Ecosystem services provided by green infrastructure in the urban environment

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Abstract

Interest in ecosystems services and green infrastructures is a result of conceptual developments in urban ecology and other environmental sciences. The impact of the urban settlements on nature and its consequences on human well-being at multi-scale levels demands for technical and social responses, whose application has been revealed to be highly dependent on the physical and socioeconomic context. We review here problems and efforts to create a solid conceptual framework and efficient tools to analyse and manage urban social-ecosystems in order to increase the benefits that green infrastructure gives to the entire society, providing the resilience of these systems. Difficulties become even higher as a result of weak institutional structures, limited capacity and poor governance strategies.

Keywords: urban ecosystems; environmental services; green infrastructure; urban greening; urban management; social-ecosystems.

Review Methodology

We have searched on SCI, SCOPUS and ResearchGate data basis for urban ecosystems, urban greening, ecosystem services, green infrastructures, etc. Main journals are: Ambio, BioScience, Biological Conservation, Ecological Economics, Environmental Economics and Management, Landscape and Urban Planning, Landscape Ecology, Urban Forestry & Urban Greening and others, including multidisciplinary journals (PNAS, Nature). We have tracked references in papers, mainly in peer-reviewed journals; explored tools used in evaluations, used books and papers, and our own data, and consulted colleagues.

Introduction

The concepts of ecosystem service (ES) and green infrastructure (GI) are born at the confluence of diverse environmental sciences. From the 1970's, an increasing interest developed in the ecological study of cities. There were several reasons for this: 1) human population was then, and in the first decades of the 21st Century, rapidly concentrating in urban systems: for instance, by approximately 2010, the ratio of population in cities was 52.1% in the world and 77.7% in the developed countries (DC) [1]. In 1950, urban population was 29.4% of total (54.5% in DC), while future estimated values are 53.9% (78.8% in DC) for 2015 and 67.2% (85.9% in DC) for 2050. 2) Cities' metabolism causes now around 80% of domestic emissions of greenhouse gases and has an increasing footprint at the biosphere level, despite cities only cover 0.5% of continental surface [2]. However, cities also generate much wealth, creativity and other benefits [3]. Cities can be designed and managed to reduce per capita resource use and emissions, and GI and its ESs are very relevant to reach this aim.

The study of GI and urban ecology is well established. Nicoletti [4] coined the term urban ecosystems. The International Biological Programme (IBP, 1964-1974) and UNESCO's Man and Biosphere Programme (MAB, launched in 1971) promoted large biome studies, some on ecosystems with social and ecological components. The first urban ecosystem analysed was probably Brussels in the late 1970's [5-7]. In 1981, a very comprehensive study on Hong Kong was published [8]. Early MAB studies of the ecology of cities were done at Rome, Barcelona [9, 10], etc. International meetings [11] discussed issues as urban nature, agriculture and forestry, environmental health, ecology in planning, public participation and emphasised the need for an urban ecological theory.

The National Science Foundation (NSF) launched in 1980 the Long Term Ecological Research (LTER) Network. LTER urban ecology main projects in Baltimore [12] and Phoenix are still alive today. Chicago, Seattle, New York, Syracuse, Stockholm, London, Liverpool, Leicester, Barcelona, Santiago de Chile, Bogotá, Guangzhou, Beijing, etc., have been active in the study of their GIs and the ESs they provide.

The concept of GI was introduced during the 1980's in the United States by authors interested in landscape architecture, like Hough [12] and Spirn [13].

Nature and cities

Early studies treated urban structure and function. Land use maps (with classes defined by degree of artificiality, building density and volume, etc.) were used to describe the structure [14]. Function was described usually by input-output analysis of energy and materials data from the records of municipalities or service companies [6-9], by direct measurements and by modelling. For green areas in cities, estimates of gross primary production, respiration and evapotranspiration were obtained using both climate data and broad ecophysiological information on either plant species or vegetation types.

During the 1990's, ecologists and ecological economists developed the idea that the ecosystem services (ESs) [14, 15] to society might be quantified, and values introduced in the economic models [16-19] used by urban planners and decision-makers. For instance, Bolund and Hunhammar [20] quantified six ESs from Stockholm local GI: air filtration, microclimate regulation, noise reduction, rainwater drainage, sewage treatment, and recreational and cultural values. They showed that each ecosystem could generate different flows of ESs (multi-functionality): many individual values were small, but the ESs discussed were only a subset of those existing. They concluded that, taken together, the total value of urban ecosystems was potentially significant.

In the early 2000s, The Millennium Ecosystem Assessment (MEA), launched by the United Nations, promoted the concept of ES [21] as a mean to change the dominant trend in urban planning that considers the non-urbanised land as “vacant or free areas”, i.e. plausible sites where to locate new developments or infrastructures. The complementary concept of GI has been defined as the spatial structure of natural and semi-natural areas and other environmental features which enable citizens to benefit from its multiple services [22]. But ESs can flow to cities from GIs that are much outside the political limits of the municipality (for instance, see Alberti [23]) and, for water resources, see Fitzhugh and Richter [24]. As a result, there are interactions of cities with peripheral green areas and even with remote ecosystems and the global environment: cities import resources from everywhere; their solid wastes and gases or liquids emissions pollute and disturb remote areas; their demand favours soil use changes or extracting activities, etc. The appropriation of vast areas of ESs beyond the city boundaries permits cities decoupling from local ecosystems [25]. Therefore, total area supporting a city is often much larger than the city’s area: 120 times for London, where the average footprint per inhabitant is 6.3 global hectares (gha) [26]; footprints for main USA cities are between 6 and 7.4 gha per inhabitant [27]. Consequently, the joint metabolism of cities has an enormous impact on the biosphere. Attempts have been undertaken to evaluate regional and global effects of the urban metabolism on climate and biodiversity and environmental aspects of ESs [28] (for Europe, see [29]) showing the relevance of that impact.

The study of a city's global impact is complex and to implement global responses is very difficult. An effective strategy is to gain experience in local planning and managing and to compare the results around the world. Protecting and restoring ESs can reduce ecological footprints and ecological debts of cities, while resilience, health, and quality of life for their inhabitants can be enhanced [25]. Urbanisation delivers high levels of societal well-being, but this is only true if, at the same time, ESs are integrated, in a robust way, into urban planning and decision-making [30] However, ES is an anthropocentric concept. It can be used to catch attention from managers and economists, but it would be dangerous to manage nature solely on the consideration of the immediate benefits or problems that she provides: ES approaches easily overlook the importance of ecological functioning to secure the long-term capacity of GI to provide services [31]. For instance, De Groot et al [32] definition of ecosystem functions as the capacity of natural processes and components to provide goods and services that satisfy human needs is very anthropocentrically biased. In many ESs studies, the lack of a firm base in science precludes ESs understanding [33]. Any strategy aimed to better planning and management of ESs or GI requires a deep knowledge (not necessarily the quantification [34]) of ecosystem functions, even of those that humans do not use directly. To put a price on ESs (monetary valuations are very variable) does not insure optimal management for conservation and for an equitable distribution of environmental benefits. Then, decisions on ESs management might not be taken just on current monetary values because this would produce very undesirable results. It is equally true that ecologists frequently study ecosystems function excluding humans: we cannot manage ESs or GI ignoring the cultural and social links and feedbacks at any stage, from analysis to strategies and action. Robertson [35] has signalled that the development of stable markets in ESs requires that ecosystem assessment describe a nature that capital can “see”, with an uncontroversial measure, in order for trade occur, and he has explained the problems that unstable data currently produced by assessment methods raise for neoliberal narratives about the commodification of ESs. But the question remains open if this is really feasible.

What are ecosystem services?

The concept of ES is not only anthropocentric but becomes unclear because many definitions exist, from “a set of ecosystem functions useful to humans” [36] to the benefits that human populations receive from ecosystems. This is a serious weakness that will be explained in this section.

Costanza et al [18] emphasized benefits derived, directly or indirectly, from ecosystem functions. Daily [19] included in ESs (or nature’s services) the conditions and processes, as well as life-support functions. The term ES cascade has been introduced recently to include ecosystem processes, functions, services, benefits and values [37]. The MEA [21] and Chan et al [38] define shortly ES as the benefits people obtain from ecosystems. Benefits include food, water, timber, leisure, spiritual benefits, etc. and result not only from ecosystem functions but also from natural or cultural elements of ecosystems or some combination of both [21]. Ecosystem conditions, processes and functions generate services, but they are not services. Services are always coproduced by humans and nature [39]. The influential MEA classification grouped ES in four categories: supporting, provisioning (food, fibres, genetic resources, chemicals, fresh water…), regulating (air quality, climate, water availability and quality, erosion, diseases and pests, pollination, natural hazards…) and cultural services (aesthetics, spirituals, leisure and sport…).

Boyd and Banzaff [34] claim for quantified evaluation of ESs: 1) units for ESs might be defined in a way methodologically and economically consistent with the definition of goods and services used in the conventional income accounts; 2) intermediate and final services have to be distinguished to avoid double counting, because many components, processes and functions of ecosystems are intermediate necessary products, but not ESs; 3) recreation is a benefit produced by ES and by conventional goods and services, not an ES itself; 4) the same thing can be a final service or not, depending on context; 5) for an economic account we do not need to measure processes, only process outcomes; 6) benefits for well-being include aesthetic issues, various forms of recreation, maintenance of human health, physical damage avoidance, and resources like wood or food. Then, benefits derive from ESs flows and are somewhere in between ecosystems and human well-being and we can put economic values on them [38-43]. These views are opposed to the idea that services and benefits are the same [21, 18].

Some authors define ESs as contributions of ecosystems to human well-being [42, 43]. However, well-being depends not only on nature but also on socio-cultural elements, and in a degree that increases with the affluence of societies [44]. Clearly, there are feedbacks between cultural products directed to increase well-being and ecosystem’s structure and function, and these interactions have to be understood to reach a sustainable social-ecological system.

The term landscape service has also been used [31, 45-48]. Landscape is a central concept for geographers, architects, urban planners, ecologists and others. The term landscape suggests the presence of: 1) cultural and aesthetic aspects relevant for human well-being, and 2) spatial heterogeneity. This becomes useful when interactions between neighbour ecosystems are considered in a geographical approach. The terms “environmental” and “green” services are used so well [47].

Summarizing, our review finds a lack of consensus about defining and valuing ESs and that associated concept can be ambiguous. This arise difficulties in comparing experiences and slow down progress in the field.

Why we need Green Infrastructures?

Whereas ESs are quite elusive, GIs are “objects” where functions and processes occur that provide ESs. GI includes urban forests, street trees and parks, bushes, grasslands, crops, etc., and blue areas such as lakes, coastal seas, streams, ponds, etc GI is a nearly fractal multi-scale system [49]: pieces of nature can be found at any scale with some similitude, from balcony flower-pots, roof-gardens or street trees to large structures such as riversides, urban forests or peri-urban parks. The Landscape Institute [50] defines GI as a network of green spaces planned and managed as an integrated system to provide synergistic benefits through multi-functionality but, in fact, few GI are actually planned and managed as an integrated system. The term “infrastructure” in GI sends to managers and decision-makers the message that GIs are as necessary for the society as highways, bridges or sewage systems. Then, a GI must be analysed, planned, and managed to optimize its benefits to the individuals and society, at multi-scale levels and from a multi-functional perspective. GIs can retire pollutants from the air, sequester C, contribute to rainwater infiltration (decreasing flood risk), provide shade, cool the air through tree transpiration and reduce energy consumption in summer and the urban island heath effect. By wise choice of species and design of spaces, and by increasing green surfaces (urban greening) at the soil level, on roofs and on vertical walls, it is possible to increase these benefits. The relationships between GI and both ecosystem and human health have been reviewed [51, 42] and an integration of the topics of GI and ecosystem health with that of human health has been proposed [52]. Green roofs and green walls are very efficient in the regulation of building temperature [53] and enhance local biodiversity [54] and large scale [55], providing ESs, health benefits and savings on energy and emissions that can be measured in monetary terms [56]. The influence of urban green infrastructure on the indoor environment has also been reviewed [57].

Lovell and Taylor [58] proposed to expand the concept of GI to include unplanned open space in both the public and private realms, considering a wide variety of ESs. This is necessary because GI programs have been criticized for a narrow focus on storm water management (ignoring opportunities for multi-functionality) [59]; for limited success in institutionalization [60] and in access to healthy food [61]; and for neglecting private spaces and their owners or managers [62]. Domestic gardens play an important role in the provision of ESs and must be included in GI inventories, but they are highly heterogeneous and they have many managers with different perceptions and, sometimes, conflicting goals. As a result, it is very difficult to include them in the frame of a general strategy addressed to environmental problems across whole urban ecosystems and/or of global significance [62, 63].

Pagano and Bowman [64] obtained data from all North-American cities over 100 000 inhabitants and found that, on average, 15% of cities land was vacant (including a large range of types: undisturbed open space, areas unbuildable due to steep slopes or flood risks, land with abandoned structures and contaminated brownfields, etc.). As with all ecosystems, conditions of vacant lands varied across regions. Vacant areas might be included in greening strategies or GI optimization for ESs [65] and projects to reuse individual vacant pieces can serve as models for other actions through the city, but this would require coordinated planning, goals and policies, capital to rehabilitate underutilized spaces and community empowerment to envision creative landscape designs that meet local needs [66].

Summarizing, there is more consensus about GIs than about ESs. Nevertheless, GIs are highly diverse in size, in physical (water, land) and biological composition and in actual possibilities for a ES-aimed management.

Trade-offs between Ecosystem Services and Ecosystem Disservices

GIs also support ecosystem disservices (EDSs): nuisances or losses and, sometimes, catastrophic events, that have to be evaluated. EDSs can be global: the increasing plantations of ornamental coniferous and broad-leaved evergreen species in urban areas strongly enhance biogenic volatile compounds (VOC's) emissions in cities, which contribute to produce smog [67]; GI can be used by disease's vectors to reach urban populations; green roofs increase water waste; alien species can spread from gardens; etc. Pataki et al [68] consider that there is scarce evidence for GI improving air quality in cities (i.e., fuel use by machines in GI management is an EDS), whereas psychological and health benefits have been demonstrated. Lyytimäki and Sipila [69] have concluded that, for northern European urban ecosystems, perceptions about ESs/EDSs have an increasing influence on how urban green areas are experienced, valued, used, managed and developed. Environmental education and community participation and empowerment [70, 71] modify perceptions, but decisions must be taken on robust, preferably quantitative, knowledge of ESs and EDSs. Therefore, much more science and knowledge are needed (factual quantitative information on specific cases, precise definitions, tools and a compromise to use the best information available) while naivety and ideology (for instance, any greening measure is not necessarily "good", nor any collective decision is always optimal) have to be avoided.

Most studies focus on a subset of ESs/EDSs and a specific typology of ecological structures (subsystems with different functional characteristics that generate different kinds or values of ESs/EDSs) for each case. In urban areas, most common ESs are often related to water drainage and retention (flood prevention), air-filtering (for different types of air pollutants), noise reduction, effects on microclimate outside and inside buildings, recreation, psychological effects, etc. EDSs include natural disasters, allergies to biogenic products, ozone and smog formation due to VOC's emissions, obstruction of views or sunlight by trees, habitats for disease's vectors, economical and ecological impacts due to invasive species, tree falls risk as a result of storms or pathogen activity, insecurity feeling associated to forest areas (but see [66]), etc. ESs/EDSs are valued on economic, social or ecological terms in non-comparable ways. An ES that promotes diversity can be considered an EDS due to insect nuisances or VOC's emissions. Management will be usually done with different perceptions, criteria and aims by stakeholders [63]. No simple solutions can be found: we cannot have ESs and exclude any EDS. Decisions need to consider trade-offs and synergies among ESs and trade-offs between ESs and EDs. This requires tools. Some exist, others have to be developed, i.e., models for optimization [72].

Assessing ESs and EDSs in urban environments

ESs/ EDSs depend on very complex sets of interacting processes and, as a result, they are difficult to evaluate. Much current research is focused on valuing them, less on quantifying them in biophysical terms [73]. Each city has a large diversity of GIs, each one with its own management history, its own specific composition, etc. Even for relatively similar GIs, processes and functions (and ESs/EDSs) are not identical. Tools are needed to analyze ESs/EDs, but they are only part of the solution. Improved awareness and understanding are also required, in parallel with other issues such as resources, capacity building, legislation and regulation, institutional change, etc. In the following lines, we will focus on the existing tools.

An array of them exists and they can be applied successfully for valuation, assessment, regulation, etc. For instance, substantial progress in the ESs/EDSs environmental and monetary valuation of urban forests has been gained with the Urban Forests Effects (UFORE) model, created by the USDA Forest Service [74]. Now called i-TREE-Eco, this model (peer-reviewed, freely available) calculates biophysical and economic values for some ESs and EDSs. It uses standard field data on the composition and structure of urban woody vegetation, obtained in sample plots, jointly with air pollution and meteorological data, to quantify the effects of urban vegetation structure on air pollution, microclimate and energy use, on the basis of species ecophysiology: VOCs emitted by plants; C sequestered annually and C stored in vegetation; the amount of pollutants (O_3, SO_2, NO_2, CO, and PM_{10}) that vegetation retains using the above mentioned data plus pollutant concentrations [75]; or tree shadow effects on building energy use and the associated emissions of carbon from power plants. Some parallel models focus on street trees (i-Tree-Streets), tree selection, pest detection, etc. These tools have been successfully used in a number of towns in America [76], Europe and other areas and they have been adapted to an increasing number of conditions. However, the use of these tools is limited to some aspects of GIs benefits and disservices linked to forests and urban trees. The evaluations of health benefits derived from urban GI in terms of reduced human mortality have been criticized, due to the high number of variables and assumptions involved in i-Tree and the feeble values obtained, and because they can drive to investments in planting trees that would be better employed in reducing emissions [77]. Results of i-Tree can be included in cost-benefit analysis and give some basis for planner and manager decisions. As an alternative to field measurements of 3D green plant biomass in urban forests, He et al [78] have employed LIDAR data for Beijing. The accuracy of 3D green biomass based on the image in SPOT5 is over 85%.

When assessing ESs/EDs, a social–ecological perspective is necessary [79-80, 32]. An outline of a framework for assessing multi-functionality in GI planning has been attempted, considering the ecological and social perspective separately [58]: the first one is aimed at data collection on the capacity of existing GI network (including small-scale landscape features such as lawns, community gardens, or playgrounds in a park) to provide ESs, and the second is covering the demands side; then, both perspectives would be integrated to set priorities for strategies and action. Using some ideas from multi-functional analysis in agro-ecosystems, landscape ecology [81-83] and on sustainability and resilience or transformability of cities [65, 84], the authors develop the Multifunctional Landscape Assessment Tool (MLAT), whose inputs include the area of each habitat type, its functional attributes and the ratings of these attributes based on user perception and expert assessment depending on the site-specific context. These ratings are subjective and qualitative because many social aspects are difficult to quantify. Local population involvement in urban greening processes increase resilience through supporting self-organization and creating constructive positive feed-back loops (acquisition of knowledge and skills to optimize ESs) [58, 84, 85]. “Adaptive management” can be reached in that way. The multi-functional landscape approach considers humans as part of the ecosystem and respects cultural functions, incorporates functions such as food production and agro-biodiversity, permits an evaluation of landscape designs and can serve as an adaptive strategy to address unknown future (climatic or socio-economic) conditions that could affect specially the most vulnerable populations [86-88].

Most studies evaluate ESs for small landscape features. A citywide approach has been undertaken by The Mersey Forest [89] in the Liverpool Green Infrastructure Strategy to maximize benefits through sustainable environmental management. The aim is to map functions of GI elements and display how many functions each element provides. A driving idea is that GI planning is scalable from the neighbourhood street to the regional or national level. At each level, the purpose of planning must be understood to gather the needed type of information with the needed resolution. This requires detailed cartography and GIS methodology. Land cover patches are assigned to a GI type and one function or more are assigned to each patch. Functions are named by the benefits they produce. So, the map of multi-functionality describes eleven benefits provided by the different GI types: climate change adaptation and mitigation; flood alleviation and water management; quality of place; health and well-being; land and property values; economic growth and investment; labour productivity; tourism; recreation and leisure; land and biodiversity; and products from the land. However, the very interesting Mersey's approach still only describes a subset of all the benefits provided by nature and this can skews decision-making.

Duvigneaud and De Smet used ecological maps in Brussels around 1975 (unpublished). Burriel et al repeated a Barcelona Ecological Map [90], three times (1977-78, 1992, 2004) to monitor land use dynamics using remote sensing and GIS, providing a spatially explicit expression of ES importance and distribution. The very fast urban growth, with serious impacts on ESs, has also been monitored in the Wuhan area of central China (1988- 2013) [91].

A major attempt to clarify concepts and provide tools at each step (from ecosystem analysis to environmental impacts and economic aspects), has been done by the UK National Ecosystem Assessment [92] and the derivate National Ecosystem Approach Toolkit (NEAT) [93]. The NEAT Tree gives literature reviews, specific guidance and case studies for each tool.

A way to approach the biophysical analysis of GI characteristics and functions is Life Cycle Assessment (LCA). The account is based on ISO 14040 and 14044. A particular case is the calculation of footprint due to greenhouse gas emissions [94]. This is useful when different alternatives in land planning are discussed [95, 96]. The LCA approaches do not include many benefits and social aspects, [but see 86]. There are also some tools designed to reduce the footprint based on GI, like the Climate Leadership in Parks (CLIP) Tool [97]. Some resources for taking decisions on GIs can be found online [i.e., 93, 98]. Indicators to assess effects of management on ESs have been reviewed recently [99].

Summarizing the section, a number of tools exist, some very useful but most of them consider only a part of ESs/EDs and social aspects involved in their management. A critical aspect is that, in any GI assessment, the long-term ability of the system to supply the desired benefit should be considered, but, unluckily, in many cases this does not occur.

The way forward

Approaches focused on ESs in direct relation to actual demand might overlook the importance of ecological functioning to secure the long-term capacity to provide services. We need a better understanding of resilience and of the ecological and social thresholds that which, once passed, a change in an ES can become irreversible [100]. Ecology has some tools that can be applied to solve ESs problems, including landscape theory and biological conservation frameworks, remote sensing applications in cartography, processes monitoring, plant ecophysiology, biological indicators, etc. On the social side, engaging civic stewards in collecting measurements offers opportunities to feedback in an adaptive co-management process, and civic ecology practices (creating GI that provides ESs) are social-ecological processes that generate ESs (e.g., recreation, education, vegetable gardens) and benefits to human well-being [58]. Multi-scale studies and comparisons between different areas must become more frequent because this is clearly necessary to obtain sound basis for understanding and managing the complexity of ESs. A combination of tools based on a common theoretical framework is likely to be the best strategy if the local human community is permanently involved in the process [101, 102]. Multi-disciplinarity is an urgent need to undertake new strategies. Pickett et al [103] proposed the metaphor of “cities’ resilience” and its technical specifications as a tool for promoting the linkage between urban designers, ecologists and social scientists. Another possibility is green city branding (raising awareness on the green space in the city as an image communication in front of other competitive sites) [104].

There is an urgent need for new tools that can be applied to non-forest ecosystems and to social processes that interact with ecological processes, in order: 1) to model and test alternatives to present land use planning and potential investment or policy, and 2) to mitigate the effects of climate and socioeconomic changes on ESs [105-108]. Carpenter et al [100] call for more integrated research: our ability to draw general conclusions remains limited by focus on discipline-bound sectors of the full social–ecological system. Everard and McInnes [101] sustain this idea: “Systemic solutions are not a panacea if applied merely as 'downstream' fixes, but are part of, and a means to accelerate, broader culture change towards more sustainable practice”. This necessarily entails connecting a wider network of interests, including for example spatial planners, engineers, regulators, managers, farming and other businesses, and researchers working on ways to quantify and optimize delivery of ecosystem services”. Another problem is that some policies and practices intended to improve ESs and human well-being are based on untested assumptions and sparse information.

There are international efforts to gain experience on ESs and GI, in order to increase urban efficiency and resilience to climate change. The Economics of Ecosystems and Biodiversity (TEEB) is a global initiative drawing attention to the economic benefits of biodiversity. The Urban Biodiversity and Ecosystem Services (URBES) Project [109] and COST Action FP1204 on Green Infrastructure Approach [110] facilitate experience exchanges in linking environmental and social aspects. Cities and Biodiversity Outlook (CBO) Scientific Foundation promotes research and practice on urban resilience and ESs [111]. Urban Planet (launched by the Stockholm Resilience Centre) offers interactive data, maps and solutions for more sustainable urban regions, with case studies [112]. The EU PHENOTYPE project [113] focuses on integrating human health needs into GI management and land planning, through a better understanding of the relation between exposure to the natural environment and health, and translates findings into potential policies and management practices involving stakeholders. Analysing ecosystems production of goods and services, how they change, and what allows and limits their performance, can add to the understanding of social–ecological dynamics and suggest new avenues for governing and managing urban system for resilience [114]. There is an urgent need to achieve methodologies for assessing the role of GI in the provision of ES in urban regions with diverse physical and socioeconomic contexts affecting their structure, functioning and sustainability [83]. Especially important is addressing the understanding of GI contribution to ES in developing countries, which will concentrate the expected urban growth in the near future [115] and highly unsustainable effects on ecosystem services can be expected [116]. Gómez- Bagghetum et al [117] describe a range of ESs/EDSs valuation approaches (cultural values, health benefits, economic costs and resilience) and explain how ESs assessment may inform urban planning and governance, with a number of study cases in highly diverse urban systems, in Africa, Europe and America.

The topic is gaining momentum [118]. Research can give confidence on the proposed actions [119] and avoid serious errors in transferring the results of local experiences to other sites with different physical and social characteristics, or in planning and managing just for one or a few ESs [120, 121, 68]. However, even with a lot of relevant research available, few results can be expected without a reinforcement of institutional structures and progress in governance: there is a need for for technical, financial and institutional capacity within urban decision-making processes. Knowledge has to be increased, but also implemented with political measures and awareness of socio-ecological context.

Conclusions

It is largely known that cities and metropolitan areas increase wealth and creativity but have an impact on the global biosphere. They have to be managed towards more efficient strategies in energy use and towards an enhanced resilience in the face of climatic and social changes, without impairing their benefits. These are major challenges for our future. To confront these challenges, cities must promote local provision of ESs flows (reducing the regional and global footprints [108]), and social involvement in sustainability. This requires a better understanding and quantification of biophysical processes that underlay ESs/ESDs and GI functions. Many assumptions used in developing strategies still lack solid scientific bases. ES conceptual ambiguity, the ES and GI multi-functional and multi-scale character and the large diversity of managers and perceptions remain serious obstacles.

We need well-defined concepts and frameworks and a large number of multi-functional and multi-scalar ESs assessments to gain experience and skills. This review has considered a non-exhaustive array of tools available for ecosystem analysis, mapping and monitoring, environmental impacts assessment, cost-benefit analysis, strategies development, social involvement, etc., that might be tested and adapted to different conditions and can aid to manage GIs to obtain optimal benefits from ESs. But, even if current progress is fast, much still remains to be done to integrate, in concept and practice, ecological and social approaches and to develop multi-disciplinary teams, to involve communities in management activities and decisions and to evolve the capacity for scaling from the local level to the global. In any case, urban GI and ESs constitute an exciting field where relevant advances can be expected. Some of key contributions of the present review are:

- Be aware of the anthropocentric conception of ES. It would be dangerous to manage nature solely on the consideration of the immediate benefits or nuisances that she provides, overlooking the importance of ecological functioning for the long-term functioning of GI.
- Monetary approaches can be dangerous. Decisions on ESs management might not be taken just on current monetary values because this would produce very undesirable results.
- In general, the concept of GI accounts for more consensus than that of ES, but its translation to ES-aimed land use planning and management is not easy, due to the diversity of physical and socio-economic contexts where to be applied. There is a great challenge on making a GI framework for the restauration and preservation of ES in urban areas, particularly in developing countries.
- In all cases, large-scale inclusive planning approaches to GI, extended to all the unplanned open space in both the public and private realms and considering a wide variety of ESs, are needed.

- Still, the focus should be put on multifunctional GI landscape approaches considering humans as part of the ecosystem, in order to properly address future challenges (either climatic or socio-economic or both) especially in the most vulnerable regions.

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