Gothenburg city planning office (one spatial planner and one landscape architect), one civil servant from the Gothenburg Park and nature management, and one landscape architect and one road architect and designer at the Swedish road and transportation agency. The resulting rankings were compared pairwise applying the Saaty scale (e.g. Saaty, 2001), based on the inverted sum of the respondents' rankings, and the geometric mean of the pairwise comparisons (Ishizaka and Lusti, 2006). For example, 6 respondents ranked perceived well-being as number 1, one ranked it as number 2 and one as number 3. The resulting sum is 11 and the inverted result is 0.09 (9%) and set equal 9 on the Saaty scale.

The resulting geometric means are shown in Fig. 5 and Table S3. As seen in Fig. 5 and Table S3 the importance of perceived well-being was regarded as the most important ES among the respondents. The perceived values of the other ES were found to be of similar importance/weight.

The perceived importance of the investigated ES in comparison to other important services was made in pair-wise comparisons involving two steps: 1) determination of whether the ES or other aspect was most important, 2) then how much more important it was on a scale from 1 (very little) to 5 (a lot more). The averaged results of the comparisons are shown in Table S4. The result of the comparison was normalised applying the geometric mean of a pairwise comparison of the results (Fig. 5 and Table S3). As seen in Fig. 5, the importance of perceived well-being was by this method regarded more similar in importance/weight compared to the other ES than found in the ranking estimates.

The same process was thereafter aimed to be applied among the public. In a first test (February 2016) it was however found that the number and type of questions, and the consequent response time, was perceived as far too long and demanding. Consequently, the public was provided a questionnaire not demanding more than maximum 10 min to respond. In the resulting questionnaire we investigated the importance of managing storm water and well-being associated with urban greenery (and biodiversity *per se*), relative to perceived needs to increase public transport provisions, housing, and cultural and entertainment facilities (theatres, restaurants etc.). The selection is based on ongoing, and planned, significant densification, land use changes and infrastructure activities in Gothenburg region initiated to facilitate population growth, commuting, transportation of people and goods and increasing the business in the region.[3] The flood risk is expected to become severe during this century due to climate change, i.e. sea level rise and more extreme precipitation (Andersson-Sköld and Davidsson, 2016a). To yet include the ES investigated here, the comparison was complemented with asking for spontaneous ratings, on a scale ranging from 1 (very little or no importance) to 5 (very important), of regulating ES, cultural ES and biodiversity *per se* (Table S5).

The measures of citizens' perceived values of the benefits considered here were obtained from face-to-face interviews, using a questionnaire, with 111 members of the public (in February–April

[3] https://www.businessregiongoteborg.se/sv/branscher-i-fokus/stadsutveckling (accessed 17.09.12).

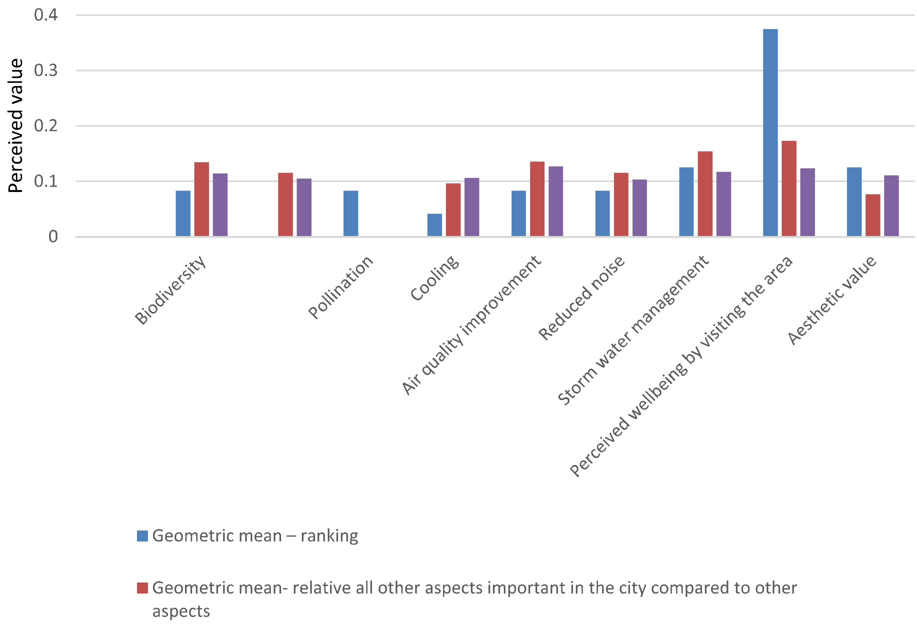

Fig. 5. Perceived relative importance of individual ES applying different estimation methods.

2016).

The interviews were conducted at six public places in Gothenburg: the central bus and rail station, a suburban indoor shopping center, a housing area, a central university area, three central parks (two not included in our study and the urban park included in it). No measurable deviations were found in the ratings obtained from interviews conducted in the six different places. Thus, the resulting rating is regarded as representative across Gothenburg (Fig. 2).

The ratings of individual ES indicate that all the considered ESs are highly valued (average score; 4.0 out of 5, Table S5). The ES ranked most highly was reduction in air pollution (4.6, Table S5). Cultural ES were also regarded as highly important (4.0–4.4, Table S5). The lowest rating was for biological control of pests and diseases (3.4, Table S5). The resulting relative normalised importance of the individual ES is rather similar as shown in Table S3 and Fig. 5.

The ES investigated in the comparison were too few for estimating the relative normalised importance. The results indicate that ES were also highly rated in relation to other important aspects in the developing city Gothenburg (Fig. 6). Both the public (N = 111), and civil servants participating in the workshop (N = 8), rated them as generally more important than the other services considered. Among the public, only increased housing was rated as more important than biodiversity, and ES were otherwise ranked higher than all the other aspects they were compared to (Fig. 6).

In the responses regarding the value (importance) of the ES (in relation to both each other and increases in public transport provisions, housing, and cultural and entertainment facilities) biodiversity *per se* was highly rated generally (Table S5). This indicates that it is important to consider biodiversity *per se*, in urban planning processes.

3.1.5. Step 5 - total value of ES at the study sites

The total value of the ES (V) provided by each investigated area, is the sum of the benefits (B(i,j)) of all the considered ES (Eq. (3)).

Among the civil servants, despite the method employed, the most important ES was perceived well-being (Fig. 5). This was most pronounced in the ranking. To what degree there is a variation

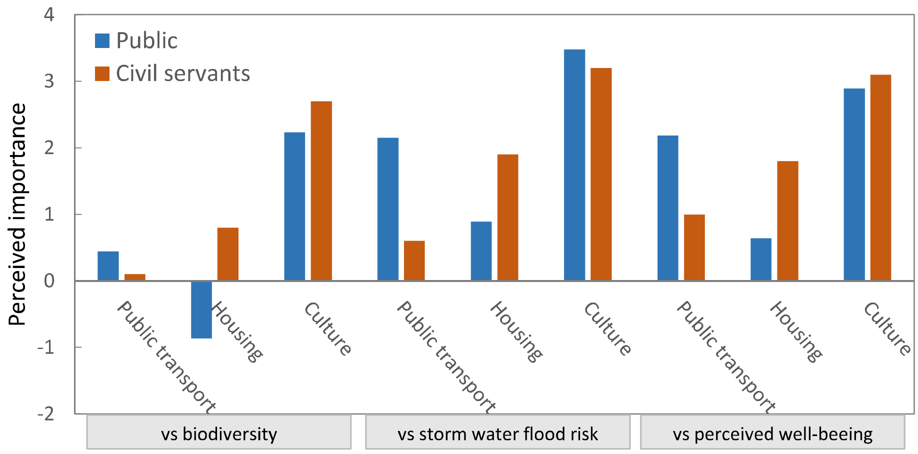

Fig. 6. Perceived values of ES and other services according to responses of participants in a workshop with civil servants (8) and interviews with the public (111). Positive and negative values respectively indicate that both groups regarded the ES as more important and less important than the other aspect.

between the perceived values of individual ES depends on the method (Fig. 5). As the perceived importance's for all the other ES considered here are high and similar, the total estimated values at the sites follow the pattern of the total effects (Fig. 7). Also, when applying the perceived values based on ranking the pattern remains similar. The similarities in pattern can be explained by the fact that the regulative ES are dominating. Applying the ranking, however, result in an increased importance of the suburban woodland (site 1 Fig. 2). This is explained by the naturalness related to a relatively high diversity of species at this site.

To make the framework further applicable by civil servants, for example applying GIS, or as part of integrated assessments in EIA, the results could be classified. Color-coding could then be used to visualize the results in maps.

4. Discussion

In this paper, we present a framework for estimating both the ES effects and total values of an urban ecosystem. The framework is based on the conceptual cascade model (TEEB, 2010, Potschin and Haines-Young, 2011) and the assumption that the functional benefits provided by an ecosystem depend on both the abundances of relevant components (represented here by selected indicators) and their ability (described by effectiveness factors) to contribute to the considered ES. The abundances are normalised to enable assessment of effects of all types of indicators on a common scale. Alternatively, a number of classes could be used, for assessments of a single site (but not over a green gradient or many sites as in the illustrative application presented here). The relevance of a common scale can be questioned, as the relative importance of the indicators may vary substantially, but compensatory adjustments can be made by applying the effectivity factors, which make the effect estimates both convenient and generically applicable as in standard EIA (Andersson-Sköld et al., 2015).

The framework proved to be applicable, and easy to use, for the study sites. However, the effects and values were largely influenced by the regulating ES, at least partly because more information is available that can be used to link regulating indicators than other indicators to effects. To allow the inclusion of more cultural ES, and separation of indicator abundance and effectivity from valuation of these ES, more research to untangle the complexity of greenery components related to cultural ES such as place-bonding is needed (see e.g. Blicharska et al., 2017; Knez and Eliasson, 2017; Knez et al., submitted).

As shown here for the regulating ES, it may be possible to rate effectivity factors of indicators on a scale from 1 (low effectivity, i.e. they make little contribution to a focal ES) to 3 (high effectivity). However, the relations involved for the cultural ES are complex, and there are likely to be both synergistic and conflicting effects, which currently prohibit such estimates.

Furthermore, we only consider positive effects of urban greenery on the regulating ESs, but it may also have negative effects (disservices), depending on its context and design. For example, it may trap air pollutants in street canyons resulting in high local concentrations, increase allergen exposure by releasing pollen, cause cooling under conditions where heating is more desirable, and dark dense foliage may reduce the feeling of safety (D'Amato, 2000; Escobedo et al., 2011; Gómez-Baggethun and Barton, 2013; Von Döhren and Haase, 2015). Further development of the framework will allow consideration of disservices by including negative effectivity factors, and in an even longer term, when there is more knowledge of the complex interactions, synergetic effects could also be included.

Clearly, ecosystems and related ESs raise highly complex issues, and any technique for estimating associated effects and benefits can be questioned. However, the systematic approach and the effectivity classification scale applied in the presented framework reduce the importance of minor uncertainties and facilitate its application in current processes such as EIA, routine mapping and planning procedures. Thus, it may have utility either as a standalone framework or as a complement or module in more advanced process models such as the i-Tree model (Nowak et al., 2008).

To estimate the benefits we have applied priority ranking of individual ES and perceived relative importance of the individual ES in comparison to other aspects important for urban development. These methods were applied among civil servants. The ranking based method revealed the importance of perceived wellbeing in comparison to other ES (Fig. 5, Table S4). Applying rating (public) and in comparision to other important aspects in the city (public and civil servants) the perceived values were more even among the different ecosystem services. In a real planning process, a ranking valuation process is recommended to be done (at least) among the responsible spatial planners and civil servants from impacted sectors. W also, however, find it important to identify the importance relative expected changes due to planned interventions. The two methods complement each other. The ranking shall be used to estimate the internal relative weights, while the

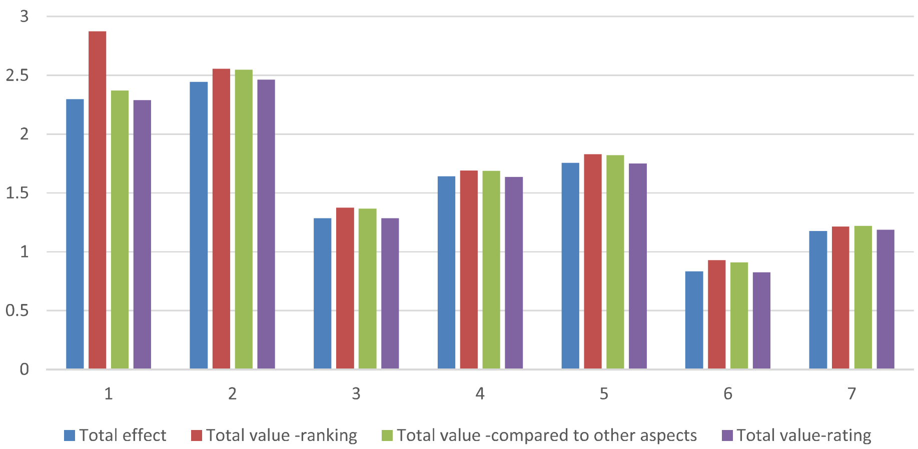

Fig. 7. Estimated total effects and total values of ecosystem services at the study sites. The maximum values for the effect and total value are 20 and 3.0, respectively. (1 = suburban woodland, 2 = urban woodland, 3 = urban park, 4 = allotment area, 5 = infrastructural green space, 6 = urban park & woodland, 7 = residential area).

comparison reveals the importance of the ecosystem services in relation to the other aspects under consideration. Such a valuation process would contribute to increased understanding on how different ES are valued under different contexts and potential spatial planning strategies. Currently there is a lack of active and transparent valuation procedures in the municipal planning and decision process. “Lack of time” being the main self- reported barrier (Andersson-Sköld et al., 2013, 2016b). Therefore, simple methods, as applied here, are recommended. The valuation method and process must, however, be adapted to the participants and the context. For large land use changes, it is essential to involve the public through more site-related questionnaires, applying a more advanced valuation methodology and/or be based on larger surveys.

The method presented here does not include non-linearities neither in understanding the links between ecosystem functions, indicators and effects nor regarding the valuations such as spatial and social variations shown in needs, demands and availabilities of ES. Greater understanding of effects, such as links to non-linearities and the complex relations especially regarding perceived well-being and other cultural ES (and robust ways to estimate them) must be developed before more refined methods can be applied. However, once the links between ecosystem components, services and effects are better understood, suitable permutations of methods based (for example) on monetary valuation can be used. These may include (for appropriate types of indicators and ES) restoration values (Elmqvist et al., 2015), avoided costs and willingness to pay (Gómez-Baggethun and Barton, 2013). However, methods like those applied here are relatively quick and convenient. Furthermore, the information they provide can be readily applied and regularly updated by urban planners, and the derived values are independent of currency rates and indices. The utility of preference ranking methods should also be recognized in the light of limitations of monetary methods; notably criticism by decision-makers that economic valuation of ecosystem services is too simplistic, insufficiently widely accepted, and flawed (Marre et al., 2016).

It should be noted that urban environments have many functions and provide or influence many ESs not considered here. For example, Goodness et al. (2016) suggest additional plant and bird trait indicators for aesthetic, recreational, spiritual, religious and heritage ESs (e.g. plant/bird size, morphology and color). Provisioning services in urban environments are also becoming increasingly important for various reasons, notably urban agriculture is advocated to help make cities more self-sufficient (Viljoen and Bohn, 2014). Provisioning ESs have often been valued in relation to current market values (e.g. TEEB, 2010), but Langemeyer (2015) shows that the major value of urban gardening, an important part of provisioning services in cities, is entangled with cultural services. Thus, valuation of urban provisioning services is also complex and merits separate and more detailed consideration.

The effectivity factors of functional traits, synergies, inhibitory effects and potential disservices require further investigation. Moreover, specific ESs should be valued robustly in relation to other relevant planning aspects in focal areas, as the values are context-dependent. A high value of an ecosystem may result in high utilisation, which may negatively affect the supply and demand. Also, the values depend on the societal context and trends. In areas where the greenery is threatened, the values may increase, while in areas where other needs and social requirements, such as housing, are more acute they may decrease.

5. Conclusions

The presented framework, based on the conceptual cascade model presented by TEEB (2010) and Potschin and Haines-Young (2011), can be applied to estimate both the total effect and value of ecosystem services (ES) of a site. The framework uses a limited number of indicators of relevant functional traits, and in contrast to other methods, it allows for separation of both different components (trees, shrubs, birds etc.) and the ES they contribute to.

A number of key indicators have been identified. The leaf area index (LAI) is applicable for several of the regulative ES, and diversity of species for the cultural ES, included here. However, more indicators of cultural ES are need. In step with increased knowledge on the links between ecosystem components, services and effects the framework can easily be updated to include more indicators as well as additional ES.

ES provided by urban green areas included here were valued as highly important and highly ranked in comparison to other important aspects in cities such as improvements in public transportation, housing, culture and entertainment. The relative importance differs when ranked or rated. In addition, which ES are most relevant differs due to different needs at different sites and might change over time. To identify the most relevant ES ranking is recommended, while for specific land use changes also a pair-wise comparison of the pros and cons of expected changes in relation to the investigated ES is thus recommended.

The framework has been developed with the idea that it should be easy to use, systematic and transparent at all stages and to be applied in the spatial planning processes. Once valuation of ES becomes a routing practice and the links between ecosystem components, services and effects especially regarding perceived wellbeing and other cultural ES, are better understood, suitable permutations of methods based (for example) on monetary valuation can be used. Meanwhile more simple and less time demanding methods like presented here are recommended.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jenvman.2017.09.071.

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