Locally-provided and globally-relevant ecosystem services: A needed distinction for quantification

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Abstract. Ecosystem services are defined as benefits obtained by humans from ecosystem functions and processes. Although the different types of ecosystem services are well defined, their measurement and quantification has remained controversial despite long last research efforts. A particularly elusive and often neglected aspect of ecosystem services quantification has been a proper identification of the beneficiaries. We argue that a clear-cut distinction between locally-provided and globally-relevant ecosystem services are necessary in order to manage a meaningful debate about ecosystem services quantification. Using a detailed spatial analysis of land-use change and residential location in The Netherlands over almost two decades, we operationalize the distinction between two types of services provided by "green" land uses (protected natural areas, agricultural areas and parks). Recreational services available to nearby dwellers are used as an example of locally-provided ecosystem services, while carbon sequestration exemplifies the globally-relevant category. The conclusion is that while monetary value can be justified as a proxy measure of globally-relevant ecosystem services, non-monetary approaches are appropriate for locally-provided ecosystem services. The distinction between both types of ecosystem services is useful also for policy-making purposes: Quantification of locally-provided services is well suited for spatial planning in general and urban planning in particular, but globally-relevant services assessment (specially its monetary approach) is more informative at national and supranational levels.

Keywords: Ecosystem services, locally-provided, globally-relevant, quantification.

1 Introduction

Since the concept of ecosystem services has been coined, the quest for an adequate method for their assessment, measurement and valuation is a central research goal in the area [17, 18, 19]. After more than two decades of intensive research efforts, the definition and categorizations of the different types of ecosystem services are well defined and widely agreed [38, 47]. The quantification and valuation efforts, in comparison, are either questioned in principle [37, 46], or are actively being discussed without an apparent convergence towards an agreed ground [16, 50]. It is not surprising thus, that a recent review of about a decade of scientific literature about the valuation of ecosystem services in urban areas [5] found that most of the studies are based on diverse types of non-monetary valuations.

One of the basic problems behind the quantification of ecosystem services is that not always is clear to whom are they provided [44]. Indeed, a particularly elusive and often neglected aspect of ecosystem services quantification has been a proper identification of the beneficiaries (for example, [20, 21]). In a world where more than half of the world population live in urban areas, cities are the places where people obtain most of the benefits from ecosystems [36], and therefore make sense to focus on them. On one hand, cities consume ecosystem services provided by areas located both nearby and far away, sometimes exerting a large influence remotely [41]. But natural and semi-natural areas also abound within and around urban boundaries, and therefore cities also consume ecosystem services produced locally [7]. This dual nature of ecosystem services through the prism of whom is able to use them lie in the suggested clear-cut distinction between locally-provided and globally-relevant ecosystem services. Carbon sequestration by a plot of forest, for example, provides few services for the people living in the area, since the same service can be provided by other, nearby and similar plots. But the accumulation of these localized services affects ultimately every human being on the planet through the atmospheric carbon balance. The decreased water storage capacity of a parcel under development is not an issue from the owner's viewpoint, but the accumulation of developed land is significant for all the inhabitants of the watershed. These are examples of globally-relevant ecosystem services. Locally-provided ecosystem services are the opposite: These affect exclusively people located in a narrow area of influence and are completely irrelevant for outsiders. Services relevant at short distances (as aesthetic landscapes, recreational opportunities in natural areas nearby or noise reduction by tree canopies) are examples of locally-provided services. In the same manner that a single place can be the source of several ecosystem services (provisioning, regulating, etc.) it can offer globally-relevant and locally-provided services simultaneously. The difference between them is conceptual and affects the way in which they can be accounted. We claim than in order to manage a meaningful debate about ecosystem services quantification (and even monetization of part of them) a clear-cut distinction between locally-provided and globally-relevant ecosystem services is necessary. The operationalization of the suggested framework is performed using a detailed spatial analysis of land-use change and residential location in The Netherlands over almost two decades, quantizing services provided by "green" land uses (protected natural areas, agricultural areas and parks). Recreational services available to nearby dwellers are used as an example of locally-provided ecosystem services, while carbon sequestration exemplifies the globally-relevant category.

This paper is structured as follows: Section 2 presents a short review of the literature on urban green areas and their associated ecosystem services. Section 3 describes the study area, data and methods used in the research, which results are presented in Section 4. Section 5 summarizes discussing the significance of the results and concludes with respect to the research questions.

2 Ecosystem services of green infrastructures in urban areas

The term urban green infrastructure designs the network of interconnected natural, semi-natural and artificial green areas within and around cities, emphasizing quality, quantity and multifunctional roles [48]. As such, urban green infrastructures provide a wide range of ecosystem services [29] ranging from wellbeing, positive physical and mental health effects [27], urban biodiversity conservation [34] and micro-climatic regulation [14]. Additional services provided by green infrastructures are runoff reduction [26] and local pollution abatement [39]. These services seem to be highly valuable since city dwellers are willing to pay high prices to live near green infrastructures [4, 15, 25]. However, not all the ecosystem services provided by urban green infrastructures are relevant for a dedicated quantification in the relatively constrained spatial context of urban and peri-urban areas [10].

In this research, we focus on the quantification of two different services provided by urban green infrastructures. The locally-provided ecosystem service is the provision of cultural services in the broadest sense: Non-material benefits obtained by people when they are in contact with natural, semi-natural or open areas. These services include mental and physical health, as mentioned previously, but also recreational opportunities [3, 32]. The globally-relevant service provided by urban green infrastructures that will be quantified by this research is carbon sequestration, that belongs to the regulating services category.

People in general, and urban dwellers in particular, appreciate the locally-provided services offered by urban green infrastructure [45]. In order to evaluate the relative preferences of people for the different types of green infrastructures discussed in this research, we rely on the literature about recreational and landscape value perception. Parks with moderately dense vegetation located in urban areas are appreciated by urbanites [6], while those perceived as natural are more valuated [40]. Landscapes of mixed rural-natural areas are more valuable than large scale agriculture landscapes [24], while natural landscapes are generally more appreciated than farm environments [33, 49].

Urban green infrastructure contributes to the balance of greenhouse gases, a globally-relevant ecosystem service, via carbon sequestration [29]. However, at a local level, the carbon balance itself and the amount of carbon eventually sequestered depend greatly on the type of green area, the specific land use and the land management [35]. For example, carbon sequestration by agricultural soils is greatly influenced by local climate, the crop type and the agricultural practices [23]. A large part of the available assessment of carbon sequestration by soils provides global figures [23] and focus more on stocks of carbon rather than on sequestration flows [30], measures that are not appropriated for our approach. Although the literature on carbon storage flows by urban green infrastructure is scarce, there are economic and quantitative assessments related to urban parks [1, 28].

3 Methods

3.1 Study area

This research focuses on selected ecosystem services provided by different land uses in The Netherlands at the national level, during the period 2000-2017. In that period, The Netherlands experienced processes of population growth and residential development. Part of the new residential stock was developed converting previous non-urban land uses into residential land, but an additional large share was built within existing urban areas, increasing the residential density [8, 9]. This dual type of residential development reflects partially the influence of the long last Dutch planning tradition that aims simultaneously to provide enough land for residential development while protecting existing open spaces in general [2, 22]. In addition, European nature conservation initiatives as Natura 2000, to whom The Netherland is committed, and local initiatives as the National Ecological Network, aim to maintain a cohesive network of natural areas and corridors between them [31]. These spatial policies contribute with a modest expansion of natural areas and further constrain residential extensions.

3.2 Data

The Dutch Central Bureau of Statistics (CBS) maintains a comprehensive set of spatial data sources, covering the entire national territory using square cells of 100 meters. These spatial data sets are consistent along time and are available for several years, in particular for the study period, in 2000 and 2017. The first dataset contains the number of housing units and the number of inhabitants in each cell during both years [13]. In the context of this research, we are interested in the number of inhabitants residing in a certain cell, regardless the type of dwelling (detached houses, apartments, etc.). The number of individual inhabitants is rounded to the nearest multiple of five, and cells with less than five inhabitants are rounded to zero, in order to maintain anonymity in scarcely populated areas. For these reasons, there is a certain mismatch between the total national population and the aggregate population of the spatial data set. The second dataset contains highly detailed vector data describing land uses observed in both years [11, 12].

3.3 Ecosystem services quantification

In the first step we define the predominant land use in each cell, based on the spatially explicit land use datasets. The original vector data are converted into a 25 square meter raster dataset, and then aggregated into the predominant land uses at a resolution of 100 square meters, using 38 land use types. For the purpose of this research, three land use types are considered part of the green infrastructure: Land used for nature conservation, agricultural land and parks. These land use types were retrieved directly from the predominant land use dataset. The fourth relevant land use is residential land, that is defined as each cell populated by 5 or more inhabitants according to the residential and the dwelling dataset from the CBS. In case of mismatch between both datasets (i.e., cells with more than 5 inhabitants in which the predominant land use is natural, agricultural or parks) the cell is defined as residential, overriding the processed land-use data by the original CBS data about population and dwellings.

At this point the spatial data required for the quantification of the globally-relevant ecosystem services is available: The green infrastructure at the national level, both within residential areas and outside them, is well defined as either natural, agricultural or park areas. For the quantification of the locally-provided ecosystem services, additional steps are required. A range of 500-meter distance from the place of residence to the nearest green area is a widely accepted metric for green area's accessibility [42, 43, 51]. Therefore, the residential cells located within a buffer of 500 meters from natural, agricultural or park areas were identified, and the inhabitants living there are considered beneficiaries of the cultural ecosystem services provided by the green infrastructures. Inhabitants, thus, can be classified in eight mutually exclusive categories: (a) People receiving services exclusively by one green land use (natural or agricultural or park areas). (b) People receiving services simultaneously by two green land uses (natural and agriculture, for example, or other bilateral combinations). (c) People receiving services by all three green land uses (living in places located near natural, agricultural and park areas). (d) Inhabitants deprived of any ecosystem service provided by the green infrastructure, i.e. living far from all the three green land uses.

The quantification of the globally-relevant service (carbon sequestration) is performed using the scarce data available in the literature [1, 28], assigning monetary values to the carbon sequestration capacity of each green land use. The quantification of the locally-provided services (cultural services and particularly recreation) is performed assigning to each inhabitant a different value according to its location regarding the green infrastructure. As the literature about landscape preferences suggests, it seems that the most valuable areas are natural, followed by parks and finally by agricultural landscapes. The respective values were defined following this ordinal principle. We assume also that the services received from different types of green areas are additive. However, it is important to stress that all the assigned values used for specific cell by cell valuation, are, by definition, not accurate. These values (defined in the following table) are used only to illustrate the suggested quantification method.

Table 1. Illustrative values of globally-relevant and locally-provided services used for their quantification.

Service	Value	Unit	Comment
Carbon sequestration by parks	126	EU ha^{-1} y^{-1}	Calculated from [1]
Carbon sequestration by natural areas	200	EU ha^{-1} y^{-1}	According to the literature review it should be higher than the carbon sequestration value by parks (*)
Carbon sequestration by agricultural areas	50	EU ha^{-1} y^{-1}	According to the literature review it should be lower than the carbon sequestration value by parks and can be negative (*)
Cultural services by natural areas	3	Unitless	According to the literature review it should be the highest among green land use types (**)
Cultural services by parks	2	Unitless	According to the literature review it should be lower than the natural area's value (**)
Cultural services by agricultural areas	1	Unitless	According to the literature review it should be the lowest among green land use types (**)

(*) Accurate values are not available. The chosen value is used only for reference.

(**) Recreational and landscape value perception. The chosen value is used only for reference.

4 Results

During the period 2000 – 2017, the Dutch residential population[1] grew by about 4.5%. The land devoted to residences, parks and nature conservation expanded by 5.5%, 2.5% and 18.4% respectively. The agricultural land, which is by far the largest land-use considered in this research, shrank by 3.1%. The following figure shows the main land uses focused on a small region. In addition, it illustrates how the locations near green infrastructures are defined: Cells within the residential areas that are locat-

[1] By residential population we denominate the population included in the CBS dataset [13]. Due to the round off to the nearest multiple of 5 and the removal of cells in which less than 5 persons live, there are differences between the official Dutch population figures and the aggregated figures presented here.

ed at a distance shorter than 500 meters from natural, agricultural or park areas are considered as places accessible to the urban green infrastructure.

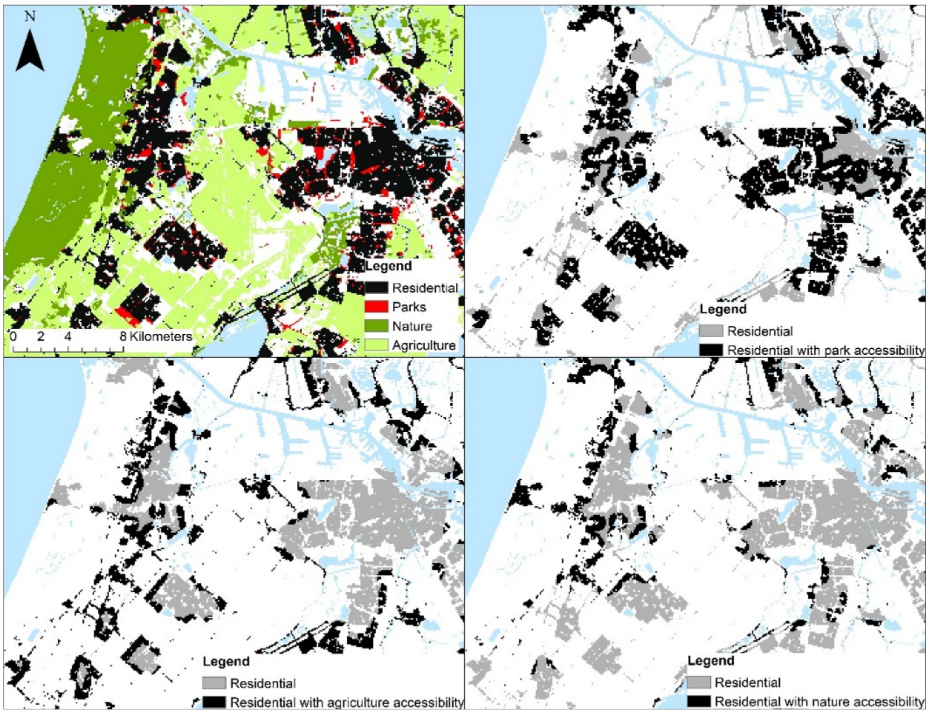

Fig. 1. Land uses in the urban area of Amsterdam and Haarlem (upper-left). Within the residential areas, there are places located near parks (upper-right), near agricultural areas (lower-left) and near nature conservation areas (lower-right). "Near" means located at less than 500 m from one of these green infrastructures.

Once the relevant areas are identified, it is possible to summarize them. For the globally-relevant ecosystem service (carbon sequestration) the total extension of the natural, agricultural and park areas, whether near residential areas or not, is the main variable. In comparison, for the locally-provided ecosystem service (cultural services), it is necessary to calculate how many persons enjoy accessibility to green infrastructures. The most important figures for the quantification of the analyzed ecosystem services are summarized in the following table.

Table 2. Land uses providing globally-relevant services and number of people receiving locally-provided services.

	2000	2017
Nature conservation area (square kilometers)	2,935	3,097
Parks (square kilometers)	193	229
Agricultural land (square kilometers)	23,436	22,714
People living in residential areas accessible to natural areas only	224,160	239,345
People living in residential areas accessible to parks only	3,413,625	4,158,015
People living in residential areas accessible to agricultural areas only	2,657,965	2,327,520
People living in residential areas accessible both to natural and agricultural (but not to parks)	1,620,310	1,483,225
People living in residential areas accessible both to natural areas and parks (but not to agriculture)	441,840	583,065
People living in residential areas accessible both to agricultural areas and parks (but not to nature)	3,562,975	3,542,760
People living in residential areas accessible to all types of green areas (nature, agriculture and parks)	1,593,980	1,693,385
People living in residential areas inaccessible to any type of green areas (i.e., farther than 500 meters from nature and agriculture and parks)	1,253,010	1,414,720

The last step of the calculation involves the values defined in Table 1. Assuming that agreed values for each type of ecosystem service are available, the carbon sequestration contribution of a certain land type that is the area multiplied by the carbon capacity per hectare. Regarding cultural and recreational services from green structure, the accessibility measure is calculated for each inhabitant. For example, if it is far away from all types of green areas its index is 0, if its location is near a park only, its index is 2. The following table summarizes the changes observed in the provisioning of both ecosystem services according to the values in Table 1:

Table 3. Change of globally-relevant and locally-provided services during the period 2000-2017 according to the illustrative values in Table 1.

Change during the period 2000 - 2017	By whom	Value
Provision of carbon sequestration	Natural areas	2.5%
	Park areas	18.4%
	Agricultural areas	-3%
	Total green areas	-0.4%
Provision of cultural and recreational services	Natural areas	3%
	Park areas	10.7%
	Agricultural areas	-4.5%
	Total green areas	4.8%

The absolute values of the calculated ecosystem services are not reported since the figures in which they are based (Table 1) are illustrative and, therefore, are inaccurate by definition and used only as a reference. The added value of the suggested clear-cut distinction between locally-provided and globally-relevant ecosystem services is the conceptual framework in which reliable and accepted figures of services (defined in units per hectare) can be simply plugged in a table in order to obtain a multi-dimensional valuation of ecosystem services. In this case study, we analysed only two services provided by the same land-uses, showing their temporal valuation during a period of time. Doing so, we obtain sensible results circumventing the problem of the lack of reliable services valuation per hectare. The extension of the framework to the quantification of additional locally-provided and globally-relevant ecosystem services is straightforward.

5 Discussion

The analysis, mapping and quantification of ecosystem services in urban areas has attracted considerable research interest in the last years producing very detailed and comprehensive studies [20, 21]. However, two aspects related to ecosystem services in urban areas remain elusive: The first is that the beneficiaries of the produced ecosystem services are not clearly identified. The second aspect, closely related to the first, is that the meaning of "urban ecosystem services" (compared to simply "ecosystem services" without additional superlatives) is unclear. The underlying and implicit definition of the existing research is that any ecosystem service produced in urban areas is "urban". But this raises the question of the urban area's boundary definition: Different boundaries necessarily will result in different assessments. Moreover, there is no reason to assume that a patch of vacant land located within an administratively defined urban area should provide different services than an identical patch located further away, outside the urban area. The water storage capacity of both patches is relevant at the regional level regarding flood prevention and at the aquifer level regarding recharging. If the patch happens to be included in an urban area or not is irrelevant. On the other hand, there are services that are inherently local. A winter puddle visited by the neighbors does not offer the same cultural, educational and recreational ecological services than a similar but inaccessible one. In order to manage a meaningful discussion about ecosystem services (in general, and urban, in particular) quantification, we argue that a clear-cut distinction is required. On one hand, locally-provided ecosystem services, focused on the people that usufruct them (or are able to use them) and depend on the accessibility of the source of the service to the beneficiaries. On the other hand, globally-relevant ecosystem services may affect people in the source's vicinity, but are relevant at larger scales (regional and even global). Globally-relevant services are provided regardless of the willingness of the potential beneficiaries to use them. Some locally-provided services are optional (as recreational services) while others are compulsive (as noise reduction or local air purification). Globally-relevant services may be quantified in geophysical terms (carbon sequestration, water storage, cooling capacity, etc.) or in monetary terms if there are markets for them (as in the case of carbon trade). Locally-provided services quantification depends on the beneficiaries and their location, and can be expressed in abstract ordinal scales (assigning larger values to more attractive supply). Monetary approaches are less appropriate for locally-provided ecosystem services [10].

From a policy-making perspective, the quantification of locally-provided services is well suited for spatial planning in general and urban planning in particular. The increase observed in the provision of cultural and recreational services by urban green infrastructure in the Netherlands is an evidence of a well-managed aspect of urban planning. Temporal comparisons of the same type, but at different administrative levels (provinces, municipalities, etc.) may shed light on the performance of the local government regarding the provision of locally-provided ecosystem services. The behavior of globally-relevant services as carbon sequestration over time is more relevant at the national level, in particular if an established market exists for the service and the country should be committed to achieve well-defined goals in the international arena, as is the case with carbon trade agreements.

The methodology developed in this research is fully portable, in the sense that it can be applied to any urban or metropolitan context, subjected to the availability of the required data. The test case described in this research was based on comprehensive and detailed spatial data, but the methods can be easily adapted to more coarse spatial data and to specific metropolitan areas. As such, the suggested methodology has a potential contribution for the research of urban ecosystem services.

This research demonstrates the usefulness of the suggested framework using a test case of the variation of two ecosystem services (one locally-provided and the other globally-relevant) during a period of time. We believe that the suggested clear-cut differentiation will contribute to defining clearer grounds to the ecosystem services quantification discussion. Since several services of both types can be provided by the same area, such differentiation allows for a refined monitoring of the implications of ongoing or planned land use changes. In addition, it allows for the use of multi-objective optimization techniques for the enhancement of ecosystem service provision.

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