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Towards a Standard Framework to Identify Green Infrastructure Key Elements in Dense Mediterranean Cities

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Abstract: Present-day dense cities are increasingly affected by the impacts associated with climate change. The recurrence of extreme climate events is projected to be intensified in cities in the next decades, especially in the most vulnerable areas of the world, such as the Mediterranean region. In this context, the urban green infrastructure (UGI) is presented as a nature-based solution that directly contributes to climate change mitigation in Mediterranean compact cities and improves health, social, welfare, and environmental conditions for inhabitants. This research sets out a manageable framework to define, locate, and categorize more functional green urban and peri-urban areas in a dense Mediterranean city. It takes spatial distribution, extension, and the capacity to improve inhabitants' wellbeing through the provision of ecosystem services as classification criteria. Results show a scenario with a greater functional green surface available for the citizens to be managed. Identified areas have been categorized as cores, nodes, links, and green spaces defined as "other" areas. In particular, the latter play a significant role at social, structural, and ecological levels. The study showcases that rethinking urban design and strategic decision-making around these areas can enhance green equity in Mediterranean dense cities, their capacity to better deal with environmental extremes, and the inhabitants' engagement with a culture of sustainability and wellbeing.

Keywords: UGI categorization; Mediterranean urban greening; climate change adaptation; urban green space availability; compact cities; green equity

1. Introduction

Climate change mitigation and adaptation are two of the main challenges faced by present-day urban environments, where densification is becoming even greater. According to the United Nations World Urbanization Prospects, 68% of the world´s population will live in urban areas by 2050 [1]. In this scenario of dense built environments with high population density, conventional urban development jeopardizes the presence of green areas and it leads to a reduced resilience and ability to buffer the cities' capacity in dealing with critical events associated to climate change, such as heat waves, abrupt changes in storm patterns, or floods [2]. The recurrence of these extreme events is projected to increase in cities in the next decades, especially in the most vulnerable areas of the world. The Mediterranean region has been identified as one of the most affected by climatic events in the coming decades, where the temperature is expected to increase 2.2 °C in 2040, and extreme events, such as droughts or heavy precipitations, are likely to intensify up to 20% in all seasons except for summer [3]. In addition, Mediterranean cities´ aging population, compactness, social inequity, and high population density make them particularly vulnerable to these environmental events [4,5]. Urban environments in this region need to consider immediate solutions to minimize this impact by synthesizing the existing scientific knowledge and providing a systematic framework across disciplines to manage climate change associated risks [6].

In this context, the urban green infrastructure (UGI) management is presented as a suitable nature-based solution (NBS) to adapt urban environments to climate change effects; to address densification in cities; to enhance green space provisioning; and, consequently, to deal with the environmental degradation and social inequity [7–10]. The suitability of the UGI is due to the versatility of its elements, which provide a wide range of ecosystem services (ES) at the city and site level, such as air filtration; microclimate regulation; cumulative effect on runoff; groundwater recharge and evapotranspiration; and social, health, and restorative benefits [11–13]. The harnessing of the UGI will be more necessary in Mediterranean medium-sized compact cities [14], where risk and disaster events associated with climate change, the loss of the traditional compact urban model, and the process of coastalization will be aggravated [15–17].

The benefits provided by the UGI assets derive from a wide variety of functional and structural elements at different scales, from smaller artificial structures—such as planter boxes, bioswales, green roofs, or green walls—to more extensive areas such as urban forests and other natural areas near the city [18,19]. It is worth mentioning that peri-urban areas also contribute to the provision of ES in the urban environment. Urban and peri-urban forests offer every type of ES (regulating, cultural, and provisioning) with relevant impact at local, regional, and global scales [20]. The strategic role these forest areas have should also be highlighted with regards to social interaction and inclusion, economic and cultural exchange [21], and risk reduction and planning for disaster management in cities [15]. Then, the management of available UGI areas and the provision of new ones not only improves urban environmental quality but also the adaptative and the resilience capacity of the city [22]. Moreover, the proximity to UGI elements is closely linked to environmental justice in urban areas. A greater level of green availability decreases the exposure surface to heat waves and waterlogging, while an enhanced accessibility to environmental refugees reduces inequity and strengthens inhabitants' welfare throughout a major provision of green spaces to a wider population, irrespective of their socioeconomic status [23,24]. This is so much so that UGI availability and accessibility are variables of major significance for green equity to be understood as a fair and equitable access to green areas and to the services they provide [25], especially during unexpected episodes of restricted mobility across the city such as the recent Coronavirus Disease 2019 (COVID-19) pandemic [26].

In fact, some studies conducted in compact Mediterranean cities, whose urban form is typically space-limited [27], have shown how the contribution of every green space—irrespectively of its size—will become even more critical for citizen welfare and for the city adaptative capacity in terms of thermal regulation, air quality improvement, water retention, and energy performance [28–30]. Moreover, recent research shows strong evidence on how the number of green areas and the greater access to them have an important role in creating a culture of well-being and in reducing social disparities [31]. An increased exposure to green spaces is associated with positive health outcomes (better cognitive function in adults, improved mental health, or lower risk of a number of chronic diseases, among others), social cohesion, and improved urban dwellers´ perception of well-being [32–35].

Therefore, the framework for UGI identification needs not only a multidisciplinary context that involves different stakeholders, from planners ("green providers") to end users ("green beneficiaries") [36,37], but also have standardized protocols with a common language that are integrated across disciplines and able to optimize the UGI functionality, accessibility, and availability [38,39]. The current methodologies for green infrastructure identification are mainly based either on geographic information system (GIS) techniques [40,41] or on spatial analysis methodology focused on the creation of structures from connectivity among the analyzed areas [42]. Pulighe et al. (2016), in their study about literature focused on urban green infrastructure mapping, setting out that there are advanced and sophisticated technical methods to assess and identify the functionality provided by green areas in cities, such as spatially-explicit InVEST, i-Tree Eco models, 3D modelling, or landscape structure models [43]. Nevertheless, it should be noted that these methods have very high application and interpretation difficulties and they are less manageable or accessible for those specialists who attend more to psycho-social and socioeconomic approaches, such as hedonic aspects, aesthetic appreciation, or well-being variables [44–46]. In the same way, green infrastructure elements are classified using many systems, which mainly respond either to structural criteria, based on land cover type, or functional criteria, based on land use type and spatial configuration of green elements [47–49].

On this basis, the current picture is defined not only by the lack of standardized and manageable frameworks for all the involved stakeholders aimed at promoting the UGI identification in Mediterranean urban environments, but also by the urgent need of compact cities—especially the Mediterranean medium-sized ones—for addressing the adaptation to climate change and inhabitants' welfare improvement through the optimization of the availability and accessibility to more functional green areas. This is the starting point of this study, which aimed at setting an UGI identification process with the capacity to maximize the functional green surface for the enhancement of ecosystem service provisioning at urban and site levels. A manageable protocol was developed and implemented for a wider identification and categorization of green areas to include in the UGI. This protocol set the criteria for the definition and selection of a greater number of available green areas on the basis of their spatial distribution, extension, and capacity to provide ecosystem services and to improve citizens' wellbeing. The city of Granada, as a representative of a medium-sized compact city located in the Mediterranean region (Southern Iberian Peninsula), was taken as a case study [50]. It is of note that Granada does not have a well-defined UGI nor an integrated plan for its promotion and management.

2. Materials and Methods

The conceptual approach of the proposed protocol supports the main principles for UGI planning, such as integration, determining the target elements within the infrastructure; connectivity, locating green elements within the urban matrix; multifunctionality, identifying the green elements that improve the adaptative capacity of the city; and social inclusion, enabling identification of those urban areas devoid of green availability [51]. In practice, the framework combines, on the one hand, the categorization of green urban and peri-urban areas in the UGI by previously defining, selecting, and classifying the target surfaces, and, on the other hand, an initial assessment on the availability and the accessibility of the categorized UGI elements. The resulting categorization responds to green areas' spatial distribution, extension, and capacity to provide ecosystem services in terms of wellbeing reinforcement and resilience to climate change.

2.1. Protocol for Target Areas Definition, Selection, and Classification

First, to define the elements to be included in the UGI, it is considered the capacity of the target areas to participate in the reinforcement of urban resilience and to mitigate the effects of climate change [52]. Therefore, areas with specific land uses especially active in terms of improving the benefits for citizens through the provision of ES, such as air quality enhancement, cooling effect in summer, or heat island effect mitigation, are identified [40]. These land use types are analogous to the land cover classes proposed by the Corine Land Cover Program (CLC) at the third level of geographical application, and at a 1:100,000 scale [53] (Table 1). In order to deal with the most recent information and to acquire spatial data at a finer scale, we made an analogy between CLC classes and land uses referred by the national land cover system (Spanish Land Use and Land Cover Information System—LCIS) for 2013 at a 1:10,000 scale [54] (Table A1, Appendix A).

Table 1. Land cover classes included in urban green infrastructure.

Land Uses with Regulating Services Capacity (Maes, Paracchini, and Zulian, 2011)	Corine Land Cover Classes (Level 3)		Correspondence with LCIS (2013)		ES Provision Capacity		
	CLC Code	CLC Description	LCIS Code Ranges	General Description	Reg. ES	Prov. ES	Cult. ES
Green urban areas	141	Green urban areas	177, 2005, 158	Green urban areas	med	low	high
Land mainly occupied by agriculture, with significant areas of natural vegetation Agro-forestry areas	243 244	Land mainly occupied by agriculture, with significant areas of natural vegetation Agro-forestry areas	410	Heterogeneous cropland	med	high	low
Broad-leaved forest Coniferous forest Mixed forest	311 312 313	Broad-leaved forest Coniferous forest Mixed forest	From 510 to 580	Woodland and forest	high	high	med
Natural grasslands Moors and heathland, Sclerophyllous vegetation, Transitional woodland-shrub, Beaches, dunes, sands	321 323 324	Natural grasslands Sclerophyllous vegetation Transitional woodland-shrub	From 611 to 921 (excluding 917)	Grassland and shrub	med low med	med low low	med low med

Land cover classes included in the urban green infrastructure (UGI) with capacity to provide ecosystem services (ES) in urban environments, and their correspondence with CLC classes (Corine Land Cover) and LCIS classes (Spanish Land Use and Land Cover Information System). Non-existent classes within the study area, such as beaches, dunes, sands, and moors and heathlands, are not included. Relative capacity of the land cover type to provide ES expressed as qualitative measure: Reg. ES = Regulating Ecosystem Services; Prov. ES = Provisioning Ecosystem Services; Cult. ES = Cultural Ecosystem Services.

Table 1 also qualitatively summarizes how these land cover types support the provision of ES. Regulating ES ("Reg. ES") considered are local and regional climate, air quality and carbon sequestration, pollination, flood prevention, erosion prevention, and nutrient sequestration. Provisioning ES ("Prov ES") targeted are crops, livestock, fodder, fiber, timber, energy, water, and medicines/biochemicals. Cultural ES ("Cult ES") are recreation and tourism, landscape aesthetics, knowledge systems, cultural heritage, and natural heritage. The qualitative assessment stems from previous research on the relative capacity of different land cover type to deliver ecosystem services [55–59] and its scale varies from low ("low") to medium ("med") and high ("high").

Second, after we defined target areas, they were selected within the study area according to their location and to the following criteria:

(i) The selected green areas should correspond to those with land uses listed in Table 1, that is, those public areas that are part of the UGI, showing the capacity to provide ES for climate change adaptation and mitigation.
(ii) The selected public areas, apart from fulfilling the previous criteria, are located within the city administrative boundaries (urban areas) or immediately adjacent to it, in contact with the urban fringe (peri-urban areas). This spatial delineation fits with the approach proposed by the European Environmental Agency in its glossary for urban green infrastructure [60], and it also fits with other proposals internationally accepted for urban and peri-urban systems, such as the approach followed by the Millennium Ecosystems Assessment Program [11] or by the Food and Agriculture Organization of the United Nations (FAO) [61].
(iii) Finally, other areas that meet the two criteria mentioned above that do not appear in any source of information are manually added to the cartography.

Two information resources were used in this study: public green areas mapping for regional capitals and municipalities with more than 100,000 inhabitants over 2004 and 2005, at a 1:5000 scale, and LCIS cartographic base, for 2013, at a 1:10,000 scale (Andalusian Environmental Information Network—REDIAM). Cartographic tasks such as map-making, map edition, and spatial data treatment were undertaken with geographic information systems (GIS).

Third and finally, the classification of the selected areas was based on three parameters: spatial distribution, surface, and capacity to improve citizens´ wellbeing through ES provisioning.

Spatial distribution of green elements in the urban and peri-urban landscape is heterogeneous. This configuration is shown as a network composed by non-linear spatial units defined as patches, connected with each other by linear areas defined as edges or links [62–64]. Patches are classified in core areas (larger patches) or node areas (smaller patches) according to their physical and ecological behavior in terms of their surface and capacity to host biodiversity [65–67] (Figure 1).

In line with the above, green area classification by surface is based on patches and corridors size [65] and refined with the proposed classification for Andalusian cities framed in the global action plan for sustainable development Agenda 21 [68]. Four types of green areas are identified according to their extension, to which a surface range is assigned accordingly:

- Large-sized areas, with an extension over 100,000 m^2, mostly occupied by natural vegetation and forests (natural parks, urban forests, or peri-urban parks).
- Medium-sized areas, with an extension ranging between 10,000 and 100,000 m^2, for communal use, where ornamental vegetation predominates (large urban parks, big squares, or vast public gardens).
- Small-sized areas, with an extension under 10,000 m^2, corresponding to supplementary areas, with service and leisure purposes (small parks, squares, or other garden areas).
- Linear spaces connecting the areas defined above are included as links. They mainly correspond to pedestrian avenues with roadways in both margins and a high density of green elements.

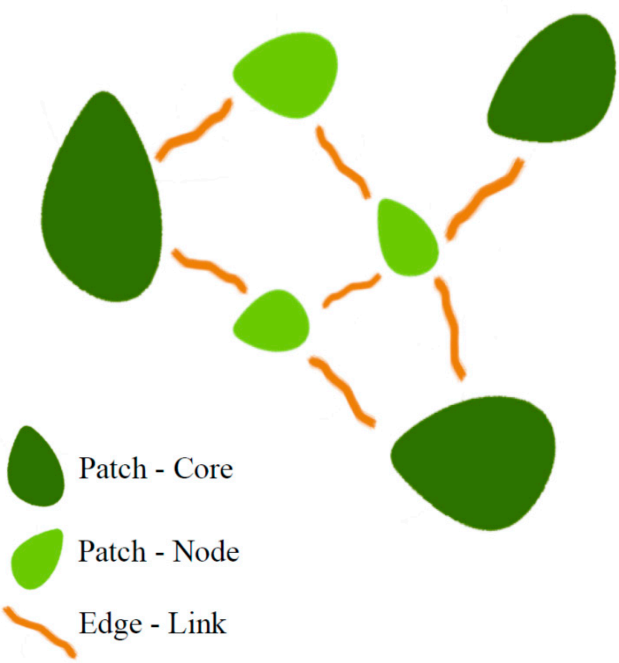

Figure 1. Spatial units identified for green infrastructure in urban environments [67].

The classification of green areas in terms of their capacity to provide ecosystem services and to improve public welfare relies on the land use type, using the Corine Land Cover classification as a reference. Woodlands and forests are shown to be more active areas due to their higher capacity to regulate local climate; offset carbon from the nearby environment; and face extreme events such as heat waves, erosion, droughts, or floods [55]. Croplands and urban green areas also contribute to the provision of ES but not as much as the previous land uses [56]. Transitional woodland/shrub, pastures, or areas with sclerophyllous vegetation are been shown active areas as well, with lower capacity to provide ES [57] (Table 1).

On this basis, and according to the land use matching with the Spanish Land Use and Land Cover Information System (LCIS), we considered the fact that land uses with high ("high") or medium ("med") capacity to provide ES actively contribute to the improvement of welfare conditions for inhabitants. These are green urban areas, heterogeneous croplands, woodland and forests, and mixed shrubs and grasslands. Those land uses presenting exclusively "med" or "low" ratings, which belong to LCIS codes 915 (scattered shrub with grasslands) and 921 (continuous grasslands), were not considered as active as the rest in terms of ES delivery (Table A1, Appendix A).

After following the processes of definition, selection, and classification, the categorization protocol developed in this study—mainly inspired in Benedict and McMahon´s approach of functional hubs and links spread across the landscape [67]—defines 4 types of green urban and peri-urban areas:

- Core areas: large-sized areas or patches that have an extension over 100,000 m^2 occupied by land uses with a high capacity to provide regulating, provisioning, and cultural ES (i.e., natural parks, urban forests, or peri-urban parks).
- Node areas: medium-sized areas (extension range between 10,000 m^2 and 100,000 m^2) with medium and high capacity to provide ES. As an exception, crowded areas (parks, gardens, or squares) smaller than 10,000 m^2 and located within the downtown district or adjacent to it, are categorized as node areas.
- Links: areas with linear spatial distribution connecting core and node areas with each other, such as pedestrian avenues or roadsides with high density of green elements. These edge areas are occupied by land uses with medium and high capacity to provide regulating and cultural ES.

- "Other" areas: these areas do not respond to any of the previous classes (cores, nodes, or links), mainly due to their low surface. Therefore, areas set as "other" correspond to every urban public space smaller than 10,000 m^2, located out of the downtown district and available to all the population. Their distribution is heterogeneous as they are present throughout the urban fringe and the urban matrix as stepping stones. Abandoned and ruderal spaces, pocket parks, green walls or green roofs, public green spaces in neighborhoods, and green spaces surrounding public and private buildings are defined as "other" areas [69]. Other areas that differ from scattered shrubs with grasslands and continuous grasslands have medium and high capacity to provide ES, especially regulating services, such as local climate regulation, air quality, pollination, or flood and erosion prevention, as well as cultural services, such as recreation, landscape aesthetics, and cultural and natural heritage.

Figure 2 shows the protocol schema followed for the categorization of urban green infrastructure elements, according to the variables defined above.

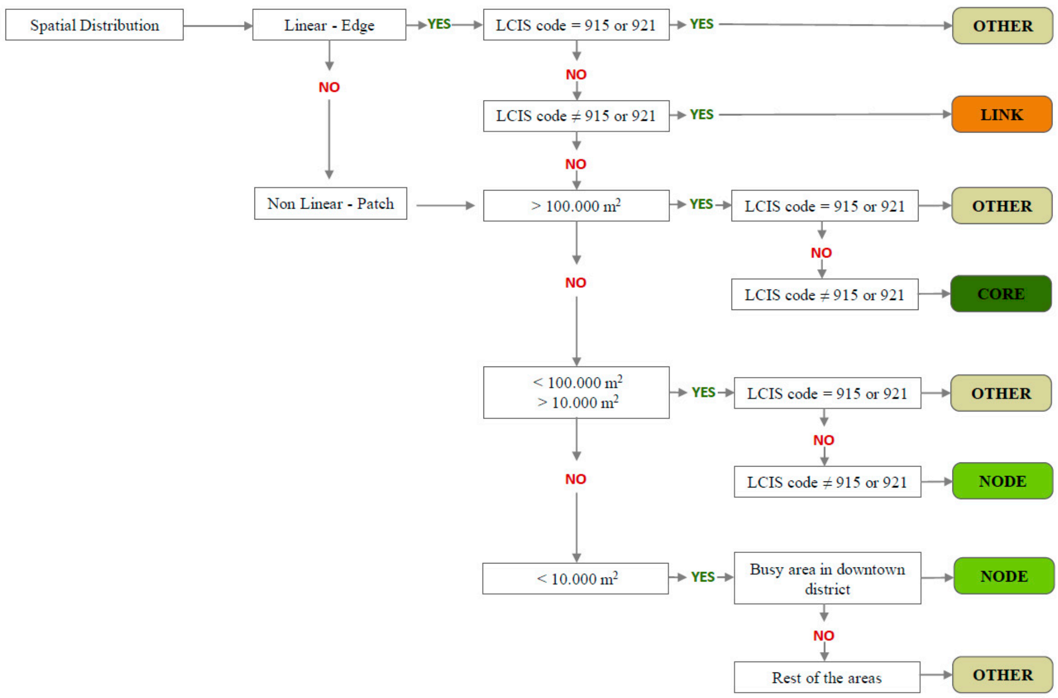

Figure 2. Protocol schema for the categorization of green areas in urban and peri-urban environments, according to their role within the urban green infrastructure.

2.2. Initial Assessment of Green Availability and Accessibility

For an initial assessment of the of the UGI availability and accessibility, we obtained surface and population data from the Municipal Register of inhabitants for 2017 for the 31 neighborhoods of the city [70].

The availability was calculated on the basis of the UGI surface per inhabitant of each neighborhood whilst the accessibility was assessed by calculating the distance as a simple measure from the identified green assets [71,72]. Considering as ideal the level of accessibility when it takes less than 8 min by walking to reach a green area [73] and on the basis of the Accessible Natural Greenspace Standards (ANGSs) [74], we set two distance thresholds: 300 m and 500 m to the nearest green space. An additional threshold at 100 m was also set to assess the immediate access to any categorized green area, which is key for vulnerable populations such as the elderly, chronically or mentally ill, disabled citizens, and other minorities. According to these criteria, the percentage of surface within these thresholds is also expressed in relation to the total urban area.

2.3. Description of the Case Study Area

The City of Granada (37.179937, −3.603489; 680 meters above sea level) is located in the southeast of the Iberian Peninsula, with an extension of 88.9 km^2 (reference spatial data of Andalusia—DERA, 2016) (Figure 3a). The study area it representative of a medium-sized compact city in the Mediterranean region according to the population rank (between 200,000 and 500,000 inhabitants), population density (2657.93 inhabitants/Km^2), high contiguity and proximity of dwelling units across districts, the clear separation between urban and rural land use at urban fringe, the existing public transport system spread throughout the town, and the accessibility to most of local services on foot or by public transport [75–78].

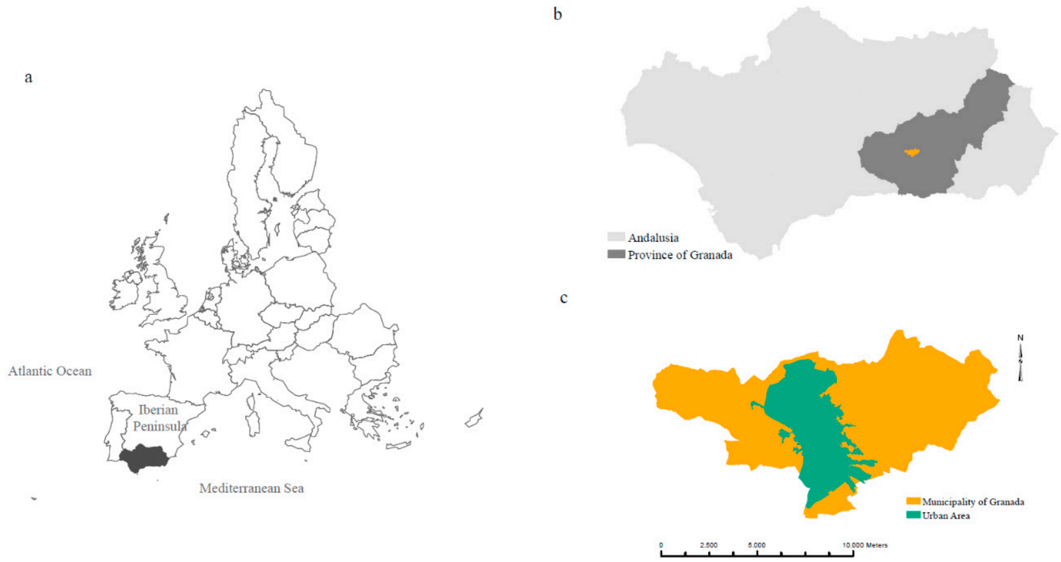

Figure 3. Case study location: (**a**) Andalusia's and Granada's locations within the Iberian Peninsula; (**b**) Granada's municipality location within the province; (**c**) urban and municipal area of Granada.

The city presents a continental Mediterranean climate, with hot, dry summers, and cold winters. The average annual temperature for the 1981–2010 period was 15.6 °C, and the average annual rainfall was 359 mm (Spanish Weather Agency—AEMET, 2016). The municipality of Granada (Figure 3b,c) shows a wide thermal amplitude due to its geographical location in a wide depression formed by the Genil River and within the valley of the Sierra Nevada mountain range [79]. The temperature range recorded in Granada for the 1981–2010 period was 14.3 °C. The greatest value was recorded during the summer period, when thermal amplitude reached 17.2 °C (Spanish Weather Agency—AEMET, 2016). Granada is one of the Mediterranean cities showing a greater frequency of heat and cold waves [80,81]. The records of heat waves occurring in Granada since 1975 show that almost 50% of these extremes have occurred since 2011 [82].

It should be also highlighted that Granada is one of the most affected cities in Spain by greenhouse gas pollution and emissions, with 2017 being the year with the worst air quality in the historical data series of the city [83–86]. As an indicative value, long-term mortality impact of decreasing ozone and $PM_{2.5}$ in Granada, expressed as the total annual number of postponed deaths, was set in 61 for the period of 2004–2006 [87].

The current scenario in the city of Granada does not yet have an integrated plan of UGI management. According to the information provided by the Environmental Information Network of Andalusia (REDIAM), Granada's urban area has 363 registered green areas, of which 341 have an extension smaller than 10,000 m^2. The remaining 22 green areas have an extension ranging between 10,000 and 100,000 m^2. The total surface of public green spaces within the urban area is 1,141,884.7 m^2.

Considering the population census for 2017, the average value of public green area per inhabitant, in square meters, is 4.9 (Table 2, Figure 4a).

Table 2. Current scenario: data for public green areas in the city of Granada, 2017.

Population (inhabitants)	232,770
Municipality area (m^2)	87,921,138.7
Urban area (m^2)	20,661,438.0
Number of public green areas	363
Number of large-sized areas (surface ≥ 100,000 m^2)	0
Number of medium-sized areas (surface 10,000–100,000 m^2)	22
Number of small-sized areas (surface < 10,000 m^2)	341
Public green urban area surface (m^2)	1,141,884.7
Public green area surface (m^2)/inhabitant	4.9

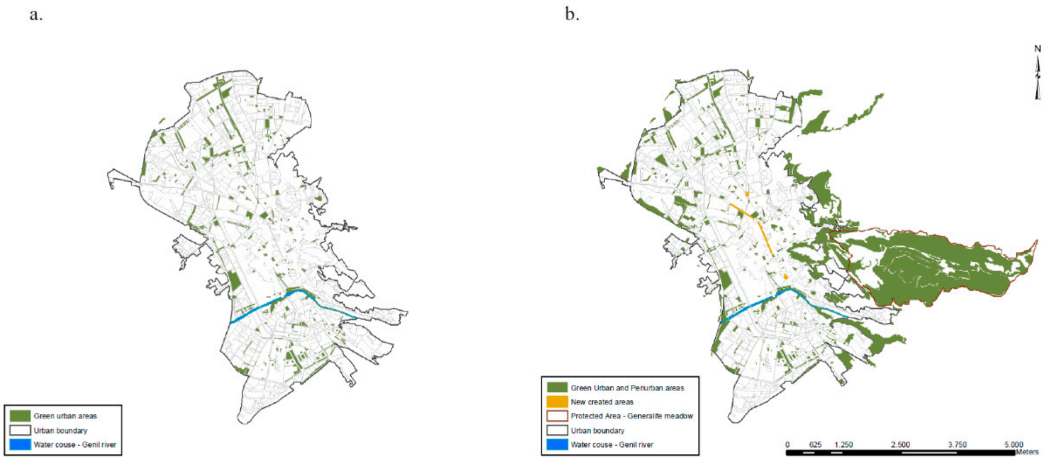

Figure 4. Green spaces in the city of Granada: (**a**) urban areas identified in the current scenario; (**b**) urban and peri-urban areas identified after protocol implementation.

3. Results

The resulting scenario after implementing the protocol described shows 443 public green areas identified, which represents a 22.1% increase as compared to the pre-existing data. Among these areas, 5 large-sized areas not considered in the current scenario and 70 medium-sized areas were identified as UGI elements. The number of large and medium-sized areas represented an increase of 100% and 218.2%, respectively. Regarding small-sized areas, 368 were recorded within the proposed scenario. A peri-urban forest adjacent to the city boundaries was included so its full extension was completely located within a unique protected area, the Generalife meadow. Nevertheless, the northern zone of the meadow is slightly distant from the city. It should be noted that this protected area represents 50.2% of the whole registered UGI in the proposed scenario (Table 3, Figure 4b).

Table 3. Data for public green spaces in Granada's urban area and increase percentages after protocol implementation.

	Value	**Δ**
Number of public green areas	443	22.1%
Number of large-sized areas (Surface ≥ 100,000 m^2)	5	100.0%
Number of medium-sized areas (Surface 10,000–100,000 m^2)	70	218.2%
Number of small-sized areas (Surface < 10,000 m^2)	368	7.9%
Public green urban area surface (m^2)	7,470,561.3	554.2%
	3,722,208.2 (49.8%) + Protected area = 3,748,353.1 (50.2%)	
Public green urban area surface (m^2), excluding protected area	3,722,208.2	
Public green area surface (m^2)/inhabitant	32.1	554.2%
Public green area surface (m^2)/inhabitant excluding protected area	15.9	226.3%

In this context, the total surface of public green spaces in urban and peri-urban areas would come to 7,470,561.3 m^2, which means a 554.8% increase if we compare both scenarios. Consequently, the mean public green area per capita would rise to 32.1 m^2/inhabitant. Even under a more restrictive approach, excluding the protected area of the Generalife meadow from the proposed scenario due to its distance from the city, the average of public green area per inhabitant would still be higher, coming to 15.9 m^2/inhabitant (Table 3, Figure 4b).

3.1. Categorized Green Areas

The major contribution to the UGI in terms of number of spatial units relies on the areas defined as "other", with 374 spaces, mostly (86.1% of them) fully located within the urban area. Land uses in these other areas mainly corresponded to parks, squares, and gardens (LCIS 177), although scattered shrub and continuous grasslands (LCIS 915 and 921) were also identified. Regarding green spaces defined as nodes, there were 49 areas homogeneously distributed within the urban (65.3%) and peri-urban area (34.7%), with most of them being parks, squares, and gardens (Table 4, Figure 5).

Table 4. Public green urban and peri-urban areas classified by type, number of areas, location, and surface.

Type of GI Element	**Number of Areas**	**%**	**Urban**	**%**	**Peri-Urban**	**%**	**Surface (m^2)**	**%**
Core areas	5	1.1%	1	20.0%	4	80.0%	4,621,460.9	61.9%
Node areas	49	11.1%	32	65.3%	17	34.7%	1,259,340.1	16.9%
"Other" areas	374	84.4%	322	86.1%	52	13.9%	1,381,624.2	18.5%
Links	15	3.4%	15	100.0%	0	0.0%	208,136.1	2.8%
Total	443	100.0%					7,470,561.3	100.0%

In terms of surface, the five core areas identified, which are composed of forests, woodlands, and dense shrub, were the greatest contributors (61.9%) to the whole green area. Four of them are along the urban fringe, and the other one is located within the urban area. Nodes and "other" areas contributed to the whole registered surface of patches identified within the GI at 16.9% and 18.5%, respectively (Table 4, Figure 5).

In addition, 15 linear spatial units defined as links were identified, all of them located within the urban area. These edges contributed least to the whole UGI area, occupying almost 3% of the total registered surface in the proposed scenario (Table 4, Figure 5). Those links located in the downtown district include many street trees along them.

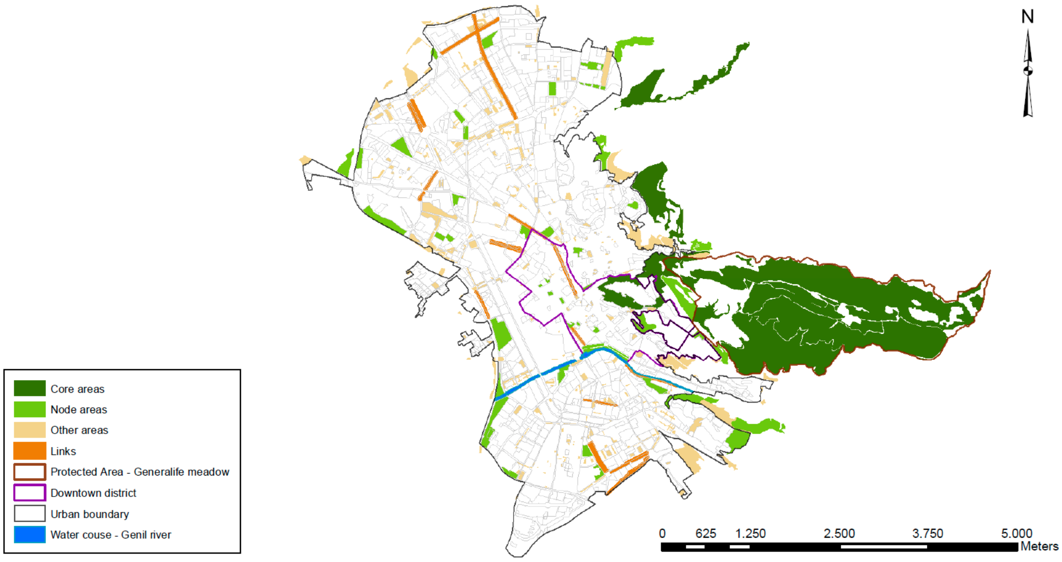

Figure 5. Green urban and peri-urban area distribution in the proposed scenario, classified by core areas, node areas, "other" areas, and links. Case study: City of Granada (southeast Iberian Peninsula).

In terms of capacity to provide ecosystem services, peri-urban core areas presented the highest capacity for regulating, provisioning, and cultural ES delivery. Despite node areas being less active for supporting provisioning ES, they presented medium and high capacity for cultural and regulating ES supply, especially for services such as recreation and tourism, cultural and natural diversity, local climate regulation, air quality, pollination, carbon sequestration, and flood and erosion prevention. Areas defined as other, different from scattered shrubs with grasslands and continuous grasslands, were also found to be active in supporting regulating ES, while their current highest contribution relied on cultural services for recreation, aesthetic appreciation, exercising, or cultural and natural heritage.

3.2. *Availability and Accessibility*

Results of availability are expressed according to two references: first, the minimum and the ideal green surface per capita recommended by the World Health Organization for urban environments (9.0 and 50 m^2/inhabitant) [88]. Second, the average calculated for the whole proposed scenario under a more restrictive approach (15.9 m^2/inhabitant) and the average calculated for the proposed scenario including the Generalife meadow (32.1 m^2/inhabitant) (Table 3). The availability assessment showed 16 neighborhoods with less than 9 m^2/inh. Two additional neighborhoods were still under the average set for a restrictive scenario, whilst five of them had between 16.0 and 32.1 m^2 of green space per capita. The remaining neighborhoods had more than 32.1 m^2/inh., and five of them exceeded the upper range of 50 m^2/inh. (Figure 6).

Regarding to the accessibility, 67.2% of the total urban area presented immediate access to any of the UGI elements categorized (less than 100 m). The surface of the city with an UGI element between 100 m and 300 m away occupied 30.5% of the total urban area whilst 1.5% had a UGI area from 300 m to 500 m. Almost 100% of the city presented an ideal level of access to any UGI element, taking less than 8 min of walking to reach any categorized area (Figure 6).

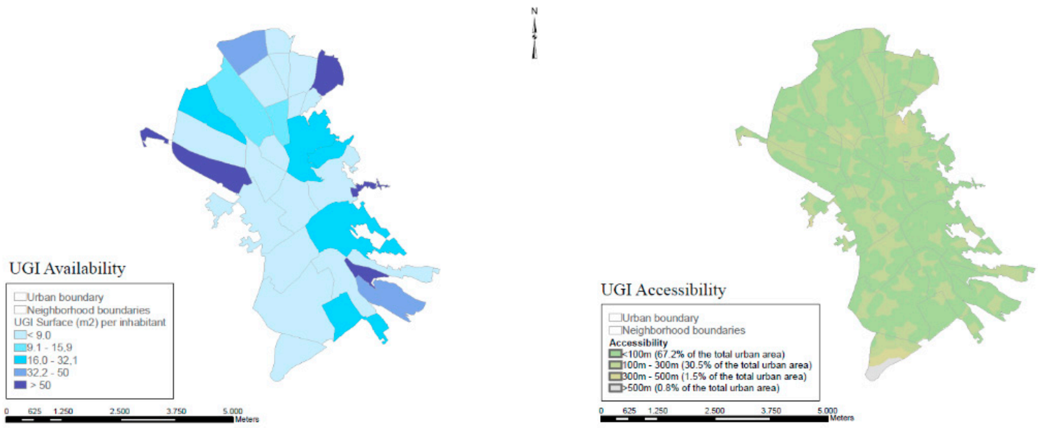

Figure 6. Initial assessment of UGI spatial distribution in terms of availability and accessibility.

4. Discussion

New urban spatial designs and the urban green infrastructure still have an unexplored potential for the response to climate and social challenges that cities must face in a near future within the built environment [89]. Due to the space limitation characteristic of compact cities, all types of urban green areas with the capacity to participate in the provision of ES should be taken into consideration as they can contribute to climate adaptation, to urban resilience, and to social cohesion [90,91], especially in the most vulnerable dense cities such as those in the Mediterranean.

To deal with these challenges, we carried out a process for UGI identification that first combined both quantitative and qualitative concepts. Second, it considered structural and functional variables for area categorization. Third, it was defined using a common language, spatial heterogeneous conditions, and finer local and site scales. The resulting scenario attended to urban and peri-urban green area spatial distribution, extension, and their capacity to provide ecosystem services. An updated picture of the city was drawn, which better fitted with the current functional green network in Granada, showing a versatile urban green infrastructure that was receptive to the implementation of specific plans and measures at district, neighborhood, and site scales.

The application of the defined protocol coped with the compact cities´ densification-associated threats by allowing the identification of a greater number of public urban green areas, typifying existing ones, and providing new green spaces on built sites. [92]. Moreover, the consideration of variables, such as the characterization of land use, the accessibility of green spaces, or the diversity of active areas in terms of ES provisioning, leads to avoidance of the complexity for UGI identification [93]. In this sense, the outcome of this methodology would be particularly relevant in the Mediterranean region, where the lack of manageable frameworks across disciplines makes difficult the settlement of the urban green infrastructure as an integrated resource for climate change management in cities [6]. Such is the case of Granada, which does not have an agreed-upon and well-defined UGI to be managed yet. This demand is responded to by the followed protocol, which offers a comprehensive way to standardize the categorization of the existing UGI assets (as core, node, and link elements) and the provision of new public green spaces to be functional and accessible, mainly corresponding to stepping stone areas defined as "other".

After UGI identification following this protocol, the surface of green area per inhabitant has clearly increased. The proposed scenario supports a green area availability of 32.1 m^2 per inhabitant when including the Generalife meadow and 15.9 m^2 when excluding this protected area (due to its distance from the city) (Table 3). Even under the most restrictive approach, this average noticeably exceeds the calculated average for the current scenario of 4.9 m^2.

Nevertheless, our result is more consistent with the average for Granada´s green area provided by the Informed Cities project, a European initiative driven by Local Governments for Sustainability, ICLEI [94], for 2009. According to this European platform, the whole green infrastructure surface for the municipal area is 7%, while our outcome sets this percentage between 4% and 8%, depending on whether we consider the contribution of the protected area to the proposed scenario or not. The ICLEI average of green area per inhabitant is calculated at 28 m^2, which is close to our result, 32.1 m^2/inh., under the least restrictive approach.

The average increase obtained after implementing our protocol should not be understood as a reduction of grey infrastructure. In fact, the current intensive urban development, particularly apparent in Mediterranean areas [95], involves the sacrifice of existing urban green spaces, especially in Southern EU cities where the average surface of urban green areas is the lowest within the European region [96]. In particular, at a national level, this average is about 12.5 m^2/inh. [97], and thus the proposed schema is a good first step for the challenge to provide a larger surface of urban green area per inhabitant. This approach is consistent with the results obtained from the availability assessment, since up to 16 neighborhoods can be observed where the average of green surface per inhabitant did not reach the minimum of 9 m^2 recommended by the WHO. In contrast, three peripheral neighborhoods far exceeded the average under the least restrictive approach (32.1 m^2/inh.), which was due to their low population density.

Apart from the total green surface increase in the proposed scenario, a greater number of green elements to be part of the UGI were identified, which were categorized as core areas, node areas, "other" areas, and links. In this respect, the set protocol enabled a clear and functional categorization for each green area on the basis of measurable variables [98] applicable for both smaller and larger urban areas. Moreover, it can be observed that the wider preexisting green areas acquired a major relevance as they were identified as cores and nodes. Our framework underlines the importance of all green areas in terms of ES provision, particularly highlighting the high capacity of core areas to provide regulating, provisioning, and cultural ES. Node areas are also presented as active in terms of capacity for regulating ES supply and high level of contribution for cultural services. Similar qualitative assessment stems from areas defined as other, however, the variability of size and land use type make them an interesting target to improve the ES delivery, especially those services related to mitigation of climate change. In addition, the spatial location of these areas is georeferenced, which is also key factor to assess the potential production and distribution of urban ecosystem services [99].

The architecture of downtown districts, with small and limited spaces and narrow or cobbled streets, prevents them from having a wider range of core and node areas. The east boundary of the city contained the identified core areas, while most of the node areas were located within the west boundary. This spatial distribution can lead to a strategical planning aiming to provide continuity between all these green spaces, consolidating a green belt around the urban outskirts. However, the protocol implementation also showed how this continuity potential between green spaces is difficult to glimpse. The identified links scarcely connected relevant green areas (cores and/or nodes) between each other, but they went through and connect areas defined as "other" within the urban matrix. The initial assessment on accessibility by distance showed 67.2% of the total urban area presenting immediate access (less than 100 m) to a green space, and 97.7% was less than 300 m from any UGI element. Almost 100% of the city was found to be 8 minutes' walk or less from any type of green area. Therefore, the spatial dissemination of other areas leads to the fact that almost 100% of the urban area presents affordable levels of accessibility, as a simple measure of distance, to any UGI element, both in downtown and peripheral neighborhoods.

The number of "other" areas was the highest, with 322 spatial units, 86.1% of which are located within the urban area (Table 4, Figure 5). It should be firstly noted that compact cities in Mediterranean regions are characterized by the archetypal image of density and urban complexity [100]. These cities have followed a monocentric growth model around a clear and a dense historical center [101]. In these terms, Granada can be considered a typical medium-sized compact city due to its population variables, density, and accessibility patterns [102]. The urban configuration for a compact city leads to a physical and spatial limitation, especially in the city of Granada, where downtown´s morphological heritage has remained unchanged over time. In the compact city model, the implementation of new green areas among interstitial spaces within the urban matrix is highly limited [92]. This is where the importance of these “other” areas, hereunder discussed, comes into play.

To understand these “other” areas within Mediterranean medium-sized compact cities, we shall have to consider the concept of stepping stones in cities, as they are shown as small green spaces connecting isolated patches that can be part of an assembled urban matrix [103]. This situation would support why the areas defined as “other”, which are typically smaller, play a multifunctional and significant role in a complex and dense urban environment, supporting and connecting local biodiversity reserves, increasing the resilience of the urban ecosystem, protecting dwellers against extremes, and providing socio-cultural services [104,105]. The typology of UGI included in the category of “other” identified within the study area mainly corresponded to pocket parks and small squares (the so-called “plazas” in Spanish). Moreover, the smallest “other” areas identified within the UGI, even single green elements such as groups of trees placed at intersections of pedestrian routes, create interesting zones, both in ecological and in social terms, to facilitate an equitable access to green spaces and improve the habitability and sustainability conditions in the city [39,106]. Actions for “other” area reinforcement among existing structures can be considered as a key measure for the enhancement of the spatial cohesion, connectivity, and resilience within the urban matrix [107], especially in Mediterranean dense cities such as Granada, which are particularly sensitive to extremes associated with climate change, such as heat waves and torrential rains. The suitability of strategies promoting “other” areas stems from the combination of their multifunctional role in terms of regulating ES provisioning (such as cooling effect or improved thermal comfort) and the strategic usability they have to promote a culture of welfare engagement [108,109]. It is also remarkable that, besides the ecological value, “other” areas could be a useful structural resource to compensate the lack of links for connecting patches as cores and nodes. Their importance for maintaining the UGI connectivity supports that even small green areas in fragmented urban environments can be significantly important for the ES provisioning [110]. In this regard, the results for areas defined as “other” also highlight a range of possibilities to trigger action measures over smaller green areas behaving as connectors and their smart integration into the compact city [111]. It can be observed that the absence of connecting linear spaces is more pronounced in the east and west margins of the urban area, where core areas and wider node areas are respectively located. In addition, the identified links are devoid of relevant areas to connect, especially in the downtown district and in north of the urban area (Figure 5).

On the basis of the proposed protocol results, three strategic lines of action aligned with the principles for UGI planning come into discussion: first, results locate the green areas that need to be managed by specific local measures at site and neighborhood scales in order to make them more active in terms of ES provisioning and usability. Second, those city sectors requiring more availability of green surface were identified—they were mainly located in the most southern part of the urban area; albeit, more availability is demanded at the whole local context. Third, results showed at the site scale the different thresholds of accessibility to any of the categorized areas; thus, green access disparities can be compensated by the reinforcement of areas defined as “other”. Indeed, due to the limited land resources and the competition between land use in Mediterranean medium-sized compact cities, the management of areas defined as “other” within the urban matrix would be the first “quick win” for policymakers to enhance an equitable access to functional green areas. They can be considered as stepping stones with the additional capacity to behave as refugees and comfort zones redistributed around the town center. Of note, their usability can also offset social disparities and stress situations during unexpected episodes of restricted mobility within the city, across neighborhoods, or between dwelling units, such as in the current COVID19 crisis [112,113].

Discussion of the results also opens the possibility for further applied research in Mediterranean compact cities under ecological and social approaches. On the one hand, this study would allow the quality of the identified areas to be defined through an exhaustive analysis of the vegetation cover, the surface permeability, present structures, or plant species and their influence on the closest environmental conditions within the urban area. On the other hand, the results achieved can trigger deeper assessment on the connectivity, green equity, and accessibility patterns to green areas within the UGI, taking into consideration specific socioeconomical and architectural variables. Further research can be also addressed on how peri-urban environments interface with the UGI, particularly in those non-urbanized areas (such as farmlands and shrubs, located on the periphery of the city). At the end, the ensemble influence of both UGI assets from the urban and peri-urban area and green infrastructure assets from surrounding rural areas can lead to an improvement in the environmental conditions in terms of ES provisioning, from a local to a regional scale [114,115]. Finally, additional research should come from the need to improve the accessibility to peri-urban core areas from high population density urban areas [116], as is currently happening in Granada for inner-city dwellers. At design and planning levels, the continuity between peri-urban and urban green areas can be enhanced by specific actions such as creating walking and cycle paths or creating dedicated public transport itineraries [117].

It should be taken into consideration that the schema for UGI identification could have some limitations. This means that other classes of land uses, such as rural areas surrounding the city, are not included in the UGI but into an extended green infrastructure beyond the urban boundary. In the case study, these peri-urban rural areas are known as "Vega" of Granada, a region where prevailing land use is farmlands and crops. This kind of vegetated peri-urban area commonly has different legal instruments for its management, but it complements UGI functionality by contributing to the biodiversity and ecosystem conservation and, in the end, to the delivery of ecosystem services in the urban area [118]. In Mediterranean environments, peri-urban rural areas provide additional ES, which significantly contributes to human well-being in urban areas [119] but it should be also mentioned that this ES supply to Mediterranean compact cities has decreased due to land cover changes during recent years [120]. Nevertheless, peri-urban areas where the land is occupied by forests have been included in the proposed scenario. These peri-urban forests—followed by urban forests and street trees—are indeed the UGI elements with highest potential for climate change adaptation and welfare improvement in Mediterranean urban environments, as compared to surrounding rural areas with other vegetation types [121].

5. Conclusions

This study defined a framework to maximize and categorize the effective surface of the UGI and to initially assess green availability and accessibility patterns in a Mediterranean medium-sized compact city. Results of the proposed scenario are useful for a better assessment of the potential urban resilience to climate change-associated extremes, through the spatial distribution of urban functional green spaces. In comparison with the existing scenario, a greater number of green areas have been included into the UGI, mainly attending to the capacity to improve inhabitants´ wellbeing through the provision of ES. Results also show an increase in the surface and number of green elements to consider for enhancement actions and strategic decision-making towards an equitable provision of green areas for dwellers. This is precisely the point where new areas categorized as "other" play a major role. Despite being mainly smaller elements and apparently less active in terms of ES provisioning, they are distributed throughout the urban matrix reducing the UGI fragmentation and enhancing the usability, the availability, and the accessibility of green spaces. By means of the management and transformation of these "other" areas into green spaces with higher ecological, cultural, and social value, the capacity of Mediterranean dense cities to deal with environmental extremes and to engage inhabitants with a culture of sustainability and wellbeing can gradually increase.

Finally, further application and research can take place for stakeholders from different disciplines. UGI assets management should integrate ecological and socioeconomical aspects, towards the immediate need to adapt to climate change associated extremes and to enhance social welfare conditions in Mediterranean urban environments.

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Appendix A Detailed Correspondence between CLC and LCIS Codes

Table A1. Analogy established between Corine Land Cover (CLC) classes and land uses referred by the national land cover system (Spanish Land Use and Land Cover Information System—LCIS) for 2013.

Land Use Source CLC (2012) Level 3	CLC Description	Correspondence with LCIS (2013)	LCIS Description
141	Green urban areas	177	Parks, squares, gardens, promenades
		2005	Landscaped zones
		158	Playgrounds
243	Land principally occupied by agriculture, with significant areas of natural vegetation	410	Mosaic: annual crops or grazing land under the wooded cover of forestry species
244	Agro-forestry areas		
311	Broad-leaved forest	510	Forests: oak
		530	Forests: eucalyptus
		540	Forests: other broad-leaved species
312	Coniferous forest	520	Forests: conifers
313	Mixed forest	550	Forests: oak + conifers
		560	Forests: oak + eucalyptus
		570	Forests: conifers + eucalyptus
		580	Mixed forests
Scrub and/or herbaceous vegetation associations (all classes within level 2)		All classes with shrubs, moors, and grasslands	
321	Natural grasslands	611	Dense shrub with trees: dense oaks
323	Sclerophyllous vegetation	615	Dense shrub with trees: scattered oaks
324	Transitional woodland/shrub	621	Dense shrub with trees: dense conifers
		625	Dense shrub with trees: scattered conifers
		630	Dense shrub with trees: eucalyptus
		640	Dense shrub with trees: other broad-leaved species
		650	Dense shrub with trees: oak + conifers
		660	Dense shrub with trees: oak + eucalyptus
		670	Dense shrub with trees: conifers + eucalyptus
		680	Dense shrub with trees: mixed tree species
		711	Scattered shrub with trees: dense oaks
		715	Scattered shrub with trees: scattered oaks
		721	Scattered shrub with trees: dense conifers
		725	Scattered shrub with trees: scattered conifers
		730	Scattered shrub with trees: eucalyptus
		740	Scattered shrub with trees: mixed tree species
		750	Scattered shrub with trees: oak + conifers

Table A1. *Cont.*

Land Use Source CLC (2012) Level 3	CLC Description	Correspondence with LCIS (2013)	LCIS Description
		760	Scattered shrub with trees: oak + eucalyptus
		770	Scattered shrub with trees: conifers + eucalyptus
		780	Scattered shrub with trees: mixed tree species
		811	Grasslands with trees: dense oaks
		815	Grasslands with trees: scattered oaks
		821	Grasslands with trees: dense conifers
		825	Grasslands with trees: scattered conifers
		830	Grasslands with trees: eucalyptus
		840	Grasslands with trees: other broad-leaved species
		850	Grasslands with trees: oak + conifers
		860	Grasslands with trees: oak + eucalyptus
		870	Grasslands with trees: conifers + eucalyptus
		880	Grasslands with trees: mixed tree species
		891	Arable crops with trees: dense oaks
		895	Arable crops with trees: scattered oaks
		911	Dense shrub
		915	Scattered shrub with grasslands
		921	Continuous grasslands

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