Assessing Ecosystem Services Provision as a Support for Metropolitan Green Infrastructure Planning: the Case of Three Spanish Metropolitan Areas

Jesús Santiago-Ramos[1] · Claudia Hurtado-Rodríguez[1]

Abstract

The main purpose of this paper is to develop a systematic, spatially explicit approach to the analysis of the ecosystem services provided by the metropolitan landscape that can act as a support for green infrastructure planning. To achieve this, we have proposed a set of indicators to assess and map nine ecosystem services—including regulating, provisioning, habitat and cultural services. This methodology has been applied three case studies in the south of Spain: the metropolitan areas of Seville, Malaga-Marbella and Cordoba. Despite the geographical proximity of these areas to one another, the indicators show that there are significant differences in their potentialities and available resources to form a multipurpose green space system. The results suggest that further reflection is needed on how the concept of green infrastructure can be applied to metropolitan areas, especially in the Mediterranean region and other similar geographical contexts. Instead of understanding green infrastructure strictly in terms of a network of interconnected green spaces and natural areas, planning initiatives should assign a more important role to the landscape matrix and, in particular, to the multifunctional cultivated space on the urban fringe. In addition, more thought needs to be given to how to create functional green corridors in the metropolitan landscape for public use and habitat conservation. From the perspective of spatial planning, the methodology proposed has been demonstrated to be a useful tool to identify key spaces for the provision of ecosystem services.

Keywords Green infrastructure · Metropolitan areas · Spatial planning · Ecosystem services mapping · Ecosystem services assessment · Landscape multifunctionality

✉ Jesús Santiago-Ramos
jsanram@upo.es

Claudia Hurtado-Rodríguez
churrod@upo.es

[1] Department of Geography, History and Philosophy, Universidad Pablo de Olavide, Ctra. de Utrera, km 1, 41013 Seville, Spain

Introduction

In recent years, green infrastructure has become a widely-used approach to the planning and management of open spaces and natural areas in urbanized environments. Its core principles are the interconnection of an area's environmentally valuable components into a coherent network, the enhancement of its multifunctionality and the adoption of a proactive, smart focus for its management (European Environment Agency, 2011a). Although the origin of the concept dates back to the 1990s, when it emerged as a response to the growing concern for the environmental implications of urban sprawl (Benedict & McMahon, 2002), the theoretical assumptions behind green infrastructure are underpinned by well-grounded concepts in the fields of urban and spatial planning. These include the creation of interconnected networks of urban and periurban parks, which can be traced back to Frederick Law Olmsted's mid-nineteenth century proposals for New York and Boston, the development of greenways and ecological networks for both public use and nature conservation (Ahern, 1995; Jongman et al., 2004; Opdam et al., 2006), or the application of principles derived from landscape ecology to the study and planning of urban regions (Forman, 2008). The concept of green infrastructure integrates these ideas by proposing an action framework adapted to the challenges faced by today's cities, positioning the nurturing of ecosystem services as one of the top priorities for intervention in urbanized areas.

The successful dissemination of the concept in recent years has resulted in its growing application on both the analytical and propositional levels (EEA, 2011a; Elmqvist et al., 2013). Green infrastructure has been incorporated into the legislative framework of the European Union through a Communication from the European Commission entitled 'Green Infrastructure - Enhancing Europe's Natural Capital' (European Commission, 2013), which ties in with the progressive integration of the concept into community actions and programs such as the Seventh Framework Program for the Environment, the European Biodiversity Strategy and the European Union Strategy for Climate Change. The European Environment Agency (EEA, 2011a, 2014) proposes two basic scales of application: on the one hand, the creation of regional- and national-scale nature protection systems, and on the other, local-level green infrastructure design, related to the planning and management of urban open spaces.

The present research assumes that the metropolitan scale—i.e., an intermediate step between the mentioned regional and local scales—can be an optimal choice for the planning of multipurpose green infrastructures in rapidly urbanizing landscapes. Current urban dynamics and processes—e.g., urban sprawl or urban mobility—are taking on an increasingly supra-municipal or metropolitan dimension, clearly extending beyond the traditional city's administrative limits in both physical and functional terms (Hall, 1998). Therefore, this scale is progressively being adopted by academia and institutions as the most suitable for the analysis and management of urban systems (Organization for Economic Co-operation and Development, 2012). From the point of view of green infrastructure planning, the adoption of a metropolitan focus allows us to consider a wide spectrum of open

spaces and territorial resources, ranging from urban trees and district parks to large forest or agricultural areas near or around the city (Feria-Toribio & Santiago-Ramos, 2017). The integration of this diverse range of elements into a single, interconnected open space system enables the city to achieve a more harmonious and sustainable relationship with the surrounding area, and allows for a better spatial articulation between the different urban nuclei that make up the metropolitan area.

From the functional perspective, this greater diversity of components opens the door to the simultaneous provision of a broad spectrum of ecosystem services:

– Regulating services that improve urban environmental conditions through the reduction of air pollution (Manes et al., 2014; Fusaro et al., 2015; Kim et al., 2015), the sustainable management of urban hydrological processes (Jia et al., 2016; Lewellyn et al., 2016), the mitigation of the urban-heat-island effect (Farrugia et al., 2013) or the adaptation to climate change (Momm-Schult et al., 2013).
– Provisioning services linked to food production (Magoni & Colucci, 2017) and primary sector production (European Commission, 2013).
– Services related to the conservation of biodiversity (Wickham et al., 2010) and the protection of natural habitats in the face of urban sprawl and the fragmentation of open spaces (Benedict & McMahon, 2002).
– Services linked to social, cultural and recreational benefits (Chiesura, 2004; Zwierzchowska et al., 2018), and the contribution to a healthier (Tzoulas et al., 2007) and more equitable (Heckert & Rosan, 2016) urban environment for citizens.

Green infrastructure design should enhance the multifunctionality of the metropolitan landscape, an objective that requires a strategic selection of the components that will form part of the open space system. In this context, a prior spatially explicit assessment of the ecosystem services generated in the metropolitan landscape can help to identify the key spaces that it is a priority to preserve (Zhang & Muñoz Ramírez, 2019). The lack of this kind of analysis may result in the urbanization of natural or semi-natural periurban areas with a significant potential for the provision of environmental functions, as has been observed in different Spanish urban agglomerations (Santiago-Ramos, 2015). Periurban croplands are especially affected by this problem, despite being a highly valuable component of the metropolitan landscape (Pedrazzini & Pedrotti, 2011; Batlle, 2011; Yacamán et al., 2020).

The present work is based on the hypothesis that the metropolitan territory as a whole constitutes a potential source of ecosystem services. The primary objective of this study is therefore to develop a systematic approach for the assessment of ecosystem services provision in metropolitan environments. The proposed methodology is not limited to evaluating the benefits for discrete components of green infrastructures –e.g., urban parks, nature reserves, etc.–, but also addresses the functionality of the metropolitan landscape from an integrating, comprehensive viewpoint. This allows for the functional dimension of the metropolitan landscape matrix –including agricultural, forestry and grazing areas, as well as artificial land-uses– to be assessed.

The second objective of this research is to exploit the application of this methodology to provide a better understanding of the environmental functionality of the metropolitan landscape. To achieve this, the proposed method will be applied to three case studies and the results obtained will be discussed from the perspective of green infrastructure planning. The cases selected for analysis are the metropolitan areas of Seville, Malaga-Marbella and Cordoba, which are all located in the south of Spain. The three areas are representative examples of medium-sized urban agglomerations in the Mediterranean region; as a result, it may be possible to extend the reflections of this study to other urban areas of similar size and characteristics.

Study Areas

fvAs can be seen in Fig. 1, the three study areas are complex, diverse territories which are rich in natural habitats and resources, with very different spatial configuration patterns. This enables us to draw up a comparative analysis of these urban areas, each having different potentialities and limitations despite their geographical proximity to one another. Table 1 sets out the main features of the three areas.

The Seville area has a population of 1,608,704 inhabitants and covers a surface area of 5756 km^2. It is the main urban agglomeration in Andalusia and the fourth largest in Spain after Madrid, Barcelona and Valencia. Of the three study areas, Seville presents
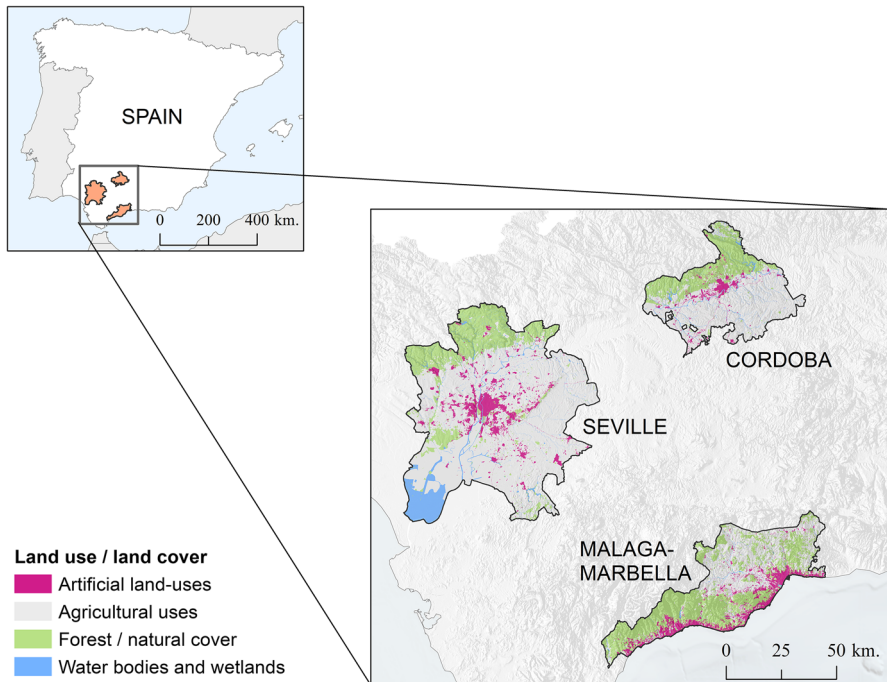

Fig. 1 Location of the study areas

Table 1 Study areas: General data

Metropolitan area	No. of municipalities	Population in 2020	Surface area (km^2)	Metropolitan Plan approval date
Cordoba	10	380,098	2108	In preparation
Malaga-Marbella	25	1,331,113	2528	2009
Sevilla	51	1,608,704	5756	2009

Prepared by authors with data from the Municipal Register of Inhabitants (National Statistics Institute, 2020)

the greatest complexity both from the administrative viewpoint—it is made up of 51 municipalities—and from the perspective of the physical environment. Its diverse landscape allows us to identify a variety of territorial sub-units, including areas of plains and river terraces with a predominance of urban uses and irrigable cropland, mountainous regions to the north, wetlands and rice paddies to the south, and large stretches of non-irrigated cropland—mainly cereals and olive groves—in the central area.

Seville is followed by the Malaga-Marbella metropolitan area in both size and complexity. With a population of 1,331,113 inhabitants and a surface area of 2528 km^2, this is the most densely populated area of all three. Its 25 municipalities are scattered over a widespread area that ranges from mountains and pre-littoral croplands to a coastline that is almost completely occupied by an unbroken tract of urban and artificial uses.

Lastly, the metropolitan area of Cordoba is the smallest in terms of population—308,098 inhabitants—and surface area—2108 km^2. It is composed of 10 municipalities, with areas of mountainous woodland to the north and mainly agricultural land associated with the Guadalquivir valley in the south. The main axis of the metropolitan area is defined by the presence of the river, around which the main nuclei of the population have been formed.

The limits for the three areas of study have been taken from the proposed delimitation of Spanish metropolitan areas developed by Feria and Martínez (2015), which is based on conventional, internationally standardized criteria of both functional (*commuting*) and morphological (*urban land-use*) references. This delimitation method can be equated to that used by the regional administration for the planning of Andalusian urban agglomerations. This guarantees both the comparability of the results for the three areas and their possible practical application in the field of spatial planning. The Seville and Malaga-Marbella areas already have metropolitan-scale planning instruments in place and the Cordoba area is in the process of drafting a metropolitan plan; as such, the results of this research could be of practical use to apply, revise or bring these plans up to date in relation to green infrastructure.

Method

The research methodology takes its general reference from the MAES approach, developed by the EU's Joint Research Centre for the evaluation and spatial representation of ecosystem services at a European scale (Maes et al., 2011), as well as the previous

advances made by the research team in the study of the structure and functionality of metropolitan open spaces (Santiago-Ramos, 2015; Feria-Toribio & Santiago-Ramos, 2019). The MAES approach provides spatially explicit indicators for several ecosystem services and identifies the contributing land cover classes for each service, facilitating the quantification and mapping of the environmental benefits considered. For this study, a set of indicators has been selected and adapted in order to analyse nine ecosystem services considered to be particularly relevant for the planning of a metropolitan green infrastructure. Table 2 shows the indicators and gives a synthetic list of land-use and land cover classes that have been taken into consideration for calculation and mapping. The services and indicators selected have been divided into four categories: regulating services, provisioning services, habitat conservation services, and cultural and public use-related services. These categories correspond to the classification of landscape services proposed by De Groot and Hein (2007), which facilitates the analysis and discussion of the results in the light of their potential application in spatial planning processes.

The spatial database used to prepare the maps and calculate the indicators was the Spanish Land Occupancy Information System (SIOSE), updated for the year 2011 by the National Geographic Institute of Spain (2015). The SIOSE spatial database has a reference scale of 1:25,000 and follows an object-oriented data model. It provides detailed information on the land-use and land cover in each of the spatial units—i.e., polygons—into which the territory is divided. For example, a polygon that represents a crop mosaic could be composed of 60% arable crops, 30% fruit crops and 10% leafy trees. When each type of cover is given a specific value for one particular ecosystem service—e.g., an average carbon storage value—, it is possible to quantify the capacity to provide this service in each of the polygons.

The combination of the chosen indicators with the object-oriented nature of SIOSE allows a spatially continuous approach to the analysis of most of the environmental functions considered. The resulting maps reflect how the provision of ecosystem services is distributed throughout the metropolitan territory. Each map shows a gradient of functionality, enabling us to identify key areas for the provision of a particular service. This approach makes it possible to assess the benefits provided by the metropolitan landscape as a whole, and helps to evaluate the contribution of different spaces and elements that are usually assigned a secondary role in terms of their environmental functionality -e.g., agricultural or pasture areas. Only the mapping of cultural and recreational services is based on the identification of discrete elements -i.e., urban and periurban parks and public use connectors.

Results

Regulating Services

The regulating services analysed are the mitigation of climate change through the capture and sequestration of atmospheric carbon, the improvement of air quality and the regulation of the urban climate by urban and periurban vegetation, and the hydrological regulation based on permeable soil (see Table 3).

Table 2 Ecosystem services and indicators

Category	Service	Indicator (units)	Calculation and land-use / land cover classes considered
Regulating services	Climate change mitigation	C storage (t, t/ha)	Reclassification of classes with herbaceous, scrub and tree vegetation, according to their C storage capacity (Olson et al., 1985; Gibbs, 2006) (See Table 7 in Annex).
	Air quality and urban climate improvement	Leaf Area Index (dimensionless)	Reclassification of classes with herbaceous, scrub and tree vegetation within a radius of 3 km around major urban areas (greater than 25 ha), according to their Leaf Area Index (Oplustilova et al., 1995; Scurlock et al., 2001; Santiago-Ramos 2010) (See Table 8 in Annex).
	Hydrological regulation	Pervious surface area (% pervious surface area)	Selection of pervious land cover classes; calculation of the percentage of pervious surface area for each sub-basin of the metropolitan area.
Provisioning services	Crop production	Cultivated area (ha, % of total surface area)	Estimation of the area dedicated to agricultural uses, including irrigated and non-irrigated crops.
	Forest production	Forest cover (ha, % of total surface area)	Estimation of the area dedicated to forest uses, including forest plantations and *dehesas* (a traditional agro-silvo-pastoral system).
	Livestock production	Grazing area (ha, % of total surface area)	Estimation of the suitable land for livestock grazing (pasture and *dehesas*).
Natural habitat conservation services	Natural habitat conservation	Protection of natural areas (natural cover, % of natural cover under legal protection)	Identification of areas with natural cover (terrestrial habitats and wetlands). Delimitation of legally protected natural areas.
		Ecological connectivity: Effective Mesh Size (ha)	Estimation of the *Effective Mesh Size* index for terrestrial natural habitats.
Cultural and public use-related services	Public recreational use	Urban and periurban parks. (number, ha, ha/10.000 inhabitants)	Mapping of urban and periurban parks.
	Non-motorized mobility	Elements that afford non-motorized mobility (km, km/10.000 inhabitants)	Mapping of cycle routes, greenways and *vías pecuarias* (traditional cattle ways).

   Metropolitan ecosystems can play a significant role in climate change mitigation, acting as CO_2 sinks and partially compensating for the emissions generated in the urban environment. In the Malaga-Marbella and Cordoba areas, the presence of extensive forest masses offers great potential for the provision of this service. Both metropolitan areas present a very significant carbon storage capacity: 24.30 t/ha and 20.39 t/ha, respectively. As can be seen on the maps (Fig. 2), in Cordoba and, above all, in Malaga-Marbella, this function is more intense in sectors located to the north of the main urban nuclei, corresponding to areas of mountainous woodland. In the case of Seville, carbon sequestration presents a more even distribution, due to the presence of large masses of olive trees and mosaics of woody crops that extend throughout the metropolitan landscape. Although these agricultural land-uses have a lower carbon storage index per hectare than forest masses, their widespread distribution makes them a highly valuable resource for helping to mitigate climate change and represent a high total value for carbon storage in the area.

   Urban and periurban vegetation also contributes to improving air quality in cities, whether by capturing polluting compounds, dissolving hydro soluble pollutants on the damp leaf surfaces or intercepting particles suspended in the air. The presence of vegetation also has a notable effect on the temperature and helps to lessen the urban heat island effect. To estimate the contribution made to these benefits by open urban and periurban spaces, the land cover classes with vegetation have been identified within a radius of 3 km around the urban areas—with urban areas under 25 ha omitted to avoid distortion in the results. The spaces delimited in this way have been reclassified according to their leaf area index (LAI), which can be considered a synthetic indicator of their contribution to this service. Figure 3 shows how the zones that contribute to improving the air quality in the Malaga-Marbella area are distributed in a marked linear pattern and form an unbroken sector of forest and agricultural spaces along the perimeter of the coastal conurbation. In the case of the Cordoba area, the distribution of this service is more polycentric, although the natural spaces associated with the Guadalquivir River—the central axis of the urban agglomeration—clearly stand out. In the case of Seville, the provision of this service is markedly polycentric, in keeping with the complex urban system defined by a powerful central urban nucleus and a broad set of secondary nuclei. The variation in the LAI value (see Table 3) depends on the predominance of areas of woodland, crops, green zones and other land-uses in these periurban belts. The Seville area stands out for a greater average LAI value (2.09), largely due to the contribution of farmland –the majority component of the periurban landscape.

   As regards hydrological regulation, the analysis focuses on soil sealing as the main disturbance factor in the urban environment. The replacement of natural cover by sealed surfaces reduces soil infiltration capacity and rainwater interception by plants, leading to a significant increase in surface run-off and diffuse pollution. According to Arnold and Gibbons (1996) and Paul and Meyer (2008), when soil sealing exceeds 10% of the surface of a water basin, the impact on the receiving watercourse starts to become significant. The analysis of sealing in the study areas has been conducted on the sub-basin scale (Fig. 4), in order to

identify the sectors in the metropolitan space where greater pressure exists from artificial sealing.

The results show that there are two sub-basins with sealing scores of over 10% in the Seville area (with percentages of 13.63% and 15.07%) and one in the Cordoba area (13.19%). The preservation of non-built-up space in these sectors should be regarded as a priority in the design of the metropolitan green infrastructure so as to prevent a greater impact on local water systems. The results reveal that a major part of this regulatory function is provided by periurban crops and pasture areas, which normally lack solid protection against future urban growth processes.

Provisioning Services

The provisioning services analysed in this study are forest, crop and livestock production. Table 4 gives the values obtained for the indicators related to these functions. As can be seen, over half of the territory in two of the analysed metropolitan areas -Cordoba and Seville- is dedicated to crops. In both cases, agricultural uses are the main components of the metropolitan landscape matrix, both in terms of surface area and spatial continuity. The case of Seville stands out, both in terms of total surface area and in relative surface area used for crop-growing (366,518 ha, 63.7% of metropolitan territory). In this case, the periurban cultivated spaces form a kind of agricultural belt that surrounds the central city and, in practice, acts as an equivalent to a *green belt* in the absence of other less anthropised open spaces (see Fig. 5). The important presence of irrigated crops (e.g., rice crops, fruit trees, and extensive crops like cotton or sunflower) in the areas of Seville and Cordoba should also be highlighted. The economic potential of irrigation crops makes them more resistant to the expansion of urban land uses than non-irrigated crops (e.g., cereal, olive trees), so they can play an important role in containing urban sprawl and conurbation processes –one of the main functions assigned to green belts.

As for forestry provision, total forest areas in the metropolitan territory have been quantified, as well as plantation forests and the *dehesas*—a type of traditional agro-silvo-pastoral system (see Table 4 and Fig. 6). The three metropolitan areas analysed show a substantial amount of woodland cover, with values over 30,000 ha. As far as forest plantations are concerned, the case of Malaga-Marbella is particularly noteworthy, as this kind of economic exploitation occupies over 9000 ha. Meanwhile, the presence of the *dehesas* can be highlighted in the Cordoba area, where they occupy over 7% of the metropolitan territory, and in terms of total surface area in the Seville area, with over 27,000 ha of cover. The multifunctional nature of *dehesas* and their outstanding economic, environmental and heritage value make them especially suitable as potential components of a green infrastructure.

As regards pasture provision (Fig. 7), the areas of Seville and Malaga-Marbella stand out in terms of net surface area with potential for livestock feeding (e.g., cattle, pig, sheep, goat), over 50,000 ha in both cases. Due to their close connections with natural spaces of greater ecological value, many pasture areas have great potential for being included in a metropolitan green infrastructure,

Table 3 Indicators for regulating services

Service	Indicator	Metropolitan area		
		Cordoba	Malaga-Marbella	Sevilla
Climate change mitigation	C storage (t)	4,297,535	6,144,591	8,655,253
	C storage (t/ha)	20.39	24.30	15.04
Air quality and urban climate improvement	Leaf Area Index	1.94	1.84	2.09
Hydrological regulation	Pervious surface area (ha and % of total surface area)	197,112 (93.51%)	239,260 (94.63%)	504,029 (93.04%)
	Number of sub-basins above the threshold of 10% impervious surface	1 (of 9)	0 (of 4)	2 (of 14)

Prepared by authors with data from SIOSE
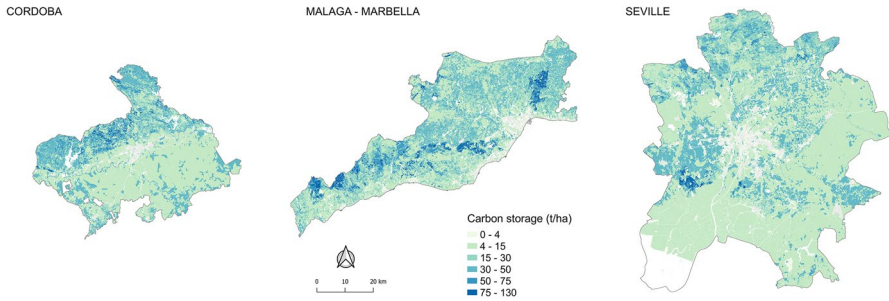
Fig. 2 Carbon storage (t/ha) in metropolitan ecosystems in the areas of Cordoba, Malaga-Marbella and Sevilla. Source: Prepared by authors with data from SIOSE
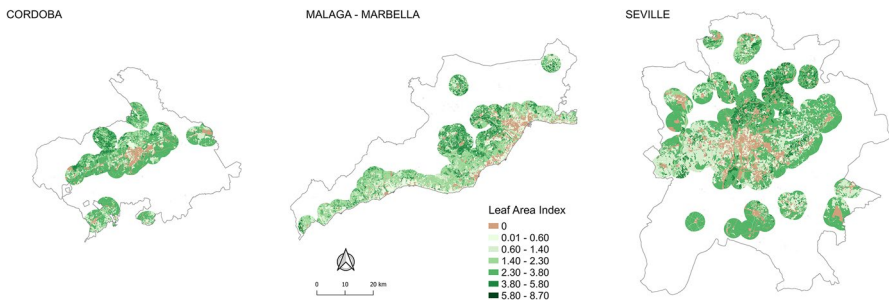

Fig. 3 Estimation of urban and periurban leaf area index in the areas of Cordoba, Malaga-Marbella and Sevilla. Source: Prepared by authors with data from SIOSE

especially as areas to strengthen ecological connectivity. One example of this is the pastures in the western sector of the Seville metropolitan area, which, as can be observed in Fig. 7, contribute to the creation of a north-south green corridor along one of the urban agglomeration's major rivers.

Habitat Conservation Services

One of the main objectives of a metropolitan green infrastructure is to preserve natural areas from processes of land-use change. In global terms, the indicators show a more than notable presence of natural habitats in the three metropolitan areas (see Table 5 and Fig. 8). Malaga-Marbella stands out especially, with over half of its territory occupied by natural cover. Legally-protected natural areas are also abundant in the three case studies, reflecting the significant ecological value of the land which makes up the metropolitan landscape. In this respect, the Cordoba area stands out, with 70% of its habitat currently affected by different categories of protection.

Metropolitan natural habitats must also be addressed in terms of their spatial configuration. Habitat fragmentation is particularly detrimental, as this process reduces the capacity of natural areas to maintain biodiversity (Hedrick, 2001) and is
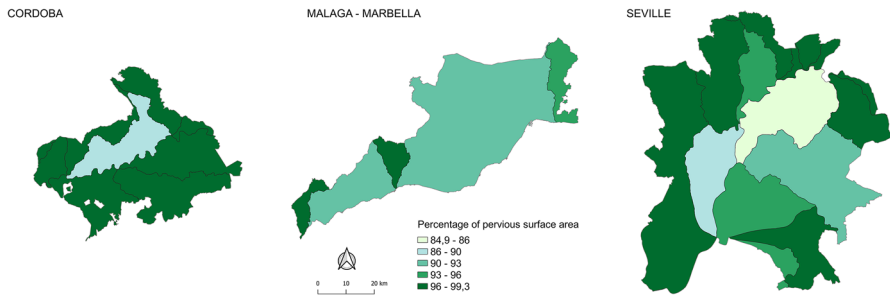
Fig. 4 Percentage of pervious surface area in metropolitan sub-basins in the areas of Cordoba, Malaga-Marbella and Sevilla. Source: Prepared by authors with data from SIOSE

currently considered one of the main threats to nature conservation in Europe (EEA, 2011b). A landscape metric –Effective Mesh Size (Jaeger, 2000; EEA, 2011b)- has been applied to analyse the spatial continuity of habitats. This index shows the likelihood of two random points in a landscape being connected in a single patch of natural cover. The lower the Effective Mesh Size, the greater the level of fragmentation of the natural cover, and vice-versa. The results reveal that the lowest degree of fragmentation is found in the Malaga-Marbella area –with an Effective Mesh Size value of 48.732 ha-. In this case, as well as in Cordoba, the natural habitat is shaped by large, continuous patches mainly corresponding to mountain forest areas (see Fig. 8). The case of Seville contrasts with the other two, as it is divided into the northern and western sectors of the metropolitan area with quite extensive and continuous natural patches, whereas in the centre, the east and the south of the urban agglomeration the natural patches are highly fragmented by agricultural and artificial land-uses.

Cultural and Public-Use Related Services

The analysis of public-recreational use has focused on two types of elements: urban parks (located within the urban area and with a fundamentally municipal reach) and periurban parks (larger in size, with a higher degree of naturalness and a supra-municipal reach, and situated more often on the periphery of the urban area). Table 6 shows the values obtained in the analysis. A significant disparity can be seen in the amount of surface area devoted to these two elements in the three areas under study.

The Seville area stands out for the number of urban parks (41) and for the total surface area that they occupy (over 860 ha), which is in keeping with the larger size and population of this urban agglomeration. Seville also has the highest park surface area per number of inhabitants (5.39 ha/10,000 inhabitants). The presence of urban parks is significantly lower in Cordoba, with 2.34 ha/10,000 inhabitants, and Malaga-Marbella, with only 1.19 ha/10,000 inhabitants. As far as periurban parks are concerned, the Cordoba area stands out, with three areas of this type occupying a total of 900 ha. In contrast, the Seville area has three periurban parks covering a total area of 128 ha, while there is only

Table 4 Indicators for provisioning services

| Service	Indicator	Metropolitan areas		
		Cordoba	Malaga-Marbella	Sevilla
–	Total forest cover (ha and % of total surface area)	30,010 (14.1%)	30,160 (11.9%)	42,611 (7.4%)
	Forest plantations (ha and % of total surface area)	1938 (0.9%)	9027 (3.6%)	3404 (0.6%)
	Dehesas (ha and % of total surface area)	15,285 (7.3%)	7634 (3.0%)	27,480 (4.8%)
Crop production	Total cultivated area (ha and % of total surface area)	125,911 (59.7%)	73,545 (29.1%)	366,518 (63.7%)
	Non-irrigated crops (ha and % of total surface area)	84,996 (40.3%)	57,644 (22.8%)	208,273 (36.2%)
	Irrigated crops (ha and % of total surface area)	40,915 (19.4%)	15,901 (6.3%)	158,245 (27.5%)
Livestock production	Grazing area (ha and % of total surface area)	27,816 (13.2%)	53,875 (21.3%)	66,623 (11.6%)

Prepared by authors with data from SIOSE
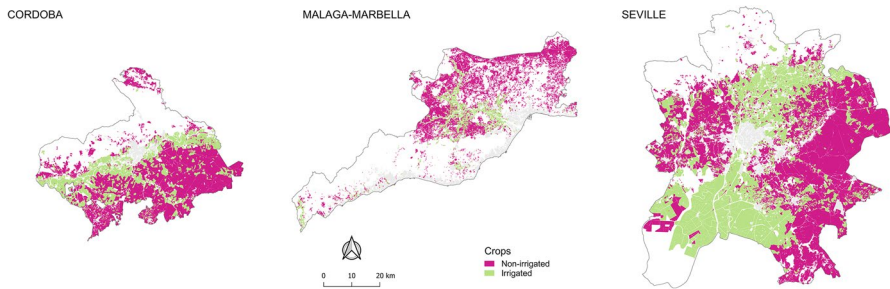
Fig. 5 Irrigated and non-irrigated agriculture in the areas of Cordoba, Malaga-Marbella and Sevilla. Source: Prepared by authors with data from SIOSE
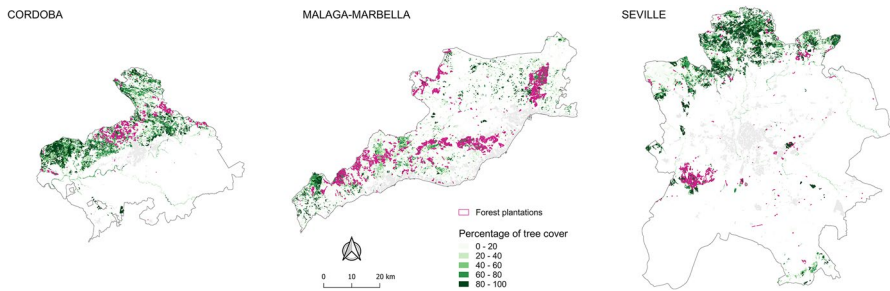

Fig. 6 Woodland cover (%) and forest plantations in the areas of Cordoba, Malaga-Marbella and Sevilla. Source: Prepared by authors with data from SIOSE
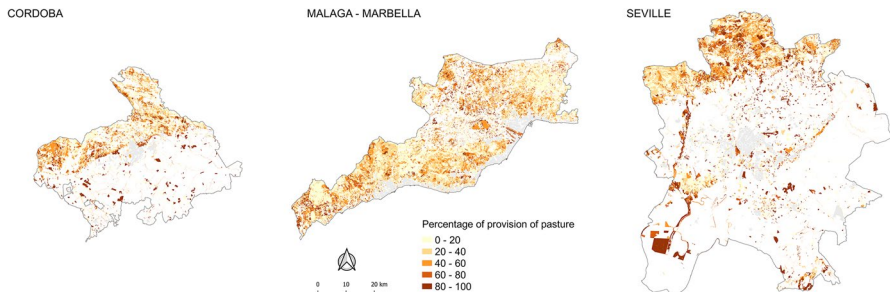

Fig. 7 Pastureland cover (%) in the areas of Cordoba, Malaga-Marbella and Sevilla. Source: Prepared by authors with data from SIOSE

one in the Malaga-Marbella area, occupying 11 ha. Finally, in the case of Cordoba, the greater extension of natural areas near the centre of the urban agglomeration can act –to some extent- as compensation for the smaller number of urban parks.

In the category of non-motorized mobility, the presence of cycle routes, signposted greenways and paths, and *vias pecuarias*—a network of historic cattle trails, currently used as public, legally-protected country lanes—has been mapped (see Fig. 9) and quantified.

The most extensive cycle routes are found in Seville (294 km) and Malaga-Marbella (102 km), whereas the Cordoba area has the greatest length per inhabitant (1.82 km/10,000 inhabitants). Seville stands out as the only area with a highly-developed cycle lane network within the city's urban fabric that offers a fully-functional option for mobility, although it is patchy and poorly articulated in the periurban sector (see Fig. 9). On the other hand, the presence of greenways and paths is especially significant in the Cordoba area, with a total of 76 km and 2 km/10,000 inhabitants. The location of these elements and their adaptation for public use enables citizens to travel between parks, natural areas and periurban rural spaces.

The results reveal that cattle trails are far more common than the other connecting elements which makes them a resource with enormous potential for green infrastructure planning, especially since that are perfectly articulated into a network. These lanes and tracks cover large expanses in the areas of Seville (2402 km, 14.93 km/10,000 inhabitants) and Cordoba (926 km, 24.36 km/10,000 inhabitants).

Discussion

The results obtained for the three case studies confirm that the metropolitan landscape can provide a wide range of environmental functions and benefits. However, the areas differ significantly in the size, distribution and spatial configuration of the landscape components that provide those services. Consequently, from a functional perspective, the optimal configuration of a metropolitan green infrastructure would be very different for each of the three urban agglomerations. It is therefore recommendable to avoid the application of pre-established and rigid planning models—for example, based on the *green belt* or the *urban-rural gradient* concepts—, and to adapt green infrastructure design to the specific potential and characteristics of each metropolitan area. The optimal planning choices can also vary depending on the services that are considered a priority in each case.

Despite these inherent differences, the three case studies share some relevant features in common that must be discussed, as they can provide a deeper understanding of the environmental functionality of metropolitan landscapes. In this case, two main implications can be drawn from the results. First, the analysis suggests that planning initiatives should assign a more important role to the landscape matrix and, in particular, to the multifunctional agricultural areas on the urban fringe. Second, further thought should be given to how to improve the connectivity of open spaces in metropolitan areas in terms of public use and habitat conservation.

The Functional Role of the Metropolitan Landscape Matrix

Our research reveals that the provision of regulating services in the three areas studied is of a spatially continuous nature. None of the services analysed can be assigned in particular to any one (or more) specific types of open space. On the contrary, they depend on different cross factors, such as the type and abundance of vegetation or the degree of soil sealing. In consequence, there is a wide range of components of the land-use mosaic that can act as a source for these services. In the absence of more natural areas, human-dominated

Table 5 Indicators for habitat conservation services

Service	Indicator	Metropolitan area		
		Cordoba	Malaga-Marbella	Sevilla
Conservation of natural habitats	Natural cover (ha)	72,263	144,952	157,848
	Natural cover (ha/10,000 inhabitants)	1901.17	1088.95	981.21
	Natural cover (% of metropolitan surface area)	34.3%	57.3%	27.4%
	Natural cover under legal protection (ha)	50,378	66,476	56,036
	Natural cover under legal protection (ha/10,000 inhabitants)	1325.40	499.40	348.33
	Natural cover under legal protection (% of total natural cover)	69.7%	45.9%	35.5%
	Ecological connectivity: Effective Mesh Size (ha)	15,822	48,732	25,773

Prepared by authors with data from SIOSE and the Andalusian Department of Agriculture, Livestock, Fisheries and Sustainable Development
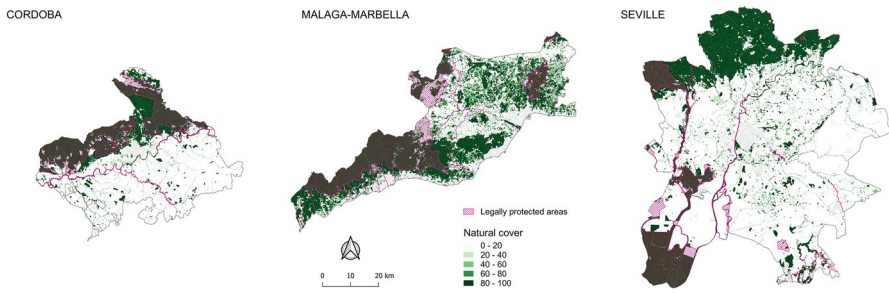
Fig. 8 Natural cover and protected natural spaces in the areas of Cordoba, Malaga-Marbella and Sevilla. Source: Prepared by authors with data from SIOSE and the Andalusian Department of Agriculture, livestock, fisheries and sustainable development

or semi-natural ecosystems such as agricultural areas—i.e., the majority component of the landscape matrix in the cases of Seville and Cordoba—can be the main local source of regulating functions. Here, green infrastructure planning should give those productive spaces a leading role in order to boost their environmental functions. Additionally, if provision services are also to be considered a relevant part of the functionality provided by metropolitan green infrastructures, it seems clear that planners and policy makers need to explore new planning possibilities beyond the traditional *nodes and corridors* model, which is mostly comprised of parks, natural areas and connecting elements.

Urban agriculture is still largely neglected in urban and regional planning, and planners often view periurban croplands primarily as areas for future urban development (Lovell, 2010). Justifying the conservation of periurban croplands based solely on their production functions can be a challenge, so it is necessary to assess urban agriculture from a multifunctional landscape framework (Lovell & Johnston, 2009). In other words, in the longer term, metropolitan agriculture will only be sustainable if its potential to provide different ecosystem services is fully recognized and developed (Van Veenhuizen, 2006). In this context, greater social recognition should be given to the multiple functions and benefits that agriculture can provide to the urban public (Zasada, 2011). Our study suggests that ecosystem services mapping can be a useful tool to present these functions to policy makers, planners and citizens in general.

Over recent years, numerous initiatives have been developed around the world to preserve agriculture in the proximity of urban centres, either through agri-environmental schemes (Darly & Torre, 2013), promotion of local food networks (Paül & McKenzie, 2013) or the development of land use zoning strategies (Akimowicz et al., 2016). The creation of agricultural parks—i.e., a large, legally protected periurban area where multifunctional agricultural activities are carried out—may represent one of the most suitable options for preserving multifunctional farmland within the green infrastructure framework. The best known example of this is the Milan South Agricultural Park, which extends over 47,000 ha, more than three quarters of which is farmed land, and stands out as a model for other international initiatives (Corrado, 2013). In Spain, the agricultural parks of Sabadell and Baix Llobregat in Catalonia, and the initiatives carried out in the Guadalhorce Valley and the Granada Plain in Andalusia are also prime examples of how to contain urban sprawl and preserve the periurban agricultural

Table 6 Indicators for cultural services

Service	Indicator		Metropolitan area		
			Cordoba	Malaga-Marbella	Sevilla
Public-recreational use	Urban parks	No. of parks	5	17	41
		Total surface area (ha)	88.88	158.02	867.89
		Density (ha/10,000 inhabitants)	2.34	1.19	5.39
	Periurban parks	No. of parks	3	1	3
		Total surface area (ha)	941	11	128
		Density (ha/10,000 inhabitants)	24.76	0.08	0.80
Non-motorised mobility	Length (km)	Cycle routes	69	102	264
		Greenways and paths	76	72	99
		Cattle trails	926	687	2402
	Length by inhabitant (km/10,000 inhabitants)	Cycle routes	1.82	0.77	1.64
		Greenways and paths	2.00	0.54	0.62
		Cattle trails	24.36	5.16	14.93

Prepared by authors with data from SIOSE and the Institute of Statistics and Cartography of Andalusia
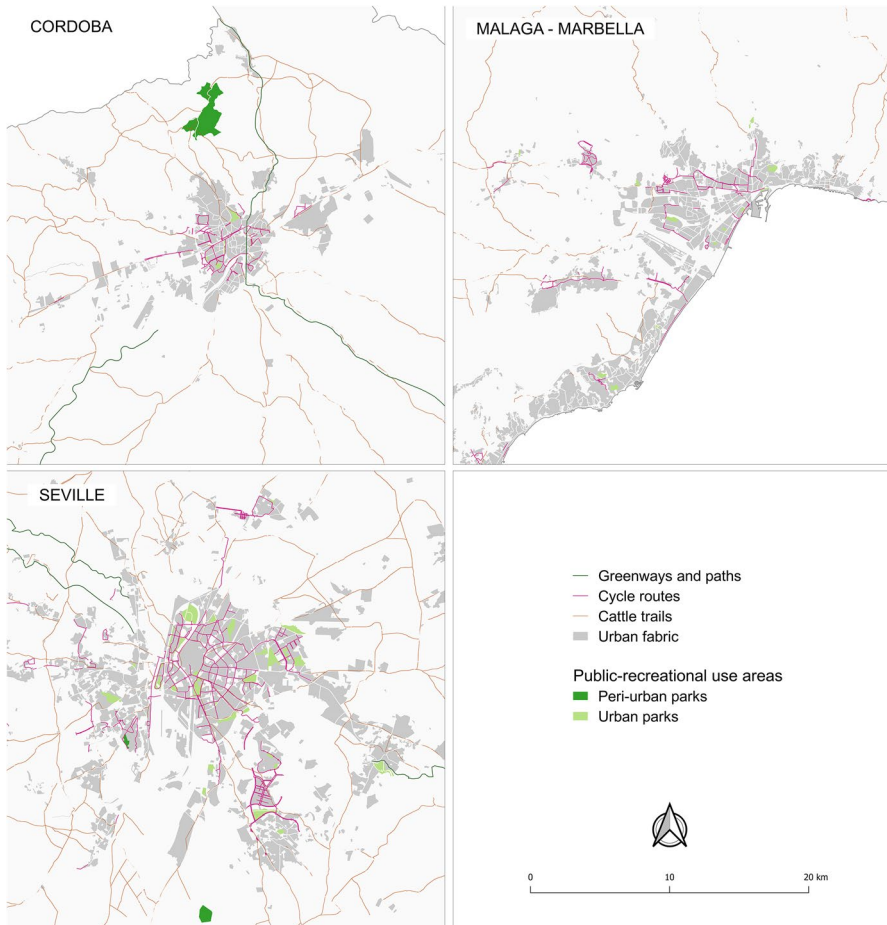
Fig. 9 Areas and connectors for public recreation. Source: Prepared by authors with data from SIOSE and the Institute of Statistics and Cartography of Andalusia

landscape (Yacamán & Zazo, 2015). Integrating this new type of park as a key functional and structural component of metropolitan green infrastructures seems to be a highly recommended strategy to preserve the diverse functions of periurban farmland.

Finally, it should be noted that agricultural areas are not only a source of beneficial environmental functions, but also of different ecosystem dis-services—e.g., loss of natural habitats, nutrient runoff, or damage caused by pesticides—(Zhang et al., 2007). Additionally, C emissions can overcome C sequestration due to intensive management practices. The adoption of ecologically-sound management strategies is essential to minimize those dis-services, as well as to guarantee the compatibility of farmland production with the provision of regulating services. Again, the integration of these areas in a metropolitan green infrastructure can facilitate the implementation of agri-environmental measures and lead to a more positive net balance at the functional level.

Building Functional Networks: Public Use and Ecological Connectivity

Unlike regulating and provisioning services, functions like the protection of natural habitats and the promotion of public use activities are necessarily linked to the design of cohesive open space networks and functional corridors. With regard to public use, it is essential to promote the interconnection of the recreational spaces present in the metropolitan territory, so that they are made accessible to the urban public by non-motorized means. At the same time, effective ecological corridors should be set up to connect the fragmented natural areas and allow the movement of species throughout the highly anthropised metropolitan landscape. In those cases in which the degree of habitat fragmentation is higher—e.g., the central, south and east sectors of the metropolitan area of Seville—the creation of ecological networks must be considered a priority objective of green infrastructure design.

In the context of urban and metropolitan planning in Spain, it is usual for green corridors to be designed with a dual functionality: as elements of ecological connection and as a platform for non-motorized travel (Cruz et al., 2017). However, the effectiveness of conservation networks and corridors can be diminished by this dual approach. Our analysis suggests that ecological and public use networks should be conceived as two different, complementary systems, since they are articulated around different nodal elements and have specific spatial requirements.

On one hand, the planning of public use connectors should prioritize the articulation of recreational spaces into a coherent and accessible network. Our study shows that there is a clear need to advance in this regard in the three areas under study, also revealing that each of the areas has a particular range of resources available for building up a public, non-motorized travel network. The role of public cattle trails—the traditional *vias pecuarias*—should be highlighted in this regard. Despite the irregular state of conservation of these trails and, in many cases, issues with private owners occupying the public realm, a great number of these country lanes and tracks are currently used by citizens for country walks or cycle rides and for moving from one green space to another. Together with the existing cycle routes and greenways, the reconditioning of part of this cattle trail network can help to significantly enhance non-motorized mobility in the metropolitan areas. However, many of these public lanes are extremely narrow and intensively used, which, in some sections, can hamper their compatibility with ecological connectivity functions.

On the other hand, the effectiveness of ecological corridors depends on their capacity to connect isolated natural habitat patches—not necessarily accessible to the public—and counteract the effect of habitat fragmentation. Ecological corridors and networks are often created on the basis of pre-established spatial assumptions and the oversimplification of complex ecological concepts (Boitani et al., 2007; Battisti, 2013). The creation of new ecological connectors should be a context-specific strategy and be based on local-scale ecological analysis, in order to guarantee that the configuration of corridors responds to the requirements of fragmentation-sensitive species (Gippoliti & Battisti, 2017). The assessment of habitat fragmentation carried out in this study can provide a reasonable starting point for this objective, as it allows to detect those areas where the lack of connectivity is especially significant and where, as a result, a detailed, species-focused analysis would be advisable.

Lastly, it is also important to emphasise the role of the landscape matrix in complementing the functionality of ecological corridors (Battisti, 2013). The matrix acts as

an important driver of ecological dynamics in heterogeneous landscapes such as those analysed here (Watling et al., 2011) and can influence species dispersal and migration rates between natural fragments (Jules & Shahani, 2003). Consequently, the landscape matrix should be given a more prominent role in habitat conservation strategies (Debinski, 2006; Watling et al., 2011). In this respect, integrating matrix components—such as periurban cultivated areas—into the metropolitan green infrastructure seems to be highly advisable, as it could facilitate the application of agri-environmental measures designed to enhance landscape connectivity and permeability.

Conclusions

The methodology applied in this study has been demonstrated to provide a useful support for planning practice. The spatially-explicit approach to ecosystem services analysis enables the key functional components of the metropolitan territory to be identified, and provides valuable information for decision-making in the green infrastructure design process. It can facilitate an ex-ante evaluation of different land-use planning options for the provision of ecosystem services and help to identify strategic areas for future, more detailed analysis, prior to the formulation of specific planning proposals. Maps of the ecosystem services can also help foster public participation in the planning process as a tool to discuss the complex environmental and social functionality of the metropolitan landscape.

The results also allow us to make some general reflections on metropolitan green infrastructure planning. Firstly, the study confirms the suitability of the metropolitan scale for the articulation of truly multifunctional open space systems. This scale allows the urban and periurban green spaces to be integrated into the same planning proposal with large, peripheral rural and natural areas, thus combining their recreational, environmental and nature protection functions from a unitary, comprehensive perspective. Likewise, it makes it possible to complement the functionality of the most common components of open space systems—e.g., parks, nature reserves—with that linked to other, often overlooked territorial resources present in the metropolitan landscape matrix.

In this context, the comprehensive approach of the methodology has allowed us to verify the important role that the matrix can play as a functional component of the metropolitan green infrastructure. The results show that, taken as a whole, extensive cultivation areas, forest plantations and pasture areas –which do not usually stand out as relevant nodes in urban or metropolitan green space systems– represent a highly valuable source of ecosystem services. These productive spaces can strengthen or complement many of the benefits provided by other more natural spaces, improving the resilience of the urban system through the reinforcement of regulating and provisioning services.

In settings such as those analysed here, it would be recommendable to revise the concept of green infrastructure in order to fully integrate farmland as one of the green system's main structural and functional components. This reconceptualization involves going beyond the creation of a network of interconnected discrete open spaces and assigning the metropolitan landscape matrix a greater functional role in planning strategies. At the same time, it is necessary to advance in the study of the ecosystem services and dis-services trade-offs linked to periurban agriculture, in order to apply suitable management strategies.

Appendix

Table 7 Land cover classes (SIOSE), ecosystem categories and C storage

GLC2000 Land cover class	Olson et al. (1985) ecosystem category	SIOSE Land cover class	Revised Medium Carbon Values (metric tons C/ha)
Tree Cover, Broadleaved Evergreen	Temperate Broad-leaved Forest	Broadleaf evergreen tree cover	90
Tree Cover, Broadleaved Deciduous, Closed	Temperate Broad-leaved Forest	Broadleaf deciduous tree cover	90
Tree Cover, Broadleaved Deciduous, Open			
Tree Cover, Needleleaved Evergreen	Other Conifer	Conifer tree cover	130
Tree Cover, Needleleaved Deciduous			
Mosaic: Tree cover/other natural vegetation	Fields/Woods Mosaics	Urban green areas and street trees	30
Shrub cover, closed-open, evergreen	Grassland or Shrubland complex	Meadows	9
Shrub cover, closed-open, deciduous		Grassland	
Herbaceous cover, closed-open,		Shrubland	
Sparse Herbaceous or sparse shrub cover			
Regularly flooded shrub and/or herbaceous cover			
Cultivated and managed areas	Non-irrigated croplands	Herbaceous crops	8
Mosaic: Cropland/Tree cover	Secondary Forest/field mosaics	Woody crops	40

Prepared by authors with data from Olson et al. (1985), Gibbs (2006)

Table 8 Land cover classes (SIOSE) and average values of Leaf Area Index (LAI)

SIOSE Land cover class	LAI	Source
Urban green areas and street trees	2.75	Oplustilova et al. (1995); URGE Team (2004)
Rice crops	3.00	Oplustilova et al. (1995); URGE Team (2004)
Other irrigated crops	3.00	Oplustilova et al. (1995); URGE Team (2004)
Citric fruit trees	5.00	Oplustilova et al. (1995); URGE Team (2004)
Non-citric fruit trees	5.00	Oplustilova et al. (1995); URGE Team (2004)
Vineyards	1.50	Santiago-Ramos (2010)
Olive groves	1.10	Santiago-Ramos (2010)
Other woody crops	5.00	Oplustilova et al. (1995); URGE Team (2004)
Meadows	5.00	Oplustilova et al. (1995); URGE Team (2004)
Grassland	1.70	Scurlock et al. (2001)
Broadleaf deciduous tree cover (plantations)	8.70	Scurlock et al. (2001)
Broadleaf deciduous tree cover	5.00	Scurlock et al. (2001)
Broadleaf evergreen tree cover (plantations)	8.70	Scurlock et al. (2001)
Broadleaf evergreen tree cover	5.70	Scurlock et al. (2001)
Conifer tree cover	5.50	Scurlock et al. (2001)
Shrubland	2.00	Scurlock et al. (2001)

Prepared by authors with data from Oplustilova et al. (1995), Scurlock et al. (2001), URGE Team (2004), Santiago-Ramos (2010)

Data Availability Not applicable.

Code Availability Not applicable.

Declarations

Conflicts of Interest/Competing Interests The authors have no conflicts of interest to declare that are relevant to the content of this article.

References

Ahern, J. (1995). Greenways as a planning strategy. *Landscape and Urban Planning, 33*(1–3), 131–155. https://doi.org/10.1016/0169-2046(95)02039-V

Akimowicz, M., Cummings, H., & Landman, K. (2016). Green lights in the greenbelt? A qualitative analysis of farm investment decision-making in peri-urban southern Ontario. *Land Use Policy, 55*, 24–36. https://doi.org/10.1016/j.landusepol.2016.03.024

Arnold, C. L., & Gibbons, C. J. (1996). Impervious surface coverage: The emergence of a key environmental indicator. *Journal of the American Planning Association*, *62*(2), 243–258. https://doi.org/10.1080/01944369608975688

Batlle, E. (2011). *El jardín de la metrópoli. Del paisaje romántico al espacio libre para una ciudad sostenible*. Gustavo Gili.

Battisti, C. (2013). Ecological network planning - from paradigms to design and back: A cautionary note. *Journal of Land Use Science, 8*(2), 215–223. https://doi.org/10.1080/1747423X.2011.639098

Benedict, M., & McMahon, E. (2002). *Green infrastructure: Smart conservation for the 21st century*. Sprawl Watch Clearinghouse.

Boitani, L., Falcucci, A., Maiorano, L., & Rondinini, C. (2007). Ecological networks as conceptual frameworks or operational tools in conservation. *Conservation Biology, 21*(6), 1414–1422. https://doi.org/10.1111/j.1523-1739.2007.00828.x

Chiesura, A. (2004). The role of urban parks for the sustainable city. *Landscape and Urban Planning, 68*(1), 129–138. https://doi.org/10.1016/j.landurbplan.2003.08.003

Corrado, A. (2013). Alternative food systems and Peri-urban agriculture in Milan, Italy. *Habitat y Sociedad, 6*, 65–83. https://doi.org/10.12795/HabitatySociedad.2013.i6.04

Cruz, J., De Oliveira, G., & Santiago-Ramos, J. (2017). El espacio libre en la planificación territorial: análisis comparado de las áreas metropolitanas en España. *Ciudad y Territorio Estudios Territoriales*, *49*(193), 401–416. Retrieved 15 April, 2021, from https://recyt.fecyt.es/index.php/CyTET/article/view/76569

Darly, S., & Torre, A. (2013). Conflicts over farmland uses and the dynamics of " Agri-urban" localities in the greater Paris region: An empirical analysis based on daily regional press and field interviews. *Land Use Policy, 33*(August 2017), 90–99. https://doi.org/10.1016/j.landusepol.2012.12.014

De Groot, R., & Hein, L. (2007). Concept and valuation of landscape functions at different scales. In Mander, Ü., Wiggering, H., & Helming, K. (Eds.) *Multifunctional land use. Meeting future demands for landscape goods and services* (pp. 15–36). Springer.

Debinski, D. M. (2006). Forest fragmentation and matrix effects: The matrix does matter. *Journal of Biogeography, 33*(10), 1791–1792. https://doi.org/10.1111/j.1365-2699.2006.01596.x

Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K. C., & Wilkinson, C. (Eds.). (2013). *Urbanization, biodiversity and ecosystem services: Challenges and opportunities*. Springer.

European Commission (2013). *Green Infrastructure (GI) - Enhancing Europe's Natural Capital. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. [COM (2013) 249 final].* European Commission. Retrieved April 29, 2021, from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52013DC0249

European Environment Agency (2011a). *Green infrastructure and territorial cohesion. The concept of green infrastructure and its integration into policies using monitoring systems*. European Environment Agency. Retrieved April 29, 2021, from https://www.eea.europa.eu/publications/green-infrastructure-and-territorial-cohesion

European Environment Agency (2011b) *Landscape fragmentation in Europe*. European Environment Agency. Retrieved April 29, 2021, from https://www.eea.europa.eu/publications/landscape-fragmentation-in-europe

European Environment Agency (2014) *Spatial analysis of green infrastructure in Europe*. European Environment Agency. Retrieved April 29, 2021, from https://www.eea.europa.eu/publications/spatial-analysis-of-green-infrastructure

Farrugia, S., Hudson, M. D., & Mcculloch, L. (2013). An evaluation of flood control and urban cooling ecosystem services delivered by urban green infrastructure. *International Journal of Biodiversity Science, Ecosystem Services & Management, 9*(2), 136–145. https://doi.org/10.1080/21513732.2013.782342

Feria, J. M., & Martínez, L. (2015). La definición y delimitación del sistema metropolitano español: permanencias y cambios entre 2001 y 2011. *Ciudad y Territorio. Estudios Territoriales, 1*, 9–24.

Feria-Toribio, J. M., & Santiago-Ramos, J. (2017). Naturaleza y ciudad. Perspectivas para la ordenación de la infraestructura verde en los planes territoriales metropolitanos en España. *Boletín de la Asociación Española de Geografía, 74*, 117–141. https://doi.org/10.21138/bage.2447

Feria-Toribio, J. M., & Santiago-Ramos, J. (2019). Landscape spatial analysis for sustainable land use planning: A two-scale approach to the Seville Metropolitan area. *Journal of Planning Education and Research.* https://doi.org/10.1177/0739456X19845439

Forman, R. T. T. (2008). *Urban regions. Ecology and planning beyond the City*. Cambridge University Press.

Fusaro, L., Salvatori, E., Mereu, S., Marando, F., Scassellati, E., Abbate, G., & Manes, F. (2015). Urban and peri-urban forests in the metropolitan area of Rome: Ecophysiological response of Quercus ilex L. in two green infrastructures in an ecosystem services perspective. *Urban Forestry and Urban Greening, 14*(4), 1147–1156. https://doi.org/10.1016/j.ufug.2015.10.013

Gibbs, H. K. (2006). Olson's major world ecosystem complexes ranked by carbon in live vegetation: an updated database using the GLC2000 land cover product (NDP-017b, a 2006 update of the original 1985 and 2001 data file). *Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (United States), ESS-DIVE repository*, https://doi.org/10.3334/CDIAC/LUE.NDP017.2006

Gippoliti, S., & Battisti, C. (2017). More cool than tool: Equivoques, conceptual traps and weaknesses of ecological networks in environmental planning and conservation. *Land Use Policy, 68*(April), 686–691. https://doi.org/10.1016/j.landusepol.2017.08.001

Hall, P. (1998). *Cities in civilization: Culture, technology, and urban order*. Pantheon Books.

Heckert, M., & Rosan, C. D. (2016). Developing a green infrastructure equity index to promote equity planning. *Urban Forestry and Urban Greening, 19*, 263–270. https://doi.org/10.1016/j.ufug.2015.12.011

Hedrick, P. W. (2001). Conservation genetics: Where are we now? *Trends in Ecology & Evolution, 16*, 629–636.

Jaeger, J. A. G. (2000). Landscape division, splitting index, and effective mesh size: New measures of landscape fragmentation. *Landscape Ecology, 15*(2), 115–130. https://doi.org/10.1023/A:1008129329289

Jia, Z., Tang, S., Luo, W., Li, S., & Zhou, M. (2016). Small scale green infrastructure design to meet different urban hydrological criteria. *Journal of Environmental Management, 171*, 92–100. https://doi.org/10.1016/j.jenvman.2016.01.016

Jongman, R. H. G., Külvik, M., & Kristiansen, I. (2004). European ecological networks and greenways. *Landscape and Urban Planning, 68*(2–3), 305–319. https://doi.org/10.1016/S0169-2046(03)00163-4

Jules, E. S., & Shahani, P. (2003). A broader ecological context to habitat fragmentation: Why matrix habitat is more important than we thought. *Journal of Vegetation Science, 14*(3), 459–464. https://doi.org/10.1111/j.1654-1103.2003.tb02172.x

Kim, G., Miller, P. A., & Nowak, D. J. (2015). Assessing urban vacant land ecosystem services: Urban vacant land as green infrastructure in the City of Roanoke, Virginia. *Urban Forestry & Urban Greening, 14*, 519–526. https://doi.org/10.1016/j.ufug.2015.05.003

Lewellyn, C., Lyons, C. E., Traver, R. G., & Wadzuk, B. M. (2016). Evaluation of seasonal and large storm runoff volume capture of an infiltration green infrastructure system. *Journal of Hydrologic Engineering, 21*(1), 04015047. https://doi.org/10.1061/(asce)he.1943-5584.0001257

Lovell, S. T. (2010). Multifunctional urban agriculture for sustainable land use planning in the United States. *Sustainability, 2*(8), 2499–2522. https://doi.org/10.3390/su2082499

Lovell, S. T., & Johnston, D. M. (2009). Creating multifunctional landscapes: How can the field of ecology inform the design of the landscape? *Frontiers in Ecology and the Environment, 7*(4), 212–220. https://doi.org/10.1890/070178

Maes, J., Paracchini, M. l., & Zulian, G. (2011). *A European assessment of the provision of ecosystem services. Towards an atlas of ecosystem services*. .

Magoni, M., & Colucci, A. (2017). Protection of Peri-urban open spaces and food-system strategies. The case of Parco delle Risaie in Milan. *Planning Practice and Research, 32*(1), 40–54. https://doi.org/10.1080/02697459.2015.1028251

Manes, F., Silli, V., Salvatori, E., Incerti, G., Galante, G., Fusaro, L., & Perrino, C. (2014). Urban ecosystem services: Tree diversity and stability of PM10 removal in the metropolitan area of Rome. *Annali Di Botanica, 4*(0), 19–26. https://doi.org/10.4462/annbotrm-11746

Momm-Schult, S. I., Piper, J., Denaldi, R., Freitas, S. R., de Lourdes Pereira Fonseca, M., & de Oliveira, V. E. (2013). Integration of urban and environmental policies in the metropolitan area of São Paulo and in greater London: The value of establishing and protecting green open spaces. *International Journal of Urban Sustainable Development, 5*(1), 89–104. https://doi.org/10.1080/19463138.2013.777671

National Geographic Institute of Spain (2015). *Spanish Land Occupancy Information System (SIOSE). Technical report SIOSE 2011*. National Geographic Institute of Spain. Retrieved April 29, 2021, from https://www.siose.es/SIOSEtheme-theme/documentos/pdf/Doc_tec_SIOSE2011_v1.1.pdf

Olson, J. S., Watts, J. A., &Allison, L.J. (1985). *Major world ecosystem complexes ranked by carbon in live vegetation: A Database. NDP-017*. Carbon Dioxide Information Center, Oak Ridge National Laboratory. Retrieved April 29, 2021, from https://cdiac.ess-dive.lbl.gov/epubs/ndp/ndp017/ndp017_1985.html

Opdam, P., Steingröver, E., & Van Rooij, S. (2006). Ecological networks: A spatial concept for multi-actor planning of sustainable landscapes. *Landscape and Urban Planning, 75*(3–4), 322–332. https://doi.org/10.1016/j.landurbplan.2005.02.015

Oplustilova, M., Dvorak, V., Marek, M. V., & Vyskot, I. (1995). Leaf area index, its significance and methods of estimation. *Lesnictvi, 41*(8), 353–359.

Organization for Economic Co-operation and Development (2012). *Redefining "Urban". A new Way to Measure Metropolitan Areas*. OECD. Retrieved April 29, 2021, from http://www.oecd.org/regional/redefiningurbananewwaytomeasuremetropolitanareas.htm

Paül, V., & McKenzie, F. H. (2013). Peri-urban farmland conservation and development of alternative food networks: Insights from a case-study area in metropolitan Barcelona (Catalonia, Spain). *Land Use Policy, 30*(1), 94–105. https://doi.org/10.1016/j.landusepol.2012.02.009

Paul, J. P., & Meyer, J. L. (2008). Streams in the urban landscape. In J. M. Marzluff, E. Shulenberger, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, C. Zumbrunnen, & U. Simon (Eds.), *Urban ecology. An international perspective on the interaction between humans and nature* (pp. 207–231). Springer.

Pedrazzini, L., Pedrotti, C. (2011). *Periurban landscapes: landscape planning guidelines*. Regione Lombardia.

Santiago-Ramos, J. (2015). *Áreas metropolitanas andaluzas. Análisis estructural del territorio metropolitano: espacio libre y espacio construido*. Regional Government of Andalusia, Department of Development, Infrastructure and Planning. Retrieved April 15, 2021, from https://www.aopandalucia.es/innovacion/principal.asp?alias=%C1reas_Metropolitanas

Santiago-Ramos, J. (2010). *Ciudad, espacio libre y funcionalidad ecológica. Una aproximación territorial al estudio del medio ambiente en el área metropolitana de Sevilla* [Doctoral dissertation, Universidad Pablo de Olavide, Spain]. TESEO Database. Retrieved April 15, 2021, from https://www.educacion.gob.es/teseo/imprimirFicheroTesis.do?idFichero=Nx1g9xNV1tQ%3D

Scurlock, J. M. O., Asner, G. P., Gower, S. T. (2001). *Worldwide Historical Estimates and Bibliography of Leaf Area Index, 1932–2000. ORNL Technical Memorandum 2001/268*. Oak Ridge National Laboratory. Retrieved April 29, 2021, from https://www.researchgate.net/publication/23821646_Worldwide_Historical_Estimates_of_Leaf_Area_Index_1932-2000

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., & James, P. (2007). Promoting ecosystem and human health in urban areas using green infrastructure: A literature review. *Landscape and Urban Planning, 81*(3), 167–178. https://doi.org/10.1016/j.landurbplan.2007.02.001

URGE Team (2004). *Making greener cities – A practical guide, No. 8/2004*. UFZ Centre for Environmental Research.

Van Veenhuizen, R. (Ed.) (2006). *Cities Farming for the Future. Urban Agriculture for Green and Productive Cities*. RUAF Foundation, International Institute of Rural Reconstruction and International Development Research Centre.

Watling, J. I., Nowakowski, A. J., Donnelly, M. A., & Orrock, J. L. (2011). Meta-analysis reveals the importance of matrix composition for animals in fragmented habitat. *Global Ecology and Biogeography, 20*(2), 209–217. https://doi.org/10.1111/j.1466-8238.2010.00586.x

Wickham, J. D., Riitters, K. H., Wade, T. G., & Vogt, P. (2010). A national assessment of green infrastructure and change for the conterminous United States using morphological image processing. *Landscape and Urban Planning, 94*, 109. https://doi.org/10.1016/j.landurbplan.2009.10.003

Yacamán, C, & Zazo, A. (Eds.) (2015). *El Parque Agrario: una figura de transición hacia nuevos modelos de gobernanza territorial y alimentaria*. Heliconia.

Yacamán, C., Ferrer, D., & Mata, R. (2020). Green infrastructure planning in metropolitan regions to improve the connectivity of agricultural landscapes and food security. *Land, 9*(11), 414. https://doi.org/10.3390/land9110414

Zasada, I. (2011). Multifunctional peri-urban agriculture-a review of societal demands and the provision of goods and services by farming. *Land Use Policy, 28*(4), 639–648. https://doi.org/10.1016/j.landusepol.2011.01.008

Zhang, S., & Muñoz Ramírez, F. (2019). Assessing and mapping ecosystem services to support urban green infrastructure: The case of Barcelona, Spain. *Cities, 92*, 59–70. https://doi.org/10.1016/j.cities.2019.03.016

Zhang, W., Ricketts, T. H., Kremen, C., Carney, K., & Swinton, S. M. (2007). Ecosystem services and dis-services to agriculture. *Ecological Economics, 64*(2), 253–260. https://doi.org/10.1016/j.ecolecon.2007.02.024

Zwierzchowska, I., Hof, A., Iojă, I. C., Mueller, C., Poniży, L., Breuste, J., & Mizgajski, A. (2018). Multi-scale assessment of cultural ecosystem services of parks in central European cities. *Urban Forestry and Urban Greening, 30*, 84–97. https://doi.org/10.1016/j.ufug.2017.12.017