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Assessing and mapping ecosystem services to support urban green infrastructure: The case of Barcelona, Spain

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ABSTRACT

The ecosystem services approach provides an efficient way to support urban green infrastructure planning. Such an assessment, together with mapping, can effectively produce spatial analyses on a specific scale, helping to maintain multi-functional landscapes and plan urban green infrastructure. In turn, green infrastructure can offer a wide variety of ecosystem services, promoting landscape sustainability. This study develops a methodology for the planning of urban green infrastructure based on an ecosystem services approach that assesses the supply capacity of ecosystem services, and identifies possible spatial characteristic areas for interlinking urban green infrastructure within the study area. More specifically, from a landscape perspective, we use 32 ecosystem services (as X-axis) and different land use types (as Y-axis) to build an ecosystem service assessment matrix. We then take the municipality of Barcelona as an example, using the latter to assess and map ecosystem services within the city through ArcGIS, which shows the spatial distribution characteristics of ecosystem services provision. We identify possible spatial areas - which include ecosystem services provision, barren, and obstructed areas - by overlapping the ecosystem services assessment maps. Ultimately, the results provide a reference for urban green infrastructure planning by recognizing priority protected areas, new construction areas, potential areas, and renewal areas.

1. Introduction

Nature capital is a vital resource for providing numerous ecosystem services important for human welfare and survival (Costanza et al., 1997), yet it is negatively affected by urban expansion (Zank, Bagstad, Voigt, & Villa, 2016). Rapid urbanization leads to environmental deterioration, landscape fragmentation, and unbalanced urban ecosystems. Such robust human activity not only significantly undermines urban ecosystems but can also reduce ecosystem functions and capacities to provide services (Kreuter, Harris, Matlock, & Lacey, 2001).

The publication of the Millennium Ecosystem Assessment (MA) (2005a) reports triggered much discussion over ecosystem functions, goods, and services, including the relationship between biodiversity and ecosystem services (Hooper et al., 2005; Ingram, Redford, & Watson, 2012) and the impact of climatic and land-use change on ecosystem services (Lautenbach, Kugel, Lausch, & Seppelt, 2011). The last twenty years has also seen the development of the value and evaluation of ecosystem services (Costanza et al., 1997; Daily, 1997; Hein, van Koppen, de Groot, & van Ierland, 2006).

Over the last decade, the concept and approach of ecosystem services (ES) have been mainstreamed. Assessment research and the mapping of ES have contributed to supporting decision-making (Beier, Patterson, & Chapin, 2008; Daily et al., 2009) and landscape planning (Frank, Fürst, Koschke, & Makeschin, 2012; Koschke, Fürst, Frank, & Makeschin, 2012), and improving the planning of urban green spaces (Niemelä et al., 2010).

Currently, the quantitative mapping and evaluation of ES delivery rely mainly on literature surveys and model methods, which make the most of current knowledge and theories. These include, for example, the market-valuing method (Bateman et al., 2002; de Groot, Alkemade, Braat, Hein, & Willemen, 2010), ecological process simulation (Nedkov, 2012; Stürck, Poortinga, & Verburg, 2014), data space stacking (e.g., Serna-Chavez et al., 2014), and InVEST models (e.g., Arcidiacono, Ronchi, & Salata, 2015; Boithias et al., 2014). In addition, the land-cover based approach (Burkhard et al., 2015; Burkhard, Kroll, Müller, & Windhorst, 2009; Burkhard, Kroll, Nedkov, & Müller, 2012), a quantitative assessment of the supply capacity of ES in specific land cover types, is widely used. To this regard, the work of Burkhard et al. (2009) has been widely acknowledged for its advantages over other methods. It is, in fact, a rapid assessment procedure with clear benefits for the decision-making process. Moreover, it can be applied to different regions and has a low requirement in terms of initial data, necessitating

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Table 1
List of Main Ecosystem Services and their Related Sub-Categories, adapted from (Costanza et al., 1997; de Groot et al., 2002; MA, 2005b; de Groot, 2006).

	Ecosystem services	Definition	Benefits to human welfare and society (examples)
	Regulating services	The maintenance of essential ecological processes and life support systems, which influence climate, hydrological, and biochemical cycles, earth surface processes, and biological process.	
1	Local climate regulation	The influence and regulating of ecosystems on local climatic conditions	Favor local climate, such as alleviating the urban heat island effect
2	Global climate regulation	The impact on global climatic conditions	Control global warming
3	Gas regulation	The effect of ecosystems on bio-geochemical cycles	CO_2/O_2 balance, ozone layer protection
4	Disturbance prevention	The ability of ecosystems to moderate adverse natural events and environmental disturbances	Flood prevention, storm protection, human and city safety
5	Natural hazard mitigation	The mitigation of natural disasters	Creation of stable life-communities and safe environments for human societies
6	Air quality regulation	The improvement of air quality through ecological processes and components	Access to cleaner air
7	Water regulation	The regulation of runoff and river discharge	Irrigation and drainage maintenance
8	Water purification	The purification and filtering of water	Water security for human, flora, and fauna
9	Groundwater recharge	Underground water supplement	Optimal allocation of water resources
10	Soil retention	The role of vegetation root matrix and soil biota in soil retention	Maintenance of agricultural productivity and prevention of damage due to soil erosion
11	Soil formation	The weathering of rock, accumulation of organic matter	Maintenance of crop productivity and natural productive soils
12	Nutrient regulation	The role of biota in storage and recycling of nutrients	Local plant growth, migration of animals
13	Pollination	The role of biota in the movement of floral gametes	Improvement of biodiversity, protection of certain species
14	Waste treatment/ disposal	The dilution, assimilation, and chemical re-composition of certain waste	Pollution control, filtering of dust particles, noise abatement, space for solid waste disposal, effective use of organic wastes
15	Erosion protection	The role of vegetation and biota in erosion protection	Flood, agriculture, and coastal erosion protection
16	Biological control	Population control through trophic-dynamic relations	Control of pests and diseases, reduction of herbivory
17	Disease regulation	The role of biota in disease control	Prevention of the outbreak of diseases
	Provisioning services	The provision of natural resources	
18	Food	The conversion of solar energy into wild edible plants and animals	Provision of certain food production for humans (e.g., crops, livestock, capture fisheries, fodder)
19	Water	The filtering, retention, and storage of fresh water	Consumptive use (e.g., domestic water, irrigation, industrial use)
20	Raw materials	The conversion of solar energy into biomass	Human construction (i.e., wood and sturdy fibers for building, oils and latex for industrial purposes, and energy resources like fuel-wood and bio-chemicals)
21	Genetic resources	Genetic material and evolution in wild plants and animals	Maintain cultivars productivity, improvement of individual quality and adaptability, such as resistance to pests
22	Medicinal resources	Variety in chemical substances in natural biota	Maintenance of human health, e.g., drugs and pharmaceuticals, animals tests
23	Ornamental resources	Variety use of wild plants and animals for ornamental purposes	Resources for fashion, handicrafts, jewelry, pets, worship, decoration, souvenirs, etc.
	Habitat services	The provision of habitats (suitable living spaces) for wild plant and animal species and the maintenance of ecological processes	
24	Habitation	Suitable living spaces for wild plants and animals, and sustainable spaces for human living	Maintenance of biodiversity
25	Nursery	Suitable reproduction habitats	Provision of breeding and nursery areas for commercially harvested species
	Cultural services	The provision of opportunities for recreation, cognitive development, relaxation, spiritual reflection, to the benefit of human beings	
26	Identity	The strong feeling of belonging to a particular community	Improve sense of regional, cultural, landscape identity, etc.
27	Aesthetic	Attractive landscape features and views	Satisfy human enjoyment of scenery and aesthetic experience
28	Recreation	Landscapes for (potential) recreation or amusement use	Provision of daily or periodic recreation activities for people
29	Cultural and artistic	Variety in natural and semi-natural features with cultural and artistic value	Nature and cultural landscape as sources of inspiration to promote the development of art and cultural industry (e.g., film, painting, architect, literature, etc.)
30	History and religion	The spiritual and historical value of nature and semi-natural landscapes	Religious purposes and historical values (natural and semi-natural ecosystems and features, and heritages values)
31	Science and education	The scientific and educational value of nature	Natural elements and features provide a range of opportunities for scientific research, excursion, nature study, environmental education
32	Tourism	Variety in nature with (potential) tourism value	Travel to natural ecosystems for eco-tourism

only land cover type data and experts' experience and knowledge. Hence, in recent years, many researchers have adopted this method to assess ES on a large instead of small scale (e.g., Tao, Wang, Ou, & Guo, 2018), given that there is no need for overly detailed data processing. Given these reasons, we use this approach here to assess ES provision potential.

In order to emphasize multi-functional green spaces and attain urban sustainability, Sandström (2002) introduced the concept of green infrastructure (GI) as a coherent planning entity. GI is defined as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ES" (European Comission, 2010). It aims to optimize human living environments and life quality (Lafortezza, Davies, Sanesi, & Konijnendijk, 2013; van den Berg et al., 2016; van den Berg, Maas, Verheij, & Groenewegen, 2010) and to protect urban biodiversity (Goddard, Dougill, & Benton, 2010; Hostetler, Allen, & Meurk, 2011). The European Comission (2013) has recognized GI as smart solution for providing people and societies with a broad range of goods and services.

In recent years, a growing number of researchers and decision-makers have begun to integrate the concept of ES into urban policy and decision-making processes. In England, for example, urban GI planning has become a core strategy in efforts to mitigate climate change (Bonan, 2008). The city of Essen, in Germany, was named European Green Capital 2017, thanks to its urban ecological regeneration strategies. Particularly, brownfield land and wasteland have been transformed into hundreds of acres of green space, with the aim of ensuring that every resident can access the city's green and blue infrastructure within a range of 500 m, and benefit from the ES (Kotzeva & Brandmüller, 2016).

Although research on applying the ES concept to GI planning has grown considerably in recent years, the majority of studies propose planning GI from the perspective of spatial patterns (Goddard et al., 2010) or focus on shaping the ideal form of the region (e.g., aesthetic functions), neither of which comprehensively adopt an ES approach (Swaffield, 2013). Moreover, to our knowledge, no GI analyses integrate the complete spectrum of ES (e.g., Liquete et al., 2015). Generally, GI planning based on the ES approach for practical planning remains understudied (e.g., Kopperoinen & Itkonen, 2014; Niemelä et al., 2010).

Yet ES provides an effective means of supporting general planning processes and GI planning specifically, given the possibility of identifying priority protected areas (Egoh et al., 2007; Egoh et al., 2010; McDonald, Allen, Benedict, & O'connor, 2005). This study argues for a methodology that establishes urban GI based on the ES approach, through the assessment of the supply capacity of ES and the identification of possible spatial characteristic areas such as priority protected areas, new construction areas, potential areas, and renewal areas. To this end, we focus primarily on how to quantify and visualize ES provision units, how to integrate an ES approach in the identification of possible spatial areas showing different supply capacities of ES, and how these areas can be used to guide urban GI planning.

2. Materials and methods

2.1. Ecosystem services and land cover classes

2.1.1. The concept of ecosystem services

Ecosystem services are identified as the benefits humans derive, directly or indirectly, from nature (Costanza et al., 1997; Daily, 1997; de Groot, 1992; MA, 2005a). In practice, this means that the capacity to deliver ecosystem services differs relative to individual ecosystems, depending particularly on their state and quality. A number of different classification categories have been developed (i.e., Costanza et al., 1997; Daily, 1999; de Groot, Wilson, & Boumans, 2002; Wallace, 2007), but that of the MA (2005a), which includes provisioning services, supporting services, regulating services, and cultural services, is the most widely accepted in academia.

Based on the lists developed by Costanza et al. (1997), de Groot et al. (2002), the MA (MA, 2005a), and de Groot (2006), we have constructed a general set of ES, as shown in Table 1. The ES are grouped into four main categories: provisioning services, regulating services, habitat services and cultural services. As described in the table, the first column lists 32 sub-categories of ES. Regulating services refer to the capacity of ecosystems to maintain essential ecological processes and life support systems, such as regulating climatic, hydrological, and biochemical cycles, earth surface processes, and biological process. Provisioning services instead concern the provisioning capacity of natural resources while habitat services aim to maintain ecological processes by providing suitable living spaces. Cultural services regard opportunities and capacities for spiritual experiences, cognitive development, and recreation. The second column contains a more detailed definition of each ES, while the third column provides examples of benefits to human welfare and human society (not exhaustive).

2.1.2. Land cover classes

The quality and quantity of ES are directly affected by structural and functional change in land use types. For example, shifts in land use can affect regional or global climate (resulting, for example, in global warming) (Pielke, 2002), which in turn can mean a decrease in the capacity of local and global climate regulation services. Moreover, improper land use can lead to habitat and landscape fragmentation (Mitchell et al., 2015; Mitchell, Bennett, & Gonzalez, 2013), resulting in the destruction of wildlife habitats and changing landscape connectivity, which can further affect, directly or indirectly, the formation and supply of ES. That said, the impact of land-use change on ES can also be positive. For instance, Lovell (2010) argues that urban agriculture is a sustainable and multifunctional land use option for cities. Hostetler et al. (2011) find that establishing urban GI is crucial to conserving biodiversity, instead of constructing commercial areas. Hence, the implementation of land management and the optimization of land use structures can ensure and improve the formation of ES (de Groot et al., 2010).

There exists much shared geographical information and data regarding land cover classes. This study uses the CORINE (Coordination of Information on the Environment) land cover (CLC) data as the reference. The CORINE program was initiated in the European Union in 1985 (EEA, 1994), and the database includes 44 land cover classes in Europe, ten of them present in our study area, according to the CLC in 2012 (See Fig. 4). The CLC dataset uses a minimum mapping unit of 25 ha, and a minimum width of 100 m (EEA, 1994). We incorporate vector data and ES matrices in ArcGIS in order to visualize the spatial distribution of ES in the study area.

2.2. Ecosystem services assessment matrix

For the ecosystem services assessment matrix (ESAM), we propose six common steps for evaluating the supply capacity of ES based upon the land-cover approach in the investigated area (Fig. 1):

1) Selection of study area.
2) We choose an applicable and scientific land use database within the investigated area. This is important because the ES matrix consists of supply capacities of various ecosystem services (x-axis) and different land cover types (y-axis).
3) In order to build the ESAM, we selected the relevant ES, and respective indicators.
4) Diverse experts scored the supply capacities of the ES, assigning a value of 0–5 for each entry in the matrix, or that of a given ES capacity on a relative land unit. A score of 0 represents no relevant capacity of ecosystem service, while 5 represents very high relevant capacity. In this step, the data was double checked and a consensus reached.
5) After acquiring the expert scores, the delivery capacity of the ES was

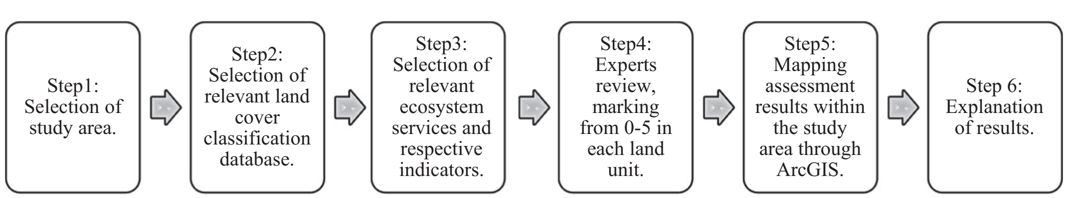

Fig. 1. Typical steps for land-cover based ecosystem services supply assessment (modelled after Hou, Burkhard, & Müller, 2013).

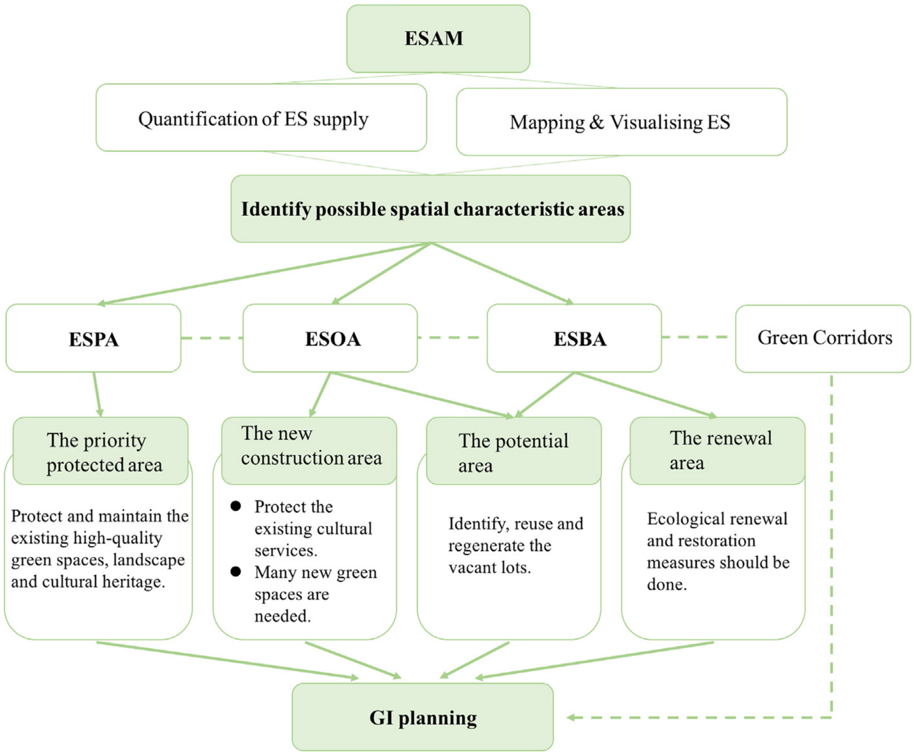

Fig. 2. Framework for green infrastructure planning based on ecosystem services. (own elaboration).

mapped and visualized using ArcGIS to interlink the assessment results and the spatial land units. The mapping of ES shows its characteristics and spatial distribution within the investigated area, providing an intuitive reference for land planners and decision-makers.

6) An explanation of the results is provided.

2.3. A framework for GI planning based on ecosystem services

Based on the above, we classified the possible spatial characteristic areas using the results of ESAM. The spatial characteristics of ES delivery reflect the relationships among service providing areas where ecosystem services are produced, services benefiting areas where ecosystem services are required, and connecting areas (Fisher, Turner, & Morling, 2009; Syrbe & Walz, 2012). Thus priority protected areas, new construction areas, potential areas, and renewal areas can be identified within different possible spatial regions, offering a useful reference for GI planning. Fig. 2 shows the framework for GI planning based on ESAM.

3. Case study

3.1. Study area

The Municipality of Barcelona is the capital of the autonomous community of Catalonia as well as that of the Province of Barcelona (Fig. 3). It is the second largest city in Spain with approximately 1.61 million inhabitants in 2016 (Barcelona City Council Statistical Yearbook, 2018).

The city stretches across the so-called Barcelona plain, along the northwest coast of the Mediterranean Sea, known for its sandy beaches and the landmark of Montjuïc hill. It is bordered by Collserola natural park to the northwest, the Besòs river to the northeast and the Llobregat river to the southwest, both opening up into the sea.

Barcelona has long promoted the establishment and development of urban public areas and green space systems. For example, the city hosted the International Exposition in 1929. In 1976, Barcelona and 26 surrounding towns together formed the “Metropolitan Overall Plan (PGM).” The hosting of the 25th Summer Olympic Games in 1992 then contributed significantly to urban infrastructure construction and space renewal. In 2013, the government published the “Barcelona Green Infrastructure and Biodiversity Plan 2020,” which aims to enhance biodiversity and build a better life for residents with greater GI (Ajuntament de Barcelona, 2013). With excellent urban planning and design, the city's park and green space system have become essential parts of the public space system and have provided a good foundation for the city's GI.

Within the Municipality of Barcelona, the total green area amounts to 28.34 km^2 (or 17.6 m^2 per inhabitant). This includes, however, the green area of Collserola natural park, which amounts to about 16.99 km^2, meaning that the inner city of Barcelona (excluding Collserola) has insufficient green space (about 11.35 km^2), reaching 7.0 m^2 per inhabitant (Barcelona City Council Statistical Yearbook, 2018). This ratio is far below that of other cities in Europe (Kotzeva & Brandmüller, 2016; Littke, 2015).

3.2. Quantification of the ecosystem service supply

3.2.1. Land cover classes of Barcelona municipality

We derived the land cover classes within the Municipality of Barcelona from the CLC database in 2012. Ten land use types are present in the study area: continuous urban fabric, discontinuous urban fabric, industrial or commercial units, green urban areas, sport and leisure facilities, coniferous forest, sclerophyllous vegetation, pastures, port areas and road and rail networks, and associated land (See Fig. 4).

3.2.2. Assessment of ecosystem services provision

Based on the ES matrix described above, we use four categories of ES as the X-axis, which include 32 sub-categories, and ten different urban land cover types in Barcelona as the Y-axis. The matrix contains a total of 320 entries. The score for each entry in the matrix indicates the supply capacity of ES per unit of a certain land use type in Barcelona.

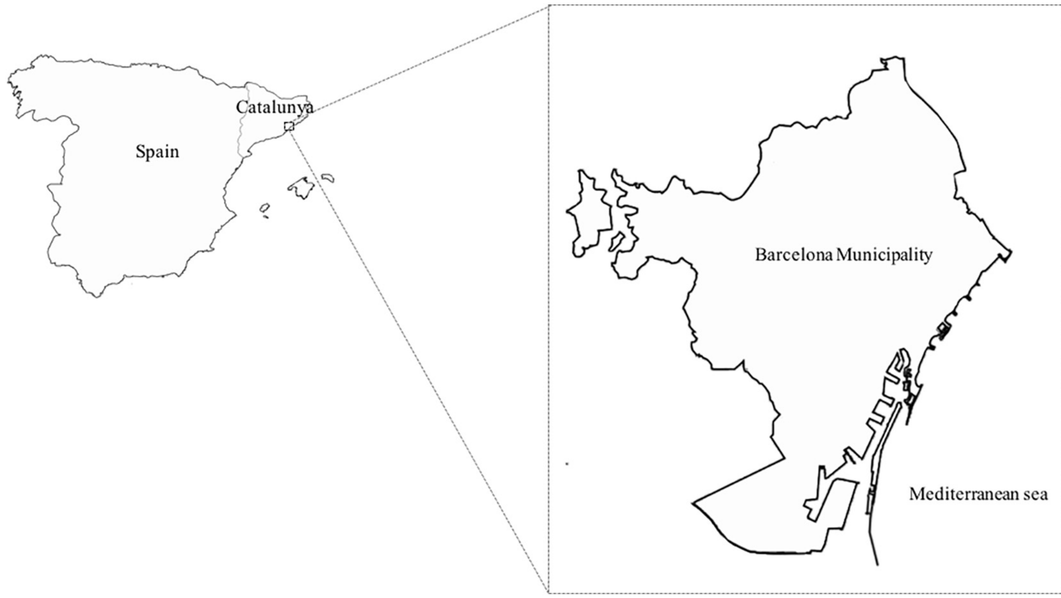

Fig. 3. Location of the Barcelona Municipality. (own elaboration).

The values were determined following three steps. First, we assigned a score for each entry ranging from 0 to 5. A value of 0 represents no relevant capacity to supply ecosystem services, while the highest score indicates great relevant capacity. Second, through interviews and questionnaires, the group of experts individually ranked each entry for the investigated area. The experts had different backgrounds, ranging from ecologists, geographers, and botanists, to residents of Barcelona and employees of Collserola natural park. Third, several rounds of panel discussions were held with the experts to finalize the scores. From these results, we produced the evaluation matrix, as shown in Fig. 5.

Fig. 5 clearly shows the different supply capacities of ES in the various land cover types in the study area. We observe that artificial areas with strong human intervention, such as continuous urban fabric, discontinuous urban fabric, transport networks, industrial or commercial units, and ports areas have almost no capacity to deliver regulating services, provisioning services, or habitat services, and insufficient capacity to offer cultural services. In other words, these artificial areas of the urban ecosystem, particularly grey infrastructure, do not, compared to GI, contribute substantial ES. On the contrary, green urban areas,

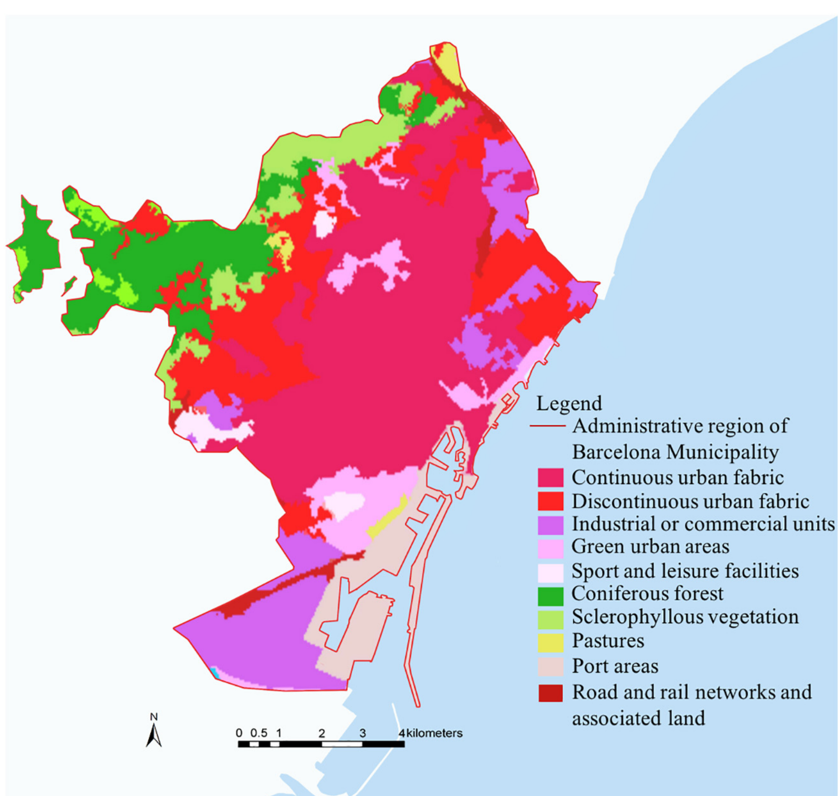

Fig. 4. The map of land cover classes in the Municipality of Barcelona. (own elaboration based on CLC (2012)).

LUT \ ES	Regulation Services	Local climate regulation	Global climate regulation	Gas regulation	Disturbance prevention	Natural hazard mitigation	Air quality regulation	Water regulation	Water purification	Groundwater recharge	Soil retention	Soil formation	Nutrient regulation	Pollination	Waste treatment	Erosion protection	Biological control	Disease regulation
Continuous urban fabric		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Discontinuous urban fabric		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Road and rail networks and associated land		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Industrial or commercial units		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Green urban areas		3	2	2	0	1	3	1	1	2	1	1	1	1	1	2	1	1
Sport and leisure facilities		1	1	1	0	0	1	1	1	2	0	0	1	1	0	1	0	0
Coniferous forest		5	4	3	3	4	5	5	5	2	5	5	5	5	4	5	5	4
Sclerophyllous vegetation		3	1	1	1	1	1	0	0	1	1	1	3	2	1	0	3	2
Pastures		1	1	0	1	0	4	1	0	1	0	0	0	0	0	0	2	2
Port areas		0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	1	0

LUT \ ES	Provision services	Food	Water	Raw materials	Genetic resources	Medicinal resources	Ornamental resources	Habitat services	Habitation	Nursery	Cultural services	Identity	Aesthetic	Recreation	Cultural and artistic	History and religion	Science and education	Tourism
Continuous urban fabric		0	0	0	0	0	0		0	0		2	2	2	2	2	2	3
Discontinuous urban fabric		1	0	1	0	0	0		1	1		1	1	1	1	1	1	1
Road and rail networks and associated land		0	0	0	0	0	0		0	0		0	0	0	0	0	0	4
Industrial or commercial units		0	0	0	0	0	0		0	0		0	0	0	0	0	0	3
Green urban areas		1	0	0	1	1	4		3	2		3	3	3	2	2	2	4
Sport and leisure facilities		0	0	0	0	0	0		1	1		2	3	5	3	2	2	2
Coniferous forest		1	0	5	4	4	5		4	4		4	5	5	3	4	4	4
Sclerophyllous vegetation		1	0	0	0	2	1		2	1		0	2	2	1	0	1	1
Pastures		4	0	4	2	2	1		2	2		1	1	3	1	0	0	1
Port areas		0	0	0	0	0	0		0	0		0	0	1	0	0	0	1

Fig. 5. Ecosystem services assessment matrix, illustrating capacities to deliver ecosystem services relative to different land use types in Barcelona municipality (modelled after Burkhard et al., 2009; Burkhard et al., 2012; Burkhard et al., 2015).

Notes: The assessment scale ranges from 0 to 5, indicated by different colors: 0/yellow = no relevant capacity to provide the ecosystem service; 1/blue = low relevant capacity; 2/green = relevant capacity; 3/red = medium relevant capacity; 4/turquoise = high relevant capacity; 5/purple = very high relevant capacity. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

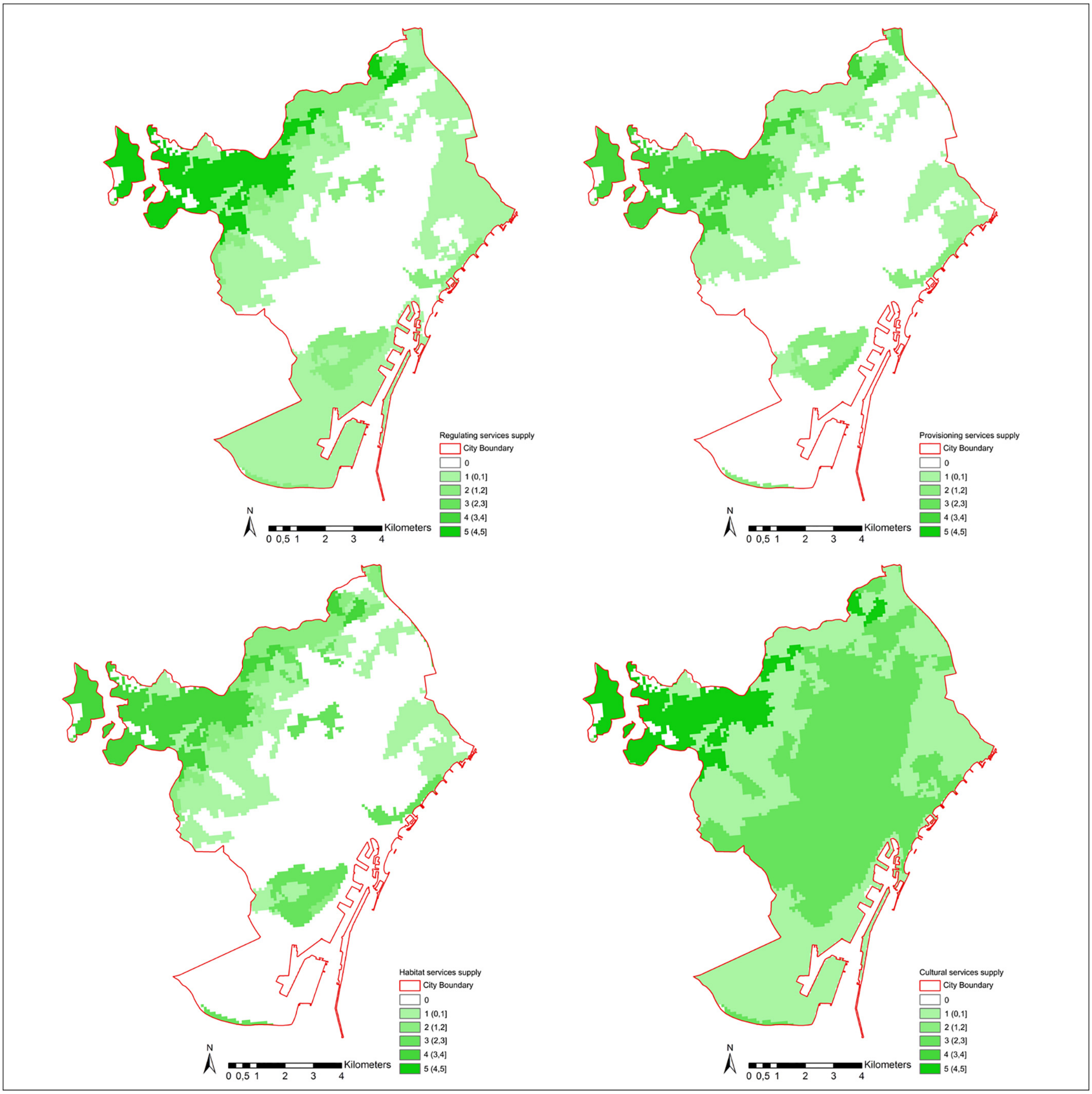

Fig. 6. Spatial distribution of the supply of ecosystem services in Barcelona Municipality. (own elaboration).

coniferous forest, sclerophyllous vegetation, and pastures can provide many ES. Coniferous forest in particular have a considerable influence on improving air quality, regulating climate, offering recreation facilities, and cultural edification opportunities.

3.3. Spatial distribution of the ecosystem services supply

The information obtained from Fig. 5, together with the land cover types in the study area, can be visualized by joining the data to the attribute table of the polygon shape-file in ArcGIS. The data is then projected onto the urban spaces in order to obtain assessment maps of the spatial distribution of the four ES categories (Fig. 6). These four maps are in turn overlapped, resulting in the final ES assessment map (Fig. 7), which intuitively shows the spatial distribution characteristics of ES in the study area. We observe that the highest capacity places are the city's natural and semi-natural green areas, like Collserola natural park and Montjuïc hill, meaning that these are important supports for Barcelona's urban GI. We also see that the fragmentation of the urban landscape has resulted in an extremely unbalance provision of ES in the city. The providing capacity of large-scale hardened areas is weak, and they become isolated as they have almost no borders with urban forest and parks. Quantification mapping of ES thus provides an important reference for decision-making processes and the weighing of pros and cons in the assessment and planning of GI.

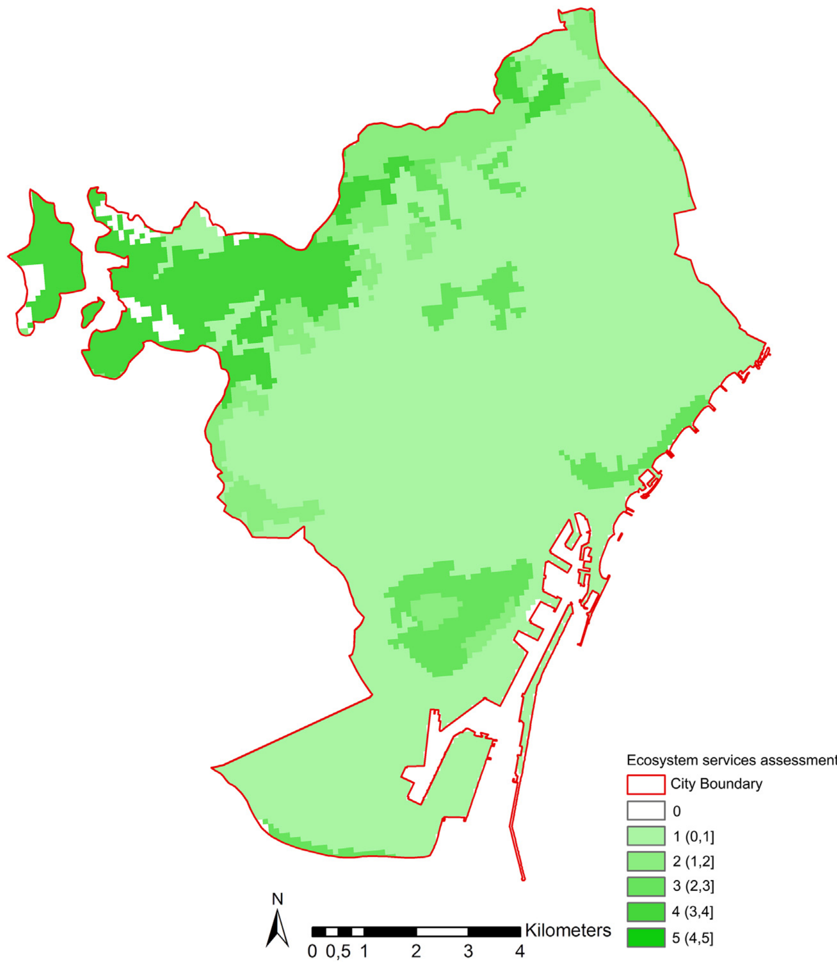

Fig. 7. The assessment of ecosystem services supply in Barcelona Municipality. (own elaboration).

4. Results

4.1. Identification of ecosystem services spatial areas

When identifying the spatial distribution of areas providing ES purely from a production point of view, quantitative data proves useful. In particular, from a landscape planning perspective, quantitative data (Fig. 5) and maps (Fig. 6 and Fig. 7) can be used to identify possible areas (Fisher et al., 2009; Syrbe & Walz, 2012) relative to the degree of ES provision capacity by interlinking the spatial characteristics of ES provision and urban green space.

More specifically, we identify three spatial areas that reflect the various relationships between different services. In line with the results presented above, we code places with high ecosystem services capacity ($3 < \text{score} \leq 5$) as the “ecosystem service provision area” (ESPA). Those with low capacity ($1 < \text{score} \leq 3$) are coded as the “ecosystem service barren area” (ESBA), while places lacking capacity ($0 \leq \text{score} \leq 1$) are coded as the “ecosystem service obstructed area” (ESOA). This coding allows to map the possible spatial areas of ES, reflecting the current situation of ES assessment (Fig. 8). Meanwhile, the map of the main green areas of Barcelona city is developed (Fig. 8). Comparing these two maps, we can see that ESPA mainly includes urban forest, while urban parks, pastures, and leisure facilities belong to ESPA or ESBA. Urban brownfield land, industrial or commercial units, transport networks and building environment are in the ESOA. Importantly, ESPA and ESBA are not always adjacent, such that there is not always continuity of green areas.

4.2. Green infrastructure planning based on the ecosystem services

In addition to representing the different provision capacities of ES, the various spatial areas (ESPA, ESBA, ESOA) contain different land use types and diverse urban green space conditions, all of which helps to verify the protected areas, renewal areas, new construction areas, and potential areas in urban GI planning. In what follows, we outline important considerations relative to these areas and land use types when planning urban GI by integrating an ES approach:

(1) The priority protected area

The ESPA is primarily a protected area since it includes many high quality green spaces that deliver a variety of ES. For example, the urban forest provides an essential habitat to wildlife, ameliorates micro-climate, improves air quality, and reduces noise service. As Fig. 5 shows, many of the ES provision capacity scores reach up to 5. It is therefore vital to protect and maintain the existing high-quality forest.

Moreover, this area has a very high capacity to deliver cultural services, which offer recreation opportunities, science and education services, and aesthetic value for people. Scientific and effective management policies and protective measures of cultural and landscape heritage in ESPA are thus a necessity.

(2) The new construction area

The new construction area refers to those places extremely lacking in ES, where one hardly finds green spaces. According to Fig. 8, the

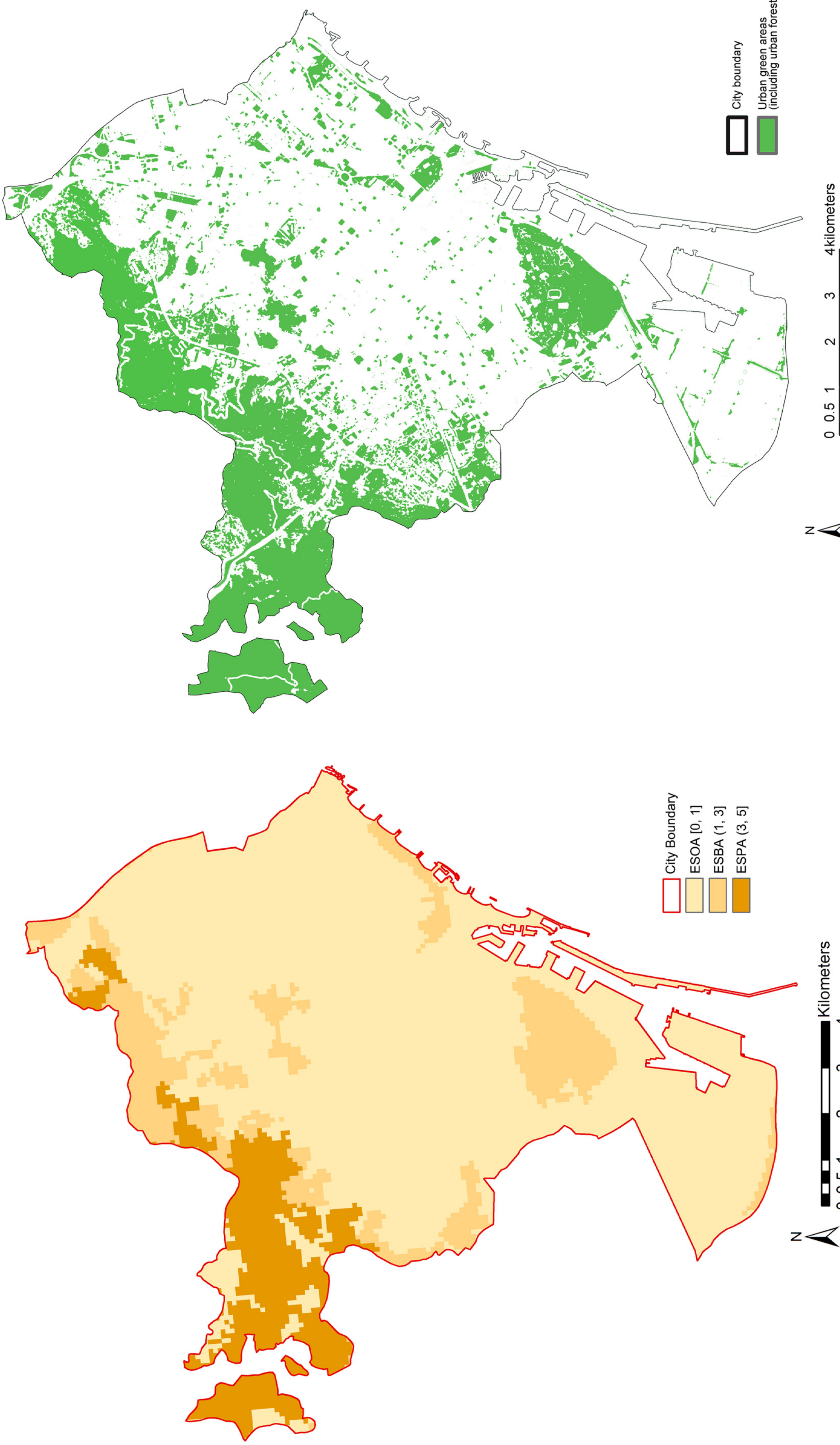

Fig. 8. Map of spatial areas of ecosystem services (left) and the main green areas of Barcelona (right). (own elaboration based on Barcelona city datasets https://w33.bcn.cat/PlanolBCN/en/).

ESOA is full of industrial buildings and units, transport networks, port areas. The ecosystem services assessment matrix illustrates that this type of area delivers few and low-quality cultural services, such as recreation and tourism services, and almost no supply regulating, provisioning, and habitat services.

It is thus essential to preserve and develop the existing cultural services in this type of area. GI is, in fact, composed of various types of green spaces with different landscape functions and ecological functions. In order to develop regulating, provisioning, and habitat services, it is crucial to increase the coverage of multi-type green spaces. For instance, the government and the media could encourage citizens and communities to carry out voluntary greenery activities through the afforestation of residential zones, such as creating green roofs, green walls, and balconies, re-naturalizing and re-vitalizing. Port areas could perform functions like storm water management and biological habitation by building more green zones and belts (Krause, Culmsee, Wesche, Bergmeier, & Leuschner, 2011).

(3) The renewal area

The renewal area is found in the ESBA as it has GI with low capacity to deliver ES. Here we find some green zones of moderate quality, like urban parks with a medium capacity to deliver regulating, provisioning, and habitat services, and pastures and vegetation covers with medium capacity to offer habitations; they all could deliver average capacity cultural services.

In such areas there is a need to implement ecological renewal, restoration, and landscape improvement measures to advance the delivery capacity of ES, rather than focusing solely on the structure and aesthetic form of GI.

(4) The potential area

There are many potential areas in both ESBA and ESOA, which have often been neglected or abandoned. Thanks to “Identification and Evaluation of Metropolitan Voids in the Barcelona Region” Project, developed by Observatory of Urbanization, Geography Department, Autonomous University of Barcelona, 134 empty spaces in the Barcelona metropolitan area have been identified. Fig. 9 provides several example images of empty spaces in the city. Abandoned lands, such as those belonging to former factories or disused infrastructure can be converted into community gardens or public parks to enhance social cohesion and regenerate multi-functional urban open public spaces.

(5) The green corridor

A green corridor is a banded landscape element, both natural and artificial, that includes, for example, green belts and landscape streets. Urban green corridors can connect outlying natural and semi-natural areas with downtown green spaces and urban fabric, and in so doing provide a backbone for the city's GI by incorporating green spaces and linking ESPA, ESBA and ESOA. Rather than a number of isolated spots, the aim should be to forge a genuine network of green spaces, conceived as GI and providing ES. Indeed, such services are enhanced when GI connectivity is achieved.

5. Discussion

In this paper, we assess and visualize the ES supply in the city of Barcelona based on integrating an ESAM with quantitative results and spatial mapping, which allows to identify different types of areas (ES provision, ES barren and ES obstructed areas), planning zones, and measures. The results provide a reference and guide to the city's GI planning — not only relative to formal green spaces (e.g. urban parks and gardens, natural preserves), but also potential areas such as vacant lots. We thus offer a specific method that can be used in decision-making and planning processes. More specifically, from an urban planning and landscape planning perspective, we combine GI with an ES approach, building on previous work on urban GI and ES (Kopperoinen & Itkonen, 2014; Liquete et al., 2015).

Compared to a recent report on Barcelona's GI network (Ajuntament de Barcelona, 2013), which aims to link and integrate all green spaces in the city and its surrounding areas, this study fills an important gap. Indeed, the aforementioned report is limited to the analysis of the quality of diverse types of green spaces, but excludes other public spaces or land use types in the city. Moreover, it focuses mostly on urban green spaces and connectivity, without identifying the core protected area and vacant urban lots.

That said, achieving a truly holistic picture of such a complex system remains a challenge. One limitation is the ES evaluation matrix (Hou et al., 2013). While the contributing experts are of different disciplinary origin and professional knowledge, data from their scores remain somewhat subjective (Jacobs, Burkhard, Van Daele, Staes, & Schneiders, 2015). The values given are derived from their experience, and are thus based on general theoretical assumptions, rather than a specific quantitative relationship within the particular space. This means that sometimes the actual role of different services may be underestimated or overestimated, such that the score reflects the ES supply of a relative capacity, rather than the absolute value.

The capacity to deliver certain ES can also vary among different land use types (Sohel, Ahmed Mukul, & Burkhard, 2015), as the latter are often more complex than that portrayed by the CORINE database. Moreover, land use types and ecosystems are not stable entities but constantly changing on different spatial and temporal scales, which can affect ES supply and distribution. There also are distinct social, economic, cultural, political, and demographic differences. A dynamic analysis of land cover types could help to develop better GI planning.

In addition, the establishment of GI should be led by the government, from top to bottom, and in close connection with stakeholders and the general public (McDonald et al., 2005), working closely with local departments in order to avoid separate planning and execution. Generally, consideration should be given to participatory processes, socio-economic evaluation, and population, aspects that are beyond the scope of this particular paper.

However, the results here could prove useful to urban planners, landscape architects, land-use planners, and researchers, among others. More generally, the framework of supporting urban GI planning based on the ES approach helps to identify priority protected areas, new construction areas, and renewal areas, which in turn can contribute to informed GI planning in any city. This method is thus both a useful theoretical and practical tool, and provides a reference for promoting sustainable development in cities.

6. Conclusions

In this paper, we argue that using an ES framework is an efficient way to identify the potentials for GI planning and management, in particular by detecting ESPA, ESBA and ESOA.

Our spatial analysis suggests that decision-makers should consider implementing policies and strategies for building urban GI in different ES spatial areas. Although the expert-based approach has limitations, it is very useful for acquiring rapid overviews in data-poor situations.

This study differs from traditional structural planning by innovatively using the method of ES quantification and mapping in support of GI planning, and identifying planning goals for various land units. However, we only provide the first identification of various spaces, aimed at determining different planning methods and measures. Further research might quantitatively ascertain the numbers and types of GI that should be planned and designed in a particular area, and investigate how to best provide a quantitative approach to sustainable development and the management of land resources.

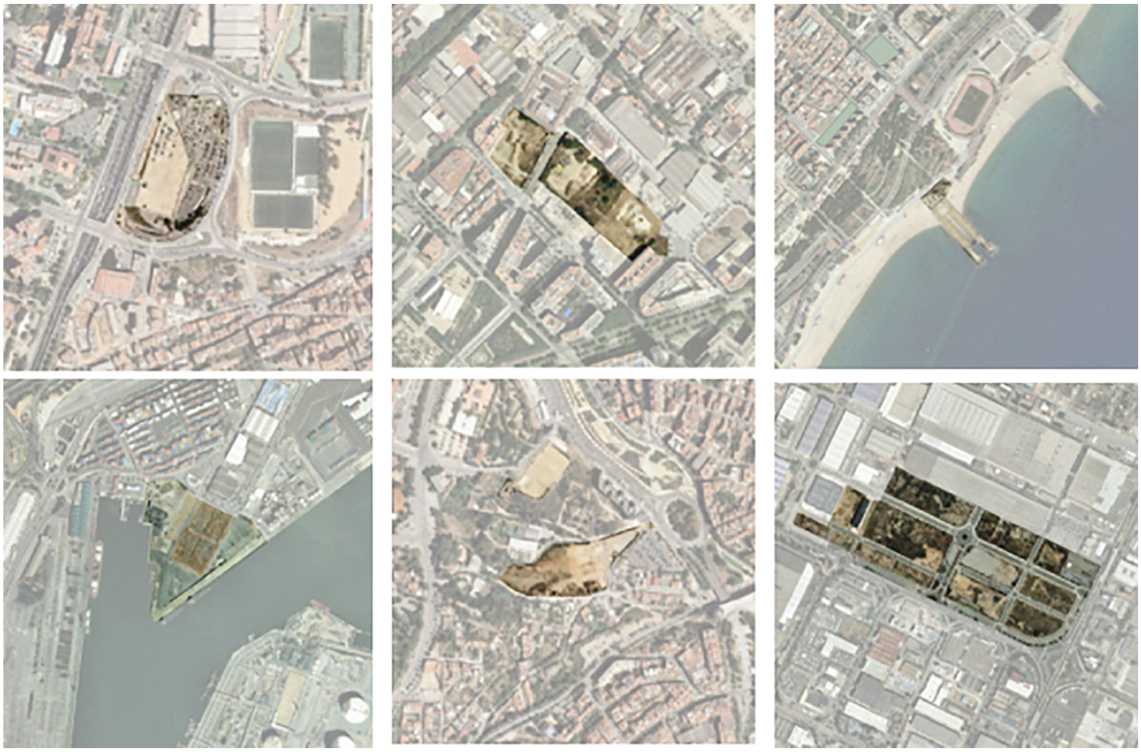

Fig. 9. Example images of empty spaces in the Municipality of Barcelona (Identification and Evaluation of Metropolitan Voids in the Barcelona Region Project, Observatory of Urbanization, Geography Department, Autonomous Universtiy of Barcelona, 2017).

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