Universitat Autònoma de Barcelona

Urban Green Infrastructure: Sustainable Regional Development Based On Landscape Services

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Urban Green Infrastructure:

Sustainable Regional Development Based On Landscape Services

PhD Dissertation

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"***The road ahead is long and has no ending; yet high and low I will search with my will unbending.***"

"*路漫漫其修远兮，吾将上下而求索。*"

- *Chu Ci* anthology

Written by Qu Yuan (c. 340 - 278 BC)

(He was a Chinese poet who lived during the Warring States period of ancient China.)

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MAIN ABBREVIATIONS AND ACRONYMS

C	Cultural and social services
CICES	Common International Classification of Ecosystem Services
CLC	The Coordination of Information on the Environment (CORINE) Land Cover
CNP	The Collserola Natural Park
CO^2	Carbon dioxide
CORINE	The Coordination of Information on the Environment
CSC	The China Scholarship Council
EEA	European Environment Agency
ES	Ecosystem services
EU	European Union
GI	Green infrastructure
GIS	Geographic information system
InVEST	The Integrated Valuation of Ecosystem Services and Trade-offs tool
IPBES	International Panel on Biodiversity and Ecosystem Services
LS	Landscape services
LSAM	The Landscape Services Assessment Matrix
LSBA	The landscape services barren area
LSOA	The landscape services obstructed area
LSPA	The landscape services provision area
LUCC	Land use / cover change
MA	Millennium Ecosystem Assessment
MUHBA	The History Museum of Barcelona
NO^2	Nitrogen dioxide
O^2	Oxygen

P	Provisioning services
PEIN	The Plan for Spaces of Natural Interest
PEPCo	The Organisation and Protection of the Natural Environmental of Collserola Park
PGM	Metropolitan Overall Plan
PM	Particular matter
R	Regulating and maintenance services
SO^2	Sulfur dioxide
TEEB	The Economics of Ecosystems and Biodiversity
UAB	Universitat Autònoma de Barcelona
UGI	Urban green infrastructure
USDA	The Department of Agriculture of the United States

PREFACE

This dissertation is submitted in fulfilment of the requirements for the doctoral degree in Geography, organised by the Department of Geography of the Universitat Autònoma de Barcelona (UAB), Spain. The PhD Program in Geography is under the legal framework of the Spanish Royal Decree 99/2011, of 28 January, by means of which official PhD studies are regulated in Spain. The dissertation is the culmination of four years' doctoral research (2015-2019), supervised by Dr. Francesc Muñoz Ramírez. My doctoral research was funded by the China Scholarship Council (CSC) (Grant No. 201506910063).

This dissertation is an individual and original work. It has been completed with the unremitting efforts of individuals, the guidance of tutors, and the results of research projects. As far as I know, in addition to the special marks and acknowledgements in the text, the dissertation does not contain research results that have been published or written by other individuals or groups. Also, the acknowledgements made a clear statement and expressed appreciation for every contribution that colleagues who have contributed to this research.

This dissertation meets the requirements of the doctoral thesis of UAB. It includes five chapters, reference and the main appendices. The first one includes a general introduction, research objectives and methodologies. There are three original research chapters. Each of them aims to deal with different issues with different case studies, as well as includes an introduction, material and methods, results and discussion. The last one is a general discussion and conclusion chapter. In this dissertation, a part of research chapters has been published as an article in a peer-reviewed scientific journal, as well as another one is submitted for publication.

My research achievements during my PhD period are far more than the completion of this dissertation. During this period, I had the opportunity to participate in other international conferences and seminars, and to show and present my research in these conferences and seminars. In addition, I participated in other research projects, for

example, I participated in the project 'Observatori de la Urbanització (2018) Identification and Evaluation of Metropolitan Voids in the Barcelona Region', developed by Geography Department of UAB, Diputació de Barcelona. Another project is 'Blue Heritage Management—Urban heritage as a landscape catalyst' (2017-2018), developed by the European Union. Besides, I also participated in other research activities, such as international workshops. I participated in six international workshops during my PhD period. All of these achievements are listed in Appendix C.

ABSTRACT

The ecosystems services approach has represented a hot research area in academia during the past two decades as it is an effective way of strengthening the connection between ecosystems and human well-being. Landscape services, as a particular way of ecosystem services, have been increasingly valued highly by researchers. However, the scientific and systematic general theory of landscape services is still blank. Landscape services assessment and mapping can effectively carry out the spatial analysis on a specific scale that helps to maintain multi-functional landscapes and plan urban green infrastructure. In return, green infrastructure can deliver a wide variety of landscape functions and services, which promotes landscape sustainability. However, there is still a huge challenge regarding quantitative assessment and mapping of landscape services to support urban / landscape planning.

This dissertation assumes landscape services approach is a much better and suitable methodology than ecosystem services approach, so the assessment and spatial analysis of the supply capacity of landscape services would be better guide urban green infrastructure planning. Besides, the consideration of landscape services offers the possibility for including in the definition of urban green infrastructures a different type of areas playing different roles and supplying different services (environmental plus cultural).

In order to verify the hypotheses, first, this study proposes the general theory of landscape services in the context of landscape, including identification and classification, through the case study (the Collserola Natural Park) that justifying in which situation the landscape services can replace the ecosystem services. Second, this study uses various landscape services (as X-axis) and different land use types (as Y-axis) to build a landscape service assessment matrix, which contributes to assess and map the supply of landscape services. It takes the Barcelona municipality as the case study to analyse the spatial distribution characteristics of landscapes services within the investigation area. Then, this dissertation identifies the possible spatial characteristic

areas, which are the landscape services provision, barren and obstructed areas by overlapping the supply of landscape services assessment maps. Finally, on this basis, it provides a reference for urban green infrastructure planning by recognising the priority protected areas, new construction areas, potential areas and renewal areas. In these different areas, several strategies for urban green infrastructure planning and landscape planning are provided, including: (1) the protection and maintenance of the existing high-quality green spaces, landscape and cultural heritage in the priority protected area; (2) the protection of the existing cultural services and consideration of the demand for other landscape services in the new construction area; (3) identification and regeneration of new green spaces in the vacant lots of compact urban cores using innovative strategies (e.g., green roof and wall); (4) ecological renewal and restoration measures should be done in the renewal area.

To sum up, this dissertation aims to seek a methodology to plan urban green infrastructure better based on the landscape services approach, and to provide a new vision to promote sustainable regional development by integrating the concept and approach of landscape services into urban green infrastructure planning.

KEYWORDS:

Ecosystem services; Landscape services; Assessment matrix; Mapping; Green infrastructure; Sustainable development

RESUMEN

La aproximación a los servicios del ecosistema ha constituido un campo de investigación puntero en el mundo académico durante las últimas dos décadas, ya que se trata de una vía efectiva para reforzar la conexión entre los ecosistemas y el bienestar humano. Los servicios de paisajismo, en tanto que una rama particular de los servicios del ecosistema, progresivamente han ido suscitado interés entre los investigadores. Sin embargo, aún no disponemos de una teoría general científica y sistematizada de los servicios de paisajismo. La evaluación y el mapeo de los servicios de paisajismo pueden llevar a cabo, de una manera efectiva, el análisis espacial en una escala específica que ayude a mantener paisajes multifuncionales, así como la planificación de la infraestructura verde urbana. A su vez, la infraestructura verde puede proporcionar una amplia variedad de servicios y funciones paisajísticos, lo que promueve la sostenibilidad de los paisajes. Aun así, todavía se mantiene el gran desafío relativo a la evaluación cuantitativa y al mapeo de los servicios de paisajismo para que sirvan de apoyo a la planificación urbana y del paisaje.

Esta tesis adopta la idea de que la aproximación de los servicios de paisajismo es una metodología mejor y mucho más adecuada que la aproximación de los servicios del ecosistema, de modo que la evaluación y los análisis espaciales de la capacidad de suministro de los servicios de paisajismo funcionarían mejor como guía para la planificación de infraestructuras verdes urbanas. Además, el hecho de tomar en cuenta los servicios de paisajismo ofrece la posibilidad de incluir en la definición de las infraestructuras verdes urbanas a un tipo diferente de áreas que jueguen diferentes roles y que suministren diferentes servicios (medioambientales y culturales).

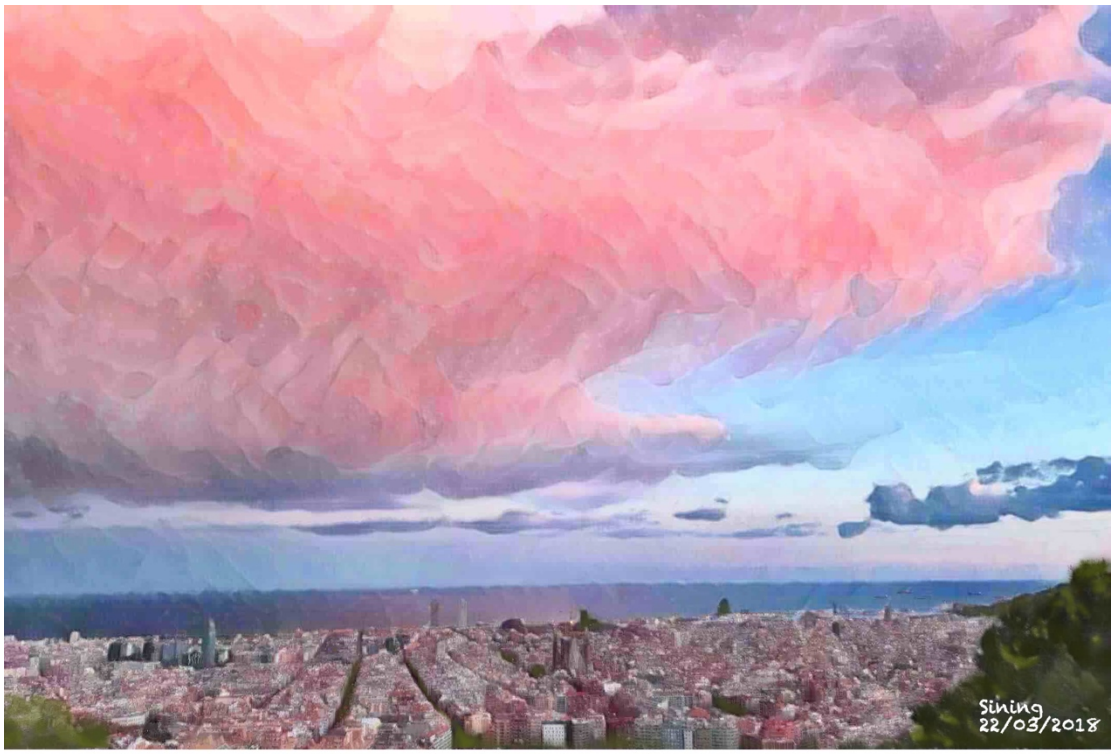
Con el fin de verificar las hipótesis, en primer lugar este estudio propone una teoría general de los servicios de paisajismo en el contexto del paisaje, incluyendo la identificación y la clasificación, mediante un estudio de caso (el Parque Natural de Collserola) que justifica en qué situaciones los servicios de paisajismo pueden tomar el relevo a los sistemas del ecosistema. En segundo lugar, el presente estudio utiliza varios

servicios de paisajismo (como eje X) y diferentes usos del suelo (como eje Y) para crear una matriz de evaluación de servicios de paisajismo que contribuya a evaluar y a mapear el suministro de servicios de paisajismo. En el caso de estudio se toma el municipio de Barcelona para analizar las características de la distribución espacial de los servicios de paisajismo dentro del campo de investigación. A continuación, se identifican las posibles áreas espaciales características —es decir, las que pueden suministrar servicios de paisajismo, las infértiles y las obstruidas— mediante la superposición de los mapas de evaluación de los servicios de paisajismo. Finalmente, y sobre esta base, se ofrece una referencia para la planificación de infraestructuras verdes urbanas a través del reconocimiento de las áreas protegidas prioritarias, las áreas de nueva construcción, las áreas potenciales y las áreas de renovación. En estas distintas áreas se proporcionan varias estrategias para la planificación de infraestructuras verdes urbanas y para la planificación de paisajes, en las que se incluye: (1) la protección y el mantenimiento de los espacios verdes de alta calidad existentes y del patrimonio paisajístico y cultural en las áreas protegidas prioritarias; (2) la protección de los servicios culturales existentes y la consideración de la demanda de nuevos servicios paisajísticos en las áreas de nueva construcción; (3) la identificación y regeneración de nuevos espacios verdes en las parcelas vacías de los centros urbanos mediante el uso de estrategias innovadoras (por ejemplo, cubierta y paredes verdes); (4) se debería emprender una renovación ecológica y aplicar medidas de restauración en las áreas de renovación.

En resumen, este trabajo pretende establecer una metodología para planificar mejor la infraestructura verde urbana basándose en la aproximación de los servicios de paisajismo, y proporcionar una nueva visión para promover un desarrollo sostenible regional con la integración del concepto y del enfoque de los servicios de paisajismo en la planificación de infraestructuras verdes urbanas.

PALABRAS CLAVE:

Los servicios del ecosistema; Los servicios de paisajismo; Matriz de evaluación; El mapeo; La infraestructura verde; Desarrollo sostenible



The view from Turó de la Rovira, Barcelona, Spain (illustration by author.)

1 CHAPTER ONE: INTRODUCTION

1.1 Background and Significance

Nowadays the world is seeing and experiencing the huge changes, such as a burst of urban expansion, population explosion, environmental pollution, ecosystem destruction, ecological imbalance, landscape fragmentation and climate change and so on, at a speed and on a scale never before witnessed in human history over the last few decades. These negative and irreversible changes grave threaten creatures' survival environment and human well-being physically and mentally, as well as the future generations.

Nevertheless, many problems mentioned above could be avoided or solved by adopting scientific and reasonable approaches. Therefore, improving urban areas' sustainability and resilience should be the main objectives of the policy agenda from local to global authorities. Obviously, it is splendid meaningful to have the correct knowledge about our territory and environment and to improve sustainable development when facing these environmental changes.

Natural capital is a vital resource for human beings, which concerns human welfare and survival. Ecosystems provide all the resources and conditions for surviving of creatures. Ecosystem service is the expression and an effective way to link ecosystems and human well-being, as well as an essential criterion to detect whether the ecosystem or environment is healthy or not. The terminology 'ecosystem services' was firstly used by Ehrlich and Ehrlich (1981). In the beginning, the concept of ecosystem services is the critical research agenda in the trans-disciplinary field of ecological economics, aiming to bridge the gap between the ecosystem ecology community and the environmental and resource economics community (Costanza et al., 2017). In order to attract public interest in biodiversity conservation, the societal and economic value on natural assets is emphasised. The mainstreaming of ecosystem services were marked by two publications marked in 1997. One is an edited book *Nature's services: societal*

dependence on natural ecosystems by Daily (1997), another one is a paper in *Nature* by R. Costanza et al. (1997).

In the past twenty years, the concept of ecosystem services has become a hot spot among different scientific study areas, such as the ecology, ecological economics, landscape ecology and urban geography. Plentiful publications are created. More specifically, ecosystem services have made a significant progress in the integration of ecosystem structures, functions, processes and human activities, including the relationship between biodiversity and ecosystem services (Hooper et al., 2005), the study of ecosystem services and human well-being (MA (Millennium Ecosystem Assessment), 2005a), the impact of climatic and land-use change on ecosystem services (Lautenbach, Kugel, Lausch, & Seppelt, 2011). Especially the value and evaluation of ecosystem services has been fully developed (Daily 1997; Costanza et al. 1997; Su et al. 2012). However, the research of ecosystem services (ES) mainly focus on the classification, functions, values and benefits of the ecological components and processes, modelling and mapping approaches, and policies. The relationship among the landscape structure, pattern and process, and the multi-functional services of the ecological components are neglected. Meanwhile, many derived topics have become hot topics among multidisciplinary researches. The concept of landscape services (LS) is one of them (Bennett et al., 2015). The concept of LS is mentioned and discussed inevitably when it comes to landscape research.

From the perspective of landscape, landscape service is quite a new concept and research area, which is different with ecosystem services but also has similar aspects in terms of ecological and landscape functions and goods. The concept of LS provides the foundation for the establishment of green infrastructure and offers a new research way for the study of landscape ecology and landscape sustainable development. Landscape Sustainability is defined as “the capacity of a landscape to consistently provide long-term, landscape-specific ecosystem services essential for maintaining and improve human well-being” (Jianguo Wu, 2013). So landscape service is a significant concept

in the Landscape Sustainability research. It is a key bridge between natural capital and human-being; and the closely linking bonds between landscape sustainability and regional ecological landscape. Ecosystem services and landscape services are not always the same in a certain scenario. In reality, this research area shows the vigorous vitality and powerful life force. People and government start to pay more attention to our environment and show more respect to it in face of the eco-environmental changes.

However, Landscape Sustainability Science is still in the formative stage, and few of related researchers have had study systematic theories and methods of regional ecological landscape. Also, there are still many challenges and obstacles in LS, for example, the typology, the relationship with ecosystem services, the evaluation and visualisation approach (Mander, Helming, & Wiggering, 2007) and the application in practical planning and landscape research (de Groot et al., 2010). Especially, in order to get a more accurate assessment result and to be better applied to the landscape planning and decision-making process, it is necessary to develop the assessment methods to evaluate LS instead of the ES.

Comparing with ES assessment results, the results of LS assessment can provide more accurate and valuable information and therefore being the knowledge basis in broader decision processes. Because, first, LS assessment and mapping approach is helpful for (community/regional) stakeholders and land managers (Kienast et al., 2009; Fagerholm et al., 2012; Bernard, Barbosa, & Carvalho, 2011). Second, LS assessment and mapping approach can be used in a broader way in decision making process, especially in landscape planning (Willemen et al., 2012; Hermann et al., 2014). Third, in order to promote landscape sustainability research, LS assessment and mapping approach is necessity (Termorshuizen & Opdam, 2009).

Landscape is the most practical spatial scale for the research of sustainable process and mechanism (Jianguo Wu, 2013). Meanwhile, the European Commission (2013) has recognised green infrastructure as smart solution for providing people and societies with a broad range of goods and services. Green infrastructure aims to optimise human

living environments and life quality (van den Berg et al., 2016; A. E. van den Berg et al., 2010; Lafortezza et al., 2013) and to protect urban biodiversity (Goddard et al., 2010; Hostetler, M. et al., 2011). It is not only the most operational scale for understanding and shaping the relationship between human society and green spaces, but also the most important places for delivering services as well as achieving human welfare.

Hence, in order to create urban ecological restoration and urban sustainable development, it is essential to establish urban green infrastructure through integrating the concept and approach of LS.

Barcelona is the second largest city in Spain. It is an international famous tourism city and an extremely crowed and compact city. Currently, the long-term rapid economic and tourism development has neglected the protection of ecological landscape, resulting in the sharp contradiction between economic development and ecological environment construction and people's needs, and the gradual degradation of regional ecological functions. Even in recent years, the government has paid more and more attention to relevant ecological construction, such as in 2013, the government published the *Barcelona Green Infrastructure and Biodiversity Plan 2020*, which seeks to build a better life for citizens with greater green infrastructure. However, the city still faces great challenges, such as the excessive pressure of urban development, the citizens' growing desire for green spaces, and the shortage of LS.

Indeed, urban green infrastructure offers a large number of LS, such as urban parks and green spaces can provide recreational venues and amenity resources for the public, some mountain parks have also become important tourist attractions, such as Mount Montjuïc), they also play a role in purifying air, reducing noises and regulating the role of local microclimate.

The hypotheses in this dissertation assumes the supply capacity of landscape services in certain area would be a better guide for the planning of urban green infrastructures to be developed by urban and regional planning schemes and strategies,

since a very wide range of spaces, not necessarily green or natural, could eventually be considered as playing different roles on those future green infrastructures with the consideration of the ES; the assessment and spatial analysis of the supply capacity of landscape services would be better guide urban green infrastructure planning, considering the landscape services approach is a much better and suitable methodology than the ecosystem services approach.

Hence, in order to answer and verify the hypotheses in this dissertation, this study aims to develop the general theory of LS from the perspective of landscape, including identification and classification. Then it develops a methodology that assessing and mapping the supply capacity of LS in a certain area, and provides a framework to identify possible spatial characteristic areas where various interlinking regions of the capacity of LS supply within the study area. Furthermore, it provides practice guidelines and strategies of green infrastructure planning, which helps to plan urban green infrastructure and creates the connectivity and well-rounded urban green infrastructure. It also offers a scientific basis of sustainable regional development.

This research is challenging and innovative. It is of great academic value and practical significance to the development of the theory of LS, and the quantitative and mapping research of LS and the related research of urban green infrastructure. At the same time, this study takes Barcelona as the main case study, which contributes to the planning of urban green infrastructure in Barcelona, as well as to provide a reference to the reasonable planning, protection and management of green infrastructure among other cities. For instance, how to enhance and maintain the landscape services in the regional area and develop the scientific and rational green infrastructure plan associating with the landscape services approach, so as to avoid the fundamental damage of the structure and function of ecological landscape system while in a rapid and high-pressure urbanisation process. More importantly, it also provides advice and references for regional ecological landscape sustainable development.

1.2 Objectives

The starting point of all this research is to answer a research question: How to better guide landscape planning?

Therefore, the main goal of this dissertation is seeking a methodology to plan urban green infrastructure better based on the concept and approach of landscape services.

This study aims to develop the theory and approach of landscape services that can replace the ecosystem services in the context of landscape. Then it applies the approach of landscape services to support urban green infrastructure planning, which also contributes to promote regional sustainable development and provide theoretical and practical guidance for its related researches.

The paper focuses on the following key issues:

a) Several key scientific theoretical questions need to answer. First, how to develop the general theory of landscape services that including the identification and classification system? Second, how to identify, quantify and map the supply of landscape service? Third, how to recognise the possible spatial characteristic areas based on the assessment results of LS to support urban green infrastructure planning and to promote regional sustainable development?

b) Two key practical questions should be resolved. The first one is how to apply landscape services theory to the process of decision-making. Second, how to develop the strategies of green infrastructure planning within different regions where have a low-high capacity of landscape services supply? These can help the landscape service theory to be more operational.

1.3 Hypotheses

In this dissertation, there are two main hypotheses considered. The first one is general and refers to the main goal of the research. The second one is much more specific and directly related to the applied research work which has been developed.

1. Considering the landscape approach to planning, taking into account the landscape services provided by a very specific territory represents a broader assessment

in comparison with the classical environmental approach based on the consideration of ecosystem services. In this view, the supply capacity of landscape services in an area would be a better guide for the definition and implementation of green urban infrastructures to be developed by urban and regional planning schemes and strategies, since a very wide range of spaces, not necessarily green or natural, could eventually be considered as playing different roles on those future green infrastructures.

2. Considering not only natural, wilderness or green areas but a very wide range of spaces such as intermediate corridors, urban fringes and even voids and empty areas located in different sections of a city, the scope and possibilities for designing urban green infrastructures are bigger and more complex. This is to say, moving from the idea of ecosystem services only to the consideration of landscape services offers the possibility for including in the definition of urban green infrastructures a different type of areas playing different roles and supplying different services (environmental plus cultural).

The thesis is considering the application of an original methodology mixing quantitative and qualitative methods to identify these very different areas and potentials in the case of Barcelona.

1.4 Methodologies

(1) Literature review

The collection and research of theoretical literature is the basic link of the research of this thesis, and provides the basic theoretical support for later research and thesis writing through extensive examination and summary of previous research results.

(2) Technique methodology

This thesis applies some technique methodologies. First, ArcGIS is an important tool in the process of ecosystem service mapping. It integrates multi-source data types and needs for decision-making and integrates a variety of evaluation and mapping methods quickly and effectively. It is widely used in ecosystem service mapping and

spatial explicit analysis. In this dissertation, ArcGIS is applied to analyse the spatial characteristics of landscape services supply within the study area.

Second, Interview and Questionnaires methods are required. In this thesis, these methods are applied to the research of the first case study - the Collserola natural park (See Chapter Two). Also, the interview method is used to know the supply capacity of landscape services in a certain land use type among people such as the locals. As well as these two methods can help to make a quantitative assessment of some invisible landscape services, such as cultural services.

Last but not least, in order to achieve the visual effect of the images, Adobe Photoshop and R are required.

(3) Case studies

In this dissertation, there are two case studies: The Collserola Natural Park and the municipality of Barcelona. In the general theory research of landscape services, taking the Collserola Natural Park as the case study, it aims to justify the rationality of landscape services instead of ecosystem services in the context of the landscape. Afterwards, the case study of Barcelona municipality aims to assess and map the supply of LS and analyse the spatial distribution characteristics. As well as it can help to integrate landscape services approach into urban green infrastructure planning.

This section shows the general methodology in this dissertation. The specific and original methods in details, such as the method of assessing the LS and the method of the application of results to plan urban green infrastructure, will explain in each corresponding chapter later.

1.5 Research Contents

This dissertation includes two main research contents as well as the research findings. The first one is the general theory of landscape services. The second one is the methodology of urban green infrastructure planning based on landscape services approach.

1.5.1 Landscape service theory

(1) Justify the landscape services in which situation can replace ecosystem services through the case study - the Collserola Natural Park, considering the aspects such as landscape elements and features and landscape planning and management.

(2) Identify and classify landscape services in the context of the landscape.

(3) Develop the landscape services assessment matrix to assess, map and analyse the spatial distribution characteristics of landscape services supply within the investigation area.

1.5.2 Green Infrastructure planning

(1) Take the Barcelona municipality as the case study to build the database of public green spaces within the city.

(2) Identify the possible spatial characteristic areas, which are the landscape services provision, barren and obstructed areas by overlapping the supply of landscape services assessment maps through ArcGIS.

(3) Finally, on the basis of the above achievements, it provides a reference for urban green infrastructure planning by recognising the priority protected areas, new construction areas, potential areas and renewal areas.

(4) Different strategies of green infrastructure planning and management are made on a 'case by case' basis.

(5) Provide a new vision on regional sustainable development.

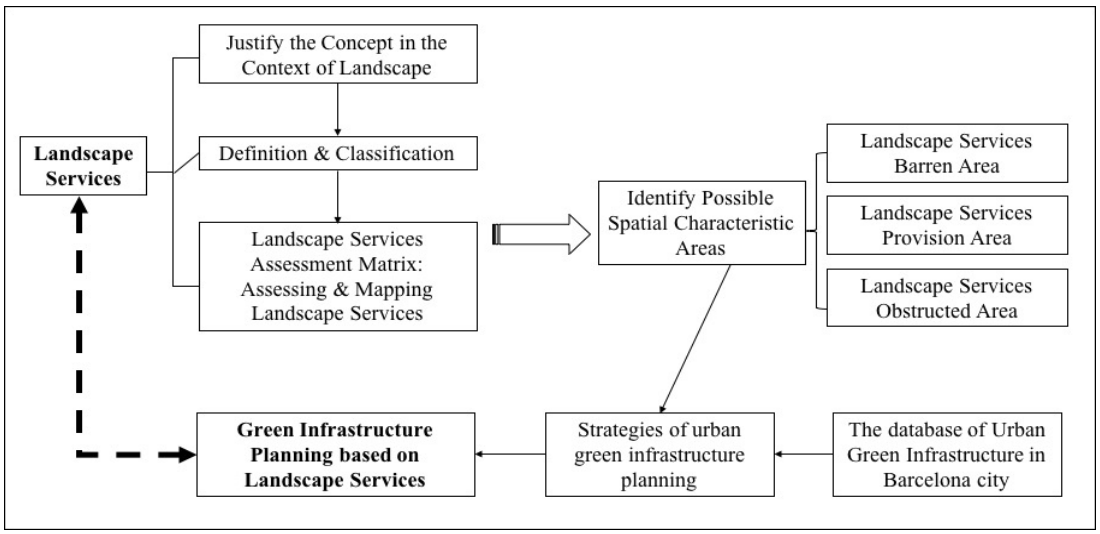


Fig. 1-1 Theoretical framework. *Source: author drawing*

1.6 Research Status Review

1.6.1 Ecosystem services and landscape services

1.6.1.1 Development of definition and classification of ecosystem services and landscape services

Since the late 1960s (E. P. Odum & Odum, 1972), ecosystem services have received close attention in scientific literature (Lars Hein 2006). In 1990s, there is the first paper that fits in and uses the terminology 'ecosystem services'. In the past several decades, it has become an important research area in various disciplines, such as ecology, ecological economy and landscape ecology, with a large amount of papers are rising exponentially (Fisher, Turner, & Morling, 2009). Many researches discussed the definition and classification of ES, which results in a clear and complete theoretical system that has been formed and recognised by the mainstream (i.e., Costanza et al., 1997, 2017; de Groot et al., 2010; de Groot, Wilson, & Boumans, 2002; Gómez-Baggethun & Barton, 2013; MA, 2005a) and has been provided a basis for further study.

However, despite the rapid progress of research on ES, there is still no same cognition on it up to now. Different scholars have proposed distinctive definition based on multi-disciplinary contexts. For example, Daily (1997) and de Groot (1992) propose the concept of ecosystem services and functions as "the conditions and processes that provided by natural ecosystems and their species to meet and sustain human living and needs". And this explanation emphasises the concept of ecosystem functionality (de Groot et al., 2002), pays more attention to the ecological process and ecosystem structures. Cairns (1997) thinks that ecosystem services are the functions which can contribute to human existence and development by standing the functions point of view. Meanwhile, from the perspective of benefits and values, some researchers believe that ecosystem goods and services are the benefits from ecosystem functions contribute to human beings, directly or indirectly (Costanza et al., 1997; MA, 2005a), which means this concept considers ecosystem goods and services together as ecosystem services.

However, Boyd and Banzhaf (2007) take a different view. They regard the ES as "the ecological components directly consumed or enjoyed to produce human well-

being". Obviously, they do not think the invisible ecological processes and functions, and those services what only be used indirectly, such as culture services, are ecosystem services. And basing his viewpoint on this definition, Fisher et al. (2009) propose that "ecosystem services are the aspects of ecosystems utilised (actively or passively) to produce human well-being".

Now, the most widely used and recognised definition and typologies are derived from the MA (MA, 2005a). In 2005, an international cooperation project named Millennium Ecosystem Assessment with more than $14 million of grants, aims to collect and analyse scientific data and information of the interrelationship between ecosystems and human welfare, which contributes to meet the needs of decision-makers. It was collaborated by more than 1000 researchers who are from 95 different countries and disciplines. It defines the terminology 'ecosystem service' as "the benefits that humans obtain from ecosystems" (MA, 2005a). The term 'services' for goods, functions and services is used to avoid lengthy texts-'the benefits people obtained from ecosystems' (MA, 2005, p. v). It also uses the terminology 'function' to underlie ecological processes and ecosystem components to provide goods and services. The MA also evaluates the effects of human activities on the environment on a global scale. Even though it still has some limitations and great controversy, it has aroused a spectacular discussion of ecosystem functions, goods and services, and has brought the term of ecosystem services to a global stage.

The language surrounding this terminology has taken various forms, as illustrated above. But they have a same point (Fisher et al., 2009), they all argue that ecosystem services are complicated of ecosystem structure, progress and function.

Meanwhile, there are a number of researchers have made a lot of efforts to classify ES regarding ecosystem services assessment, valuation, modelling and policy-making (i.e. Daily, 1997; de Groot et al., 2002; Syrbe & Walz, 2012; MA, 2005a), since R. Costanza et al. (1997) provide a list of 17 ecosystem services. Look back the main development history and the status quo of classification systems of ES as follow.

Several aspects have an influence on the typology of ES, for example, the spatial and temporal dynamics of ecological process, as well as the inherent characteristics, such as the characteristics of public and private good aspect, which are illustrating that there are various classification schemes (Fisher et al., 2009). In order to clear the driving relationship between human needs and ES, Costaza et al. (1997) integrate the existing data and information, based on previous studies, to evaluate the economic values of the ecosystem services per unit area of the biome. And they classifies ecosystem services into 17 main categories by key functions, not including the non-renewable goods and services, such as minerals, fuels and the atmosphere. Similarly, de Groot et al. (2002) propose a list of 23 ecological functions, goods and services, which are grouped into four categories: regulation functions, habitat functions, production functions and information functions, respectively. In other words, 'functions' and 'goods' will be translated into 'services' when they benefit for human beings. This typology also focuses on integrating ecosystem functions, goods and services into related ecological structures and process. In the MA (MA, 2005a), it classifies ES as four main categories: provisioning services, supporting services, cultural services and regulating services. Even though in some extent this typology confuses the process and values of ecosystem services, it is also most widely accepted in recent years.

Moreover, from another point of view, there are some researchers devote themselves to study different typologies from ones are outlined above. For instance, in order to sustain Earth's life support system, Daily (1999) proposes a general conceptual ecosystem services framework, which categorised ES into five categories, the production of goods, regeneration processes, stabilizing processes, life-fulfilling functions, and conservation of opinions, respectively. Wallace (2007) classifies services according to the specific human values they support, including adequate resources, benign physical and chemical environment, protection from predators, disease and parasites, and socio-cultural fulfilment.

In general, the current classification systems largely regard the ecological processes and structures, and the function of transmission as the key factors, also including the relation with human welfare. Although each classification method, based on different perspectives, exists with enough academic background and rationality, while it is not commonly for observing the landscape spatial patterns, landscape elements and landscape characteristics. Although there is a large body of literature on ecosystem functions, goods and services, there is no agreement on definition and typology of ecosystem functions, goods and services. Considering the complexity of ecosystems and man-environment interactions, it will probably never be found (de Groot & Hein, 2007).

Basically, the current research on ES emphasises the functional relationship between ecological processes and composition, while the spatial relationship between landscape structure and pattern is neglected. However, the concept of LS proposes a new way and view to look multifunctional landscape and spatial heterogeneity, and offers alternative methods to tackle the issue of quantifying invisible services, such as cultural services and aesthetic values and so on.

Currently, the landscape service has not yet formed a unified concept. This concept was first used in the article title regarding an urban agricultural sector (Leones, 1994). Termorshuizen and Opdam (2009) propose the terminology “landscape services” that developing an appreciate concept to link landscape ecological knowledge and the theory of sustainable development. In the multifunctional view, they define landscape services are based on the landscapes, in which as “a spatial human-ecosystems that offering additional ecological, social and economic values based on human activities and landscape changes”. This concept considers the interrelationship among the local, stakeholders and environment, better unifies scientific disciplines and highlights the spatial and landscape patterns. Next, de Groot et al. (2010) believe that landscape service is one special service of ecosystem services, as well as the landscape function that depending on the consequence of the integrated landscape pattern. They also

emphasise the link of landscape pattern characteristics, functions, and supply and demand for landscape services. Willemen et al. (2012) think that "landscape service is the flowing service from ecosystem to society that are provided within a landscape".

Not only that, but the classification system of LS is still lacking, especially a systematic typology and comprehensive framework for LS.

In order to integrate ES easier into landscape research and to apply in landscape planning and decision-making processes, de Groot et al. (2010), Bastian et al. (2014) and Vallés-Planells et al., (2014) propose the classification systems of landscape services, which root in the classification systems of ES, but differentiated from it. The categorisation in de Groot et al. (2010), is adapted from the classification system of ecosystem services, since the terminology 'ecosystem services' and 'landscape services' are the synonym in the authors' view, which includes supply services, regulatory services, habitat services and cultural services. However, this category is only based on the initial exploration of landscape perspective. Some questions, for instance, whether it can effectively contact human needs and landscape services or not, whether it can effectively integrate human needs into landscape services or not, still need further study.

Vallés-Planells et al. (2014) develop a categorisation system that is built on the Common International Classification of Ecosystem Services (CICES) and integrates the existing literature on the social dimension of landscape and landscape dimension regarding ES. Thus LS are divided into three categories, provisioning, regulation and maintenance, cultural and social life fulfilment services. This typology considers human well-being, social and cultural dimension at the landscape scale that is normally neglected in most cases. Especially in the cultural category, it emphasises the comprehensive way of landscape benefits the human welfare that considering human satisfaction.

Bastian et al. (2014) advance a typology that classified landscape services (or ecosystem services) into the provisioning services, regulating services and social-cultural services under certain conditions, which fully considers landscape character,

spatial aspects and landscape elements in the manner of landscape planning and landscape ecology.

An effective classification system is able to consider landscape features in comprehensive ways, to express the particularity of the service delivery process, and is able to relate to human values and apply them to decision-making processes (Wallace, 2007). Therefore, it is essential to seek an effective, scientific and rational classification system of landscape services with considering the landscape pattern and spatial characteristics.

1.6.1.2 The relationship between ecosystem services and landscape services

The terminology 'landscape services' evolved from the terminology 'ecosystem services', but they are not owner-member relationship (Figure 1-2). ES and LS are not always the same in a certain scenario. A landscape includes different kinds of ecosystems (usually a mix of ecosystems). It indicates that the landscape services are the mixture and/or the superposing of ecosystem services, with different functions at the landscape level is different (e.g., aesthetic attractiveness).

The terminology 'ecosystem services' originates from ecology and economics by tracing its disciplinary backgrounds. It is also an essential part of the research outline of ecological economics (Rudolf S De Groot, 1987; Braat & de Groot, 2012). ES is the bridge between ecosystems and human well-being, focusing on the natural capital.

However, the landscape is a socio-natural system, which is a holistic, appreciable and dynamic entity (Antrop, 2000), changing from the interaction with human activities. Compared with ecosystems (scales), a regional ecological landscape is the most practical scale for the research of sustainable process and mechanism (Jianguo Wu, 2013). LS, focusing on the relationship between human interactions and landscape process and structure, is a hot research topic in the science context of landscape ecology and landscape sustainability (Termorshuizen & Opdam, 2009). The concept of LS better highlights the essential of spatial pattern and the landscape features and the

spatial relationship of service provider and service beneficiaries. Landscape services play a supporting role in assessing ES from space index (Syrbe & Walz, 2012).

No matter LS or ES, both of them highlight the link between ecosystem and human values, and all focus on the human dimensions of the ecosystem. Moreover, the term 'landscape services' can describe the benefits provided by both natural, semi-natural and artificial landscapes, whereas the term 'ecosystem services' only focuses on natural systems.

Obviously, it seems to be a tough and hard work to establish a scientific theory of landscape services for the long-term development, because it is a new research area evolved from ES, which means a lot of scientific researches and examples verification are required.

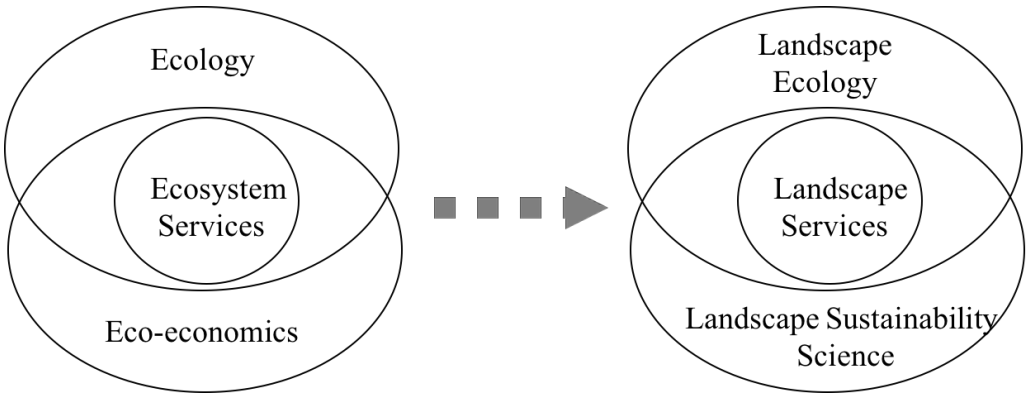


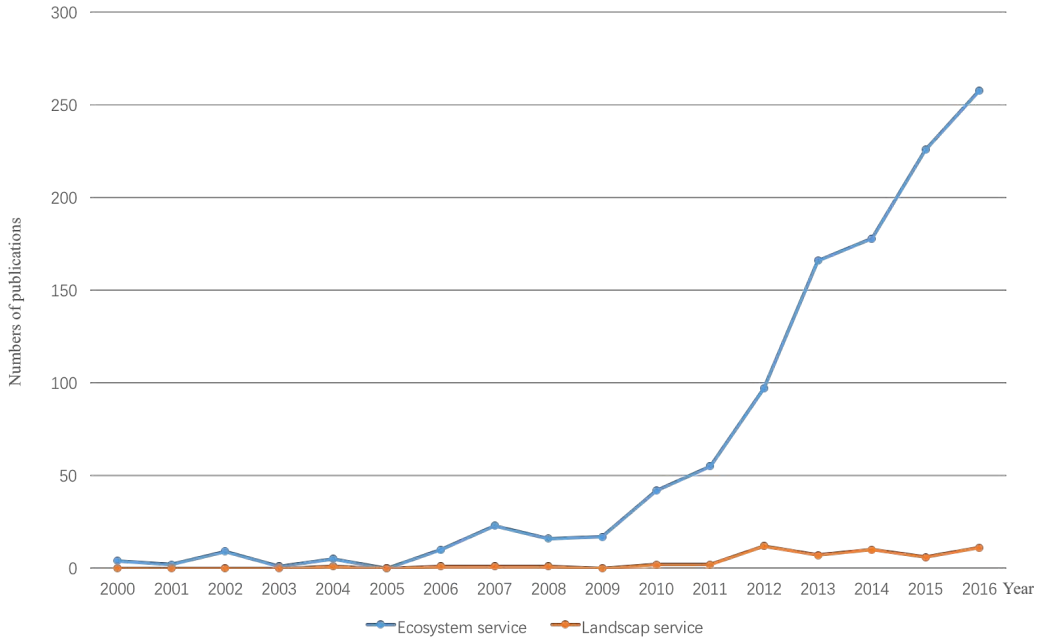
Fig. 1-2 The relationship between ecosystem service and landscape service. *Source*: author drawing

1.6.1.3 Overview of research contents

With the rapid development of ecosystem services research area, there is an obvious sign to see this speed that is soaring quantity of literatures, which is almost linear.

By searching papers in what taking 'ecosystem service' as the keyword and title in the SCOPUS in October, 2017, there are 813 academic publications from 2000 to 2013; from 2000 to 2016, there are 1027 ones, which means it has increased 213 ones during three years. Likewise, by searching papers in what taking 'landscape service' as the keyword and title in the Scopus from 2000 to 2016. There are only 54 publications. The

publication numbers of LS only accounts for 5% in terms of the results of publication on ES, which we can see in the curve chart (See Figure 1-3).



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Ecosystem Services	4	2	9	1	5	0	10	23	16	17	42	55	97	166	178	226	258
Landscape Services	0	0	0	0	1	0	1	1	1	0	2	2	12	7	10	6	11

Fig. 1-3 Data Comparison chart of ecosystem service and landscape service. *Source: author elaboration, adapting from* SCOPUS search, October, 07,2017.

Also, there are over 13,500 academic publications what used ecosystem services as the theme of their titles by searching google scholar, and over 843 ones in terms of landscape services.

Those papers with the term 'landscape services' in title, abstract and keywords, are mostly published in *Ecological Indicators* and *Landscape Ecology* - 9 articles are published in these two journals since 2009, followed by *Shengtai Xuebao Acta Ecologica Sinica* and *Sustainability Switzerland* (5 papers respectively) from 2013 to 2018. *Horttechnology* published 4 papers (2013-2016) (Fig. 1-4). In these publications,

issues such as landscape planning, landscape structure and pattern at landscape scale, are the most discussed topics.

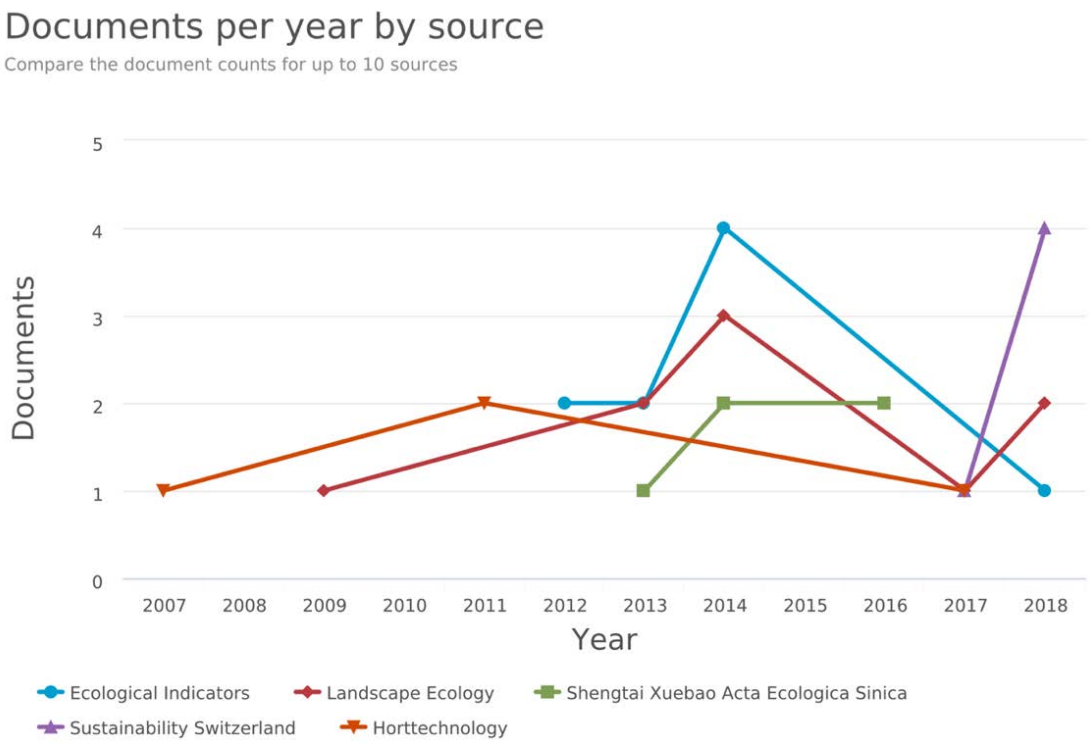


Fig. 1-4 Top journals publishing papers on landscape services. *Source*: SCOPUS search, November 11, 2018.

All of the above data shows that more joint efforts in the research area of LS are required, even though the area in LS becomes the new research interesting topic and attracts more attention now.

Nowadays, the ES studies focus on the spatial characteristics and differences of the spatial and temporal scales, and the ecosystem service assessment framework, the mapping method, the establishment and quantification of the index system, and the relationship between ecosystem services and human welfare.

Next, considering the main research contents of ES, we mainly discuss two points as follows.

(1) Multi-scales views research

Since the development of the first stage of conceptual framework of ES is becoming mature, many researchers who are from different disciplines are starting devote themselves to multi-scales research of ES.

ES can only fully express their dominant role and effect on specific spatial and temporal scales, which can be generated on all ecological scales (Hein, van Koppen, de Groot, & van Ierland, 2006). Plenty of researches of ES are in a static state. But actually ecosystem services, no matter the research of the supply and demand, or the flow of information, are in a dynamic state in the different spatial scale (i.e., local, regional, national and global scales) and temporal scale (i.e., short, medium and long time scale). To date, there has been a growing awareness of the importance of spatial and temporal scales in terms of analysing and valuating ES (de Groot et al., 2002). For instance, Syrbe and Walz (2012) investigate the spatial characteristics of ES and how they relate to quantified measures of landscape structure. The spatial scales of ES are analysed and the outcome is applied to the practical case (Hein et al., 2006). Also the importance of scales in economics and ecology have been widely recognised, De Groot et al. (2010) analyse the implications in these two key scales and describe remaining challenges for ecosystem management. When it comes to different economics areas, the poor normally more depend on common property assets than the rich (Costanza et al., 2017). So even though in the same spatial or temporal scale, it is not fair and balance to deliver ecosystem services.

When ecosystem services are applied to landscape scales, often due to over-emphasis in landscape functions, resulting in loss or degradation of other functions (Costanza, 2008). For example, emphasis on recreational functions overly may lead to the destruction of historical heritage, and the reduction of biodiversity. So it is important to balance various landscape scales while exploring the interrelation among deliveries of ES. Meanwhile, in order to explain and analyse the complicated relationship of landscape services at various scales, on the one hand, it is essential to

know the association relationship among different LS (Aertsen, Kint, Muys, & Van Orshoven, 2012). On the other hand, on the basis of considering the dominant services, coordination of different scales of services and functions should be considered on the same spatial-temporal scale, as well as the different communities demands should be meet through scale correlation and regional balance (Hein et al., 2006).

However, services and functions on one specific scale are always associated with other scales, albeit with different priorities. The phenomenon at the macroscopic scale and in the long-term time will affect and bound the phenomenon on the microscopic scale and in the short-term time. At the same time, each phenomenon on the local or regional scale also associated drives the process and dynamic changes on a global scale (Limburg, O'Neill, Costanza, & Farber, 2002).

Hence, it is essential to take the various scales of landscape services into account, in order to better apply the analysis and assessment of LS into the landscape research, such as landscape planning and management and decision-making processes. The spatial and temporal transmission mechanism of multi-scales ecosystem services and landscape services is a requisite issue that needs further study in future research.

(2) Assessment framework and quantification mapping

Ecosystem services mapping is a process of quantifying ecosystem services on a specific special and temporal scale by using the ecosystem service evaluation methodologies (Zhang Liwei, 2014), which can provide an intuitive image and reference for eco-environmental protection planning and decision-making. On a specific spatial-temporal scale, the content of quantification of ES includes the composition, quantity, spatial distribution, supply and demand of ES, and their interrelationships, as well as a description of the characteristics of scenarios with different natural, social and economic factors. And its ultimate goal is to provide quantitative visualisation for people such as decision makers, stakeholders, beneficiaries and land use planners, including the static display and dynamic simulation and other forms of expression, as well as for future decision-making reference (Fisher

et al. 2009; Beier et al. 2008; Daily & Matson 2008; Daily et al. 2009; O'Farrell & Anderson 2010).

In recent years, with the great development of spatial data and the continuous improvement of research methods, different approaches and frameworks have been promoted to carry out the ES mapping work on different scales, which have been proved that it contributes to supporting decision-making (Beier, Patterson, & Chapin, 2008; Daily et al., 2009) and landscape planning (Frank, Fürst, Koschke, & Makeschin, 2012; Koschke, Fürst, Frank, & Makeschin, 2012; Niemelä J et al., 2010).

On a global scale, literature or model-based mapping and assessment methods make the most of current theoretical knowledge. For instance, Wageningen University and Research Centre (de Groot et al., 2010) develop a coherent framework, which aims to connect ecosystem and landscape character with services, to assess the values, to develop trade-off instruments, planning tools and financing mechanisms in the joint efforts of many researchers. Kienast et al. (2009) provide an approach by using expert- and literature-driven modelling methods, which links land use, net primary production, bioclimatic and landscape properties. They also generate an assessment framework of landscape functions and services in the Europe scale. Meanwhile, based on this study, Haines-Young et al. (2012) propose "an approach to mapping indicators of the potential of ecosystems to offer ecosystem services, and the impact of changes in land cover and use upon them".

Also, Burkhard et al. (2012) establish an ecosystem evaluation system with 29 ecosystem services for the X-axis and 44 different land cover types for the Y-axis, combining with socio-economic data, which helps to improve an assessment system of ecosystem services, and to verify and implement in real cases. However, the land-cover based approach (Burkhard et al., 2015; Burkhard, Kroll, Müller, & Windhorst, 2009; Burkhard et al., 2012) only considers the land use patches, but ignores the mosaics of boundaries, which is also important in landscape assessment (Martín de Agar, Ortega, & de Pablo, 2016). Furthermore, the spatial distribution of ES is closely related to land

use/cover change (LUCC), but land use data do not fully reflect the spatial distribution of ES (Verburg, Schot, Dijst, & Veldkamp, 2004). In this dissertation, the author believes that this evaluation system reflects that the supply and demand of ES tend to be a relative capacity, rather than absolute value. This system can not fully reflect the real supply and demand situation.

On the regional scale, the assessment of ES requires to combine social, economic and cultural data and information, in order to propose research framework. Because the land use/cover-based approach is not sufficiently detailed and only can be applied on the macro scale (Burkhard et al., 2009). For example, take a study region in the Sacony, Eastern Germany, as a case study, Koschke et al. (2012) developed a multi-criteria approach, comparing with the MA (Millennium Ecosystem Assessment). This approach assesses the contribution of the land cover classes in the study area to the supply of ecosystem services, by using the "benefit transfer methods", and "expert-based assessment".

Besides, the index evaluation method uses criterion and indicators to evaluate and visualise ES, including the monetary evaluation methods, such as the market-valuing method (de Groot et al., 2010; Bateman et al., 2002), the value of monetization, emery evaluation, ecological footprint analysis and so on (Farber et al., 2002; Busch et al., 2012; Martín-López et al. 2014; Odum 2002; Haines-Young et al. 2012). More specifically, the monetary valuation of ecosystem services enables more accurate accounting of the environmental costs and benefits of policies. However, the assessment method of value quantification is closely related to the willingness to pay for ecosystem services, and the market value is not the quantification of the ecosystem service itself. It is only another form of market of service and function. There exist results within subjectivities and uncertainties, it can be seen that there are a large limitation and defects of these methods (Jacobs et al., 2017), which means it is difficult to better apply to the environment management, landscape planning, and decision-making practice.

In addition, there are some non-economic technology evaluation methods, such as group-based participatory approach, deliberative choice experiment approach (Kenter, Hyde, Christie, & Fazey, 2011). It is a new way to evaluate ES. But because of public welfare of landscape products and services of the ecological systems, and because they can not be stored and moved, has yet to form a unified and standardised quantitative standard.

At present, the research of landscape service evaluation and quantitative mapping depend on the existing research results of ES largely, of which there is not a really reasonable and feasible way to quantify its functions and values. The existing scientific literature with the terminology “landscape services”, as the article title, only has 26 papers (in SCOPUS search, November 14, 2018) that the most of them (17 articles) focus on the research of assessment and (or) quantification mapping of landscape services in the context of landscape.

In the landscape research dimension, in order to get the more valuable information and accurate assessment result, and to better apply into the landscape planning and decision-making process, the above assessment and mapping methods of ES would be integrated into landscape research.

For example, Willemen et al. (2008) developed a methodological framework that combining the landscape functions with land cover or policy defined areas. They aim to visualise and quantify LS with empirical models by using spatial indicators and literature reviews.

Then, Willemen et al. (2012) develop a modelling approach, taking the landscape characteristics of Gelderse Vallei area in the Netherlands as an example, which aims to tackle the multifunctional character of a landscape, to classify different spatial levels and to propose a spatially explicit way that shows the potential relevance of landscape services for decision-making.

Nowak and Grunewald, (2018) assessed the LS delivery in seven different study areas to characterise the landscape sustainability by combining the qualitative

assessment with the quantitative analysis. Besides, Hermann et al. (2014) assessed and visualised a bundle of LS with considering different spatial scales and levels of services to adopt three different approaches - the Broader Habitat Approach, the Socio-cultural Approach and the Landform Approach.

Also, in order to promote landscape sustainability research, from the perspective of landscape service, Termorshuizen and Opdam (2009) propose a knowledge framework elaborately, which is 'structure-function-value chain'. Fang, Xuening, Wenwu Zhao, Bojie Fu, (2015) provide the landscape services capability-flow-demand framework that could implement LS into the practical application.

Besides, the public participatory approach utilises community stakeholders' knowledge (Fagerholm et al., 2012) to reach true collaborative, bottom-up landscape management and capture the non-utilitarian value of landscapes and sensitivity to cultural services while many experts' evaluations would fail to do justice. However, this approach would be restricted by the stakeholders' experience and knowledge.

Moreover, some researchers focus on evaluating specific landscape service within the study area. For instance, Gulickx et al. (2013) identify and visualise four specific landscape services in a multifunctional rural landscape, in Netherland. This method uses the field survey data and spatial index data related analysis, and then assesses and visualises the area of a bundle of landscape services. Wu et al. (2013) evaluated and mapped five landscape services, including material production, carbon sequestration, soil conservation, habitat maintenance and population support in Beijing and its surrounding areas, and analysed the relationships and effects among themselves.

To sum up, the assessment and mapping approach of LS is mostly derived from the related ES approach but has its characteristics. It synthesised various methods into evaluating and visualising the LS in the landscape dimension that better meet human values. It enhances the participatory of the public and stakeholders, promotes the actual practices and develops the landscape sustainability in the context of trans-disciplinary research.

However, the spatial landscape patterns, landscape elements and features, landscape heterogeneity also should be fully developed in the context of landscape services. Besides, it still lacks the test in different types of landscape and practical cases to verify and support the theoretical development of LS. Furthermore, the landscape is in a dynamic state, the ecosystem services and landscape services are also dynamic changes in the development process. The landscape service dynamics have much potential relevance in environmental management and decision making (Hermann et al., 2014). So how to identify its dynamic changes and determine its potential critical thresholds are the difficult study areas for future research.

1.6.2 Green infrastructure

Urbanisation has become one of the main ways of global social and economic development. However, no matter how urbanisation is carried out, the scarcity of land resources and the damages caused by an excessive human disturbance to living systems and ecosystems are still the most basic constraints of its development.

In the face of increasing expansion of urban population and density, human beings respond in a simple and brutal way by constructing more grey infrastructure and continuing urban expansion. Such a strong human activity greatly undermines the ecosystems but also reduces the ecosystem functions and the capacities to provide services (Kreuter Harris et al., 2001).

For the past few years, many researchers start to study the scientific strategies in order to support sustainable development, such as the development of ecological city (i.e. Platt et al., 1994). Furthermore, people are beginning to realise the importance of green infrastructure for sustainable development, and many countries and regions have incorporated them into urban, regional sustainable development strategies and policies.

What needs illustration, here, is that the terminology of ‘green infrastructure’ is similar with the term ‘green space’ and ‘open space’. Traditionally, the terminology ‘green spaces’ tends to be a narrowly definition, of which are normally refer to urban parks and other green areas (Sandström 2002).

The Conservation Fund and the Department of Agriculture of the United States (USDA) Forest Service, in 1999, have jointly defined the terminology 'green infrastructure' as "green infrastructure is our nation's natural life support system, is an interconnected network of waterways, wetlands, woodlands, wildlife habitats, and other natural areas; greenways, parks and other conservation lands; working farms, ranches and forests; and wilderness and other open spaces that support native species, maintain natural ecological processes, sustain air and water resources and contribute to the health and quality of life for America's communities and people" (Benedict & McMahon, 2000). GI is also defined as "a strategically planned network of natural and semi-natural areas with other environmental features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas, designed and managed, to deliver a wide range of ecosystem services" (European Comission, 2010; Naumann et al., 2011).

In order to emphasise multi-functional green space and to attain urban sustainability, Sandström (2002) has introduced the concept of green infrastructure (GI) as a coherent planning entity, and has evaluated seven cities in Sweden in a broad urban planning manner.

GI delivers plenty of ecosystem services, performs various functions and benefits people and society. GI is the foundation of natural life supporting and sustaining systems (Benedict & McMahon, 2000; Tzoulas et al., 2007), as well as the key carrier between land resources supply and human needs (Ted Weber, Anne Sloan, 2006). Unlike the methodology of traditional resource conservation, the green infrastructure emphasises the coordination and mutual benefits between nature conservation and urban construction and development, management, maintenance, restoration and reconstruction in a more proactive way (Lafortezza et al., 2013). As well as a way to coordinate with the natural environment, and to find both land development and protection of the shrewd growth (Lovell, 2010). The goal of GI is to seek the optimisation of both supply and demand, to provide more and better goods and services with reasonable resource allocation (Kindlmann & Burel, 2008). Besides, in terms of

human wellbeing, van den Berg A.E., Maas J., Verheij R. A. (2010) demonstrate that large number of green space, in a 3-km radius, can provide a buffer for people who suffer from stressful life events and health problem. And thanks to amounts of ES provided by GI, people who are living around them obtain welfares and benefits from healthy environments and physical and mental health (Tzoulas K., Korpela K., Venn S., Yli-Pelkonen V., Kamierczak A., Niemela J., 2007). These characteristics of GI are in the balance of land supply and demand, especially in the land sustainable planning and design (Lovell & Johnston, 2009).

Therefore, it comes as no surprise that upgrading of interest in the urban green space or in the GI to positive promote decision-making process; and also in the ways in which green infrastructure can benefit people; and the effects and relationships among green spaces, human welfare and urban sustainability. So in recent years, it is increasingly frequent apply the concept of green infrastructure into different regions and scales in order to promote regional sustainable development.

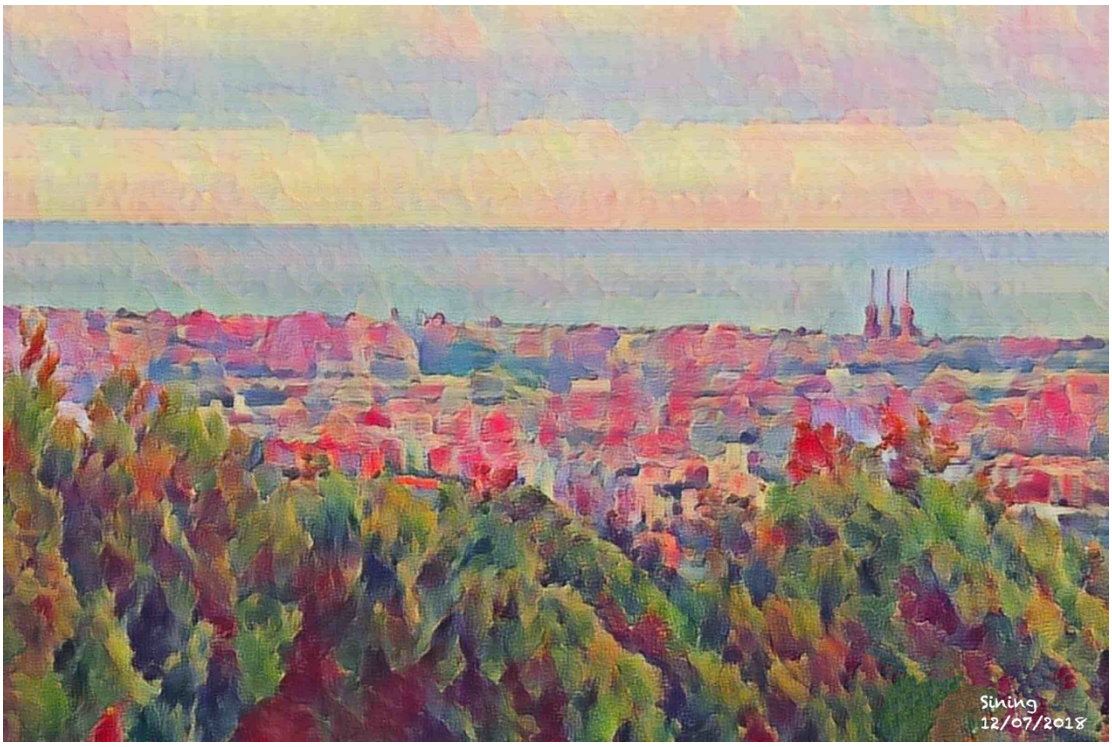
The Commission of European Communities has examined urban sustainability in the local policy area, of which focusing on urban green spaces management in four cities in Britain and Italy (L. Mazza, 1997).

The United Kingdom has taken into the GI consideration in land use planning, of which dealing with climate change by using GI plans as climatic adaptation and mitigation strategies (Bonan, 2008). Alike, in UK, taking the Metropolitan County of Greater Manchester, researchers (Gill, Handley, Ennos, & Pauleit, 2007) have studied the potential of urban green space in adapting cities to climate change, and quantified specific environmental functions.

European Comission (2010) aims to enhance ecosystem versatility and achieve the EU's objective of biodiversity conservation 2020 by applying GI plan. European Comission (2013) takes GI as an intelligent way to provide people and society with a number of goods and services, such as environmental benefits and social benefits, and also to deal with climate change.

Besides, Barcelona has been actively committed to preserve and enhance urban sustainability for the past decades through its Agenda 21. Little by little, Barcelona has generated a genuine network of GI (Ajuntament de Barcelona, 2013), which is the way to link and integrate all green spaces in the city and areas surrounding the city contributes to benefit people from higher levels of health and wellbeing. *Barcelona's Green infrastructure and Biodiversity Plan 2020* (Ajuntament de Barcelona, 2013) defines the green infrastructure as "a network of spaces with public or private agricultural or landscape natural vegetation, a multi-purpose resource providing ecological, environmental, social and economic services. These services are enhanced further when connectivity of green infrastructure is achieved."

Obviously, all of these successful case studies and practices partly attribute to the capacities of GI to provide amount of ES (Ted Weber, Anne Sloan, 2006; R. Costanza et al., 1997). Above all, green infrastructure focuses on regional research and scale, the core idea is "to protect the natural system connectivity, build a coherent natural system network", so the connectivity is also the key element (Benedict & McMahon, 2000).



The view from the Collserola Natural Park, Barcelona, Spain (illustration by author.)

2 CHAPTER TWO: THE GENERAL THEORY OF LANDSCAPE SERVICES

2.1 Introduction

In the past few decades, various topics derived from ecosystem services have become the hot topics in the world and have been fully developed. However, the research of ES mainly focuses on the ecosystem functions or values of ecological processes and components, which makes it is challenging to incorporate decision makers in the decision-making process (Termorshuizen & Opdam, 2009).

Compared with ecosystem (scale), a landscape (scale) is a range that is a holistic, mental and spatially heterogeneous entity results from the human interactions (M. G. Turner, 1989; Antrop, 2000). It not only refers to the geographical entity composed of abiotic and biotic with human-made essentials but also relates to the perceived environment (Vallés-Planells et al., 2014).

A regional ecological landscape is the most operational scale for understanding and shaping the relationship between human society and environment (Jianguo Wu, 2013). The multi-disciplinary nature of the landscape is a vital subject basis for geography, ecology, landscape architecture and landscape ecology. The object of research of the landscape is landscape ecology and sustainable landscape science. The former has a strong vitality from its multidisciplinary foundation. The latter is a cross-discipline of landscape ecology and sustainable science. The core content is the dynamic relationship among landscape pattern, landscape service, and human well-being. It can be seen that only by translating and integrating the concept of ES into the landscape scale can we effectively interpret the influence of the spatial distribution of human activities on the pattern and process of ecosystem components, and apply theoretical research results to practical cases, such as landscape planning and design.

Indeed, researchers tried to integrate the concept of ES into landscape research in the last dozen years. By searching ‘ecosystem services’ and ‘landscape’ in the title in

SCOPUS (November 11, 2018), there are 333 relevant papers from 2008 to 2018, over 50 papers per year from 2016 to 2018 (See Figure 2-1). 225 papers deal with case studies within the globe.

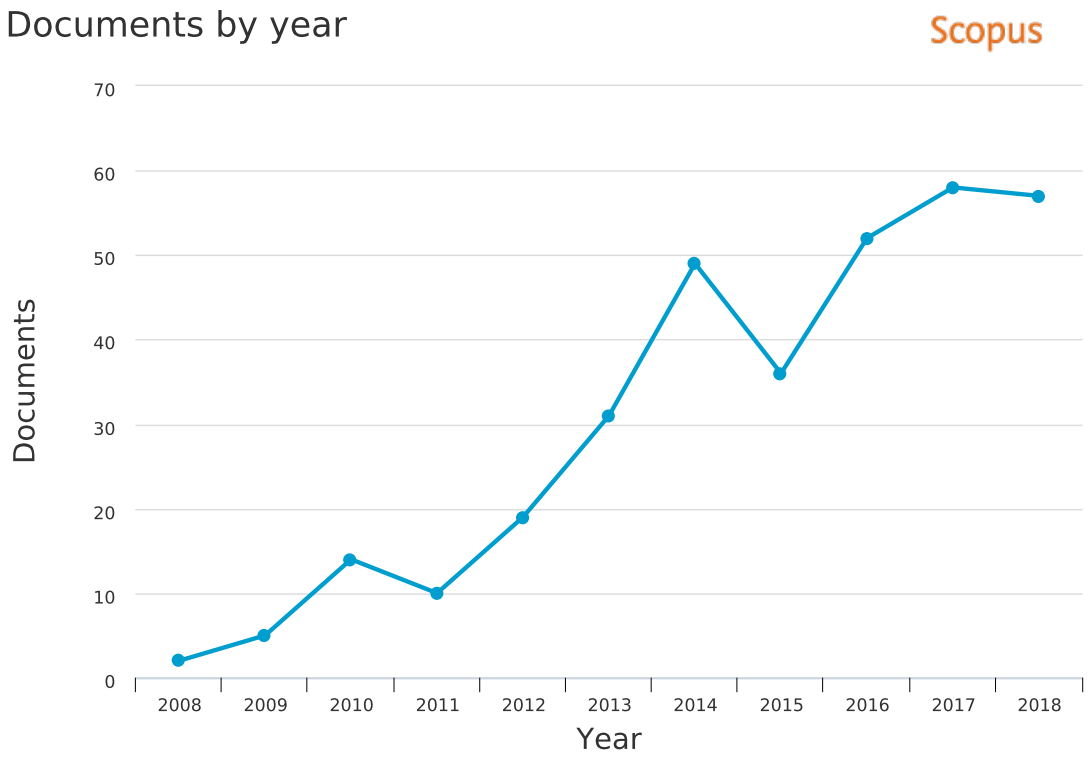


Fig. 2-1 The publishing papers of integrating ecosystem services concept into landscape research.

Source: SCOPUS search, November 11, 2018

Plenty of research on the study of integrating ecosystem services and landscape planning has been done, such as, the impact of climatic and land-use changing on ecosystem services (Lautenbach et al., 2011), the impact of changes in landscape pattern on ecosystem services (Hao et al., 2017; Duarte et al., 2018), the development and planning of green infrastructure (Niemelä J et al., 2010; Kopperoinen & Itkonen, 2014; Maes et al., 2015; Liquete et al., 2015); the great advancing of landscape planning (Ahern, Cilliers, & Niemelä, 2014; Musacchio, 2018). However, LS is inevitably mentioned in these topics, because LS is the core concept in analysing the relationship between landscape spatial patterns and scales related to human activities.

Yet, despite the increase in publications on ES and LS, a systematic typology or comprehensive framework of LS is elusive, and this is almost a blank in this field. In general, the current classification system of LS largely depends on the typology of ES, which causes much controversy between 'ecosystem services' and 'landscape services' that leads to confusion. Moreover, the existing classification systems mainly regard the ecological structures and functions of transmission as the key factors, also include the relation with human welfare. Besides, the systems of ES categorisation are not common for observing the landscape spatial pattern, landscape element and characteristics. So the scientific and reasonable definition and classification system of LS is the foundation of the general theory study of LS.

Therefore, in response to this challenge, this chapter aims to address these questions: How to justify LS is different from ES and in which situation ES should be replaced by LS? Which factors decide or affect LS in the context of landscape? How to define and classify LS by the achievements?

So, in this chapter, first, it justifies LS by the literature review and the case study – the urban forest park (the Collserola Natural Park), in which situation LS can replace and differentiate ES. Second, it aims to develop a classification of LS that related to the integrated concept of landscape, the social dimension of landscape and human well-being, and its application in landscape planning. I propose the classification system of LS that adopting the common typologies of ES, especially the provisioning services and regulating services. Regarding the socio-cultural services, I justify the cultural and social services in the context of the landscape by discussing and analysing the case of the Collserola Natural Park. Besides, this chapter also presents a conceptual framework and typology for describing, classifying landscape functions, goods and services in a clear and consistent manner.

2.2 The development of the definition of landscape services

In the literature review of LS previously (see chapter one), the formation and development of the terminology 'landscape services' have been discussed and organised.

Currently, the landscape service has not yet formed a unified concept, even if there are increasing publications related to it. Many researchers elaborate and propose the definition of landscape services from their disciplinary perspective. Still, there are some confusions and fuzzy boundaries. In order to better understand the development of LS. Here, the leading developers of definitions of LS is sorted out in Table 2-1. It shows that some foremost relevant researchers' arguments on the definition and discussion of LS, which can be seen that most of them believe that the terminology 'ecosystem services' and the terminology 'landscape services' are the synonyms, only a matter of scale, rather than fundamentally different.

However, the term 'landscape service' is a different term from other disciplinary perspectives, such as landscape planning, landscape ecology and landscape sustainability science; and different stakeholders such as services managers and decision makers. It is not the whole new concept compared with the term 'ecosystem service'. Here, this study prefers the former than the latter as spatial patterns relationships at the landscape scale are more clearly understood within this study.

Table 2-1 Definitions of landscape services.

Source	Definition	Key points/ Features
Termorshuizen and Opdam, (2009)	"Landscape services as a unifying multi-disciplinary common ground integrated into multifunctional, actor-led landscape development, and as a bridge between landscape ecology and landscape sustainability." LS is a specification, not an alternative of ES,	It is a generally recognised concept of LS that defined base on landscape structure, functions and values. They argue that LS helps landscape planning process from theory to practice.

Source	Definition	Key points/ Features
	is a core application of landscape ecology base on interdisciplinary science development.	
de Groot et al., (2010)	Landscape functions and services are, same with the concept of Ecosystem functions and services, defined as "capacity of ecosystems to provide goods and services that satisfy human needs, directly and indirectly"(de Groot, 1992).	They regard the term 'ES' and the term 'LS' are the same, without fundamentally differences, mainly a matter of scale.
Louise Willemen, (2010); L. Willemen et al. (2012)	Landscape services are "the flow of goods and services provided by the landscape to society".	A modelling approach is elaborated to visualise the regional spatial and temporal dynamics in landscape services provision.
Syrbe and Walz, (2012)	The term 'ES' is enlarged to 'LS'. LS is a broader perception manner and highlights the spatial characteristics and relationships.	The landscape services assessment by means of landscape metrics, integrating three different service provision areas, which contributes to the development of LS approach.
Jianguo Wu, (2013)	Landscape services are " ecosystem services provided by multiple landscape elements in combination as emergent properties".	He argued that LS is the core of landscape sustainability science in changing landscapes. But this narrow definition of LS refers to ecological services generated by landscape pattern or configuration"(Bastian et al., 2014).

Source	Definition	Key points/ Features
Bastian et al. (2014)	"Landscape services are the contributions of landscapes and landscape elements to human well-being". They argue that ES synonymous with LS. Within the context of spatial aspects, landscape elements and landscape units are highlighted.	They have proposed that spatial aspects, landscape elements, landscape character and landscape planning impact the capacity of LS supply. Also almost all ES can be considered as LS to use.
Hermann et al. (2014)	Landscape services are defined as "all goods and services that landscape provides for well-being," and are classified as five categories, regulation, habitat, provision, information and carrier services.	They argued that LS is more related to human habitat and cultural patterns, rather than only natural process and conservation.
Vallés-Planells et al. (2014)	"The concept of landscape services, compared with ES, involves the social dimension of landscape and the spatial pattern resulting from both natural and human processes in the provision of benefits for human well-being."	They developed a classification for landscape services base on the Common International Classification of Ecosystem Services(CICES) and review of the literature.
Westerink, Opdam, van Rooij, and Steingröver, (2017)	Landscape services are delivered effectively by the biophysical landscape conditions, with a new role, enhancing social capital in landscape governance.	In the context of landscape governance, LS is more suitable for studying social capital and ecological networks.

2.3 The landscape services in the context of landscape

According to the Table 2-1, the terminology 'landscape services' is commonly regard as the synonymous with ES. It is true that the landscape includes different kinds of ecosystems that usually consists of a mix of ecosystems, which means the landscape services are the mix of ecosystem services as well, or just a matter of adding up, or the functioning at the landscape level is different (e.g., aesthetic attractiveness). But it does not mean that they are the same.

The landscape is seen as the spatial human-ecological systems that providing a wide variety of LS with additional economic, social-cultural and ecological values, rather than being regarded as a synonym for ecosystem or being considered to be a group of ecosystems (Termorshuizen & Opdam, 2009). Landscape services in the context of landscape should be stressed the role of landscape dimension: the explicit of spatial aspects; the interactions with human mind and activities, particularly the historical heritage and cultural products; the landscape characteristics (e.g., natural and semi-natural scenery); and the effect of landscape planning and management on the role of LS. Only when the services are clearly reconnected with the landscape (e.g. pattern, element, character) that can be regarded as the landscape services. Therefore, in order to address the question of whether and in which cases LS is much more appropriate than ES towards landscape research, this section will review landscape specific features and applications as follow, referring to service-providing landscape elements and characteristics, the role of landscape patterns, and Landscape practices in planning and management.

2.3.1 Landscape elements and landscape characteristics

A landscape is the heterogeneous spatial mosaics that interaction between humans and nature (Forman, 1986). It can be seen that different landscape elements, such as the vegetation cover, geology, topography, soil, land use and human settlement forms, together constitute a heterogeneous landscape (Jellema et al. 2009; Van Eetvelde & Antrop 2009). It is also called the geo-complex, natural complex, land units. Landscape character is defined as a unique and recognisable pattern of components

that occurs consistently in a particular type of landscape (S. C. Turner, 2005). It is important to consider the landscape features into the policy making since they can reflect the state and quality of the landscape (Atik, Işikli, Ortaçeşme, & Yildirim, 2015), both biophysical and visual (Will, 2005).

Various landscape elements shaped the landscape character. Landscape characters are formed or influenced by those landscape components. Both of them have important implications for the landscape research. For instance, field investigation, data collection, and in the criteria and indicators development process and the assessment procedure.

In general, the landscape services highlight the society property since the landscape can provide social benefits to human beings and better describe the effects of human activities. The concept of LS consider cultural and social aspects more in the foreground than the concept of ES (Syrbe & Walz, 2012), since most heritage assets, historical conditions and cultural products commonly result from the interactions between landscape and human civilisation, instead of the ecosystems. Many ecosystems cannot include all cultural scene, for example, the historical heritage and buildings, cultural specifics and products. In most cases, the local and regional identity is also shaped and impacted by the landscape character, for instance, the development of tourism, the products related to the unique culture or natural scenery, and a sense of spiritual belonging and identity to a particular place.

Besides, cultural services are not only the amenities regarding pleasant and enjoyment (Haines-Young & Potschin, 2010b), it is essential to deliberate the services that help to fulfil the human needs related to personal and social satisfaction. Moreover, from the perspective of ES, it is hardly to assess and value the cultural services unless associating with the information on the spatial patterns and landscape functions (Hermann et al., 2014).

Therefore, these aspects would change by the human activities and the human mind, which can hardly explain by the term ‘ecosystems’ but the term ‘landscape’.

2.3.2 Landscape patterns

The core scientific agenda of landscape ecology is the landscape pattern and process that landscape patterns matter to the functioning of a landscape (Termorshuizen & Opdam, 2009). Landscape ecology studies shows that it is a vital part to integrate a broad perspective of spatial relationships into land-use planning that including the creation or protection of sustainable landscapes (M. G. Turner, 1989).

The importance of landscape pattern and spatial aspects has been discussed. For instance, the spatial characteristics and interactions of landscape services (Syrbe & Walz, 2012). The heterogeneity and change of landscape pattern will affect the values of landscape services by altering the land use types and the ecosystem or landscape structure and functions (Wu 2013; Hao et al. 2017; Duarte et al. 2018). The landscape pattern and spatial characteristics are essential for classifying since an effective classification system is able to consider landscape features in comprehensive ways, to express the particularity of the service delivery process and to relate to human values (Wallace, 2007).

The values of landscape services are not only dependent on the value of a single ecosystem plaque or a landscape patch, but also on the value between these patches and boundaries, the combined value of these patches, and the interaction of plaques with human activities (Martín de Agar et al., 2016).

Furthermore, in the speaking of the geographic scale, the ecosystems tend to be limited in the certain scope. However, from the perspective of landscape, the geographic scale of landscape pattern involving larger geographic areas.

The concept of LS highlights the significance of spatial aspects, while the concept of ecosystem and ES are focusing on the functional (vertical) relationship between ecosystem components (Termorshuizen & Opdam, 2009). Hence, this research prefers the term ‘landscape service’ in the context of the landscape.

2.3.3 Landscape practices in planning and management

For several decades now, landscape planning is an ecological-aesthetic planning way to conserve and improve landscape at various scales (Bastian et al., 2014).

Although the terms ES and LS are not actually mentioned, landscape functions are well known, that is, the concept of landscape is most relevant to landscape planning and management, rather than ecosystems. Landscape planning and management are essential to make sure that the ecosystems and landscape can provide services permanently (Bastian et al., 2014), and make for an overall increase in service provision (Hodder, Newton, Cantarello, & Perrella, 2014).

In general, the language of ecosystems mainly focuses on the ecological and economic area related to the environmental science while the language of landscape is popular with landscape planning and management in the ecological, social and aesthetic planning process (Bastian et al., 2014; Dramstad, Tveit, Fjellstad, & Fry, 2006) 'Landscape' is a broader concept than 'ecosystem' as it has a much deeper and wider disciplines unity (Dramstad et al., 2006). So in a multi-disciplinary context, the concept of landscape services is a better choice than the concept of ecosystem services. Although in the context of landscape research, the term 'landscape functions' are used more often, especially in the landscape design. The terminology 'landscape services' was chosen on the basis of landscape practices. As the transfer of complex functions, goods and services to practical planning and management remains a challenge. So the LS as the expression for decision makers and stakeholders that are more easier to be understood and described in landscape planning and management.

Although there are increasingly researches and publications that focus on integrating the concept of ES into the landscape planning. In practice, the practical implementation of landscape plans is not so satisfactory. So in order to maintain and protect the values and functions provided by the landscape, the efficient landscape planning and management measures are required.

2.4 The case study—The Collserola Natural Park

There is one case study from Barcelona (Spain). It is the Collserola Natural Park. This section will analyse one case study in which it might represent and be related to LS, which would explain the theoretical basis for classifying LS and add new ones into

the categorisation, especially the services referring to landscape elements, landscape features and landscape patterns.

Hence, according to the case study, the landscape elements and characteristics, landscape pattern and landscape planning are involved to justify the definition and classification of LS.

2.4.1 Study area

The Collserola Natural Park (Parc Natural de la Serra de Collserola) (CNP) is located in the north of Barcelona city, which has great privilege for the huge population that lives around (Figure 2-2). The Collserola Massif forms part of the central sector of the Serralada Litoral Catalana mountains. It stretches three counties: Baix Llobregat, Vallès Occidental and Barcelonès. It occupies part of the territory of the following nine towns: Barcelona; Montcada i Reixac; Cerdanyola del Vallès; Sant Cugat del Vallès; El Papiol; Molins de Rei; Sant Feliu de Llobregat; Sant Just Desvern; Esplugues de Llobregat[1]. The Collserola Park Consortium now manages the park.

It is a well-preserved urban forest park that accounting 8,460 hectares' natural area in which forest predominates (7516 hectares are forestland) and a variety of other plant formations, which provides the habitats for valuable biodiversity while it has multi-functional landscapes. There are various eco-environments in CNP (See Figure 2-3), such as forest environment, riparian environment, aquatic environment, scrub, meadows, rocky environment. Also, the human-made environment is included. Hence, although there are various ecosystems within CNP, the landscape would be a better dimension for protecting and maintaining it.

It has a direct impact on the health of the millions of people who live around it since it can delivery a lot of ES to contribute the city and citizens. For example, air purification, global climate regulation and runoff mitigation (Baró et al., 2014). Besides, there are renewable resources within the park, such as the medicinal, aromatic and ornamental plants.

[1] A part of the information of the Collserola natural park is adapted from its official website: https://www.parcnaturalcollserola.cat/en/

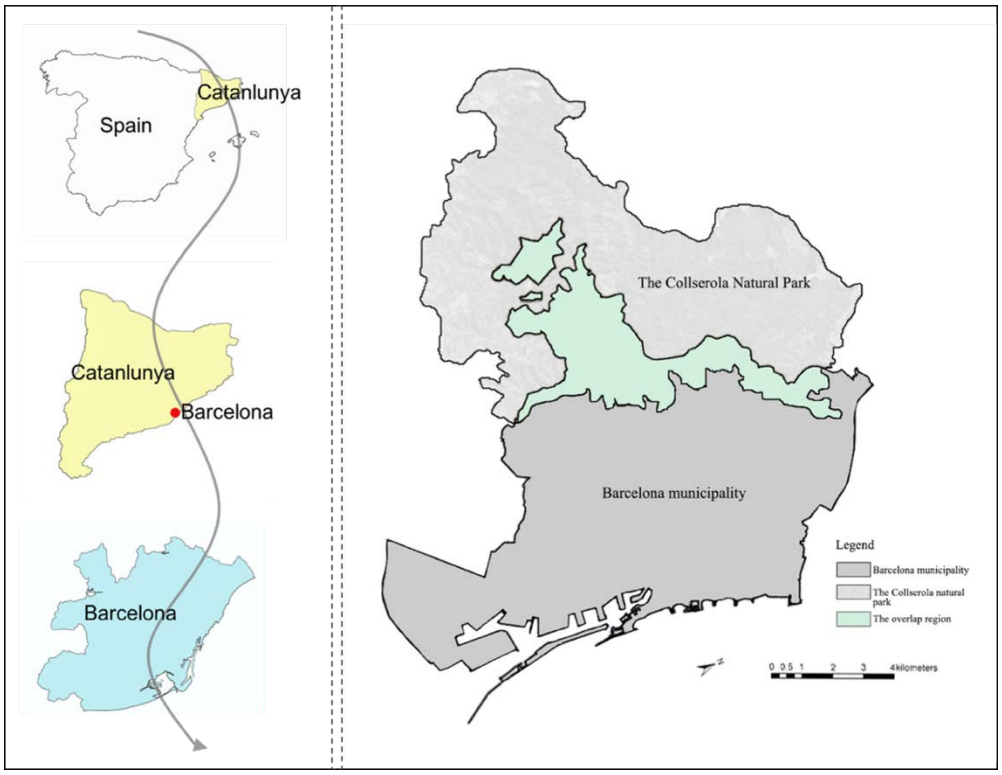


Fig. 2-2 The location of the Collserola natural park and Barcelona municipality. *Source*: author elaboration based on https://www.parcnaturalcollserola.cat/ac-administracions-consorciades/

Fig. 2-3 The images of the Collserola Natural Park regarding various environments. *Source*: https://www.parcnaturalcollserola.cat/es/

Also, as a large urban natural park it is, CNP has many commonalities in the context of spatial aspects and functions of urban parks. It is a part of the urban public green spaces and a part of the urban forest protection systems. It has both ecological protection and maintenance functions as well as urban public space purposes. When it is facing to Barcelona, the attitude of 'restrictive opening to the city' is necessary. Firstly, the primary objectives are the ecological conservation and protection of nature and habitat. Secondly, with the permission of the ecological carrying capacity, the public is provided with leisure and entertainment places, which they can be close to nature.

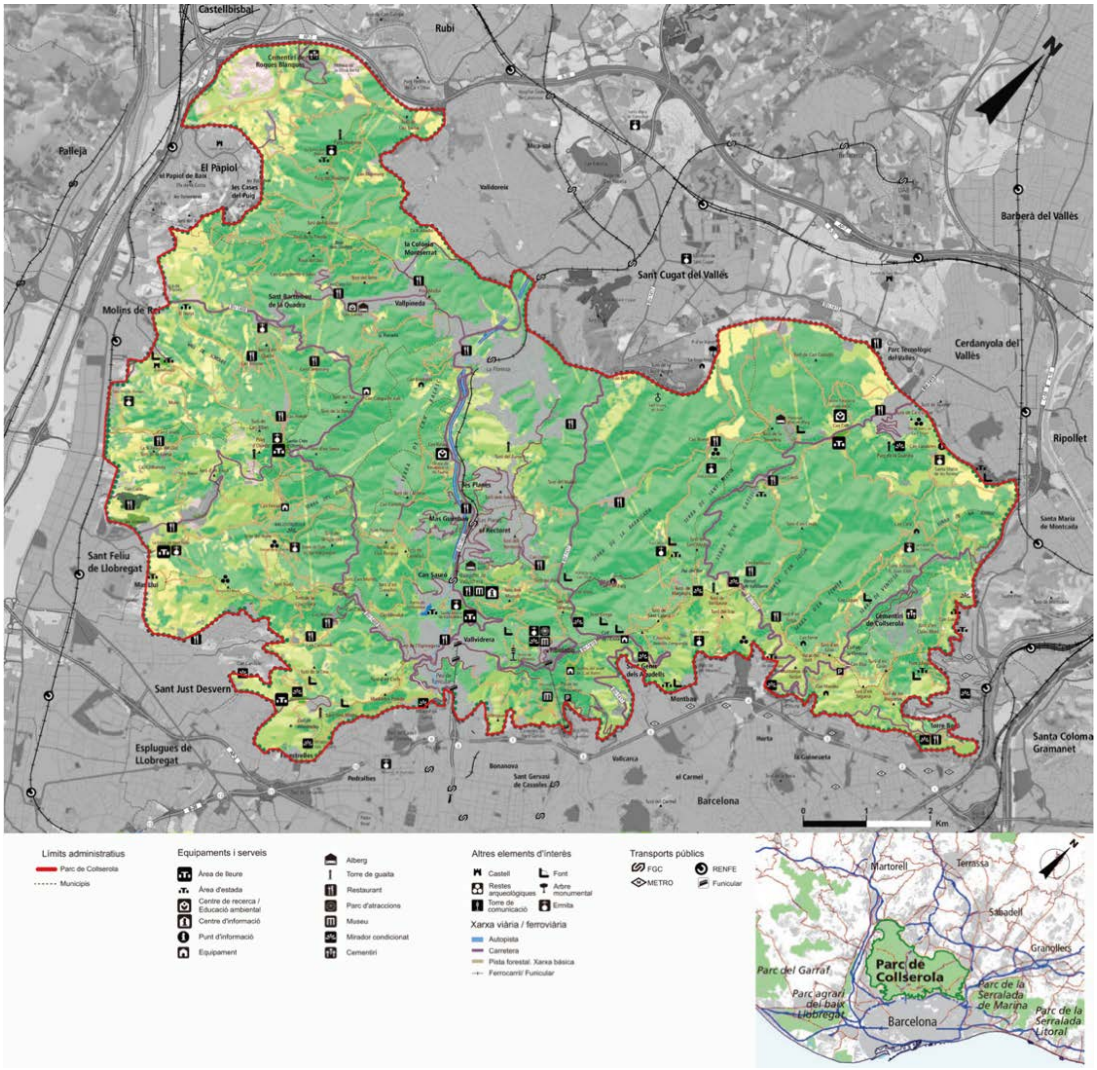


Fig. 2-4 The boundary of the Collserola natural park and its basic information. *Source*: adapted from http://www.parcnaturalcollserola.cat/en

2.4.2 Socio-cultural services and landscape element and character

The Collserola Natural Park is an excellent area for recreation with considerable aesthetic value and vital educational resources.

A survey on the landscape appreciation of landscape scenery in CNP in Barcelona (Spain) was carried out among visitors and park users. The aim is the analysis of socio-cultural ecosystem services related to landscape aesthetics and the human needs for landscape. The survey is designed that including sixteen questions about the use of the park and their purposes[2] (See Appendix A). The sample was taken from May to December, 2017.

These investigation results were determined by three steps as follow.

In the first step, we posted questionnaires through face-to-face interviews and the internet. Via interviews and questionnaires, we posted 250 questionnaires that 212 of them are collected, and we interviewed 200 park visitors with 100 summer and 100 winter tourists by alternating working days, weekends and public holidays and at different times of day (in the morning, in the afternoon, in the evening). Besides, we posted the survey to 100 citizens who are living in Barcelona by E-mail.

In the second step, we collected and organised all the results, then inputted all of the information into the computer.

In the third step, the results were analysed and presented: where users come from; users' profiles; reasons for visits and length of stay; visitors' needs for a single landscape/single landscape function, e.g., the visitors can only have one thing to do (do sports) or to enjoy (one view-point to see the landscape scenery). Or a composite landscape/multi-functions in a certain place.

Most of the park users are the locals, about 90% of them live in Barcelona city or its surrounding towns, especially Sant Cugat del Vallès and Cerdanyola del Vallès. 62% of visits are in the morning, 48% at midday and 8% in the afternoon (multiple-choice

[2] The website of the survey is: https://docs.google.com/forms/d/e/1FAIpQLScUZ2pXixeINH_WYBNgJ3BKnvVEVN1wyNoWZJyYhhmfpsKB4w/viewform?usp=sf_link

question). The majority of visits, 38% of visits would like to stay less than two hours, with 57% park users prefer to stay in the park between two and five hours that being more common. The rest of people (5%) prefer to enjoy the park more than five hours (See Figure 2-5). Moreover, 50% of users visit the park at least once a week.

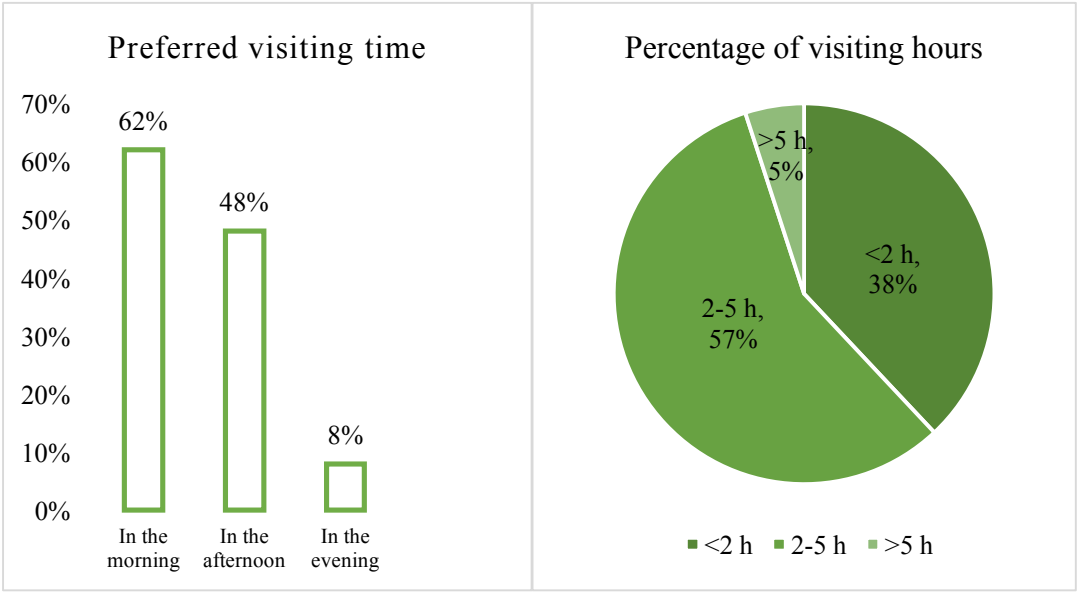


Fig. 2-5 The percentage of preferred visiting time of visitors during the day (left); the percentage of visiting hours each time (right). *Source:* own elaboration

Visitors perceive CNP as a place for both leisure and enjoying nature. According to Figure 2-6, we can see that there are three reasons were chosen by visitors that the main activities going on in CNP (multiple-choice question): walking and strolling; enjoying nature; the visual enjoyment. Over 50% of users chosen these three reasons simultaneously.

Over 15% of users prefer to have sports (17%), have a picnic (17%), look for the inspiration from nature (15%). Other reasons to visit CNP are cycling (6.7%), participating in the scientific and educational activities (5.6%) and religious activities (2%), using the recreation areas (10.7%). All these activities are particularly popular in the spring and autumn periods.

This result shows that the visitors attach great importance to the satisfaction of their own physical and mental needs. The public goods and services are seen extraordinary value in the landscape context that associating the specific elements at a

particular place.

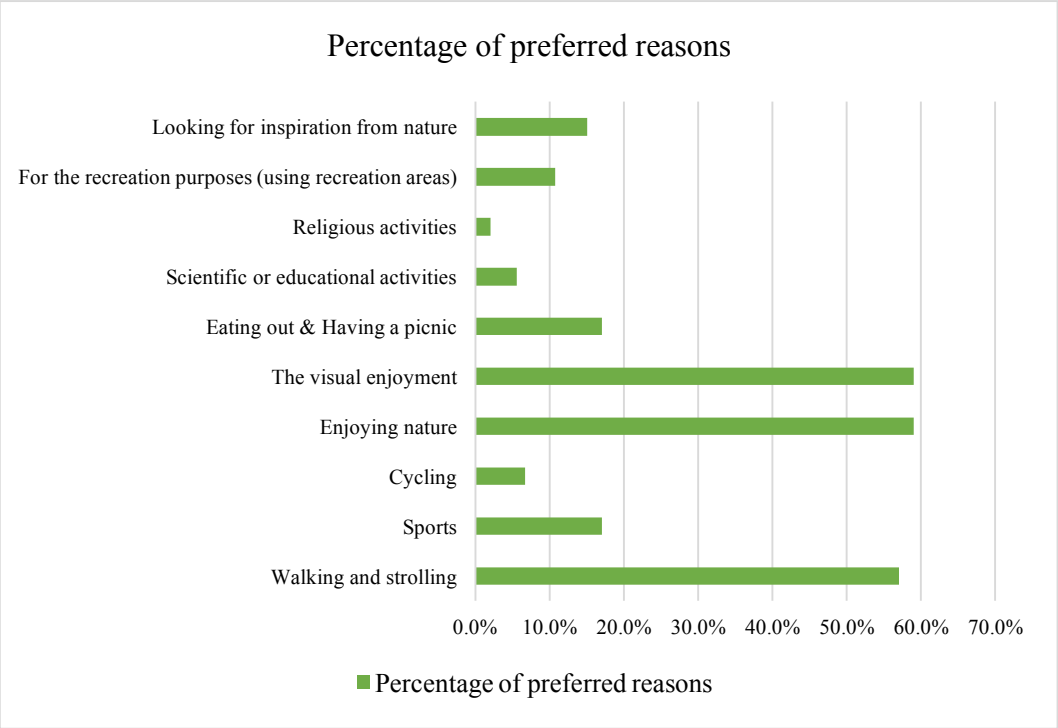


Fig. 2-6 The percentage of various preferred reasons to visit Collserola natural park. *Source*: own elaboration.

Fig. 2-7 The images of activities and sceneries in the Collserola natural park. *Source*: photos are taken by author.

Furthermore, more than 80% of the park users assigned greater significance to the various landscape elements and multi-functions associating the interaction of landscape attributes, i.e. to the overall landscape character, than to single-function of landscape attributes (approximately 20%). This result shows that the visitors highly value the landscape integrity and multi-functionality that a multi--functional landscape was the primary reason for spending time there.

So those services relating to the socio-cultural dimensions, such as landscape aesthetics, spiritual experience and leisure ones should be seen and assessed only in a landscape context.

2.4.3 Landscape planning and management

Top-down landscape planning and management play a key role in the establishment and development of CNP. The authorities at all levels worked together and made a significant effort to build an effective and stable management system.

The Organisation and Protection of the Natural Environmental of Collserola Park (Pla especial d'ordenació i de protecció del medi natural del Parc de Collserola) (PEPCo) Act was enacted in 1985. It is the main bill to support the development of CNP, which defined the boundaries and shape of the park and plans for different functional areas and ensured that leisure activities are compatible with environmental protection and conservation within the park.

On this basis, in 1992, the Catalan government developed the "the Plan for Spaces of Natural Interest" (PEIN), which aims to establish an ecological protection network, including 165 nature reserves and 12 natural parks. Protected areas are classified as prohibited development sites in the regulations, playing an important role in protecting biodiversity and ecological balance.

In order to protect natural habitats and wildlife and to establish a coherent European ecological system of special conservation areas, the directive 'the Nature 2000 Network' was set up. CNP has also been included in this protection network.

In 2004, the Catalan Parliament issued the 1347/VI decree. It aims to propose targeted protection measures, improve the recreational facilities in the park, and enhance the versatility of the landscape.

In 2009, the declaration of Collserola as a Natural Park statement was published. Barcelona Metropolitan Territorial Plan (2010) includes the Serra de Collserola in the special protection category.

To sum up, a series of protection bills and measures effectively prevent urban expansion from encroaching on the space of CNP and also protect the ecosystem and landscape integrity of the park that not affected by commercial construction and urban land use. All these efforts provide a foundation for the sustainable development of the park and the city.

Furthermore, landscape planning and management can efficiently protect and maintain historical sites and cultural heritage. There is much ancient cultural heritage in CNP that including gatherings and religious activities, art, legends; architectural heritage that including prehistoric relics, fountains, chapels and churches, medieval castles, farmhouses. These precious remains are important local cultural heritage. In order to better protect them, the park established a heritage management department and issued a unique protection plan. Moreover, the park attaches great weight to the protection of local culture, such as local festivals, art forms and folk customs.

All these plans contribute to the development of CNP. They aim to promote environmentally-friendly and sustainable use of the reserve while conserving the natural heritage it contains. The adequate and long-term protection plans deal with an urban invasion by joining the regional ecological network (even the broader scope of environmental protection), establishing the natural park status according to law and building a stable government joint management mechanism.

2.5 A typology for the definition, classification, description of landscape services.

2.5.1 The definition of landscape services

According to the above two case studies, the identification of LS should consider the spatial aspects, landscape elements and characteristics, and landscape planning and management.

Therefore, this dissertation redefines landscape services explicitly from the perspective of landscape science and landscape ecology. The landscapes service is defined as "the functions and goods for human survival and well-being that are formed and maintained by ecosystems, landscape patterns and processes at the landscape scale. Landscape services are the basis for life support and human welfare in a given region".

2.5.2 Classification and description of landscape services

2.5.2.1 Classification of landscape services

Although there is not a uniform typology of ES that is accepted by this whole academia, still existing ones are the most accepted.

Figure 2-12 shows that comparison of seven selected of the main ES and LS classification systems, which are applied in many research. Differences and similarities are also presented classification of ES and the comparison of typologies among different researches.

Although R. Costanza et al., (1997) classified ES into 17 major groups rather than classifying ES into provisioning services, regulating services, supporting services and cultural services. According to this diagram, the ecosystem services are classified into five main themes in other researches: provisioning services, regulating services, supporting services, habitat services, and cultural services. From first column to fifth column (R. Costanza et al., 1997; de Groot, Wilson, & Boumans, 2002; R. S. de Groot, 2006; R. S. de Groot et al., 2010; MA, 2005b; TEEB, 2010; Haines-Young & Potschin, 2010a), they show the different classification systems of ES. Then, Vallés-Planells, Galiana, & Van Eetvelde, (2014) and Bastian, Grunewald, Syrbe, Walz, & Wende,

(2014) developed the landscape services classification systems based on the ecosystem services classification systems that refers to landscape related aspects.

Even though each classification system does not contain all themes that figure shows, they also almost have the same typology. For instance, only the typology of MA includes the supporting services, but actually, the other two typologies also include some services from supporting services, such as soil formation (corresponding to 'soil formation and regeneration'), nutrient cycling ('nutrient regulation' in the de Groot et al. (2002) typology).

As discusses previously, it is generally recognised that the classification mechanism of landscape services largely depends on the ecosystem services category system. This graph also proved that the basic structure of the typology of LS adapted from the typology of ES, but not the same, depending on the context of landscape. According to this figure, the landscape services are classified into three themes (provisioning services, regulating and maintenance services and cultural services). However, the most different thing here is the personal feelings and emotions are taken into account and are distinguished from social or general human goods and services in the classification system of ES. Also, the typology of LS tends to highlight cultural and social values and considers the effects of human activities in the landscape.

Therefore, Figure 2-12 illustrates that these systems are broadly similar, especially the five classification systems regarding ES, even though there are some differences in details. Also, the classification systems of LS are generally derived from the ecosystem services typology, so it is essential to seek a practical, scientific and rational classification system of LS.

So far, after the literature review in the Chapter One and the above discussion and comparison. Here I clear the relationship and development between the typology of ES and LS, which contributes to better classified LS now. In the context of landscape, the author argue that all ES can also be considered as LS, but the classification system of ES do not include all LS. Although a wide range of LS have been referred to in

literature, regarding landscape context, our experience and research result suggests that it is convenient to divide LS into three key themes: provisioning services; regulating and maintenance services; cultural and social services. Table 2-2 shows an overview of the main landscape services, examples, definition, benefits to human beings (with examples) that can be attributed to natural ecosystems and landscapes. As this table shows, the landscape services are divided into 36 sub-services.

Given the restrictions that only those services can be attributed to a particular ecosystem type or landscape pattern and structure are included, such as energy sources (e.g., wind and solar energy) are not included.

Source / ES/LS	Costanza et al. (1997)	De Groot and other researchers (de Groot, 2006; de Groot et al., 2010, 2002)	MA (Millennium Ecosystem Assessment), (2005a)	TEEB, (2010)	CICES 2010 (Haines-Young & Potschin, 2010a)		Vallés-Planells et al. (2014)		Bastian et al. (2014)	
Theme	**Categories**	**Categories**	**Categories**	**Categories**	**Categories**	**Classes**	**Categories**	**Classes**	**Categories**	**Classes**
Provisioning services	Food production	Food	Food	Food	Nutrition	Terrestrial plant and animal	Nutrition	Terrestrial plant and animal	Food	Food and fodder plants
										Livestock
						Marine plant and animal		Marine plant and animal		Wild fruit and game
						Freshwater plant and animal		Freshwater plant and animal		Wild fish
										Aquaculture
	Water supply	Water	Freshwater	Water		Potable water		Potable water	Renewable raw materials &other natural resources	Fresh-water
	Raw materials	Fibre, fuel other raw materials	Fibre	Raw materials	Materials	Biotic materials (non-food plant fibres; non-food animal fibres; ornamental resources; genetic resources; medicinal resources)	Materials	Biotic materials (Non-food plant fibres; Non-food animal fibres; Ornamental resources; Genetic resources; Medicinal resources)		Fibres
			\							Timber and tree products
	\	Ornamental species	Ornamental resources	Ornamental resources						Other natural materials
	\	Biochemical products and medicinal resources	Biochemical, natural medicines, and pharmaceuticals	Medicinal resources						Bio-chemicals, natural medicine
	Genetic resources	Genetic resources	Genetic resources	Genetic resources						Genetic resources
	\	\	\	\		Abiotic materials		Abiotic materials		\
	\	\	\	\	Energy	Renewable biofuels	Energy	Renewable biofuels		Bio-energy (i.e. firewood, charcoal.)
	\	\	\	\		Renewable abiotic energy (i.e. wind, hydro, solar)		Renewable abiotic energy (i.e. wind, hydro, solar)	\	

Source / ES/LS	Costanza et al. (1997)	De Groot and other researchers (de Groot, 2006; de Groot et al., 2010, 2002)	MA (Millennium Ecosystem Assessment), (2005a)	TEEB, (2010)	CICES 2010 (Haines-Young & Potschin, 2010a)		Vallés-Planells et al. (2014)		Bastian et al. (2014)	
	\	\	\	\	\		Daily activities	Place to live	\	
								Place to work		
								Place to move		
Regulating services	Waste treatment	Waste treatment	Waste treatment	Waste treatment	Regulation of wastes	Bioremediation (i.e. remediation using plants, remediation using micro-organisms)	Regulation of wastes	Bioremediation (i.e. remediation using plants, remediation using micro-organisms)	\	\
						Dilution and sequestration		Dilution and sequestration	\	\
					Regulation of physical environment	Water quality regulation	Regulation of physical environment	Water quality regulation	Hydrological services	Water purification
	Soil formation	Soil formation and regeneration	soil formation (supporting service)	Maintaining soil fertility		Pedogenesis and soil quality regulation		Pedogenesis and soil quality regulation	Pedological services	Maintenance of soil fertility
	Climate regulation	Climate regulation	Climate regulation	Climate regulation		Atmospheric regulation (global, local & regional climate regulation)		Atmospheric regulation (global, local & regional climate regulation)	Meteorological services	Climate regulation
	\	\	\	\	\		\			Noise protection (Reducing noise through vegetation and relief)
	Gas regulation	Gas regulation	Air quality regulation	Air purification	Flow regulation	Air flow regulation	Flow regulation	Air flow regulation		Carbon sequestration
		Air quality regulation								Air quality regulation
	Water regulation	Water regulation	Water regulation	Regulation of water flows		Water flow regulation		Water flow regulation	Hydrological services	Water regulation

Source / ES/LS	Costanza et al. (1997)	De Groot and other researchers (de Groot, 2006; de Groot et al., 2010, 2002)	MA (Millennium Ecosystem Assessment), (2005a)	TEEB, (2010)	CICES 2010 (Haines-Young & Potschin, 2010a)		Vallés-Planells et al. (2014)		Bastian et al. (2014)	
	Erosion control and sediment retention	Erosion protection	Erosion regulation	Erosion regulation		Mass flow regulation		Mass flow regulation	Pedological services	Erosion prevention
	Disturbance regulation	Natural hazard regulation/Disturbance prevention	Natural hazard regulation	Disturbance prevention or moderation	Flow regulation		Flow regulation		\	
	Biological control	Biological regulation	Disease regulation	Biological control	Regulation of biotic environment	Pest and disease control	Regulation of biotic environment	Pest and disease control	Biological services	Regulation of pests and diseased
			Pest regulation							
	Pollination	Pollination	Pollination	Pollination		Lifecycle maintenance(i.e. pollination) & Habitat protection		Lifecycle maintenance & Habitat protection		Pollination
	Refugia (nursery, migration habitat)(supporting service)	Nursery habitat (Habitat service)	\	Lifecycle maintenance						
		Gene pool protection (habitat service)	\	Gene pool protection (habitat service)		Gene pool protection		Gene pool protection		Conserving biodiversity
	\	\	\	\	\		Regulation of the spatial structure	Connection of spaces	\	
	\	\	\	\				Buffer disturbing use		
	\	\	\	\				Provision of spatial complexity		
Supporting & Habitat services	Nutrient cycling	Nutrient regulation	Photosynthesis	\	\		\		\	
			Primary production							
			Nutrient cycling							
			Water cycling							

Source / ES/LS	Costanza et al. (1997)	De Groot and other researchers (de Groot, 2006; de Groot et al., 2010, 2002)	MA (Millennium Ecosystem Assessment), (2005a)	TEEB, (2010)	CICES 2010 (Haines-Young & Potschin, 2010a)		Vallés-Planells et al. (2014)		Bastian et al. (2014)	
Cultural Services	\	\	\	\	\		\		Information services	Environmental indication
	\	\	\	\	\		\			Archive function
	Cultural (incl. aesthetic, artistic, spiritual, education, science)	Education & Science opportunities for formal and informal education & training	Knowledge system	Information for cognitive development	Intellectual and Experiential	Information& Knowledge (scientific & education)	Self-fulfilment	Didactic resources		Education and training
								way-finding		
								Scientific resources		
		Inspiration for culture, art and design	Inspiration	Inspiration for culture, art and design	\			Source of inspiration		Intellectual and artistic inspiration (information service)
		Spiritual and religious inspiration	Spiritual and religious values	Spiritual experience	Symbolic	Spiritual		Spiritual experience	Psychological goods and services	Ethical, spiritual, religious values
		Aesthetic appreciation of natural scenery	Aesthetic values	Aesthetic information		Aesthetic & Heritage (landscape character, cultural landscapes)	\			Aesthetic values
		Cultural heritage and identity: sense of place and belonging	Sense of place	\			Social fulfilment	Place identity		Identification
			Cultural heritage values	\				Sense of continuity		
			Cultural Diversity	\	\			\	\	
		\	Social relations	\	\			Social interactions	\	

Source / ES/LS	Costanza et al. (1997)	De Groot and other researchers (de Groot, 2006; de Groot et al., 2010, 2002)	MA (Millennium Ecosystem Assessment), (2005a)	TEEB, (2010)	CICES 2010 (Haines-Young & Potschin, 2010a)		Vallés-Planells et al. (2014)		Bastian et al. (2014)	
	Recreation (incl. outdoor activities & eco-tourism)	Recreational opportunities s	Recreation and Ecotourism	Recreation & Tourism	Intellectual and Experiential	Recreation and community activities	Enjoyment	Passive enjoyment	Psychological goods and services	Recreation
								Active enjoyment		
	\	\	\	\	\		Health	Mental health	\	
								Physical health		

Fig. 2-8 Comparison of seven selected of the main ecosystem services and landscape services classification systems, which are applied in many researches. Differences and similarities are also presented (R. Costanza et al., 1997; de Groot, Wilson, & Boumans, 2002; R. S. de Groot, 2006; R. S. de Groot et al., 2010; MA, 2005b; TEEB, 2010; Haines-Young & Potschin, 2010a; Vallés-Planells et al., 2014; Bastian et al., 2014).

Table 2-2 An overview of the main landscape services, examples, definition, benefits to human beings (with examples). *Source*: own elaboration, adapted from (de Groot et al., 2002; MA, 2005b; Haines-Young & Potschin, 2010a; Vallés-Planells et al., 2014; Bastian et al., 2014).

No.	Name of landscape service	Examples	Definition	Benefits to human welfare and human society (Examples)
Provisioning services (P)				
P I Food				
P 1	Wild food (excluding rare or protected species)	Wild fruits, plants, animals (including fish) for food.	Edible wild plant fruits, plants and animals.	Providing food or shelter for wild animals.
P 2	livestock	Pigs, cows, horses, rabbits, etc.	Animals that are fed and domesticated by humans and can be controlled artificially.	They are generally used for functions, such as food, labour, fur, pets, and experiments.
P 3	Cereal crops	Tuber crop; bean crop; grain crop, e.g., rice, corn, beans, potatoes, barley, broad beans, wheat, etc.	Food crops are a source of basic human food.	Safeguarding the human basic survival needs.
P 4	Cash crops	Oil crops; vegetable crops; feed crops; medicinal crops, e.g., grass, green manure, honeysuckle, mint.	Crops with specific economic uses, usually for industrial demands.	They are conducive to meeting the needs of human beings for a high quality of life, with high economic value.
P 5	Aquaculture	By fishery species, e.g., shrimp, oysters, carp, etc.	Aquaculture is a production activity that reproduces, breeds, and harvests of aquatic animals and plants under human control.	Satisfy human needs for aquatic products.
P II Water				

No.	Name of landscape service	Examples	Definition	Benefits to human welfare and human society (Examples)
P 6	Freshwater	Lake, river, underground water, glacier, wetland, etc.	Filtering, retention and storage of fresh water.	For agricultural, irrigation purpose; for industrial consumption; for domestic use (drinking).
P 7	Salt water	Sea-water.	Water in the ocean.	By distillation and reverse osmosis, salt water is converted to fresh water for human use.
P III Materials				
P 8	Raw materials	Timber, fibre, fuel wood, fodder, fertilize.	Conversion of solar energy into biomass.	Human construction (i.e., wood and strong fibres for building, oils and latex for industrial purposes).
P 9	Ornamental resources	Decorative plants, ornamental plants, pet animals, leather, feather, etc.	Variety use of wild plants and animals for ornamental purposes.	Resources for fashion, handicraft, jewel, pets, worship, decoration, and souvenirs, etc.
P 10	Genetic resources	Seeds, breeds of animals and plants.	Genetic material and evolution in wild plants and animals.	To maintain cultivars productivity, and to improve certain quality and adaptability.
P 11	Medicinal resources	Biochemical products, models & test-organisms.	Variety in chemical substances in natural biota.	Maintenance of human health, e.g., the application of drugs and pharmaceuticals, animals test.

No.	Name of landscape service	Examples	Definition	Benefits to human welfare and human society (Examples)
P 12	Abiotic materials	Mineral resources, e.g., salt, aggregates (excluding subsurface assets).	Minerals or useful elements that have been developed through the formation of geological mineralization.	The critical material basis of economic and social development.
P IV Habitat				
P 13	Habitation	Terrestrial habitats, marine habitats and inland water habitats.	To provide suitable living space and shelter for wild plants and animals.	Maintenance of biodiversity and genetic diversity.
P 14	Nursery	Fruits, vegetables, flowers, and landscape nursery.	Suitable reproduction habitat that provides breeding and nursery areas to commercially harvested species.	Satisfy human's needs for maintenance of biodiversity, industrial production, city greenery and environmental protective.
Regulating and maintenance services (R)				
R I Meteorological services				
R 1	Air quality regulation	Different gas regulation and PM (particulate matter) control.	To improve air quality by ecological processes and components.	Access to cleaner air; CO^2/ O^2 balance, ozone layer protection.
R 2	Local and regional climate	Cold air and moisture supply; modification of temperature and humidity.	Influence and regulating of ecosystems on local and regional climatic conditions.	Favourable local climate, such as relieving the urban heat island effect.
R 3	Global climate (incl. Carbon sequestration)	Limit the emissions of greenhouse gases.	Influence of landscapes on global climatic conditions through land-cover and biologically-mediated processes.	Control global warming, greenhouse gas-balance.

No.	Name of landscape service	Examples	Definition	Benefits to human welfare and human society (Examples)
R 4	Disturbance prevention (incl. natural hazard mitigation)	Flood prevention (by wetlands and forests); storm protection (by coral reefs).	The ability of ecosystems or landscapes to moderate negative natural events and environmental disturbances.	To safeguard human's life and property safety, to create stable life-communities and prevent the outbreak of diseases.
R II Hydrological services				
R 5	Water regulation	Drainage and natural irrigation; medium of transport.	Regulating runoff and river discharge.	Irrigation and drainage maintenance.
R 6	Water purification	Self-purification of running and standing water.	The role of purifying and filtering water.	Water security for human, flora and fauna.
R 7	Groundwater recharge	Atmospheric precipitation, infiltration of surface water.	It refers to the supplementation of groundwater in various ways (e.g., rainfall, irrigation, underground runoff, channel or water leakage).	The optimal allocation of water resources.
R III Pedologic services				
R 8	Soil retention	Maintenance of soil structure.	The role of vegetation root matrix and biota in soil retention.	Maintain agricultural productivity and prevent damage due to soil erosion.
R 9	Soil formation	Nitrogen fixation, waste decomposition.	Protect and improve soil fertility.	Maintenance of crop productivity and natural productive soils.
R IV Biological services				

No.	Name of landscape service	Examples	Definition	Benefits to human welfare and human society (Examples)
R 10	Pollination	Wind-pollinated; water-borne; bird media.	Role of biota in the movement of floral gametes.	Improve biodiversity and protect certain species.
R 11	Pest and disease control	Biological control mechanisms, control of pathogens.	Population control through trophic-dynamic relations.	Reduce human diseases.
R 12	Nutrient regulation	Chemical elements regulation, macro-nutrients regulation, trace elements, e.g. carbon, oxygen, hydrogen , nitrogen.	Role of biota in storage and recycling of nutrients.	Maintain productive ecosystems and healthy soils.
R 13	Waste treatment & disposal	Dilution; sequestration; absorption; Filtration.	Role of vegetation and biota in dilution, assimilation and chemical re-composition of certain waste.	Pollution control; filtering of dust particles; noise abatement; space for solid waste disposal; practical use of organic wastes.
Cultural and social services (C)				
C I Physical health services				
C 1	Medical / healthcare	Horticultural therapy & Aroma therapy.	Treat illnesses and rejuvenate the mind by contacting the natural environment, using horticultural materials, carrying out and performing horticultural activities.	Improve and regulate emotions, increase energy, etc.
C II Psychological services (health & enjoyment)				

No.	Name of landscape service	Examples	Definition	Benefits to human welfare and human society (Examples)
C 2	Aesthetic value and enjoyment	Landscape aesthetic; garden aesthetic, etc.	Attractive, diversity, beauty and uniqueness of nature and landscape features and views.	Satisfy human's enjoyment of scenery and aesthetic.
C 3	Artistic conception	Inspiration	Subjective thinking is pinned on unbiased objects. Landscape features or species have inspiration value to human arts.	The inspiration for culture, art and design.
C 4	Identity	Place identity, cultural identity and national identity.	The role of landscape in identification shaping process.	Landscape identity for human beings.
C III Experiential services				
C 5	Recreation	Outdoor recreation, indoor recreation, adventure recreation, such as opportunities for walking, climbing, playing with family.	The leisure or amusement activity in the natural, semi-natural and urban area.	Provide daily or periodic recreation activities for people.
C 6	Tourism	Eco-tourism	The role of protecting the natural environment and safeguarding the lives of local people, and providing natural resources for tourists refer to eco-tourism activities.	The sustainable development of tourism.
C 7	Scientific and education	Knowledge gain, scientific research and technical innovations.	Scientific and education values in natural elements and landscape features.	Provide plenty of opportunities for scientific research, excursion, nature study, environmental education.

No.	Name of landscape service	Examples	Definition	Benefits to human welfare and human society (Examples)
C 8	Landscape / Historical heritages	Places of remembrance, traditional cultural landscape.	Cultural important landscape features, species or places.	Protective of cultural heritage, and raising awareness of cultural heritage protection.
C 9	Ethical, spiritual, religious information	Built heritage with spiritual or religious values.	Various natural and landscape features with ethical, spiritual and religious values.	Use of nature for religious purposes, and in greater harmony with nature.

2.5.2.2 The detail description of each landscape service

Table 2-2 demonstrates that an overview of the main landscape services, examples, definition, benefits to human beings (with examples). According to this table, we can see that the first column indicates specific names of LS (including 36 different landscape services). Of which, providing services include four sub-categories: food, water, materials and habitat; regulating and maintenance services include four subcategories: meteorological services, hydrological services, pedologic services and biological services; and the cultural and social services include three sub-categories (physical health services, psychological services, experiential services). The second column gives the specific examples related to each service; the third column describes the definition of each service with simple sentences; the fourth column explains the benefits to human beings and society with some examples (not exhaustive).

Notably, in Table 2-2, 'P', 'R', 'C' represents the three main themes (providing services, regulating and maintenance services, cultural and social services, respectively). Roman numerals mean sub-categories: this column divides three themes into main sub-categories of outputs or processes, while Arabic numerals number those classes. For ease of identification, the same numerical expressions in the table are also taken below.

In order to better understand services, each of 36 landscape services is explained in more detail with short but not exhaustive descriptions in the following, including the 14 provisioning services, the 13 regulating and maintenance services, and the 9 cultural and social services.

(1) P: Provisioning services

This theme includes all natural resources, goods and products from ecosystems and landscapes that provide to people. Indeed, it also includes those services that are manipulated by humans to provide certain products in more significant quantities than natural native products.

They are tangible things that can be consumed and used directly (products from nature directly, such as fish, tropical hardwoods, wild fruits or leaves) or indirectly

(such as products from cultivated plants or animals) by people, or exchanged and traded by people. But in the context of energy outputs, such as oil, solar and wind, are excluded.

Within the provisioning services theme, five major categories of services are recognised, ranging from food, water, materials to habitat.

P I Food

It is classified into further five classes: wild food, livestock, cereal crops, cash crops and aquaculture. This group includes wild food and human domestic and cultivated food, which are all ecosystem and landscape outputs and goods that are used directly or indirectly for food.

P1. Wild food

It includes wild fruits, plants and animals (incl. fish) for food, which means edible wild plant fruits, plants and animals, but excluding rare or protected species. Although today most food is derived from human domestic and cultivated food, a massive part of the human diet comes from wild fruits, plants and animals, ranging from fish, vegetables to fungi and berries.

P2. Livestock

As a social product of long-term human labour, livestock is defined as animals that are fed and domesticated by humans and can be controlled artificially, generally used and traded for food, labour, pets or experiments, such as pigs, sheep, cows, horses, rabbits, dogs.

P3. Cereal crops

Cereal crops are a source of people's staple food, including tuber crop, bean crop, grain crop, such as rice, corn, beans, potatoes, broad beans, wheat and so on, which contribute to satisfying the human survival needs and economic needs. This type of crop is also an excellent feed for livestock, which requires an enormous amount, and has a large cultivation area and specific gravity. In general, they are cultivated in certain forms of small-scale farming and large-scale intensive farming.

P4. Cash crops

Cash crops include oil crops, vegetable crops, feed crops, and medicinal crops, such as grass, green manure, ginseng, honeysuckle, and mint, with specific economic

uses and high economic value, usually for industrial demands. Generally, the cultivation of cash crops could offer an opportunity to farmers for higher incomes within the intensive farming, and develop an integrated and powerful commercial economy. As a result, cash crops are taking the place of subsistence farming.

P5. Aquaculture

Aquaculture is a production activity that reproduces, breeds, and harvests of aquatic animals and plants under human control, including the whole process of growing aquatic products from seedlings under artificial rearing management. The proliferation of marine resources may also be included in a broad sense. In the case of scarce arable land resources in the country or region, the development of marine resources can provide more and better aquatic products, which also helps improve human food and dietary structure.

P II Water

It includes freshwater and marine water that are consumed or used by people directly or indirectly, for industrial purpose, agricultural use, and domestic use.

P6. Freshwater

This service refers to the filtering, retention and storage of fresh water in water resources, mainly consisting of lake, river, glacier, wetland, stream and underground water. The vegetative cover and soil biota can help to filter water. They also can improve the ability of the plant root system and soil water storage of ecosystem and landscape, which contribute to the retention and storage of water. Freshwater is a necessary condition for survival, and usually for agricultural, industrial and domestic use. But today the pollution of freshwater is still threatening people that leads to the global shortage of freshwater.

P7. Saltwater

Seawater accounts for about 71% of the Earth's surface area and has enormous potential for development. Moreover, in the face of the growing shortage of freshwater resources on the planet, it is a meaningful thing to convert seawater into fresh water resources that humans can use. By technological means, such as distillation and reverse osmosis, salt water can be converted to fresh water for human use.

P III Materials

It includes biotic materials, including raw materials, ornamental resources, genetic resources and medicinal resources; and abiotic materials that are used in the production of goods.

P8. Raw materials

Natural ecosystems provide many biotic resources, especially raw materials. In general, raw materials are the conversion of solar energy into biomass, including forest products (timber, fibre), biodynamic components (fertiliser, latex, oil) and energy resources (fuel wood organic matter, animal power), for different kinds of industrial purposes and human construction.

P9. Ornamental resources

Nature provides many kinds of resources and materials which are used for ornamental purposes, such as fashion (mainly animal skins and feathers), handicraft (e.g. wood, stone), jewel, pets, worship (e.g. products related to religious or traditional culture use), decoration (e.g. flowers, aromatic plants), and souvenirs (i.e. products associated with local cultural character), and collections (i.e. butterflies, birds, feathers, animal skins). Notably, for landscape architects and garden designers, the ornamental resource is one of the most crucial design elements, which is essential for the tremendous sensory experience of visiting the park or garden. Variety use of wild plants, animals and related products is one of the forms of humankind's civilisation society.

P10. Genetic resources

Genetic resources refer to genetic materials and the evolution of wild plants and animals. The support of genetic resources and technology has dramatically improved crop cultivation and certain quality and adaptability and maintained cultivars productivity. The regular inputs of the genetic resource from certain species related to wild relatives and primitive domesticated ancestors are conducive to the production of more nutritious and richer foods. Also, the cultivation of new varieties in a shorter period can increase crop yields.

P11. Medicinal resources

Many biotic resources contribute to human healthcare by providing medicinal resources. For example, biochemical products can be used as medicines and healthcare products. Although in humanitarian terms, animal experiments seem cruel as they are texted new medicines or taken as medical tools, which indeed contribute to the development of medical research and human health.

P12. Abiotic materials

Abiotic materials refer to minerals or useful elements that have been developed through the formation of geological mineralisation. Even though the abiotic resources, in terms of ecosystem services, are usually not taken into account since they are non-renewable and cannot be attributed to specific ecosystems (de Groot et al., 2002). Here, they are considered in the context of landscape services, because they are attributed to specific landscape, and the mineral resources are the significant materials basis of economic and social development.

P IV Habitat

It includes habitation and nursery service, which aims to provide a suitable living place and shelter, or reproduction habitat for all plants and animals on earth. It is the pre-condition for the provision of all ecosystem goods and services. It is split into two distinct sub-services, habitation and nursery.

P13. Habitation

Natural ecosystems provide suitable living space and shelter for wild plants and animals, ranging from terrestrial habitats and marine habitats to inland water habitats, which are essential for residents and transient. Besides, to maintain biodiversity and genetic diversity, natural habitats are crucial for animals and plants.

P14. Nursery

Here, the nursery is defined as the suitable reproduction habitat, with providing breeding and nursery areas to commercial harvested species, including natural ecosystems and human-made nursery such as landscape nursery. The maintenance and development of nursery are helpful to meet industrial production needs, city greenery and environmental protective. Besides, it also contributes to the cultivation and conservation of scarce and valuable plant species.

(2) R: Regulating and maintenance services

The regulation and maintenance of ecological processes and life support systems on earth depend in no small extent on natural ecosystems (de Groot et al., 2002), as well as on landscape patterns and processes. However, because regulating and maintenance services are normally used indirectly, people often do not realise their importance of benefits until these services are lost or disturbed. Hence, it is essential for people to ensure the continued existence and integrity of these services.

This theme relates to the role of regulating effect and maintenance within ecological processes, and landscape pattern and processes on meteorological, hydrological, biochemical cycles, earth surface processes, and biological process. Those services are not consumed or traded but affect the performance of individuals, communities and populations and their activities, provide many benefits to human beings.

Within the regulating and maintenance theme, four major categories of services are recognised, meteorological services, hydrological services, pedologic services and biological services, respectively.

R I Meteorological services

It includes air quality regulation (incl. gas regulation), local and regional climate regulation, global climate regulation (incl. carbon sequestration) and disturbance prevention.

R1. Air quality regulation

The concentration of pollutants in the air determines the quality of the air. Air quality regulation refers to different gas and particular matter (PM) control, such as $CO_2/O_2/NO_2/SO_2$ balance, ozone layer protection, and fine particulate matter and inhalable particle regulation. This service mainly provides people with clean and breathable air, and prevent diseases caused by air pollution or poor air quality. Besides, it also has a negative influence on climate due to the greenhouse gases emissions.

R2. Local and regional climate regulation

Factors for local and regional weather and climate formation usually are the complex interaction of local and regional circulation patterns and local topography,

vegetation, land use types and human activities. Besides, the urban climate is determined by specific materials of city ground and building, population density and intensive economic activities, which leads to an urban heat island effect. Regulation of local and regional climate plays an essential role in the relieving the urban heat island effect, modifying temperature and increasing air humidity.

R3. Global climate regulation (incl. Carbon sequestration)

Climate change is undergoing continuous changes in land use and the components of atmospheric gases in the global scale, with negative influence on human beings and related environments - this service is provided by the functions of landscapes on global climatic conditions through land-cover and biologically-mediated processes. By regulating global climate, the control of global warming and greenhouse gas-balance, human health, social and economic activities can be guaranteed.

R4. Disturbance prevention (incl. natural hazard mitigation)

Generally, natural ecosystems or elastic landscapes have high capacities to moderate adverse natural events and environmental disturbances, for instance, to prevent flood and storms by the capacity of water storage and surface resistance of vegetation cover (i.e., wetlands or forests). This service can safeguard a human's life and property safety, create stable life-communities and prevent the outbreak of diseases.

R II Hydrological services

This category includes water regulation, water purification and groundwater recharge.

R5. Water regulation

Even though this service refers to regulating runoff and river discharge, to regulate the hydrological flows at the earth surface, it is excluded from disturbance prevention since it only considers the state and conditions of natural watershed instead of extreme natural events. For example, it refers to the maintenance of drainage and irrigation and the effect of watersheds as the transport mediums.

R6. Water purification

Many natural resources, such as vegetation cover and structure (e.g., hygrophyte or aquatic plant), contribute to filtering and purifying water. Meanwhile, the watershed

itself has the ability to self-purify, for example, aquatic organisms and bio-chemicals reduce the concentration of pollutants in the water through strategies such as adsorption, degradation, and transformation. This service focuses primarily on the filtration and purification of water to guarantee water security for people.

R7. Groundwater recharge

Groundwater supply is stable and less polluting. Groundwater recharge is one of the critical sources of water resources. It refers to the supplementation of groundwater in various ways, for instance, rainfall, irrigation, underground runoff, channel or water leakage. It is worth noting that the blind and over-exploitation of groundwater can easily lead to a drop in groundwater levels and subsidence of the ground.

R III Pedologic services

This category includes soil retention (incl. erosion prevention) and soil formation.

R8. Soil retention

Soil retention service highlights the role of landscape structure and ecosystems, like vegetation root matrix and biota, in soil retention. For example, to prevent the slope soil from being washed by raindrops and storm-water runoff by increasing the vegetation cover on the ground. This service is significant to maintain soil structure and agricultural productivity, and prevent damage due to soil erosion.

R9. Soil formation

Soil fertility is an important indicator reflecting the fertile of soil and is a comprehensive reflection of soil physical, chemical and biological characteristics. This service provides to maintain crop productivity and natural productive soils by protecting and improve soil fertility and preventing the loss of fertility.

R IV Biological services

This category includes pollination, pest and disease control, nutrient regulation, waste treatment & disposal (incl. noise protection).

R10. Pollination

Pollination is a necessary process for a plant to produce fruit, which is essential for the reproduction of most plants and crops. Here, pollination service only considers natural pollination (i.e., wind-pollinated, water-born, bird media) without artificial

pollination, since artificial pollination is not attributed to specific landscape or ecosystem. The vast majority of pollinators are wild species, including insects and some vertebrates such as birds and bats. Only some bees (through beekeeping industries) are under management. This service contributes to spread plants' need and reproduce, as well as improve biodiversity and protect certain species.

R11. Pest and disease control

More than 95% of all the potential pests of crops and carriers of diseases to human beings are controlled by natural ecosystems (P. R. Ehrlich, 1985). Pest and disease control are the population control through trophic-dynamic relations and biological control mechanisms (i.e., control of pathogens) to reduce human diseases.

R12. Nutrient regulation

Life on earth benefits from the constant cycling of chemical elements in nature. This service refers to the role of biota in storage and (re) cycling of nutrients to maintain the productive ecosystems and healthy soils. Nutrient elements include a variety of chemical elements. For example, carbon (C), oxygen (O), hydrogen (H), nitrogen (N), sulphur (S), and phosphorous (P). These chemical elements are also discussed in the 'air quality regulation' service and 'climate regulation' service. They play a vital role in these services. Besides, a large number of trace elements and macro-nutrients are included in nutrient elements, such as calcium, magnesium, and iron and zinc.

R13. Waste treatment and disposal

Natural ecosystems and landscapes can store, recycle, regulate and control certain waste, such as organic and inorganic human waste related to control pollution from human activities. This service refers to the role of vegetation and biota in dilution, assimilation and chemical re-composition of absolute waste. For example, plants are able to filter and store dust particles from the air. Also, wetlands can treat relatively a large amounts of organic wastes to purify water, and a large area of forests can adsorb toxic substances.

(3) C: Cultural and social services

Nature is a vital role of inspiring science, art, culture and research. This theme relates to the intangible and immaterial services from the landscapes, natural

ecosystems and artificial landscape to benefit human beings, such as providing almost unlimited opportunities for recreation and relaxation, cognitive development, spiritual enrichment, and mental development and so on.

It is classified into further three categories, including physical health, psychological health and enjoyment, and experiential significance. Each of them will be explained as follow.

C I Physical health services

This category includes medical care, to contribute to the physical fitness of human or release pressure by horticultural therapy or aromatherapy.

C1. Medical/healthcare

Nature and landscape elements and characters, or landscapes that have been planned and designed by the human, have an important role of providing medical or health care to human beings. For instance, horticultural therapy and aromatherapy are best known by people. It is important and meaningful to treat illness and rejuvenate the mind by contacting the natural environment (such as national parks, forests or gardens), using horticultural materials (i.e., gardens or parks are surrounding by ornamental and aromatic plants), carrying out and performing horticultural activities.

C II Psychological services (health and enjoyment)

This category includes aesthetic value and enjoyment, artistic conception and identity, which all contribute to satisfy people's emotional needs and establish a scenario to appreciate the emotion sublimate.

C2. Aesthetic value and enjoyment

The attractive, diversity, beauty or uniqueness of scenery of landscapes and natural areas provide a great amount of aesthetic enjoyment and values for people. At the same time, people are eager for an aesthetically pleasing environment. For example, they are willing to pay a high price for living in a house near a national park, or have a beautiful scenery view. Also this kind of houses are usually much more expensive than similar houses in short of aesthetic appreciation. Furthermore, parks, gardens, or scenic roads are planned and designed by landscape architects usually with high landscape aesthetic to satisfy human needs.

C3. Artistic conception

Throughout history, in general, human beings always prefer to endow their subjective thinking on real objects. To a certain extent, this way contributes to improving inspiration for culture, art and design within landscape features or elements. Artistic conception is essential to the development of human civilisation, which is reflected in, for example, the poetry to praise nature, and their feelings and gnosis related to nature or inspired by nature.

C4. Identity

The sense of identity and belonging is essential for human beings, such as place identity, cultural identity and national identity. Generally, these kinds of feelings are aroused and inspired by landscape elements, characteristics and natural environments. A sense of identity can not only help people to enhance and consolidate political and social cognition but also help to enhance the recognition of their hometown, community or country. It can also resonate culturally and emotionally and strengthen national cohesion and cultural identity.

C III Experiential services

The category of 'Experiential services' includes recreation, tourism, scientific and education, landscape or historical heritages, and ethical, spiritual, religious information. They are related to the landscape characteristics and elements, as well as the artificial built environment within the landscape with various values to experience in the ecosystems or landscapes.

C5. Recreation

Natural ecosystems and landscapes provide a variety of places and opportunities that people can come and enjoy for leisure and relaxation. For example, outdoor recreation or adventurous entertainment such as walking, hiking, climbing, cycling or camping. As well as the regular recreation activities in communities. In order to adjust the tension and a rapid pace of life, reduce stress, release emotions, maintain harmonious family relationships and be close to nature, modern society increasingly needs to provide daily or periodic recreation activities for people to ensure people's physical and mental health.

C6. Tourism

Tourism resources include natural landscape tourism resources and cultural landscape tourism resources. Natural landscape tourism resources include mountains, valleys, forests, volcanoes, rivers, lakes, beaches, hot springs, wildlife and so on. Cultural landscape tourism resources include historical and cultural monuments, ancient architecture, modern city landmarks and cultural heritage. The development of eco-tourism not only promotes economic development but also supports the sustainable development of tourism. It means the principle of sustainable development, the premise of protecting the eco-environment, the principle of coordinating the harmonious relationships between human and nature. Besides, it also can support the way of eco-education, ecological cognition and psycho-pleasure tourism by relying on a unique humanistic ecological system and adopting an ecologically friendly approach and ecological experience.

C7. Scientific and education

Natural landscape and landscape elements and landscape characters can provide almost unlimited opportunities for scientific research (i.e., thousands of publications each year), environmental education (e.g., excursions, wildlife conservation, etc.), and nature study (e.g., bird watching or field laboratories). Natural and semi-natural areas also serve as effective reference areas for monitoring and managing environmental changes.

C8. Landscape / Historical heritage

As the common products of human civilisation and nature, landscape or historical heritages are irreplaceable, such as place of remembrance, traditional cultural landscape heritages, or religious values places to express worship or belief. This service plays a crucial role in protecting cultural and historical heritage and raising awareness of culture and tradition identity.

C9. Ethical, spiritual, religious information

Natural ecosystems and landscape elements provide a sense of continuity and understanding of places with ethical, spiritual and religious values. For example, the

usage of nature for religious purpose through the worship of holy forests, trees or animals, but this kind of use is different from the use of historical religious heritage.

2.6 Discussion

Landscape service is an emerging research topic, the number and content of research results are limited. There are no enough empirical researches as theoretical support; no sophisticated research system is formed. Even though the current ecosystem service research has gradually developed a comprehensive and mature theoretical system and has been mainstreamed in academia. It has been more than twenty years since ES approach study started. Therefore, the concept of LS with a complete scientific theoretical system still needs long-term and a large number of theoretical and empirical researches accumulated.

Through the discussion in this chapter, the concept of LS, from the perspective of the landscape, is an extension of the concept of ES. It provides a new view and approach for the development of theory of LS.

First, this chapter discusses many researchers' definitions (Bastian et al., 2014; de Groot & Hein, 2007; Haines-Young & Potschin, 2010a; Kienast et al., 2009; Nowak & Grunewald, 2018; Sun et al., 2018; Termorshuizen & Opdam, 2009; Vallés-Planells et al., 2014; L. Willemen et al., 2012). Then it discusses and contrasts different researches on ES and LS and sorts out their development contexts and classification typologies, which help to better understand the meaning of these two concepts and their relationship.

Second, it presents arguments in favour of replacing ES by LS through the case of CNP. Considering the concept and approach of ES cannot provide a broader view on landscape research, this case study is aiming to consider the identification and classification of LS in the context of landscape.

Moreover, regarding the question of how to define LS towards landscape research, basing on the theoretical considerations and the case study presented in this chapter, the author proposes and supplements the definition and classification system of LS. It is also an assessment and quantifiable method for LS to be carried out in later research. More importantly, based on the theory of LS, it provides a theoretical basis for guiding

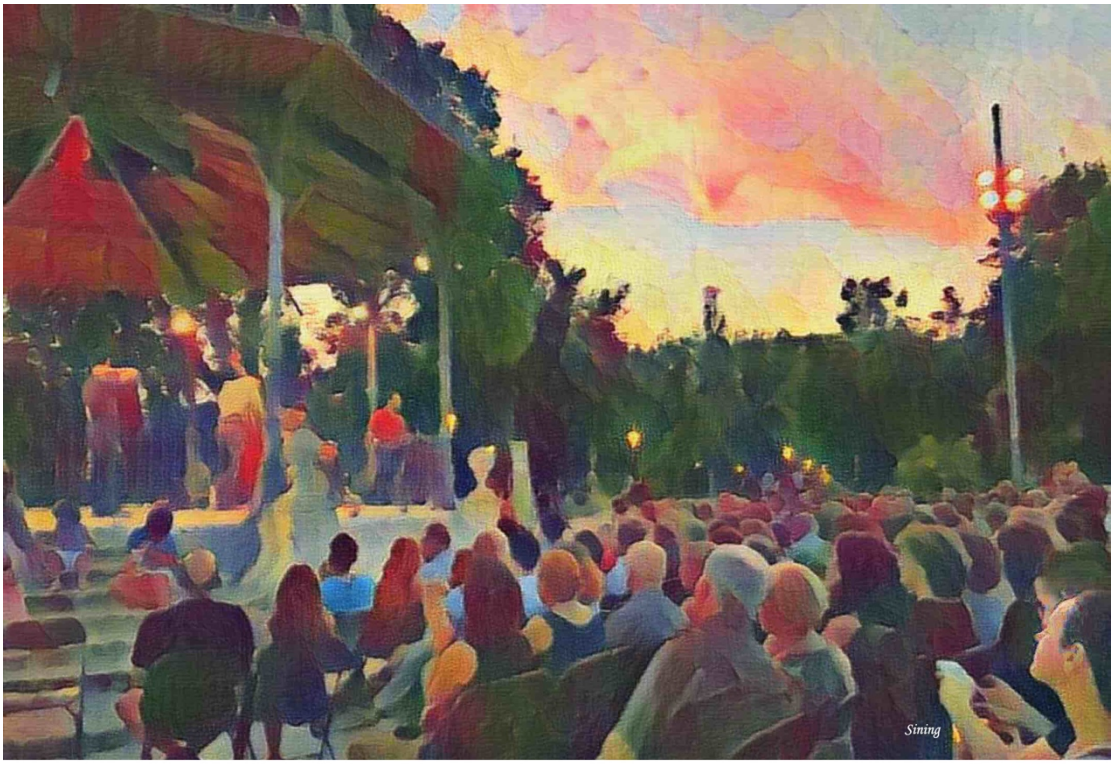
planning and building urban green infrastructure. At the same time, through empirical research, it will be better to offer empirical cases to the maturity of the academic system of LS. Therefore, this chapter has an irreplaceable influence on theoretical supporting.

Although the concept of LS is derived from ES, and in many studies, they are treated as substitutes. However, in the background of landscape ecology and landscape planning, LS can generate more added values and is a common ground to unify various disciplines (Termorshuizen & Opdam, 2009).

Therefore, in the context of landscape research, I proposed an argument to support the replacement of ES by LS.

Taking into account the literature review and my own research, we can note that LS shows the following special features compared to ES.

1) Landscape services are closely related to landscapes, especially landscape features, landscape elements, landscape structures, landscape planning and management, rather than to ecosystems.
2) In terms of LS classification, in addition to expanding the same parts as the ES classification, the LS classification system focuses on aspects that are closely related to humans, such as physical health, psychological emotions and experiences, ethics and other social and cultural aspects.
3) Expressions of spatial characteristics and landscape heterogeneity. For example, in the case of CNP, the effects of landscape characteristics and elements on regional characteristics and human activities are considered.
4) Pay more attention to human influence. Because ‘landscape’ is the product of the interaction between humans and the environment.
5) Through the case study of CNP, it can be seen that the concept of LS is more relevant to the practice of landscape planning and landscape management.
6) According to the previous discussion, LS can meet the demands of different stakeholders, promote the cross-broader decision-making process and develop the research of landscape sustainability science.



The concert in Ciutadella Park, Barcelona, Spain (illustration by author.)

3 CHAPTER THREE: ASSESSING AND MAPPING LANDSCAPE SERVICES SUPPLY

3.1 Introduction

In the previous chapter, we discussed and provided the general theory of LS. On this basis, the research of this chapter can be carried out.

The assessment and mapping of ES aim to see how to transform data using different methods and tools to assess ES and how to visualise the results to show the spatial distribution characteristics of ES in an explicit spatial way. Landscape services are based on human utilisation, and satisfy human consumption and demand for ES through natural and socio-cultural landscapes directly or indirectly. The research of assessment and mapping of ES proves that it contributes to supporting decision-making (Beier et al., 2008; Daily et al., 2009) and landscape planning (Frank et al., 2012; Koschke et al., 2012), as well as for better planning urban green spaces (Niemelä J et al., 2010).

This dissertation is considering the approach of landscape planning, taking into account the landscape services provided by a specific territory, the assessment of the supply of landscape services represents a broader way than the traditional environmental approach based on the ES approach. Rather, the landscape service supply capacity of a region will be a better guide to the definition and implementation of urban green infrastructure for urban and regional planning strategies. The assessment and mapping of LS considers not only natural, wilderness or green areas, but also the extensive spaces such as intermediate corridors, urban fringes and even voids and blank areas located in different areas of the city. The scope and possibilities of planning a city's green infrastructure are more complicated.

Therefore, quantitative assessment and mapping of landscape services are extremely critical.

It becomes a critical research agenda with the great development of advanced GIS technology that different approaches and frameworks have been promoted to create and analyse ES on different scales. Currently, in the existing literature, the main research methodologies rely mainly on literature survey approach or model methods, which

make the most use of current knowledge and theories. These include, for example, the market-valuing method (Bateman et al., 2002; de Groot et al., 2010), ecological process simulation (Stürck, Poortinga, & Verburg, 2014; Nedkov, 2012), data space stacking (e.g., Serna-Chavez et al., 2014), and the Integrated Valuation of Ecosystem Services and Trade-offs tool (InVEST) (e.g., Arcidiacono, Ronchi, & Salata, 2015; Boithias et al., 2014). Besides, the land-cover based approach (Burkhard et al., 2015, 2009, 2012) is a quantitative process of supply capacity of ecosystem services in specific land cover types, which is widely used. In recent years, many researchers have adopted this method in large scale instead of the small scale (e.g., Tao, Wang, Ou, & Guo, 2018), because there is no need for overly detailed data processing.

Although the great interest in research topics of ES and LS, LS still lacks in landscape models and tools to address the evaluation and quantification (Mander et al., 2007).

In the landscape research dimension, in order to get a more accurate assessment result and to better apply to the landscape planning and decision-making process, the above assessment and mapping methods can be used in combination with each other generally (e.g., Kienast et al. 2009; Willemen et al. 2008; Nowak & Grunewald, 2018; Hermann et al., 2014).

Therefore, this chapter aims to provide one methodology for assessing and mapping the supply of landscape services. In this chapter, I build the landscape services assessment matrix (LSAM) adapted from the land-cover based approach to quantify the LS provision potential. Because the land-cover based approach is a rapid assessment procedure with strong implications for the decision-making process. It could be applied to different regions and has a lower requirement for the initial data, only requiring the land cover types data and the experts' experience and knowledge. Besides, in LSAM, there are six common steps to assess and analyse the spatial distribution characteristics of LS within Barcelona municipality, combining with the ArcGIS to visualising the results.

3.2 Methodology

3.2.1 Study area

Catalonia is an autonomous metropolitan of Spain. It is formed by four provinces (province of Barcelona, province of Girona, province of Lleida, province of Tarragona). Barcelona is the capital of the Catalonia autonomous community, the provincial capital of Barcelona Province, and one of the municipalities of Barcelonés (Figure 3-1). It is also a leading cultural and economic city in South-western Europe. The city port is a crucial international transport harbour.

It is the second largest city in Spain. It has ten districts, including Horta-Guinardó, Gràcia, Eixample, Ciutat Vella, Nou Barris, Sant Andreu, Sant Martí, Sants-Montjuïc, Les Corts and Sarrià-Sant Gervasi.

It is also one of the most compactly and densely populated cities of Europe, with a population of 1.620.809 inhabitants, almost accounting for around 50% of the total population in the metropolitan area of Barcelona, with a population of 3.247.281 inhabitants (Barcelona City Council Statistical Yearbook, 2018). It is the eleventh populated city in the European Union.

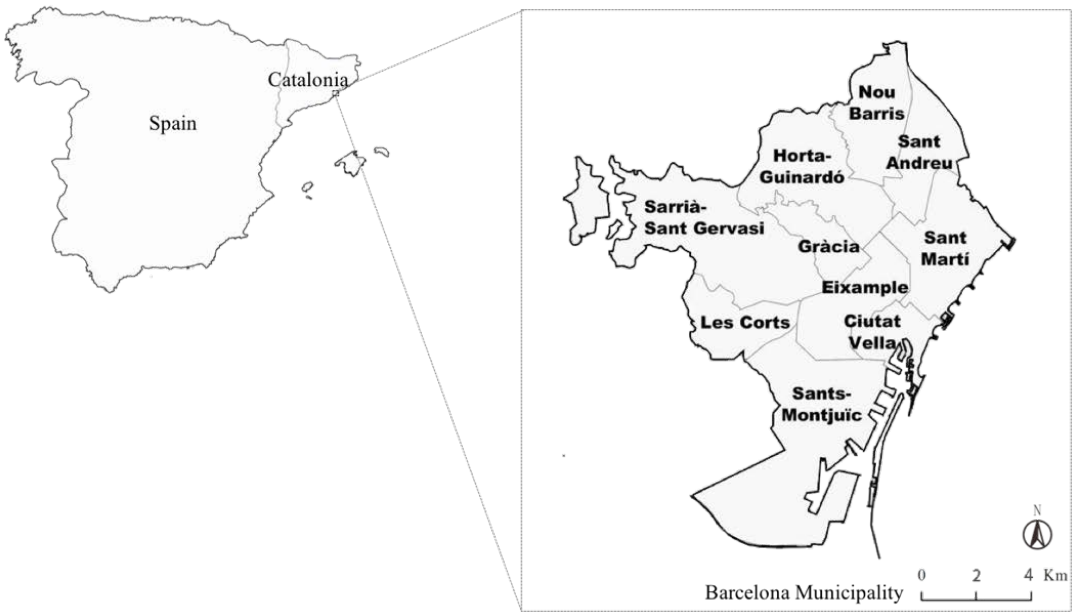


Fig. 3-1 Location of Barcelona Municipality. *Source*: author drawing based on the website: https://en.wikipedia.org/wiki/Barcelona

The city's longitude and latitude location are: 41°23′N, 2°11′E, which is located in the northeast of Iberian Peninsula and the northwest of Mediterranean Sea, with a coastline of sandy beaches and Montjuïc hill. The city stretches across Barcelona plain. It is surrounded by the Collserola Natural Park in the northwest. It borders the Besòs river to the northeast, and the Llobregat river to the southwest, with a river delta each. It remains the same range until now.

Barcelona has a Mediterranean climate. It is hot and dry in summer and mild and rainy in winter. According to the observatory Can Bruixa, the coldest months of Barcelona are January and February, the average temperature is 13.4°. The hottest months are July and August, the average temperature is 25.9° (Temperature 2012-2016). Besides, the total precipitation. According to 5 years (2012-2016) data of precipitation in the Barcelona city, the average annual total precipitation is about 490.24 mm, and it has averages 109 rainy days per year from 2012 to 2016 (Precipitation 2012-2016).

3.2.2 Land Cover Classes

The quality and quantity of landscape services are directly affected by the structural and functional changes of land use types. For example, land use change can affect regional or global climate, such as global warming (Pielke, 2002), which means, the capacity of local and global climate regulation service would decrease accordingly. Moreover, improper land use can lead to habitat and landscape fragmentation (Mitchell, Bennett, & Gonzalez, 2013; Mitchell et al., 2015), thus destroying wildlife habitats and changing landscape connectivity, which would further affect the formation and supply of LS directly or indirectly. At the same time, the impact of land-use change on landscape services is not just negative but also positive. For instance, Lovell (2010) discussed urban agriculture is a sustainable and multifunctional land use option for cities; Hostetler, M. et al. (2011) found that establishing urban green infrastructure is crucial to conserve biodiversity, instead of constructing commercial areas. Hence, the implementation of land management and optimisation of land use structure could ensure and improve the formation of LS (de Groot et al., 2010).

There are plenty of shared geographical information and data regarding land cover classes. This dissertation adopts the Coordination of Information on the Environment

(CORINE) land cover (CLC) data as the reference areas. The CORINE programme was initiated in the European Environment Agency (EEA) in 1985 (EEA, 1994). This database includes 44 land cover classes in Europe, and ten of them are presented in the study area, according to the CLC in 2012 (See Figure 3-3). CLC uses a minimum mapping unit of 25 ha, and a minimum width of 100 m (EEA, 1994). This study incorporates the vector data and landscape services matrices in ArcGIS to visualise the spatial distribution of landscape services in the study area.

3.2.3 Landscape services assessment matrix

I built the landscape services matrix to show the spatial distribution characteristics of LS within the specific area. In the LSAM, I propose six typical steps to assess the supply capacity of LS based upon the land-cover based approach in the investigated area (See Figure 3-2).

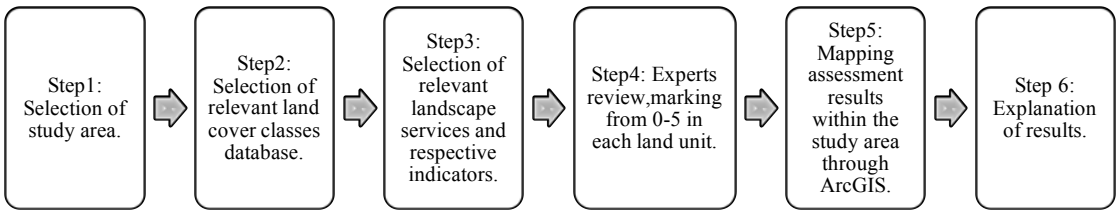


Fig. 3-2 Typical steps of land-cover based landscape services supply assessments, *Source*: own elaboration after Hou, Burkhard, and Müller, (2013).

1) The selection of study area.

2) It is vital to choose an applicable and scientific land use database within the investigated area because landscape services matrix consists of supply capacities of various landscape services (x-axis) and different land cover types (y-axis).

3) In order to build the LSAM, I propose to select the relevant LS and respective indicators.

4) Diverse experts score the supply capacities of LS. Experts assign a score for each entry in the matrix, which means certain landscape service capacity on a

relative land unit. The score ranges from 0-5. 0 represents no relevant capacity of landscape service, 5 represents very high relevant capacity, the rest can be done in the same manner. In this procedure, it is important to check data and reach a consensus.

5) After acquiring the scores from experts group, the delivery capacity of LS was mapped and visualised by using ArcGIS to interlink assessment results to spatial land units. The mapping shows the spatial distribution and characteristics of LS in the investigated area, which provides an intuitive reference for land planners and decision-makers.

6) The interpretation of results is required.

3.3 Quantification and mapping of landscape service supply

3.3.1 Land cover classes of Barcelona municipality

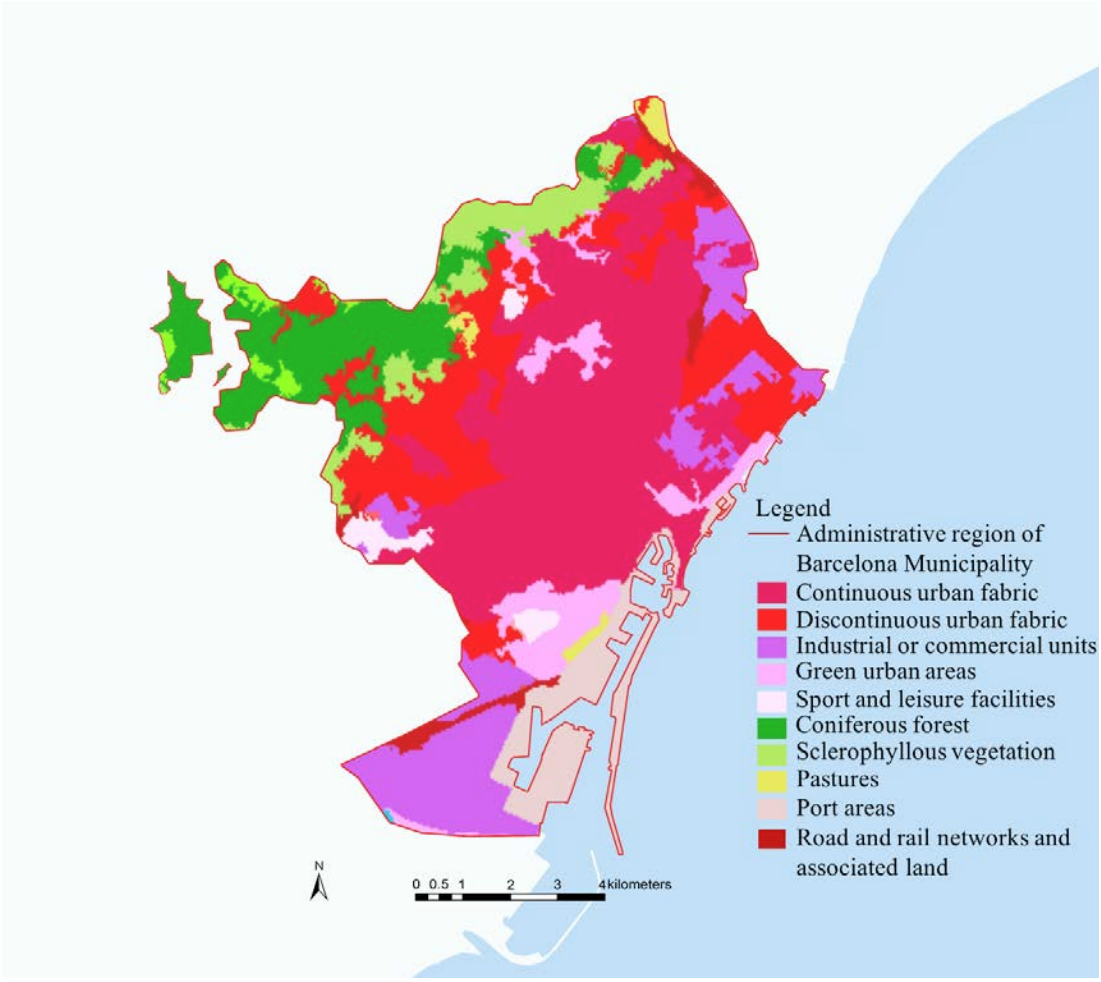


Fig. 3-3 Land cover classes of Barcelona municipality. *Source*: own elaboration based on CLC (2012).

The land cover classes within the Barcelona municipality are derived from the CLC database in 2012. According to this database, there are ten land use types are presented in the study area: continuous urban fabric, discontinuous urban fabric, industrial or commercial units, green urban areas, sport and leisure facilities, coniferous forest, sclerophyllous vegetation, pastures, port areas and road and rail networks and associated land respectively (See Figure 3-3).

The CORINE land cover report demonstrates that the nomenclature illustrations of each of ten land use types. Table 3-1 explains the definition of each land use types in Barcelona.

Table 3-1 The explanation of ten land use types. *Source*: CORINE Land Cover Report (EEA, 1994, p. 100-139).

Land cover types	**Explanation**
Continuous urban fabric	Most of the land is covered by structures and the transport network. Buildings, roads and artificially surfaced areas cover more than 80% of the total surface.
Discontinuous urban fabric	Most of the land is covered by structures. Buildings, roads and artificially surfaced areas are associated with vegetated areas and bare soil, which occupy discontinuous but significant surfaces.
Industrial or commercial units	Artificially surfaced areas (cement, asphalt, tarmacadam, or stabilised) without vegetation occupy most of the area, which also contains buildings and/or vegetation.
Green urban areas	Areas with vegetation within the urban fabric, including parks, cemeteries with vegetation, and mansions and their ground.
Sport and leisure facilities	Camping grounds, sports grounds, leisure parks, golf courses, racecourses, etc. Includes formal parks not surrounded by urban areas.
Coniferous forest	Vegetation formation composed principally of trees, including shrub and bush understoreys, where coniferous species predominate.
Sclerophyllous vegetation	Bushy sclerophyllous vegetation, including maquis and garrigue.
Pastures	Dense grass cover, of floral composition, dominated by graminaceae, not under a rotation system. Includes areas with hedges (bocage).
Port areas	Infrastructure of port areas, including quays, dockyards and marinas.
Road and rail networks and associated land	Motorways and railways, including associated installations (stations, platforms, embankments).

As can be seen from Figure 3-3, in Barcelona Municipality, the largest land use type is continuous urban fabric, followed by discontinuous urban fabric. Urban green areas, sclerophyllous vegetation and pastures occupy a small part.

3.3.2 Assessment of landscape services provision

Based on the LSAM mentioned above, this study takes the three categories of landscape services (including regulating and maintenance services, provisioning services, cultural and social services) as X-axis, which includes 29 sub-categories, and takes ten different urban land cover types in Barcelona city as Y-axis, including continuous urban fabric, discontinuous urban fabric, industrial or commercial units, green urban areas, sport and leisure facilities, coniferous forest, sclerophyllous vegetation, pastures, port areas and road and rail networks and associated land. Even though there are 36 sub-categories in the classification system of landscape services (see chapter two, Table 2-2) that I proposed. However, here, only 29 sub-categories of LS that most relevant are chosen in the LSAM. For example, five sub-categories of food provisioning services (wild food, livestock, cereal crops, cash crops, aquaculture) are all included into one sub-category 'food'; two sub-services of water (freshwater and salty water) are included into one service 'water'.

So the matrix contains a total of 290 entries. The score for each of entry in the matrix indicates the supply capacity of LS per unit of a certain land use type in Barcelona city.

The grades were determined by three steps as follow.

In the first step, we assigned a score for each entry. The score ranges from 0 to 5. 0 represents no relevant capacity to supply landscape service, and the higher score represents higher relevant capacity, the rest can be done in the same manner.

In the second step, through the interviews and questionnaires[3], the experts' group assigned a score for each entry for the investigated area in the matrix individually, which means the score represents the supply capacity of certain landscape service on a

[3] The link of questionnaire: https://docs.google.com/forms/d/e/1FAIpQLSev4QPU_VgPIFfhK2s33r0nK48xHaenh58ZJqEyq0x2DiX_0g/viewform?usp=sf_link

relative land use unit. I invited 56 experts to answer the questionnaires or to do interviews. However, there are only 36 experts responded. So the experts' group consists of 36 individuals, who are from the background of different disciplines, such as landscape architects, ecologist, geographers, botanist, the residents of Barcelona, the employers of the Collserola Natural Park. In this procedure, it is important to check data and reach a consensus.

So, in the third step, several rounds of the panel discussion among the experts' group are organised that forming the final score. Thus, from the result, the evaluation matrix is obtained as Figure 3-4 shows.

Figure 3-4 shows clearly that different supply capacity of LS in different land cover types in the study area. More specifically, artificial areas with strong human intervention, such as continuous urban fabric, discontinuous urban fabric, transport networks, industrial or commercial units and ports areas, almost have no capacities to deliver regulating services, provisioning services and habitat services. But still have insufficient capacity to offer cultural services. In other words, those artificial areas of the urban ecosystem, especially grey infrastructure, compared with green infrastructure, although do not contribute substantial LS, as well as have a contribution. On the opposite, those green areas, such as urban green areas, coniferous forest, sclerophyllous vegetation and pastures, can provide many landscape services. Particularly, the coniferous forest has a considerable influence on improving air quality, regulating climate and offering recreation facilities and cultural edification opportunities.

LS / LUT	**Regulating & Maintenance services**	Local climate regulation	Global climate regulation	Disturbance prevention	Air quality regulation	Water regulation	Water purification	Groundwater recharge	Soil retention	Soil formation	Nutrient regulation	Pollination	Waste treatment	Erosion protection	Pest and disease control	**Provisioning services**	Food	Water	Raw materials	Genetic resources	Medicinal resources	Ornamental resources	Habitation	Nursery	**Cultural & Social services**	Identity	Aesthetic value	Recreation	Artistic conception	History and religion	Science and education	Tourism
Continuous urban fabric		0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0		2	2	2	2	2	2	3
Discontinuous urban fabric		0	0	0	0	0	0	0	0	0	1	0	0	0	0		1	0	1	0	0	0	1	1		1	1	1	1	1	1	1
Road and rail networks and associated land		0	0	0	0	0	0	0	0	0	0	0	0	0	2		0	0	0	0	0	0	0	0		0	0	0	0	0	0	4
Industrial or commercial units		0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0	0	0	0	0	0	0		0	0	0	0	0	0	3
Green urban areas		3	2	0	3	1	1	2	1	1	1	1	1	2	1		1	0	0	1	1	4	3	2		3	3	3	2	2	2	4
Sport and leisure facilities		1	1	0	1	1	1	2	0	0	1	1	0	1	0		0	0	0	0	0	0	1	1		2	3	5	3	2	2	2
Coniferous forest		5	4	3	5	5	5	2	5	5	5	5	4	5	5		1	0	5	4	4	5	4	4		4	5	5	3	4	4	4
Sclerophyllous vegetation		3	1	1	1	0	0	1	1	1	3	2	1	0	3		1	0	0	0	2	1	2	1		0	2	2	1	0	1	1
Pastures		1	1	1	4	1	0	1	0	0	0	0	0	0	2		4	0	4	2	2	1	2	2		1	1	3	1	0	0	1
Port areas		0	0	3	0	0	0	0	0	0	0	0	0	0	1		0	0	0	0	0	0	0	0		0	0	1	0	0	0	1

Fig. 3-4 Landscape services assessment matrix (Burkhard et al., 2009; Burkhard et al., 2012; Burkhard et al., 2015). It illustrates different capacities to deliver landscape services in different land use types in Barcelona municipality.

Notes:

The assessment scale reaches from 0 to 5 by different colours: 0/yellow = there is no relevant capacity to provide this certain ecosystem services; 1/blue = low relevant capacity; 2/green = relevant capacity; 3/red = medium relevant capacity; 4/turquoise = high relevant capacity; 5/purple = very high relevant capacity.

3.3.3 Spatial distribution of landscape services supply

The results of the quantitative assessment are presented in a spatially visualised manner, which allows the results to be more clearly expressed. This is a very intuitive and clear way of expression for decision makers, land planners and stakeholders.

The data obtained from Figure 3-4 and land cover types within the study area, can be visualised by joining data to the attribute table of the polygon shape-file in ArcGIS. Then the data is projected onto the urban spaces in Barcelona municipality to obtain the spatial distribution of the three categories of landscape services assessment maps: the spatial distribution map of regulating and maintenance services supply (Fig. 3-5); the spatial distribution map of provisioning services supply (Fig. 3-6); the spatial distribution map of cultural and social services supply (Fig. 3-7). We can clearly see from these three maps that the spatial distribution characteristics of LS in Barcelona, as well as the significant differences between LS provided by different land use types.

Figure 3-8 shows that the partial detail map of regulating, cultural and provisioning services supply. We can see clearly that the differences among these three kinds of services supply capacity are unbalance extremely within the same area.

In order to get a clearer and more comprehensive information of supply capacity of LS within the study area, these three maps (Figure 3-5, Figure 3-6, Figure 3-7) are overlapped to get the final landscape services assessment map (Figure 3-9), which shows the spatial distribution characteristics of all landscape services in Barcelona city intuitively.

First, it can be seen that the most profitable areas are city's natural and semi-natural green areas, such as the Collserola Natural Park and the Montjuïc mountain, which means they are essential parts to support urban green infrastructure.

Second, the fragmentation of the urban landscape has resulted in the extremely unbalance provision of the landscape services in the city. The providing capacity of the large-scale hardened areas is weak (the score in LSAM is about 1), and become isolated since they almost do not have a border with urban forest and parks.

Therefore, the quantification mapping of landscape services can contribute to providing a reference for the decision-making process while weighing the pros and cons of the possible consequences of likely decisions.

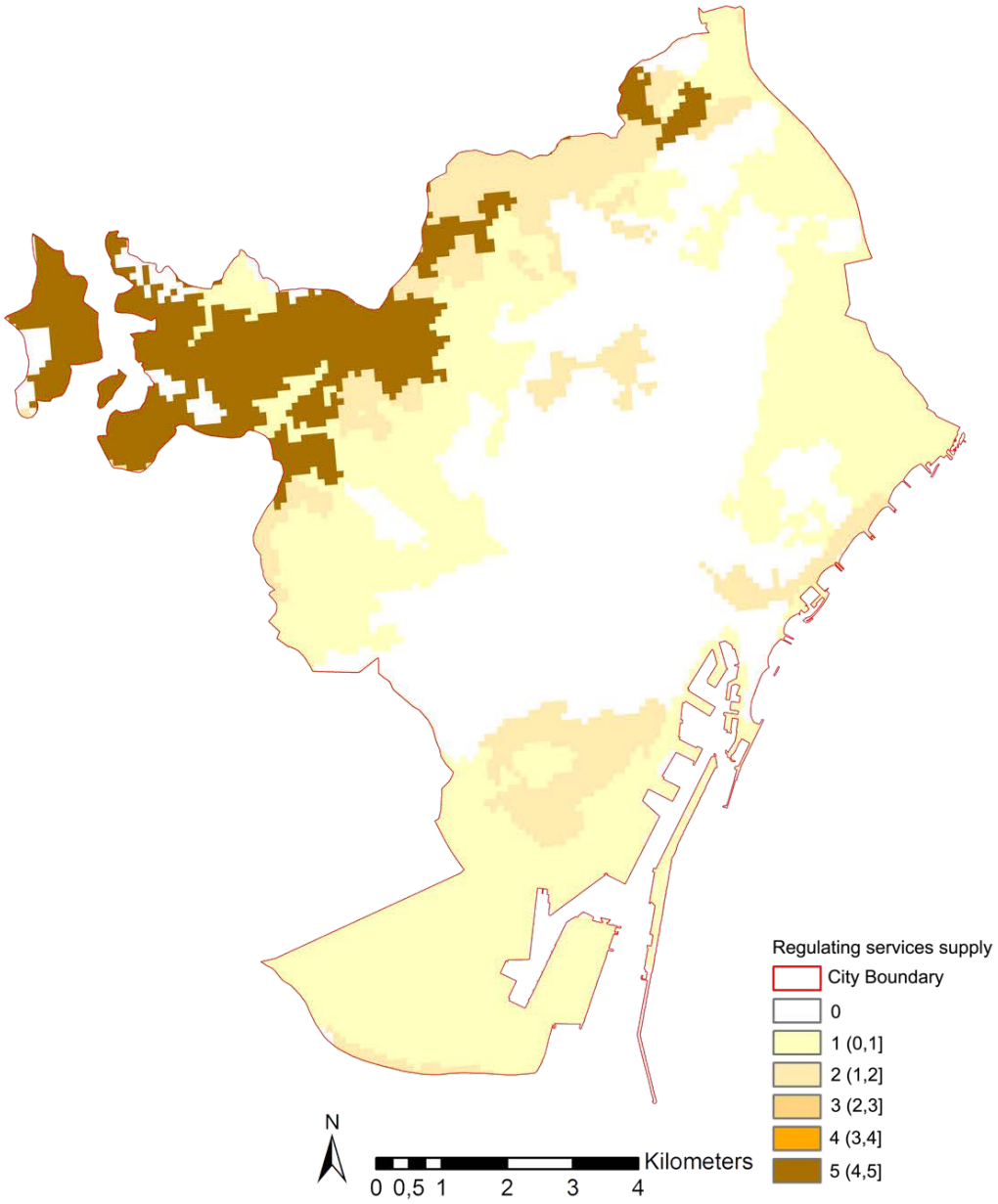


Fig. 3-5 The spatial distribution map of regulating and maintenance services supply in Barcelona municipality. *Source*: own elaboration.

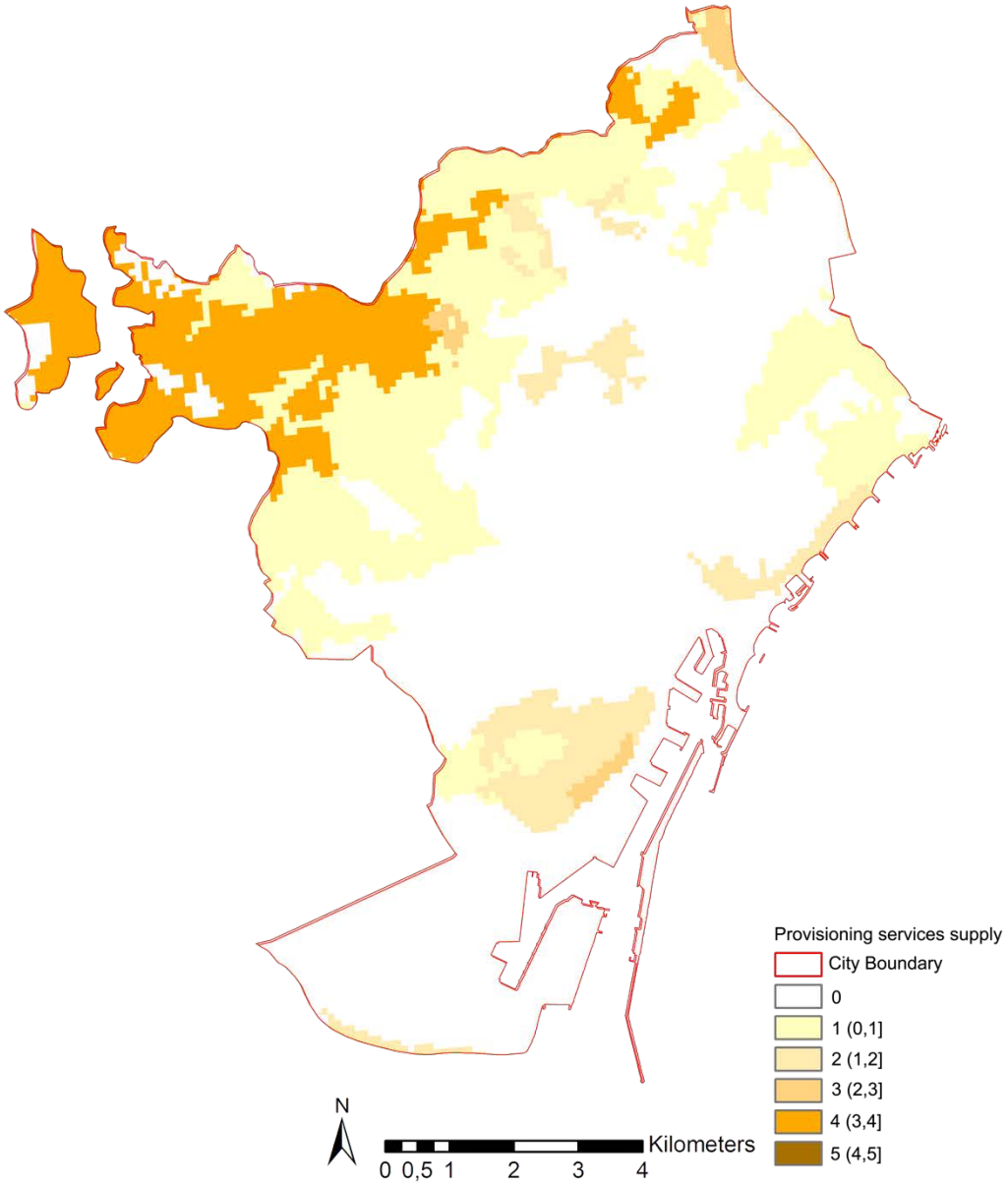


Fig. 3-6 The spatial distribution map of provisioning services supply in Barcelona municipality. *Source*: own elaboration.

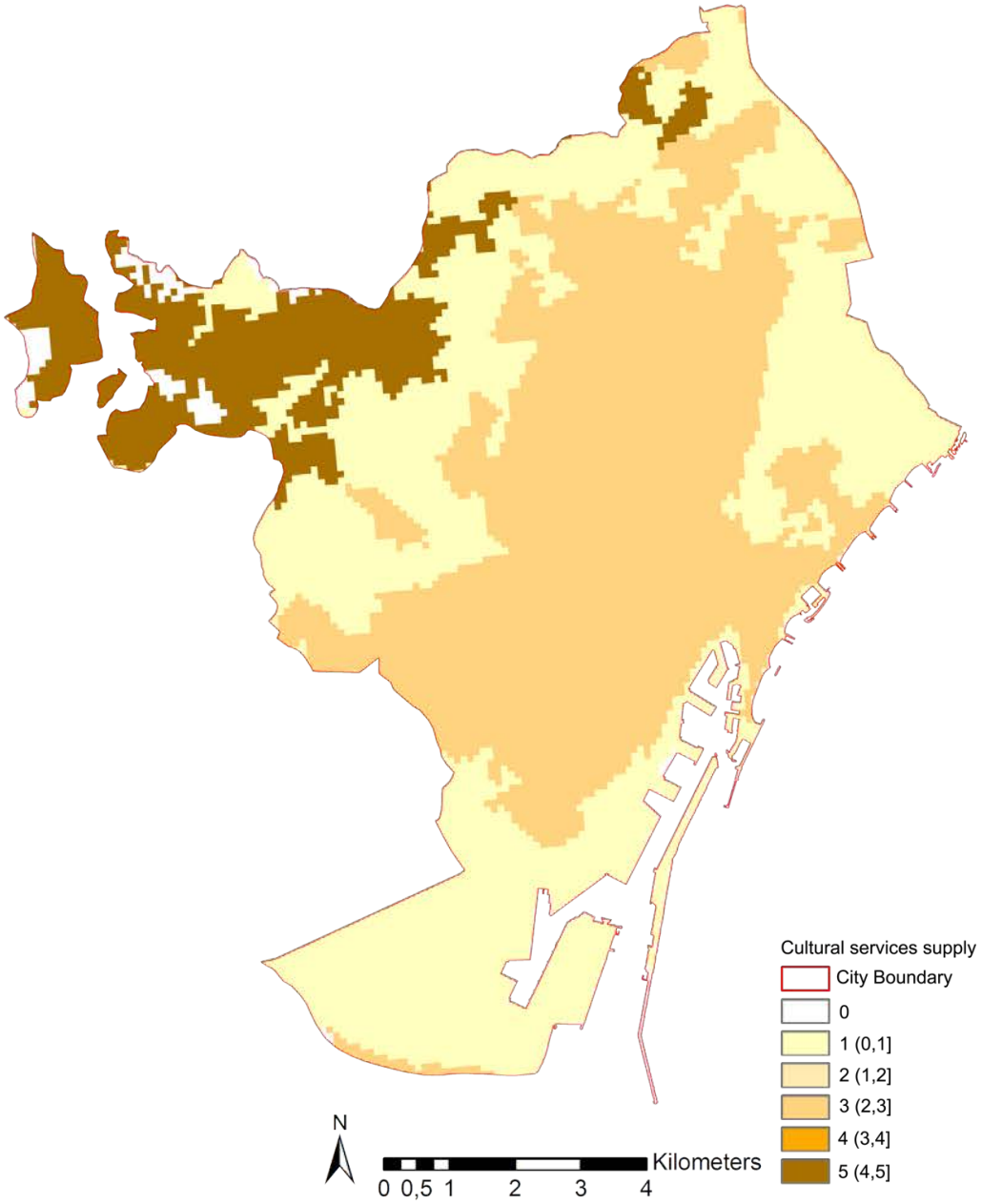


Fig. 3-7 The spatial distribution map of cultural and social services in Barcelona municipality. *Source*: own elaboration.

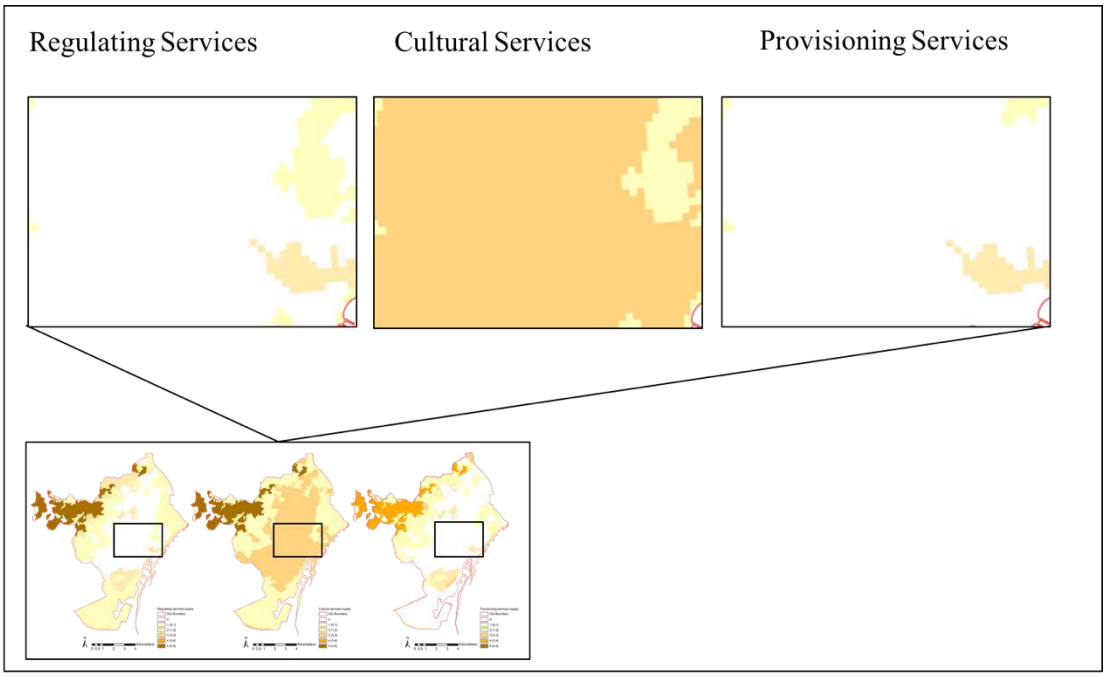


Fig. 3-8 The partial detail map of regulating services supply, cultural services supply, and provisioning services supply. *Source*: own elaboration.

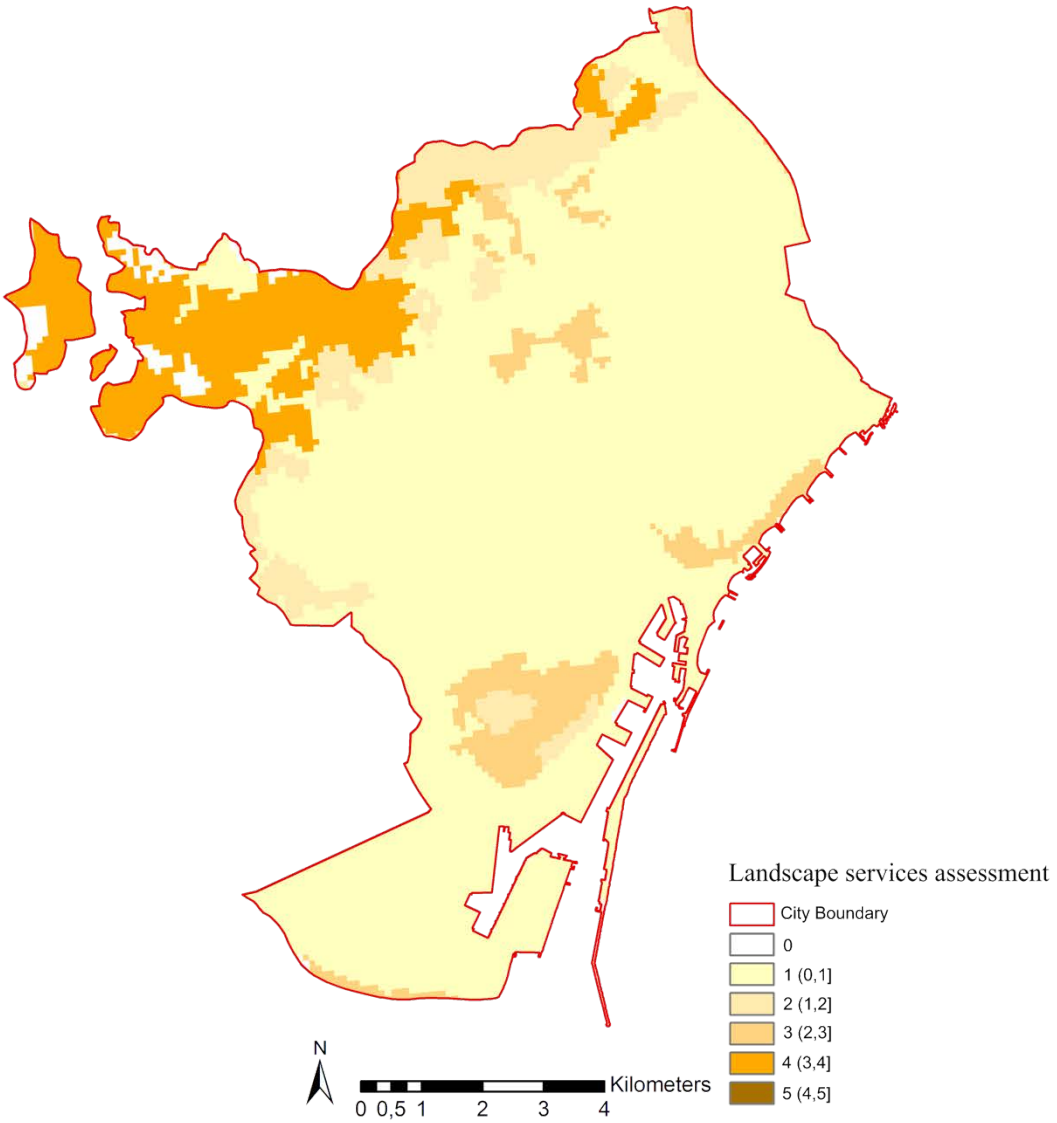


Fig. 3-9 The assessment of landscape services in Barcelona municipality. *Source*: own elaboration.

3.4 Discussion

This chapter assesses and visualises landscape services delivery of Barcelona city based on the LSAM. The methodology offers results showing clear patterns of LS distribution.

The maps show interesting patterns of LS supply in the ten land use types. Most of the results are expected. For example, green spaces such as forests have a high capacity to provide multiple LS, no relevant capacity on port areas or continuous urban fabric. Various publications (e.g. Bond, 2009; Foley et al., 2007) prove the high relevance of forest for LS supply. But compared to many traditional thoughts, unexpectedly, urban fringes or intermediate corridors also have the capacity to supply LS, although only a little.

In general, the quantitative assessment of the supply of ES is based on the relevant attribute equivalents of land use classes or based on models using empirical parameters. This study relies on expert knowledge for quantitative assessment of LS. This is a fast, low cost and effective evaluation method (Burkhard et al., 2009). Based on the land-cover based approach (Burkhard et al., 2015, 2009, 2012), this chapter further develops the assessment framework of LS by using expert knowledge as the basis for evaluation. Quantitative assessment and mapping of LS are performed in accordance with each step in the LSAM. The results not only reflect the LS spatial distribution characteristics of Barcelona but also lay the foundation for the next urban green infrastructure planning.

However, this method also has some drawbacks. Because in LSAM, the scores of the evaluation rely mainly on the experience and knowledge of experts and respondents, which leads to certain subjectivity and limitations of each score.

Besides, humans almost dominate land use/cover. So landscape services are strongly related to human perception since they are determined by land use. However, the current research on the identification of human perception of landscape services is not deep enough (Selby, Koskela, & Peta, 2007). It also needs to be further explored and studied. Therefore, in order to improve residents' understanding and perception of landscape services, more measures and tools should be considered, such as questionnaires, landscape photos surveys, and the willingness to pay and so on. All

these approaches can enhance the degree of visibility of landscape services regarding the human beings (Brown 2004; Fagerholm et al. 2012; Van Berkel & Verburg 2014), rather than only considering expert experience and knowledge.

Furthermore, the assessment and quantification methods for ES and LS are almost the same, though, in most studies of LS, several assessment methods are applied at the same time. So a further question here is how to develop some specific methods or tools to support the assessment and quantification of LS, how to advance a comprehensive framework that involving socio-cultural, ecological and economic values to support the decision making processes.

Moreover, existing literature too depends on the data about land use to ignore other choices. There are more data waiting to be exploited. Mapping LS is not only related to land use but also landscape features. The current maps of the landscape functions and services include the models and geo-statistical simulations (Ungaro, Zasada, & Piorr, 2014), the ground observation and spatial indicators (Gulickx et al., 2013), the community stakeholders' knowledge on aerial images (Fagerholm et al., 2012). Although the map of landscape functions should also show landscape heterogeneity in the quantity and quality of services provision (Meyer & Grabaum, 2008), spatial explicit on landscape heterogeneity is still missing.

So in the long term, more scientific researches and case studies are needed in order to achieve a comprehensive methodology to assess and map landscape services regarding landscape features, patterns, processes and scales.

The work done in this chapter is of great important implications for the following work. The framework of supporting urban green infrastructure planning based on the landscape service approach would be discussed in the next chapter.

The view of Laberint d'Horta Park, Barcelona, Spain (illustration by author).

4 CHAPTER FOUR: URBAN GREEN INFRASTRUCTURE PLANNING BASED ON LANDSCAPE SERVICES

4.1 Introduction

Green infrastructure (GI) plays a crucial role in achieving sustainable development goals in the city and developing the quality of life (Badiu et al., 2016). As a variety of large green areas, GI includes various ecosystems. GI also provides a number of landscape services. Meanwhile, it has a great influence on our environment and human well-being. For example, it optimises human living environment and life quality (M. van den Berg et al., 2016; A. E. van den Berg et al., 2010; Lafortezza et al., 2013), protects urban biodiversity (Goddard, Dougill, & Benton, 2010; Hostetler, M.; Allen, W. ; Meurk, 2011), promotes urban sustainable development (Lovell, 2010; Rössler, 2008) and so on.

Recently, decision makers and authorities have started to pay more attention to integrate ES or LS approach into urban policy and decision-making process, associating with the effect of urban green infrastructure (UGI). For example, Essen, in Germany, was named European Green Capital 2017, thanks to its urban ecological regeneration strategies. Specifically, the brownfield land and wasteland of the city were transformed into hundreds of hectares of green spaces, so as to make sure every resident to access the city's green and blue infrastructure within a range of 500 m (Kotzeva, M. M., & Brandmüller, 2016).

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

2014; Niemelä J., Saarela S-R., Söderman T., Kopperoinen L., Yli-Pelkonen V., Väre S., 2010).

This dissertation, regarding the UGI, not only consider natural, semi-natural or urban green areas but a very wide range of spaces such as intermediate corridors, urban fringes and even voids and empty areas located in different sections of a city, the scope and possibilities for designing UGI are bigger and more complex. In other words, the approach of LS offers the possibility for including in the definition of UGI a different type of areas playing different roles and supplying different services.

Also, LS provides an effective means of supporting general planning processes and GI planning, specifically, given the possibility of identifying priority protected areas (Egoh et al., 2007; Egoh et al., 2010; McDonald, L et al., 2005). This chapter argues for a methodology that establishes urban GI based on the LS approach, through the assessment of the supply capacity of LS in Chapter Three. Thus the possible spatial characteristic areas are identified, such as priority protected areas, new construction areas, potential areas, and renewal areas. To this end, I focus primarily on how to integrate an LS approach in the identification of possible spatial areas showing different supply capacities of LS, and how these areas can be used to guide UGI planning.

Hence, this chapter tries to develop a way to plan urban GI by assessing the supply capacity of the Barcelona municipality based on the LS approach. It aims to establish a large number of high-quality green spaces, protect and maintain the existing green space and natural and landscape heritage; and ensure its connectivity and accessibility, so that people can obtain a large number of landscape services to ensure human well-being and respond to the future of the city challenges, such as climate change.

4.2 Methodology

The spatial characteristic of LS provision illustrates the research of the relationships among service providing area where landscape services are produced, service benefiting area where landscape services are required, and connecting area (based upon Fisher, Turner, & Morling, 2009; Syrbe & Walz, 2012). These different areas, where can be identified by the capacity of the landscape services provision, are named ‘the possible characteristic areas’.

So according the above achievements, especially the map of assessment of landscape services in Barcelona municipality (See Figure 3-9), I make one hypothesis to identify the possible characteristic areas within the study area. I assume the area with high capacity to provide LS as the landscape services provision area (LSPA), the area with low capacity as the landscape service barren area (LSBA), the lacking of capacity areas as the obstructed area (LSOA).

Thus, there are three main steps regarding the framework of UGI planning based on LS.

In the first step, it is essential to identify the possible spatial characteristic areas. The possible spatial characteristic areas are divided by classifying the results of supply capacity of LS in Chapter Three. I make one classification that the areas with high capacity ($3 < score \leqslant 5$) to provide LS are coded as the landscape service provision area (LSPA). Accordingly, the areas with low capacity ($1 < score \leqslant 5$) are coded as the landscape service barren area (LSBA) and the lacking of capacity areas ($0 \leqslant score \leqslant 1$) are coded as the obstructed area (LSOA). According to the results of Chapter 3, I already get the map of the assessment of all LS supply in Barcelona municipality that shows the LS delivery capacity results (See Fig. 3-9). So after the coding, we can get the map of the possible spatial characteristic areas of LS through ArcGIS.

In the second step, in order to plan UGI in the study area, it is crucial to build the database of green spaces within the study area. Firstly, it is necessary to collect the urban green space information. Secondly, field verification and investigation work should be carried out.

Last but not the least, I can identify the different planning areas of UGI based on the results from the above achievements. Thus the priority protected areas, new construction areas, potential areas and renewal areas can be recognised in different possible spatial characteristic areas, which offers a reference to GI planning in different areas. Moreover, the related planning measures and strategies can be proposed in each planning region. Figure 4-1 shows the framework of urban GI planning based on LSAM.

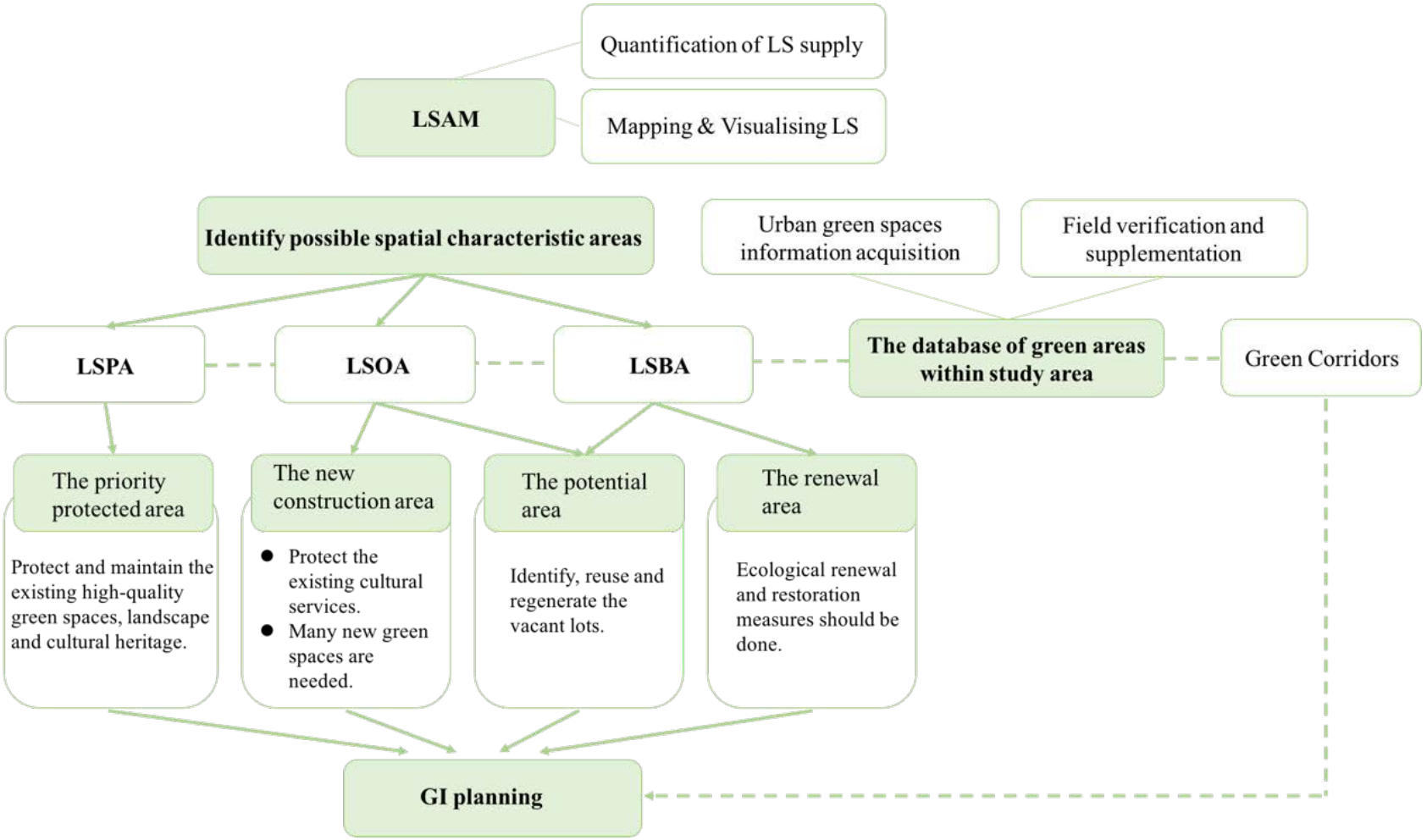


Fig. 4-1 The framework of urban green infrastructure planning based on landscape services assessment matrix. *Source*: own elaboration.

4.3 The database construction of green infrastructure

4.3.1 Urban green spaces background of Barcelona

The history and policy of Barcelona promote the establishment and development of urban public areas and green space systems. For example, Barcelona held the International Exposition in 1929; Barcelona and surrounding 26 towns together formed the 'Metropolitan Overall Plan' (PGM) in 1976. Especially, it held the 25th Summer Olympic Games in 1992, which contributed a lot to the urban infrastructure construction and urban space renewal. In 2013, the 'Barcelona green infrastructure and biodiversity plan 2020' was launched, which aims to enhance biodiversity and build a better life for residents with the greater GI (Ajuntament de Barcelona, 2013). Relying on its excellent and outstanding urban planning and design, its urban park system and green space system have provided a good foundation for the UGI.

Now, different countries have different urban green infrastructure classification systems, but there is not a unified world standard. According to the classification system in 'Barcelona green infrastructure and biodiversity plan 2020', open natural space, river area, coast, forest, park, garden, vegetable garden, pond, square, tree-lined street, landscape street, green roof and green wall all together consist the urban green network (Ajuntament de Barcelona, 2013). Besides, the parks and gardens are the most important and the biggest green areas in all of green spaces in Barcelona city. Therefore, it is significant to build a database of the Barcelona's urban green spaces, especially regarding the parks and gardens in Barcelona, to prepare the study of green infrastructure in the following study since there is not a clear and systematic database of urban green infrastructure.

4.3.2 Information acquisition

(1) Urban green space information collection

The urban public parks and gardens of Barcelona are the basic areas and structures of the urban public green spaces. So the basic information of each garden and park and green space should be collected.

First, the existing information of the official government website[4] is collected and analysed, resulting in the form the basic information of UGI in Barcelona city. Second, the remote sensing pictures are loaded in ArcGIS to establish a vector data layer on the computer, which gets the map of the main green spaces within the study area.

Finally, I get the information table regarding the main public parks and gardens (See Appendix B, Table B.1). This table includes the names of all public parks and gardens of Barcelona, the built year, the area where belongs to, the open time and the area (ha).

In order to better visual expression, these public parks and gardens are presented in the form of floor plans. Figure 4-2 shows the plane distribution map of Barcelona's urban parks and gardens. There are 69 urban public parks and gardens, 12 historic parks, 6 thematic parks and 2 forest parks in Barcelona city.

(2) Field verification and supplementation

After the indoor information is obtained, the field verification and investigation work should be carried out. It is intended to supplement and verify the insufficient information. The outdoor field survey mainly pays attention to two points. First, the investigation of points and lines. Due to the large area involved, the method of random field survey was adopted. The study area is divided into execution units of 1×1 km survey samples, and 1 or 2 landscape viewpoints (park or garden) are randomly selected for investigation (Fig. 4-3), so there are 39 investigation of points. Then, record all landscape information within the visible range of the viewpoint during the field investigation period.

Along the above survey route, whenever one survey sample rives, I use various ways to record the information, such as a 1:20000 remote sensing image map, text description, map drawing and photo recording. The survey of the landscape features and their attribute data was completed between 01, June and 28, August 2018. I analyse data refers to biodiversity, landscape design, functions of each public parks and gardens (See Appendix B, Table B.2). All the information can help to better know the

[4] https://www.barcelona.cat/ca/que-pots-fer-a-bcn/parcs-i-jardins

status quo of public parks and gardens in Barcelona.

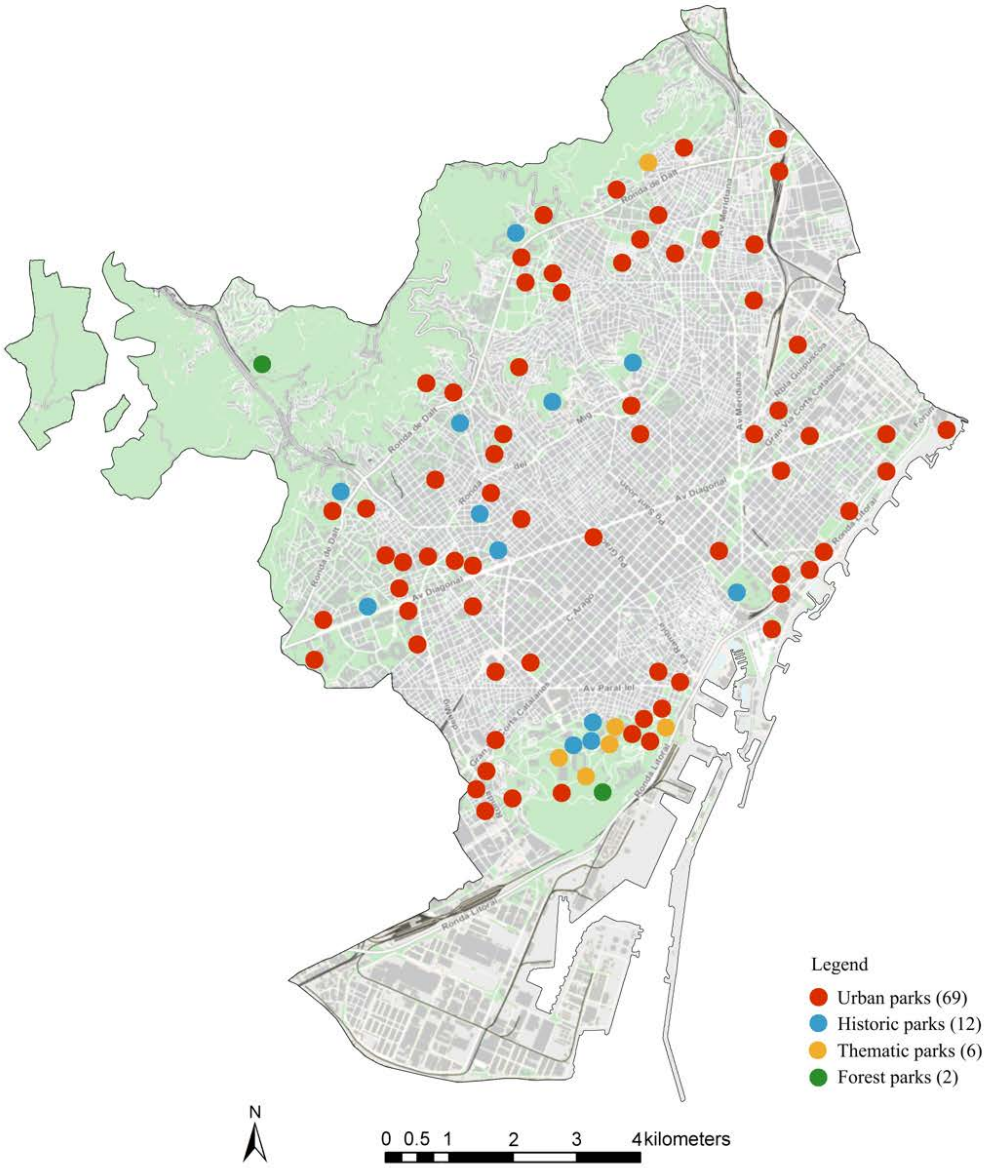


Fig. 4-2 The plane distribution map of Barcelona's urban parks and gardens. *Source*: own elaboration.

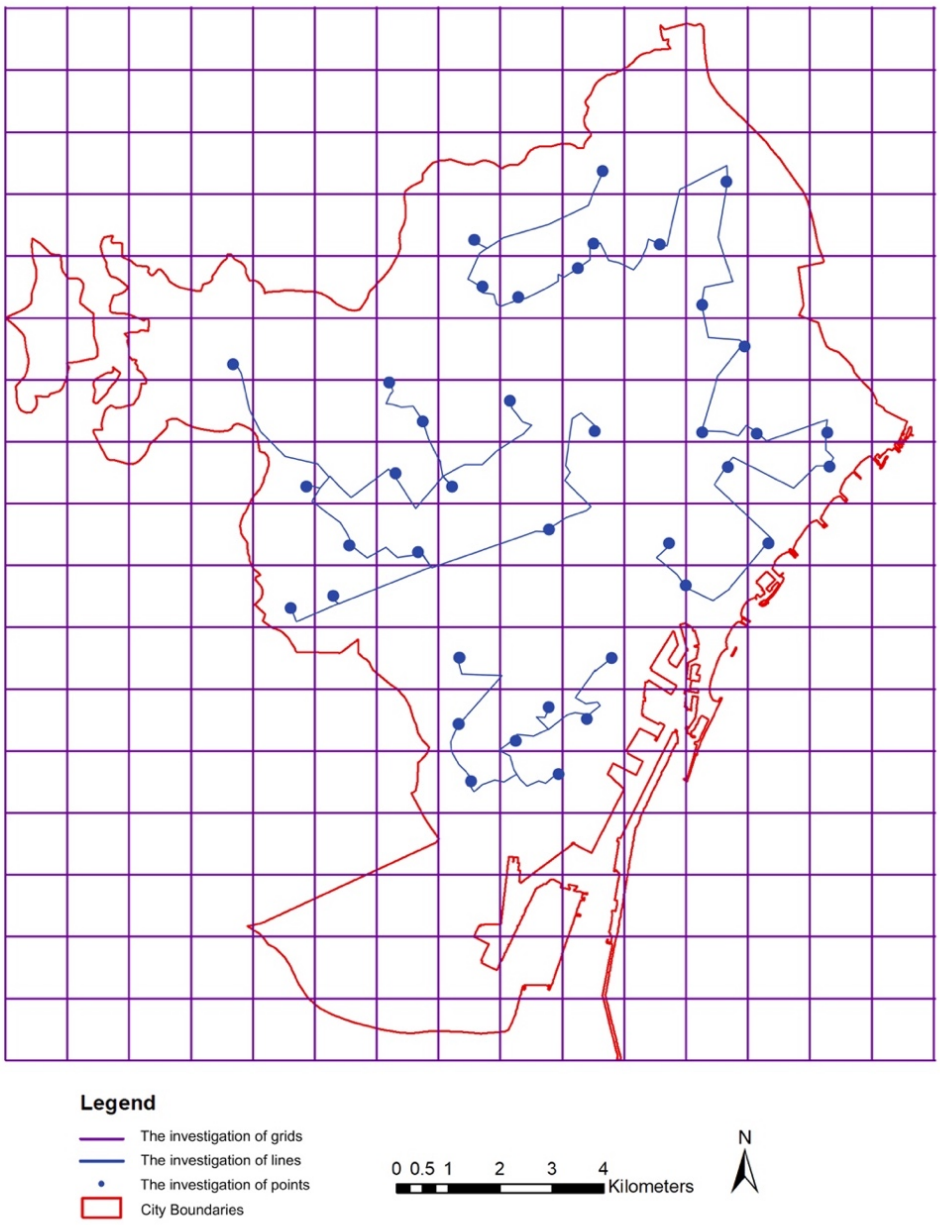


Fig. 4-3 The map of the investigation of points and lines. *Source*: own elaboration

4.3.3 The construction of Barcelona's parks and gardens

Result in the database of green spaces in Barcelona city above; I get the map of urban green areas in Barcelona municipality (Fig. 4-4).

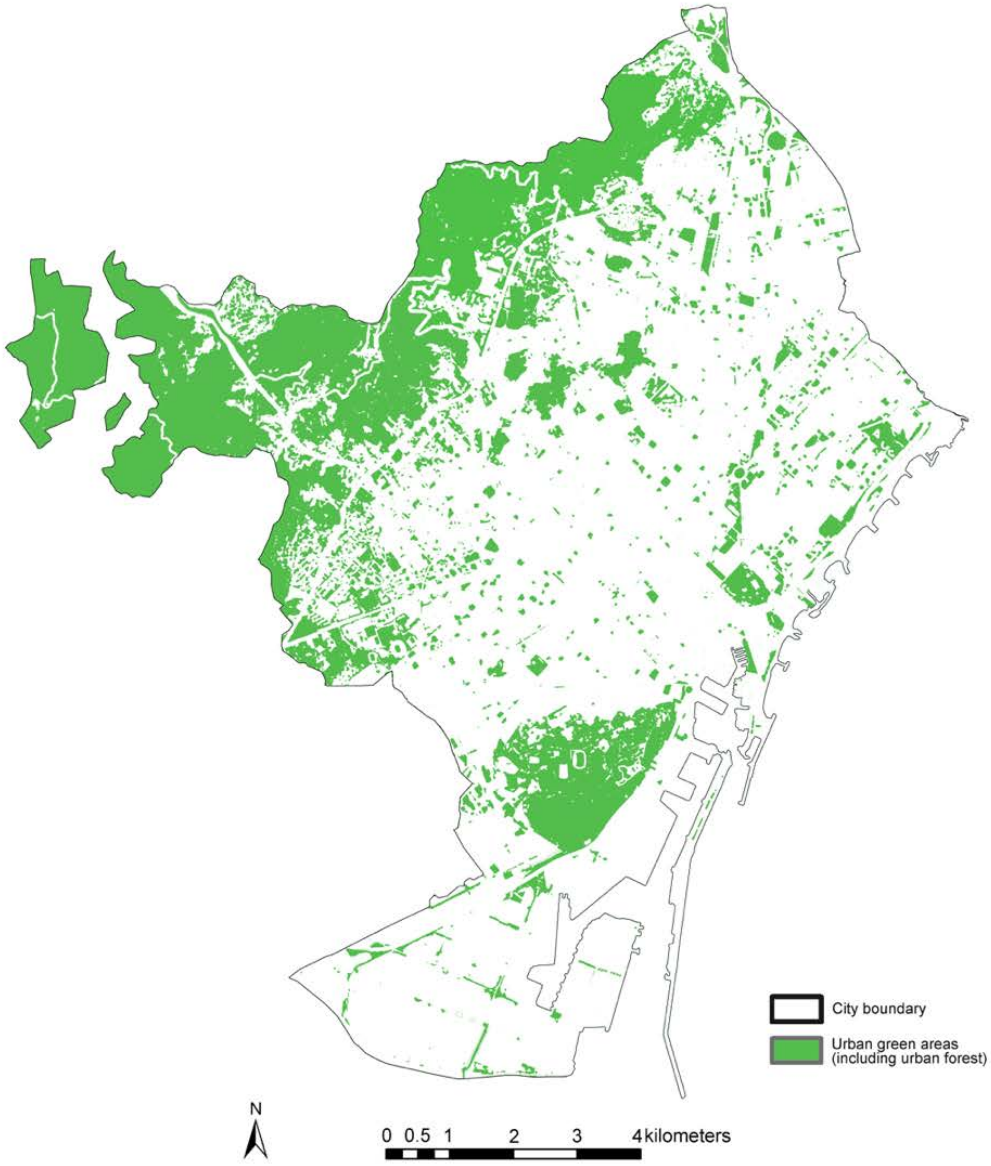


Fig. 4-4 The main urban green areas of Barcelona city. *Source:* own elaboration based on Barcelona City datasets (https://w33.bcn.cat/PlanolBCN/en/)

In Barcelona municipality, the total green area amounts to 28.34 km^2 (reaching 17.6 m^2 per inhabitant). However, the green area of the Collserola Natural Park amounts to about 16.99 km^2 (17.6 m^2 green space/inhabitant), which means the inner city of Barcelona (excluding CNP) embeds insufficient green space (about 11.35 km^2),

reaching 7.0 m^2 per inhabitant. 7.4 km^2 are private greenery generally in highest part of the city and are not valued and protected. (Barcelona City Council Statistical Yearbook, 2018). This ratio is far below other cities in Europe (Kotzeva, M. M., & Brandmüller, 2016; Littke, 2015).

Besides, as can be seen from Figure 4-4, the distribution of the green area in the downtown of Barcelona is very uneven, and the green areas are mainly concentrated in CNP and Montjuïc Mountain. In addition, the distribution of green areas in urban areas is scattered. Each green space is small. There is no ecological corridor that can connect various green patches.

4.4 Urban green infrastructure planning based on landscape services

4.4.1 Identify the possible spatial characteristic areas

When identifying the spatial distribution areas for providing LS purely from the production point of view, quantitative data is useful. From the landscape planning point of view, quantitative data in landscape services assessment matrix (See Figure 3-4) and the map of assessment of LS in Barcelona (See Figure 3-9) in Chapter Three can be used to identify possible characteristic areas (Fisher, Turner, & Morling, 2009; Syrbe & Walz, 2012), regarding the high-low of LS provision capacity by interlinking the spatial characteristics of the LS provision into urban green space.

As the result from the Chapter Three, the map of LS assessment in Barcelona municipality was done (See Fig. 3-9). Thus I divided the grades (0-5) into three classes. I assign the score from 3 to 5 (include 5) for the LSPA (LS provision area) with high capacity to provide LS; the score from 1 to 3 (include 3) for the LSBA with low capacity as the LS barren area; the score ranges from 0 to 1 represents the LSOA (LS obstructed area). Finally, the map of the possible spatial characteristic areas is achieved through ArcGIS that shows the relationships among different services within the study area (Fig. 4-5).

Compare with the map of main green areas of Barcelona city (See Figure 4-6). It is clearly shows that LSPA mainly includes urban forest, specifically the part of Collserola Natural Park. Urban parks, pastures and leisure facilities belong to LSPA or LSBA. In LSBA, these areas are almost covered with the Montjuïc Mountain

(includes many urban parks, thematic parks and historic parks), the part of Collserola Natural Park, the Ciutadella Park and some other urban parks. Urban brownfield land, industrial or commercial units, transport networks and building environment are in LSOA. In LSOA, this area has almost no large green spaces. There are only some scattered small urban parks, green streets and landscape streets. More importantly, LSPA and LSBA are not always adjacent, so the continuity of green areas is significant.

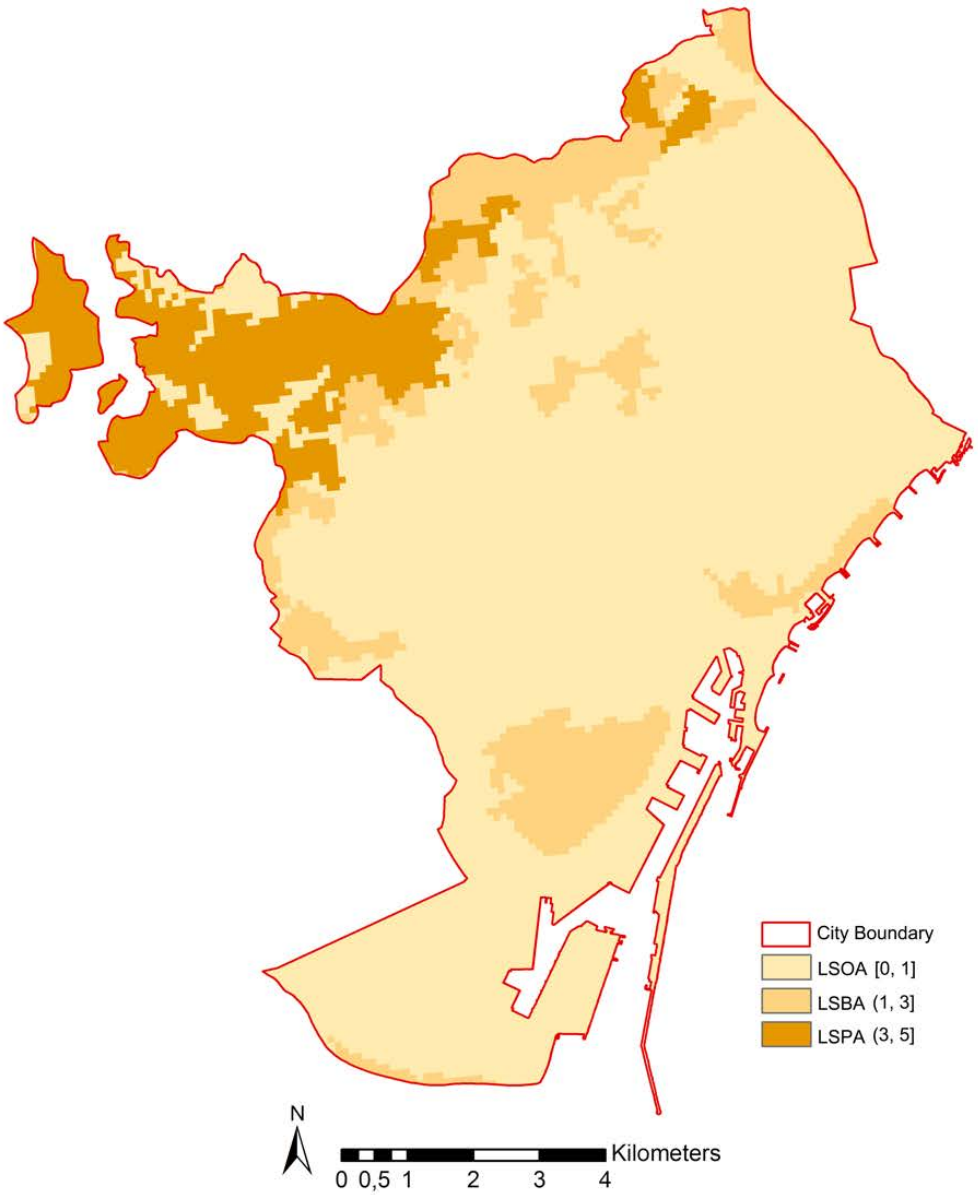


Fig. 4-5 The map of the possible spatial characteristic areas in Barcelona city. *Source:* own elaboration

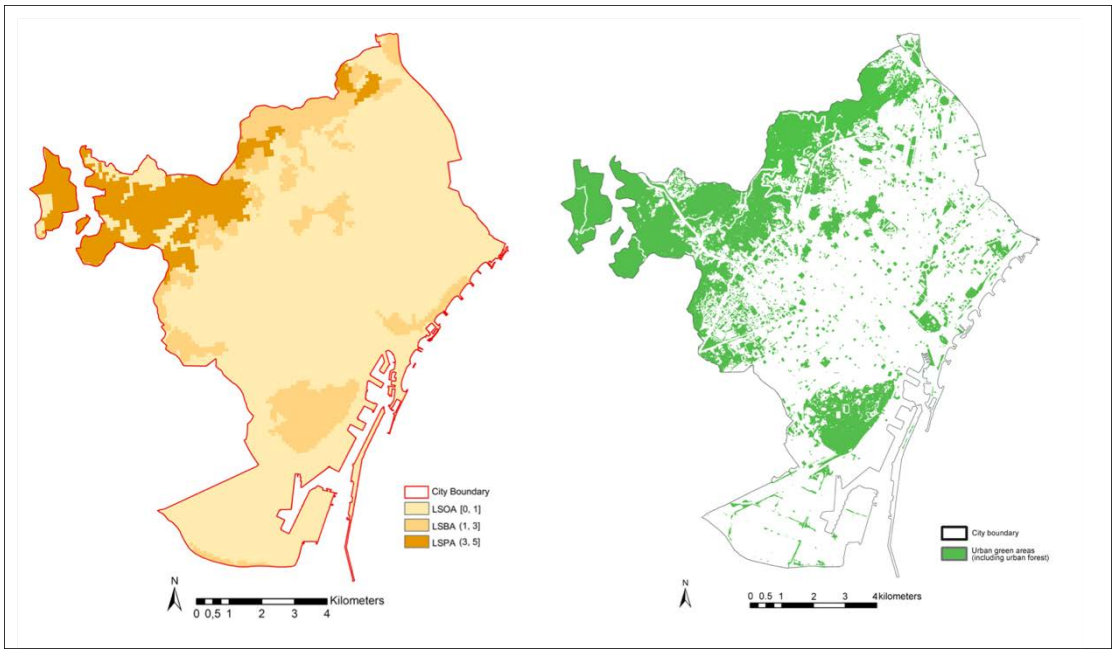


Fig. 4-6 The possible spatial characteristic areas of landscape services map (left) and the main green areas of Barcelona city (right). *Source*: own elaboration based on Barcelona city datasets (https://w33.bcn.cat/PlanolBCN/en/)

4.4.2 Urban Green infrastructure planning

As the dissertation mentioned before, the possible spatial characteristic regions (LSPA, LSBA, LSOA) represent different provision capacity of LS. They contain different land use types and show diverse urban green space conditions. Thus the zone method helps to confirm the protected areas, renewal areas, and new construction areas, and potential areas regarding UGI planning. So different UGI planning measures should be implemented in different areas. Furthermore, there are specific ways to plan UGI by integrating with the LS approach as follow.

(1) The priority protected area

It is essential to identify the priority protected areas during the UGI planning period (Egoh et al., 2007; Egoh et al., 2010; McDonald, L et al., 2005). Therefore, according to the above achievements, we can see that LSPA is primarily a protected area since there are many green spaces with high quality that delivers a variety of LS. In addition, according to Figure 4-6, we can see that this region includes the urban

forest – part of the Collserola Natural Park. CNP is an invaluable natural heritage with very high biodiversity, and many public facilities and recreation services (See Appendix B).

This region is almost a large landscape patch. It provides essential habitats to wildlife, ameliorates micro-climate, improves air quality and reduces noise service. As Figure 3-4 (Landscape services assessment matrix in Barcelona) shows, many scores of LS provision capacity reach up to 5, such as the LS provision capacity of coniferous forest. So it is vital to protect and maintain the existing high-quality forest. Moreover, this region shows a very high capacity to deliver cultural services, which offer many recreation opportunities, science and education services and aesthetic values for people. So scientific and effective management policies and protective measures of cultural and landscape heritage in LSPA are necessities.

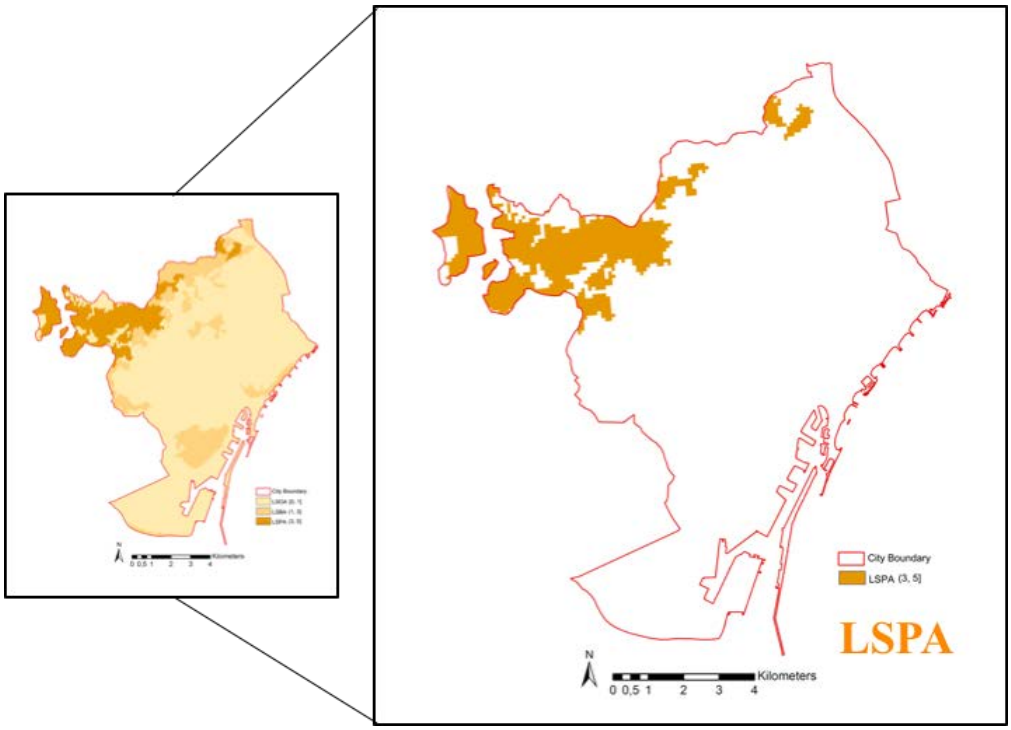


Fig. 4-7 The map of the location of LSPA. *Source*: own elaboration.

(2) The renewal area

The renewal area is in LSBA as it refers to the area with low capacity to deliver LS. The green zones have moderate quality in this region, for example, urban public parks and gardens have the medium capacity to deliver regulating, provisioning and habitat services; pastures and vegetation covers have the medium capacity to offer habitations; they all could deliver cultural services with average capacity.

Figure 4-6 shows that there are some urban public parks and gardens in this region. For example, the Monjuïc park, the park of Ciutadella. From Appendix B, we can see that these parks and gardens have a medium level of biodiversity, various social-cultural functions and services, and decent landscape aesthetic.

So in this region, it is significant to take ecological renewal, restoration and landscape improvement measures to advance the delivery capacity of LS, and improve the existing public parks and gardens such as improving their biodiversity, socio-cultural functions and services, instead of only focusing on the structure and aesthetic form of GI.

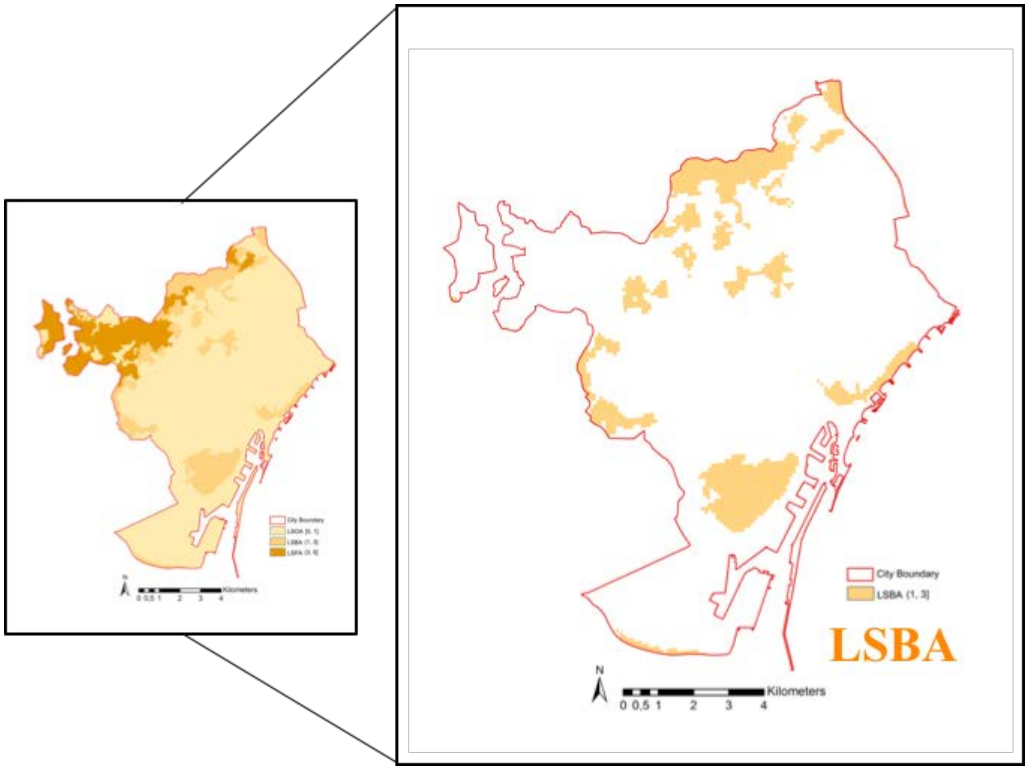


Fig. 4-8 The map of the location of LSBA. *Source*: own elaboration

(3) The new construction area

The new construction area refers to the region extremely lacks LS. According to Figure 4-9 (the map of the location of LSOA) and Figure 3-3 (Land cover classes of Barcelona municipality), the land use types in LSOA are full of industrial buildings and units, transport networks, port areas. The LSAM illustrates that these areas only deliver few and low-quality cultural services, like recreation and tourism services, but hardly supply regulating, provisioning and habitat services.

Besides, although this region has some urban public parks and gardens (See Fig. 4-6), they have low biodiversity and only a few socio-cultural functions to meet the locals' daily needs since they are generally small and no connection with each other (See Appendix B).

Hence, in this region, it is essential to preserve and develop the existing cultural services. Besides, UGI is composed of various types of green spaces with different landscape functions and ecological functions. In order to develop regulating, provisioning and habitat services, it is crucial to increase a large number of the coverage of multi-types green spaces. For instance, this dissertation recommends that the government and the media could encourage residents and communities to hold voluntary greenery activities by afforesting the residential zones, like creating green roofs, green walls and balconies, to do re-naturalisation and revitalisation. Also, the port areas should perform its functions except for cultural services, like storm water management and biological habitation, by greening and building more green zones and belts (Krause et al., 2011).

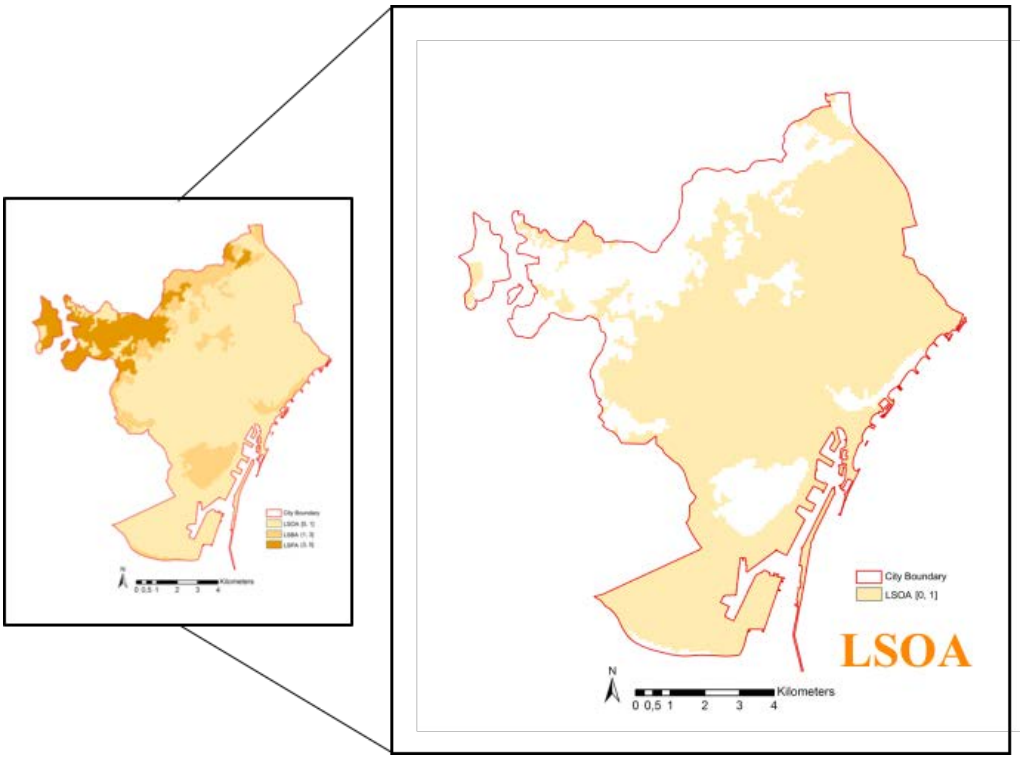


Fig. 4-9 The map of the location of LSOA. *Source*: own elaboration

(4) The potential area

There are a lot of potential spaces resting in LSBA and LSOA where have often been neglected and abandoned in reality. Thanks to the 'Identification and Evaluation of Metropolitan Voids in the Barcelona Region' Project, was developed by Observatory of Urbanisation, Geography Department Research Group in the Autonomous University of Barcelona, which identified 101 empty spaces in Barcelona (See Figure 4-10). All empty spaces are classified into three categories: compact city, discontinuous city and dispersed urbanization. Figure 4-10 shows that the Barcelona city has the largest number of empty spaces. Figure 4-11 demonstrates that the spatial distribution of all empty spaces in Barcelona municipality.

Figure 4-12 shows that some images of examples of empty spaces in Barcelona municipality. The abandoned lands, like a former factory or disused infrastructure, are converted into community gardens or public parks to enhance social cohesion and regenerate multi-functional urban open public spaces.

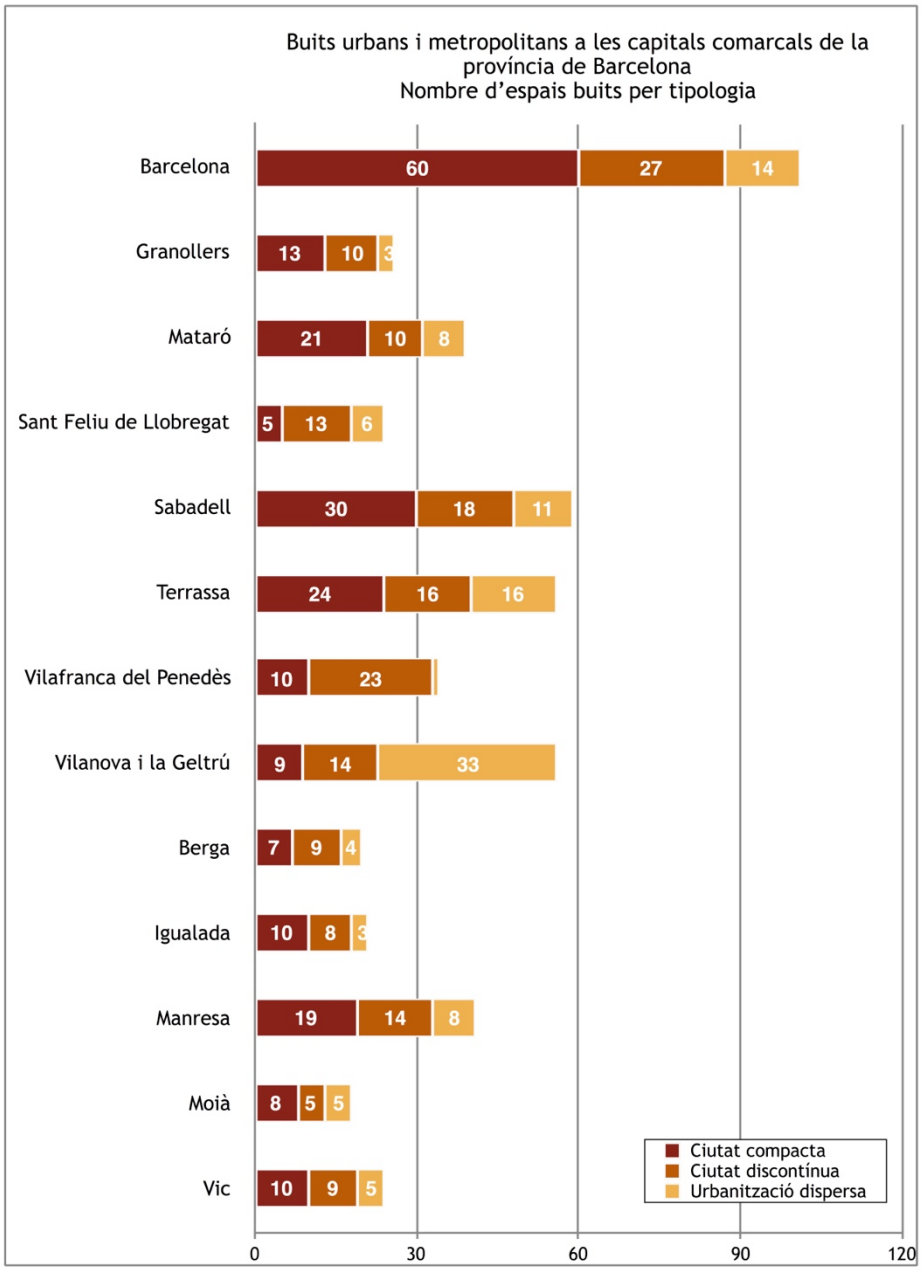


Fig. 4-10 The numbers of empty spaces in different cities at the province of Barcelona by typology.
Source: Observatori de la Urbanització (2018) Identification and Evaluation of Metropolitan Voids in the Barcelona Region. Geography Department, Universitat Autònoma de Barcelona. Diputació de Barcelona.

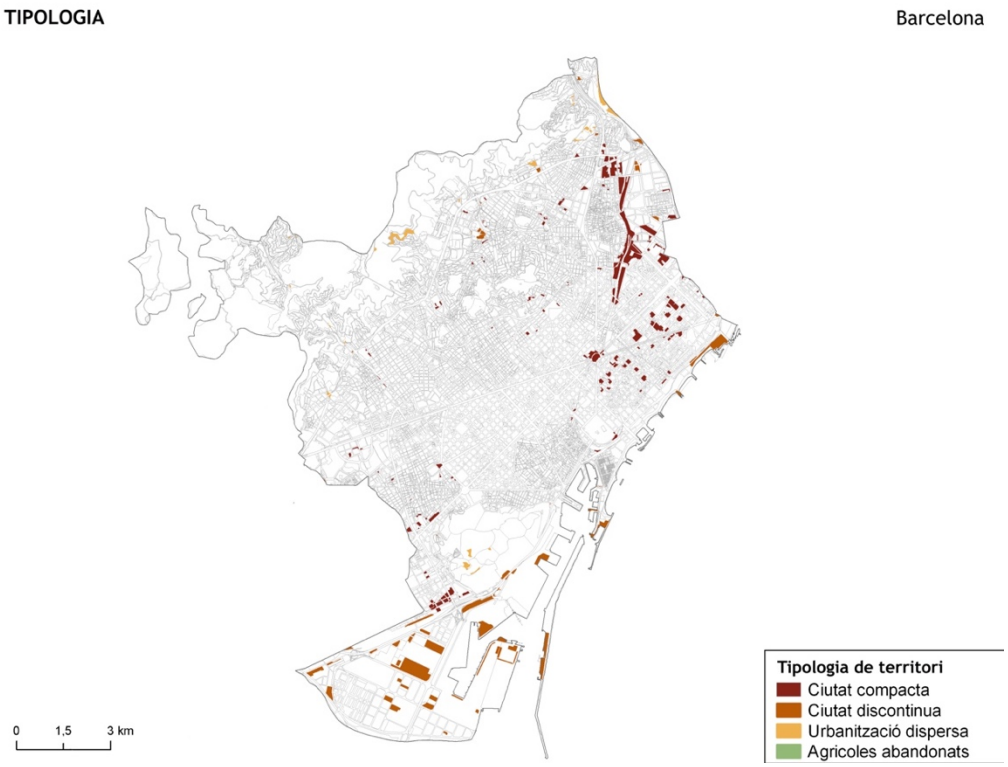


Fig. 4-11 The spatial distribution of all empty spaces in Barcelona Municipality. *Source*: Observatori de la Urbanització (2018) Identification and Evaluation of Metropolitan Voids in the Barcelona Region. Geography Department, Universitat Autònoma de Barcelona. Diputació de Barcelona.

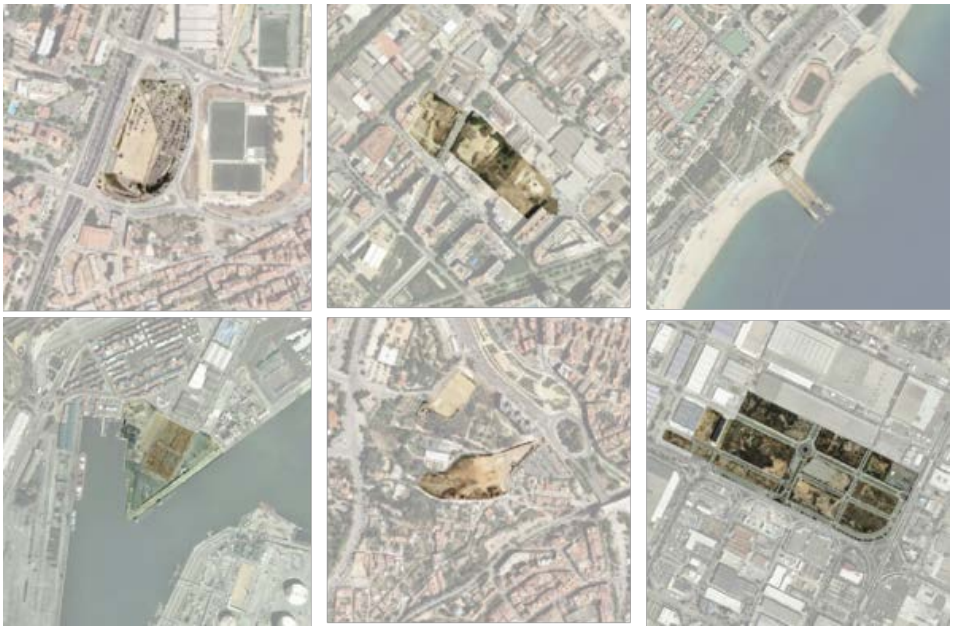


Fig. 4-12 The images of examples of empty spaces in Barcelona Municipality. Source: Observatori de la Urbanització (2018) Identification and Evaluation of Metropolitan Voids in the Barcelona Region. Geography Department, Universitat Autònoma de Barcelona. Diputació de Barcelona.

(5) The green corridor

The green corridor is a banded landscape element, both natural and artificial, such as a green belt and landscape street. To develop ecological corridors is an efficient way to reduce the negative impact of landscape fragmentation in landscape planning and design.

Figure 4-6 shows that there is almost no green corridor to connect each green patch within the study area. Urban green corridors can connect outlying natural and semi-natural areas with downtown green spaces and urban fabric, which provide a backbone for the city's GI by incorporating green spaces and linking LSPA, LSBA and LSOA to benefit each other. Instead of forming a map of isolated green spots, this dissertation seeks to forge a genuine network of green spaces, which can be conceived as UGI and provides LS. These services are enhanced further when the connectivity of GI is achieved.

4.5 Discussion

The results of analysis of the case of Barcelona shows that a combination of the hypotheses from the LSAM (See chapter three) with the framework of UGI planning is possible.

This section develops the specific planning measures for different areas, integrating with the quantitative evaluation results and spatial characteristic's map to identify the possible characteristic areas (the LS provision, barren and obstructed areas). It provides a reference and guidance to the UGI planning—not only formal green spaces (e.g. urban parks and gardens, natural preserves) but also potential areas, such as vacant lots. Besides, it offers a specific method that can be used for decision-making and planning process and is an attempt to combine UGI with LS approach in an urban planning and landscape planning manner, building on the previous work on urban GI and LS (Liquete et al., 2015; Kopperoinen & Itkonen, 2014), rather than only exploring the opportunities associating the LS approach with urban GI planning (Niemelä et al. 2010).

Comparing with the whole network of GI (Ajuntament de Barcelona, 2013) that aims to link and integrate all green spaces in Barcelona and areas surrounding the city.

This study supplies a gap, because the report of '*Barcelona green infrastructure and biodiversity plan 2020*' only diagnoses the quality of diverse types of green spaces, excluding other public spaces or land use types in the city. Also it mostly considers the area of urban green spaces and connectivity, ignoring identifying the core protected area and vacant urban lots.

In addition, the establishment of GI should be led by the government, from top to bottom, and in close connection with the stakeholders and the general public (McDonald et al., 2005), work closely with local departments to avoid the separation of planning and execution. This chapter does not consider participatory processes, socio-economic evaluation and population.

Our work has important implications for urban planners, landscape architects, land-use planners and researchers. The framework of supporting UGI planning based on the LS approach can help to identify the priority protected area, new construction and renewal area, which contributes to the thoughtful GI planning among other cities in the world. Besides, it is of great theoretical and practical significance, and referential value to promote regional sustainable development in cities.

Casa Batlló, Barcelona, Spain (illustration by author.)

5 CHAPTER FIVE: GENERAL DISCUSSION AND CONCLUSION

5.1 Conceptual and methodological contribution

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

(1) This study demonstrates the rationality of landscape services through literature review and the case study (the Collserola Natural Park), in which case landscape services can replace or distinguish from ecosystem services. Moreover, the study develops a general theory of landscape services, including the definition of landscape services, and a conceptual framework and typology for describing and classifying landscape functions, goods, and services in a clear and consistent manner. It makes up for the research gap of the current general theory of landscape services.

(2) This study combines with the land-cover based approach, further proposes the general six steps of quantitative assessment and mapping of landscape services, and establishes a landscape service assessment matrix. This assessment matrix is used to assess the supply of landscape services in a particular area (Barcelona municipality) and to visualise the results through ArcGIS. It provides a quantitative basis for dividing the characteristic areas (LSPA, LSBA, LSOA) and guiding the urban green infrastructure planning.

(3) According to the LS quantification results, this study innovatively identifies the spatial characteristic area (LSPA, LSBA, LSOA), and divides the specific planning

area into different characteristic areas through different landscape service supply values, such as the priority protected area, the new construction area, the potential area and the renewal area, to guide the urban green infrastructure planning.

(4) This dissertation builds the database of urban green spaces in Barcelona city, including the information of urban public parks and gardens in Barcelona, and the map of main urban green spaces in Barcelona city, which contribute to the planning of urban green infrastructure.

(5) This study innovatively introduces the method of LS quantification and mapping into supporting GI planning, differs from the traditional structural planning, and determines the planning goals of different land units. The planning goals and strategies of different spatial regions are finally determined, which provided a basis for the sustainable development of urban green infrastructure.

5.2 Limitations and caveats

Chapter two debates the justification of LS in which situation can replace the ES, as well as identifies and classifies LS. However, in the context of the landscape, the elements that influence the formation and supply of LS are multifaceted. For example, landscape elements, landscape patterns, and landscape features are different on different spatial scales or temporal scales. However, this dissertation does not consider the role of spatial-temporal scales when discussing the relationship between landscape elements, landscape patterns and landscape features and LS. How to fully consider the formation and taxonomy of LS in the dynamic perspective is an extremely compulsory question that is worthy of further discussion.

Besides, within this study, the methodology of land-cover based approach is not a new and original method, researchers prove that this method seems to be feasible. However, I propose the framework of UGI planning based LS that turned out to be an efficient way to describe the potentials and possibilities for UGI planning and management by finding the LSPA, the LSBA and the LSOA, which is a new approach to contribute to planning UGI.

However, in order to receive a holistic picture of complex systems, there still are tolerated lots of limitations and simplifications. It still exists plenty of uncertainties.

First is the LSAM (Hou et al., 2013). Although experts have different discipline origins and professional knowledge, the data from their scores are very subjectivity and less rigorous data (Jacobs, Burkhard, Van Daele, Staes, & Schneiders, 2015). The grades were marking by experts' experience are only based on the general theoretical assumptions, rather than the specific quantitative relationship within the particular space. Sometimes the actual role of different services is underestimated or overestimated. It reflects the LS supply of a relative capacity, rather than the absolute value. Though the expert-based approach has many shortages, it is beneficial for requiring overviews rapidly in a data-poor situation.

Moreover, the capacity to deliver certain LS is varying among different land use types (Sohel, Ahmed Mukul, & Burkhard, 2015). In reality, the land use types are way complex instead of the simplex data of the CORINE database. Also, the land use types, ecosystems and landscapes are not stable entities but always changing dynamically during different spatial and temporal scale, which would affect LS supply and distribution. There are also distinct social, economic, cultural and political demographic differences. So a dynamic analysis of land use classes can better help to develop UGI planning.

The way of coupling with the spatial analysis in maps highlights that decision-makers should consider implementing different policies and strategies for building urban GI in different provision capacities of LS areas, which emphasises the hotspot areas. Thus this research combines the quantitative research of LS with UGI planning creatively. However, this dissertation only initially identifies different spaces to determine different planning methods and measures, but does not further study how to quantitatively identify the numbers and types of GI that should be planned and designed in a particular area, how to provide a quantitative basis of sustainable development and management of land resources for the future.

5.3 Implications for planning and decision-making

Quantitative assessing and mapping the supply capacity of landscape services in a

certain area has direct implications for UGI planning and management, as well as for the decision-making (Niemelä J., Saarela S-R., Söderman T., Kopperoinen L., Yli-Pelkonen V., Väre S., 2010). This dissertation verifies two hypotheses: (1) the landscape services approach is a much better and suitable methodology than ecosystem services approach, so the assessment and spatial analysis of the supply capacity of landscape services would be better guide urban green infrastructure planning; (2) the consideration of landscape services offers the possibility for including in the definition of urban green infrastructures a different type of areas playing different roles and supplying different services (environmental plus cultural).

Chapter Two proposes the general theory of landscape services in the context of landscape, including identification and classification, through the case of the Collserola Natural Park that justifying in which situation the landscape services can replace the ecosystem services. This chapter indicates that the concept of LS includes a definition and consideration of ecosystems and landscapes in a broader way, not only considering the ecosystem functions and process but also considering the landscape elements, features and practical planning. The concept and approach of LS can better combine with practical planning, especially landscape planning.

Chapter Three uses various landscape services (as X-axis) and different land use types (as Y-axis) to build a landscape service assessment matrix, which contributes to assess and map the supply of landscape services. It takes the Barcelona municipality as the case study to analyse the spatial distribution characteristics of landscapes services within the investigation area. Then, this dissertation identifies the possible spatial characteristic areas, which are the landscape services provision, barren and obstructed areas by overlapping the supply of landscape services assessment maps. The results of this chapter indicates that the assessment and spatial analysis of the supply capacity of LS is a better guide for UGI planning, rather than the ES approach.

Chapter Four, on this basis, provides a reference for urban green infrastructure planning by recognising the priority protected areas, new construction areas, potential areas and renewal areas. In these different areas, several strategies for urban green infrastructure planning and landscape planning are provided, including: (1) the

protection and maintenance of the existing high-quality green spaces, landscape and cultural heritage in the priority protected area; (2) the protection of the existing cultural services and consideration of the demand for other landscape services in the new construction area; (3) identification and regeneration of new green spaces in the vacant lots of compact urban cores using innovative strategies (e.g., green roof and wall); (4) ecological renewal and restoration measures should be done in renewal area. The results show that not only natural, wilderness or green areas but also a very wide range of spaces such as intermediate corridors, urban fringes and even voids and empty areas located in different sections of a city, all have the possibility and potential to be the UGI. UGI is a bigger and more complex. That is to say, the consideration of LS offers the possibility for including in the definition of UGI a different type of areas playing different roles and supplying different services, such as environmental and cultural services.

This dissertation proposes a holistic approach of UGI planning and management that takes into account the whole range of LS potentially provided by various types of UGI and the interactions between them. Unlike the standard environmental or technical methods regarding grey infrastructure or ecological infrastructure which are normally designed as single-purpose, the main added value of UGI resides on its multi-functionality.

Finally, I argue that the approach of UGI planning and management requires further study considering the spatial and temporal scale of LS, together with the consideration of the landscape resilience and livability of urban areas for citizens, based on the multidisciplinary institutional organisation between all the authorities.

5.4 Concluding remarks and future research

This dissertation debates and develops the methodology of landscape services to support urban green infrastructure planning. In chapter one, it illustrates the background and significance, the objectives and research contents, the methodologies of this dissertation, and the research literature review of ES and LS. Chapter one lays a theoretical foundation for the following research from chapter two to four. In chapter

two, it develops the general theory of LS in the context of landscape, including the definition and classification system, as well as the description of each landscape service. This section lists the case study (the CNP) that justifying and demonstrating under what circumstances LS can supplant ES. Then, chapter three provides the LSAM for assessing and mapping LS within the study area. Result in the achievements in chapter three, chapter four develops a methodology to plan UGI in Barcelona, which contributes to promoting the regional sustainable development

Based on the quantification of LS supply, this study provides the different UGI planning measures for the different nature of regions (the priority protected area, the renewal area, the new construction area, the potential area). These strategies of UGI planning are supported by the LS method. They also link landscapes, human well-being and ecosystems to make them more targeted and directional. It should be an important reference for urban planning and land use planning. Planning studies on the green infrastructure in the municipality of Barcelona show that CNP should be priority protected; existing green spaces in LSBA should carry out ecological restoration and landscape enhancement; a large number of multi-type green spaces in LSOA should be constructed; all wasteland should be regarded as the potential green areas.

To our knowledge, this research gives the first assessment of LS bundles that integrating the supply of LS in an urban gradient. Besides, this research offers a new way and view to plan UGI, integrating with the LS approach.

However, the scientific knowledge of LS is still confronted with how to fully comprehend the concept of LS into landscape research (de Groot et al., 2010). In the literature, many challenges and obstacles in the application of practical planning. Therefore, in future research, we should pay more attention to the application of practice, in order to test and demonstrate the theoretical results of LS.

In addition, this study requires further in-depth research. For example, how to better understand the deeper relationship between LS and landscape research and mutual influence? How to further quantify the quantity and area required for urban green infrastructure within the study area?

In conclusion, the LS research community is still in the early stage. More efforts are required to improve the scientific knowledge bases and overcome the obstacles. Take the development of ES research as a reference, more studies and projects on LS should be advanced, such as the TEEB project and the CICES project for ES study. In addition, just as the Ecosystem Partnership (https://www.es-partnership.org) helps the communication of the frontier studies on ES, to promote the discussion of LS at different geographic scale levels and enhance the collaboration among LS researchers, some platform should be created and launched.

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APPENDICES

Appendix A. Supplementary information for Chapter II

A Survey on the landscape appreciation of landscape scenery in the Collserola Natural Park in Barcelona (Spain), from May to December, 2017.

The survey of the Collserola natural park (The top of this park is the Tibidabo)

This survey aims to know the status of the park users in the CNP for my doctoral research. Thank you so much for taking the time to fill in this survey. Welcome your Suggestions or criticisms on the research activities. All information is only used for academic research. It does not involve privacy disclosure.

1. **Email address** * _____
2. **What is your gender? / ¿Cuál es su género?**
   Mark only one oval.
   ◯ Female/Mujer ◯ Male/Hombre
3. **How old are you? / ¿Cuantos años tienes?** _____
4. **What is your nationality? / ¿Cual es tu nacionalidad?** _____
5. **Where do you live? / ¿Dónde vives? (la ciudad y el poblado)** _____
6. **Do you know the Collserola natural park? / ¿Conoces el parque natural de Collserola?**
   Mark only one oval.
   ◯ Yes ◯ No
7. **Do you prefer the place (landscape) with single-element/function or multi-functions? / ¿Preferies el lugar (paisaje) con elementos simples o multifuncionales? (e.g single or multi-landscape vegetation or color, areas with multi-purposes / Vegetación multi-paisaje, color, áreas con múltiples propósitos.)**
   _____
8. **Have you ever been in the Collserola natural park? / ¿Alguna vez has estado en el parque natural de Collserola?**
   Mark only one oval.
   ◯ Yes/Si ◯ No
9. **How often will you go to the Collserola natural park? / ¿Con qué frecuencia irás al parque natural de Collserola?**
   Mark only one oval.
   ◯ Every week / Cada semana ◯ Every month / Cada mes
   ◯ Every day / Todas los días ◯ It depends. I am not sure. / No sé
10. **Generally, when would you like to go to the CNP during the day? / En general, ¿cuándo le gustaría ir al CNP durante el día?**
    Check all that apply.
    ☐ In the morning / Por la mañana
    ☐ In the afternoon / Por la tarde
    ☐ In the evening / Por la noche
11. **Generally, when would you like to go to the CNP? / En general, ¿cuándo le gustaría ir al CNP? (You can choose more than one)**
    Check all that apply.
    ☐ The working days (from Monday to Friday) / los dias laborables
    ☐ At weekends / los fines de semana
    ☐ Public holidays / vacaciones públicas

12. **Which season do you prefer to go to the CNP? / ¿En qué temporada prefieres ir al CNP? (You can choose more than one)**
Check all that apply.

- [ ] Spring / Primavera
- [ ] Autumn / Otoño
- [ ] Summer / Verano
- [ ] Winter / Invierno

13. **How many times will you go to the CNP every year? / ¿Cuántas veces irás al CNP cada año?**

_____

14. **For what reasons you choose the CNP? / ¿Por qué motivos eliges el CNP?**
Check all that apply.

- [ ] Walking and strolling / Para pasear
- [ ] Sports / Para haver deporte
- [ ] Cycling / andar en bicicleta
- [ ] Enjoying nature / disfrutando de la naturaleza
- [ ] the visual enjoyment / disfrutar el paisaje
- [ ] Eating out & picnic / comida al are libre
- [ ] Participate in scientific or educational activities. / Participar en actividades científicas o educativas.
- [ ] Participate in religious activities / Participate in religious activities
- [ ] For the recreation purposes / recreación
- [ ] Look for the inspiration from nature / Busca la inspiración de la naturaleza (art, poem, etc.)
- [ ] Other: _____

15. **How do you go to the CNP? / ¿Cómo vas al CNP?**
Check all that apply.

- [ ] By private car / coche privado
- [ ] By public transport / Transporte público (i.e. autobus, train, metro)
- [ ] By walking / caminar
- [ ] By cycling / en bicicleta

16. **How long will you stay in the CNP during the day?**
Mark only one oval.

- ◯ <2 hours
- ◯ 5--8 hours
- ◯ 2--5 hours
- ◯ >8 hours

- [ ] **I have read, understood and completed this questionnaire. All questions are answered voluntarily.**

Appendix B. Supplementary information for Chapter IV

Table B.1. The information table of the main public parks and gardens in Barcelona Municipality.

The park's name	Built Year	Address	District	Open time	Area (ha)
Urban parks and gardens (69)					
Parque Central de Nou Barris	1997-2007	Pl Major de Nou Barris, 1	Nou Barris	Access all day	16.60
Parque de Can Dragó	1993	C Rosselló i Porcel, 7	Nou Barris	Access all day	11.86
Jardines del Campo de Sarrià	1923-1997	Ronda del General Miter, 26X	Sarrià-Sant Gervasi	Access all day	1.20
Parque lineal de Garcia Fària	2004	Pg Gracia Fària, 2-22	Sant Martí	Access all day	5.20
Parque de Xavier Montsalvatge	2007	C Síndic Rahola, 1	Horta-Guinardó	01, November--31, March: 10:00 -19:00; 01, April-31, October: 10:00-21:00	2.00
Jardines de la plaza de Can Fabra	1989	C Segre, 24-31	Sant Andreu	Access all day	1.50
Jadines de Jaume Vicens Vives	1967	Av Diagonal, 635	Les Corts	Access all day	1.37
Plaza de Sóller	1983	Pl Sóller, 1	Nou Barris	Access all day	2.20 (with 1.54 ha green space).
Jadines de Piscines i Esports	2008	C Doctor Fleming, 8-14	Sarrià-Sant Gervasi	01, May-31, August: 10:00-21:00; 1, September-30, September: 10:00-20:00; 1, Octuber-31, October: 10:00-19:00; 1, November-28, February: 10:00-18:00; 1, March-31, March: 10:00-19:00; 1, Abril-30, Abril: 10:00--20:00	1.69

The park's name	Built Year	Address	District	Open time	Area (ha)
Parque Torrent Maduixer	2013	C Josep Garí, 7	Sarrià-Sant Gervasi	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	0.41
Parque de las Rieres d'Horta	2013	Av Estatut de Catalunya, 21	Horta-Guinardó	Access all day	4.00
Parque de Can Rigal	2012	Av Albert Bastardas, 23	Les Corts	Access all day	2.00
Jardines de Miquel Martí i Pol	2013	C Llacuna, 121	Sant Martí	Access all day	Unknown
Jardines de Portolà	2009	C Portolà, 5	Sarrià-Sant Gervasi	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	0.06
Parque de Joan Reventós	2009	C Ràfols, 10	Sarrià-Sant Gervasi	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	2.00
Parque del Centre del Poblenou	2008	Av Diagonal, 130	Sant Martí	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	5.56
Parque de la Primavera	2007	C Nou de la Rambla, 203	Sants-Montjuïc	Access all day	1.95
Jardín de los Drets Humans	2007	C Foneria, 19	Sants-Montjuïc	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	1.25
Parque de los Auditoris	2000	Pl Fòrum, 1	Sant Martí	Access all day	5.20
Jardines de Joan Brossa	2003	Pl Dante, 9999	Sants-Montjuïc	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	5.30
Jadines de Frida Kahlo	Unknown	Berruguete, 85	Horta-Guinardó	Access all day	1.80
Jadines de la Font dels Ocellets	Unknown	Jiménez i lglesias, 6	Les Corts	Access all day	0.04
Jardines del Clot de la Mel	Unknown	C Lope de Vega, 280	Sant Martí	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	0.24

The park's name	Built Year	Address	District	Open time	Area (ha)
Jardines de Rosa Luxemburg	1999	Av Cardenal Vidal Barraquer, 50	Horta-Guinardó	Access all day	1.20
Parque de Diagonal Mar	2002	C Llull, 362	Sant Martí	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	34.00
Jardines de la Arboreda	Unknown	Mecànica, 10-LI	Sants-Montjuïc	Access all day	Unknown
Parque de Carles I	1992	Av lcària, 121	Sant Martí	Access all day	5.50
Parque de la Nova Icària	1992	Jaume Vicens i Vives, 1	Sant Martí	Access all day	6.34
Parque del Pla de Fornells	1991	C Nou Barris, 14	Nou Barris	Access all day	25.00
Jardins de Vil·la Cecília	1986	Santa Amèlia, 1	Sarrià-Sant Gervasi	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	1.47
Parque de las Cascades	1992	Av Litoral, 12-14	Ciutat Vella	Access all day	1.38
Parque de Josep Maria Serra Martí	1994	C Miguel Hernández, 16	Nou Barris	Access all day	4.26
Jardines de Joan Vinyoli	Unknown	Pg Sant Joan Bosco, 39	Sarrià-Sant Gervasi	Access all day	0.50
Parque de la Vall d'Hebron	1992	Juan de Mena, 2	Horta-Guinardó	Access all day	8.22
Parque de la Barceloneta	1996	Pg Marítim Barceloneta, 15-21	Ciutat Vella	Access all day	3.21
Parque del Poblenou	1992	Av Litoral, 59	Sant Martí	Access all day	11.92
Parque del Port Olímpic	1992	Av Litoral, 9994	Sant Martí	Access all day	2.99
Jardines del Palau Robert	1898-1903	Pg Gràcia, 107	Eixample	From Monday to Saturday: 10:00-20:00; Sunday and festivals: 10:00-14:30	0.39

The park's name	Built Year	Address	District	Open time	Area (ha)
Jardines de la Maternitat	1998	Trav Corts, 159	Les Corts	From Monday to Friday: 07:00-22:00; From October to March: Saturday 07:00-18:00; Sunday 10:00-18:00; April: Saturday 07:00-20:00; Sunday 10:00-20:00; From May to August: Saturday 07:00-21:00; Sunday 10:00-21:00; September: Saturday 07:00--20:00; Sunday 10:00--20:00	7.68
Parque de la Font Florida	1995	G.V. Corts Catalanes, 196	Sants-Montjuïc	Access all day	2.29
Jardines de las Tres Xemeneies	1995	Av Paral.lel, 49	Sants-Montjuïc	Access all day	0.90
Parque del Mirador del Poble Sec	1995-1997	Pg Montjuïc, 59	Sants-Montjuïc	Access all day	2.83
Jardines de Ca l'Alena	Unknown	Alts Forns, 85	Sants-Montjuïc	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	Unknown
Jardines del Príncep de Girona	1995	C Marina, 372-382	Horta-Guinardó	Access all day	1.79
Parque de la trinitat	1993	Pg Santa Coloma, 60	Sant Andreu	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	7.04
Jardines de Sant Pau del Camp	1992	Sant Pau, 99	Ciutat Vella	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	1.60
Jardines de Ca n'Altimira	1991	Maó, 9	Sarrià-Sant Gervasi	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00--21:00	0.43
Parque de Sant Martí	1979-1992	C Menorca, 64	Sant Martí	Access all day	6.80

The park's name	Built Year	Address	District	Open time	Area (ha)
Parque de Can Sabaté	1984	C Mineria, 16	Sants-Montjuïc	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	1.76
Parque de la Estació del Nord	1988	C Nàpols, 70	Eixample	All day: 10:00-22:30	3.58
Parque del Les Corts	1988	Nicaragua, 139	Les Corts	Access all day	0.71
Parque de la Creueta del Coll	1987	Pg Mare de Déu del Coll, 77	Gràcia	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	1.68
Parc del Clot	1986	Escultors Claperós, 55	Sant Martí	Access all day	4.03
Parque de La Pegaso	1986	C Sagrera,179	Sant Andreu	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	3.65
Parque de la Espanya Industrial	1985	C Muntadas,1-37	Sants-Montjuïc	1, November-31, March: From Monday to Friday10:00-24:00; Saturday and Sunday 10:00-23:00; 1, Abril-31, October: From Monday to Friday: 10:00-24:00, Saturday and Sunday (exclude 27th, August): 10:00--23:00	4.40
Jardines de Moragas	1959	Tavern, 1	Sarrià-Sant Gervasi	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	0.39
Parque de Joan Miró	1983	C Aragó, 2	Eixample	Everyday: 10:00-23:00	4.71
Parque del Turó de la Peira	1936	Pg Fabra i Puig, 396-408	Nou Barris	Access all day	7.71
Parque de la Guineueta	1971	Pl de la República, 9*LB	Nou Barris	Everyday: 10:00-23:00	3.01

The park's name	Built Year	Address	District	Open time	Area (ha)
El parque de las Aigües	1978	Pl Alfons el Savi, 3	Horta-Guinardó	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	1.95
Parque de Monterols	1947	C Muntaner, 450	Sarrià-Sant Gervasi	Everyday: 10:00-23:00	1.94
Parque del Turó del Putxet	1970	C Manacor, 9	Sarrià-Sant Gervasi	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	3.97
Parque de la Font del Racó	1926	Av Tibidabo, 72	Sarrià-Sant Gervasi	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	1.29
Parque del Castell de l'Oreneta	1978	C Montevideo, 45	Sarrià-Sant Gervasi	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	17.00
Jardines de Vil·la Amèlia	1970	Eduardo Conde, 22	Sarrià-Sant Gervasi	Everyday: 10:00-22:30	2.33
El parque de Cervantes	1965	Av Diagonal, 706	Les Corts	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	9.15
Jardines del Mirador del Alcalde	1962-1969	Ctra Montjuïc, 41-51	Sants-Montjuïc	Everyday: 10:00-19:00	1.37
Parque del Mirador del Migdia	1992	Pg Migdia, 156-174	Sants-Montjuïc	Access all day	8.73
Parque de la Maquinista de Sant Andreu	2000	C Ferran Junoy, 1	Sant Andreu	Access all day	2.10
Historic parks (12)					
Parque del Laberint d'Horta	1974-1808	Pg Castanyers, 1	Horta-Guinardó	1, Abril-31, October: 10:00-20:00; 01-05, November: 10:00-19:00; 06-30, November: Close; 01, December-31, March: Saturday and Sunday: 10:00-19:00; 25, December: 10:00-14:00	9.10

The park's name	Built Year	Address	District	Open time	Area (ha)
Park Güell	1900-1914	C Olot, 7	Gràcia	01, January-16, February & 28, October-31, December: 08:30-18:15; 17, February-24, March: 08:30-19:00; 25, March-29, April & 27, Agust-27, October: 08:00--20:30; 30, April-26, August: 08:00--21:30	17.18
Parque de la Ciutadella	1872	Pg Picasso, 21	Ciutat Vella	1, November-31, March: 10:00-22:30; 1, Abril-31, October: 10:00-22:30	17.42
Jadines de Laribal	1917-1924	Pg Santa Madrona, 2	Sants-Montjuïc	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	3.16
Jardines del Teatre Grec	1917-1924	Pg Santa Madrona, 38	Sants-Montjuïc	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	1.65
Jardines de Can Castelló	1989	Freixa 56	Sarrià-Sant Gervasi	Everyday: 10:00-23:00	0.37
Jardines de Can Sentmenat	1779	C Can Caralleu, 6-14	Sarrià-Sant Gervasi	Access all day	1.00
Jardines de la Tamarita	1918	Pg Sant Gervasi, 47-49	Sarrià-Sant Gervasi	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	1.40
Jardines Joan Maragall	1970	Av Estadi, 69	Sants-Montjuïc	Saturday and Sunday, Festivals (except 15, August): 10:00-15:00	3.63
Parque del Guinardó	1918	Garriga i Roca, 1-13	Horta-Guinardó	Access all day	15.90
Turó Park	1934	Av Pau Casals, 19	Sarrià-Sant Gervasi	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	2.88

The park's name	Built Year	Address	District	Open time	Area (ha)
Jardines del Palacio de Pedralbes	1926	Av Diagonal, 686	Les Corts	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	7.28
Thematic parks (6)					
Jardín Botánico	1999	C Doctor Font i Quer, 2	Sants-Montjuïc	1, October-31, March: 10:00-17:00 (except 25, December and 01, January); 1, Abril-30, September: 10:00-19:00 (except 01, May, 24, July)	14.00
Jadines de Rodrigo Caro	2008	C Artesania, 79-LB	Nou Barris	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	Unknown
Jardines de Mossèn Costa i Llobera	1970	Ctra Miramar, 38	Sants-Montjuïc	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	6.15
Vivero Municipal de Plantas Tres Pins	1993	Av Miramar, 2	Sants-Montjuïc	Access all day	8.80
Jardines de Mossèn Cinto Verdaguer	1970	Av Miramar, 30	Sants-Montjuïc	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	4.30
Jadín de Aclimatación de Montjuïc	1930	Av Estadi, 42*48	Sants-Montjuïc	1, November-31, March: 10:00-19:00; 1, Abril-31, October: 10:00-21:00	0.86
Forest parks (2)					
Parque de Montjuïc	1929	Pg Migdia, 147	Sants-Montjuïc	Access all day	199.00
Parque de Collserola	1987	1.Ctra. de l'Església, 0092	Sarrià-Sant Gervasi, Gràcia, Nou Barris, Horta-Guinardó, Les Corts.	Access all day	8460 ha (1698.7 ha in Barcelona in 2016)

Table B.2. The analysis of biodiversity, landscape functions and landscape planning and design of the main public parks and gardens in Barcelona Municipality.

Name	Biodiversity	Functions	Landscape plan and design
Urban Public Parks & Gardens (69)			
Parque Central de Nou Barris	Over 1,000 trees made up of 49 different species. 29 different types of palm grove trees. Plane trees, sil floss trees, jacarandas and tipu trees, ombu trees, river oaks, blue Atlas cedars, holm oaks, cypresses and a few eucalyptuses, bottlebrush, spurge olive, fragrant geraniums, etc.	1.The leisure, walking, rest area with bars, fountains, library. 2. A thoroughfare and neighbourhood connection point. 3. The site of the district offices, the Fòrum Tecnològic Nord business technology centre, a city-police station, schools and neighbourhood centres.	This is the city's second largest green space, a place that invites visitors to take a stroll and contemplate the lush vegetation it houses. The park's design was rewarded with the 2007 International Urban Landscape Award.
Parque de Can Dragó	The line of trees making up part of the landscape along this boulevard includes lime trees, poplars, black locusts, nettle trees, planes and eucalyptuses.	It is made up of four separate blocks with different functions. Two blocks have sports facilities, with the second having an outdoor pool. The third and fourth blocks are big green spaces that provide a square, resting area, kids' games area and football pitch.	The park was designed as a transition between the Meridiana's noisy traffic and the silence of the Sant Andreu cemetery. It is made up of green islands, with tree-lined leisure areas and sports facilities. In a central part of the park there is a small hill covered in grass with a replica of the Aurigues olímpics sculpture by Pau Gargallo, whose original is housed at the Olympic Stadium.
Jardines del Campo de Sarrià	Linden, deciduous trees, 4 oaks, olive and quercus coccifera. jacaranda mimosifolia, or Judas treesand red leaf plum. three palm. Warm weather prairie grass.	1. The buildings that surround the garden serve as screens to muffle the background noise of traffic in adjacent streets. 2.The vegetation is made up of trees and prairie grass with an open quality to the space.	The greenery of the area and abundance of trees made this place one of the most visited in the city.

Name	Biodiversity	Functions	Landscape plan and design
Parque lineal de Garcia Fària	The abundance of French tamarisk there. The flowerbeds looking onto the road contain several species of grass, with highly decorative combinations of height. They include Hyparrhenia sp., Festuca sp., Pennisetum setaceum and Pennisetum villosum. There are also fields of Mexican feather grass. Other important plants include oleanders, with spectacular blooms, palms, especially fan palms, dwarf palms and, small groups of paper mulberry.	1. A gateway to the beaches nearest to the Besòs river, the park links two of the city's large green areas: the parks of Poblenou and Diagonal Mar. 2. As for the sea-facing side, the boundary acts as a viewing platform over the nearby beaches. 3.There is a long, wide bicycle lane on the mountain-facing side. 4. It has leisure areas and children's play areas.	The park is the result of an intelligent combination of topography and vegetation that gives rise to very distinct parallel areas, separated by large flowerbeds, some flat and others sloping.
Parque de Xavier Montsalvatge	There is the massive presence of a very common species of grass is fescue, occupying a 4,640 m2 of the park. It includes 42 olive trees, white- and rose-flowered abelias, tamarisks shrubs and ivy. The children's play area boasts a holm oak, cherry plum trees, pine trees.	1. It offers an observation point for enjoying views of the city. 2. it deals with the collection, drainage and disposal of the rainwater that falls on the roof and is collected from the hillside when there is torrential rain.	This is a garden with a privileged panoramic view of Barcelona. It was designed by the Jaume Coll. The Coll-Leclerc team's project was shortlisted for the European Prize for Urban Public Space and the 3rd AJAC/COAC Young Architects Prize.
Jardines de la plaza de Can Fabra	There is a library on the left and a secluded garden on the right, with a pond and wooden Chinese bridge. The pond has three bald cypresses. There are stone pines, cypresses, holm oaks, an elm tree and southern nettle trees, strawberry trees, a large laurustinus, feijoas, glossy privets, cypresses, sweet bays, thorny olive trees, as well as poplars, pine trees and tipu trees and so on.	1. There is a paved square and a sheet of water in front of the library and a green space intended as a neighbourhood garden, which is for sitting and relaxing in the shade. 2. The library is for residents to read and study.	The landscaped area is distributed geometrically, which interacts with the architecture that frames the library through ramps, parterres and pergolas that catch the visitors' eyes. The landscaping at the back coincides with the factory's conversion into the library, which means there are two areas with a different layout and geometry.

Name	Biodiversity	Functions	Landscape plan and design
Jadines de Jaume Vicens Vives	These are small squares with several species of trees, such as the conifers and pines, a few Himalayan cedars, tipus and acacias, holm oaks, firethorns, tamarisks, elms, small-leaved lime trees, glossy privet and a few olive trees. There are also aromatic species such as sage and lavender. The shadiest part of the gardens has a palm tree, a large yucca, three poplars and two large pine trees.	A peaceful place for local residents to relax and walk, with green areas and a children' play area.	The access ramp takes visitors to the various parts of the gardens. Shade is always guaranteed during spring and summer. A stroll through these gardens allows you to escape from the hustle and bustle of Av Diagonal. The gardens were dedicated to the historian Jaume Vicens Vives.
Plaza de Sóller	The trees are divided into areas consisting predominantly of perennials, basically holm oaks and cypresses, as well as a deciduous area: hackberry trees. The paths are framed by rows of poplars, hackberry trees and holm oaks. Chinese weeping willows and peppercorn trees, also known as false pepper trees, grow close to the bays, on either side of the lake.	1. It has walking and rest area, with a mirador-balcony. 2. It has many aromatic plants, like the pear flowers with a strong fragrance in spring for pleasure. 3. The paved part, the stage for neighbourhood events, activities, festivals, auditions and shows. 4. The lake, waterfall and backdrop of trees act as a screen and dampen the sound of the busiest streets.	The square was officially opened for public enjoyment in 1983. It represents a local residents' victory, a demand that is now a living, active reality in the form of a landscaped, neighbourhood square. The sculptor created a sculptural ensemble for the square. The park is a recreation of the Balearic Islands and of the historical relations maintained with the neighbourhood.
Jadines de Piscines i Esports	A small pond has two Chinese weeping willows. There are specimens of ombu and tipus, a line of palm trees. The central avenue boasts a group of poplars. The route reveals several specimens of mulberries, palm trees and dwarf palms, pine trees, peppercorn trees and black locusts. The park also has Aleppo pine and holm oak plantations, with abelias, acanthus trees and mastic trees.	1. It has the most active sports and leisure facilities in the neighbourhood. 2. It can host school sports, Sardana-dancing and festive parties. 3. It has the rain-water deposit, one of those making up the municipal grid that manages the city's abundant rainwater.	It is one of Barcelona's historical parks. It is a multi-used public sports complex. The northern slope has a smaller, triangular-shaped landscaped area that closes the gardens off and insulates them from the city's hustle and bustle.

Name	Biodiversity	Functions	Landscape plan and design
Parque Torrent Maduixer	There are 79 trees from a variety of species: 13 tipu trees, 2 foxglove trees, 10 jacarandas, 5 Indian bead trees, ash trees, 7 carob trees, 5 holm oaks, 3 cork oaks, Aleppo pines, 9 stone pines, 11 hackberry trees and 5 strawberry trees. Its lateral parterres contain shrubs such as pink agapanthus, woolly Jerusalem sage, violet-flower, "Sunset" rock rose, firecracker plant, orange-flower daylilies, purpletop vervain, Chinese fountain grass and lion's tail.	1. To connect different areas that there is a fast, lateral route, via stairs, that allows visitors to cross it from north to south. 2. The second terrace has six skylights that ensure natural light enters the interior of the underground cleaning depot.	This garden lies on hilly land with a 9m gradient in the Sarrià - Sant Gervasi district, near Parc de Collserola. This urban garden was designed for the roof of the new Torrent Maduixer municipal cleaning depot, an underground building that centralises the street-cleaning services of the Sant Gervasi.
Parque de las Rieres d'Horta	The trees include cypresses, Aleppo pines, multi-stem field maples, strawberry trees, ash tree, almond trees, holm oaks, downy oaks, silver maples, hackberry trees, ginkgos, callery pear trees, bald cypresses, orchid trees, multi-stem plane trees, Armenian plum trees, purple-leaf cherry plum trees, bird cherries. Notable specimens include some recovered from the original site, such as Norfolk Island pinetrees, several Judas trees and jacarandas. Its shrubs include common boxwood, cistuses, dwarf cheesewood trees, abelias, false olive trees, mastic trees, laurustinuses, Japanese spurge, Asiatic jasmine, kiss-me-quick, southern globethistle, Joe-Pye weed, pink gaura, dwarf lilyturf, red bistort, Himalayan bistort Persicaria affinis, society garlic, purpletop vervain and Chinese fountain grass and so on.	1. This park helps to link and bring together the La Clota and Horta neighbourhoods. 2. Proximity to Collserola makes this park a biodiversity link between the mountain range and the city. 3. The park uses LED technology, rainwater for irrigation and solar energy for its lighting system.	The park boasts numerous plants and has adopted significant re-naturalisation innovations, which include planting natural-sized trees that enable a high density of biomass to be obtained. Lighting is provided by 921 LED lights mounted in the walls, which help to guide pedestrians along the routes that cross the park. There is a health and sports circuit, especially for older people. It also has an accessible children's play area and a central space with a compact, gravelled surface, paved areas with steps, and a tree-lined stage for holding neighbourhood events. The layout of the trees ensures the resting areas offer shade in the summer and sunshine during the winter.

Name	Biodiversity	Functions	Landscape plan and design
Parque de Can Rigal	It has two distinct areas. On one side there is an area of Mediterranean forest, full of pine and holm oak trees, which adds to the landscape of the Collserola range. On the other there is a large meadow with a series of platforms and geometric plantations of deciduous trees, as well as children's play areas.	1. It uses environmental sustainability standards, especially the use of vegetation and water and the use of recycled materials and controlled lighting, as electricity is generated by solar panels. 2. Rainwater is collected from the surface and guided through the drain and gravel system from saturating.	It is a large park, with an area of Mediterranean woodland and large, tree-lined leisure areas. The local residents have participated in the park's design. The central pathway breaks off into to rest areas and geometric flowerbeds with bushes and herbaceous plants. Along the pathway the colours keep alternating as the species selected throughout the year come into bloom. Pergolas and porticoes, with climbing plants and solar panels, enhance the path's central character and create areas of shade and colour, while powering the park's lighting.
Jardines de Miquel Martí i Pol	It is made up of white poplars, black poplars and holm oaks. A small natural breakwater lashed by green waves of ivy covers the entire surface. The ivy lies next to bulbous plants, with the paperwhite narcissus to the fore. It also has Spanish bluebells, seaheaths, cat's tails, red spider lilies and Osmanthus 'bicolor', autumn daffodils, several varieties of iris, etc. There are also perennials and rhizomes, such as Arum italicum, which bears fruit arranged in orange and red bunches and gives off heat when it blossoms.	1. It is in honour of the poet Miquel Martí I Pol (Roda de Ter, 1929-Vic, 2003). 2. It is a resting area with peaceful atmosphere for the locals.	These gardens were designed as a re-creation of a random wood. The gardens' design was produced by the BAAS Arquitectura Studio, and came out when the old Can Framis factory site was being redeveloped. Their landscaping project for the museum's surroundings was shortlisted for the 6th Rosa Barba European Landscape Awards and the Public Space European Space competition, both of which were held in 2010.
Jardines de Portolà	There are two palm trees, Asiatic jasmine, lilyturf, groundsel, bugles and a large wild Osmanthus heterophyllus, sweet bay, medlars, privet and African lilies, boxwood scrub , fruit	It was an outdoor extension of a study desk, a corner for meditation and recreation. The estate the garden is set in is being restored to make	The space currently occupied by the house and the Portolà Gardens had been agricultural land, a vineyard, at the turn of the 18th century. The building, constructed around 1910, has two separate structures. One is

Name	Biodiversity	Functions	Landscape plan and design
	trees, Virginia creeper, an olive tree.	the most of it as a social facility, so that it will be allocated for use by a third sector association.	made up by a ground floor and two more storeys. This higher part also has a view of the back garden and the roof opens up to the city like a bell-shaped flower.
Parque de Joan Reventós	There are ivy, bougainvillea or a combination of Virginia creeper and cats claw creeper, a number of palm trees, laurustinus and strawberry trees, Mediterranean buckthorn, a large cheesewood, large Mediterranean dwarf palms and Chusan palm, and a Mediterranean dwarf palm. There is a remarkably large Himalayan cedar.	1. It has an accessible children's play area, pedestrian, cyclist and skating circuits and drinking-water fountains. 2. The park has a complete drainage system, underneath this vegetation, for channelling water away.	This park, located in the Sarrià neighbourhood, has very good connections with Parc de Collserola. It has a small depression of the flowerbed in the lower part marked with a sign. It has a drainage shaft, made and prepared for absorbing rainwater.
Parque del Centre del Poblenou	There are about 1,000 trees, 35 palms, over 5,000 shrubs, a similar number of cactuses and succulent plants, nearly 11,000 climber plants, over 1,400 herbaceous plants or 48 different aromatic species perfuming the park. All this vegetation is intended to provide a natural ceiling that lets the light through.	1. It has a water-storage and treatment tank that ensures all the park's plants are drip-irrigated through a system which uses groundwater. 2. A mountain that closes off the view of the park and which turns out to be the roof of the pneumatic waste-collection centre.	This is a spectacular space where every piece of vegetation and urban furniture plays a dual role, practical and decorative. Censers that act as plant pots and other original, vertical, flower stands contribute to the park's character. Such a penchant for design does not exclude the presence of children's play areas, pétanque courts, bicycle parking places, table-tennis tables or areas for dogs.
Parque de la Primavera	The park's vegetation is typical of the Mediterranean and made up of trees, shrubs, climbing plants, evergreens and grasses. Such as boxwood, mastic trees, rose bushes and lavender, to name of few of the 23 species. Notable varieties of trees here include Aleppo pines, white	1. When the cleaning depot was built, it offered an opportunity to deal with the lack of services such as areas for children to play or let dogs loose in. 2. It provide an accessible link between Passeig	This is an example of how a much-needed facility for managing urban services could also be a pleasant green space.

Name	Biodiversity	Functions	Landscape plan and design
	poplars, wild cherries, holm oaks and cork oaks.	de Montjuïc and the higher level.	
Jardín de los Drets Humans	The garden preserves most of the trees and shrubs from the original arrangement. Also, 70 new specimens of trees were added to the garden. The garden has areas of grass and common ivy, which blend and mix in with the current vegetation.	The gardens represent the recovery of a space around the Philips apple, to integrate it into the urban structure of the Marina-Zona Franca neighbourhood.	It is an outstanding green space and was designed in the 1960s by Mrs Van der Harst, a landscape artist and the wife of the then manager of the Philips factory, to provide the workers there with a space for relaxing in during their working-day rest periods. Regarding the name 'Human Rights Garden', there are 30 lighting points placed at random on the route round with the 30 Articles of the Universal Declaration of Human Rights (United Nations, 1948) and another point with a poem by the Argentinian poet.
Parque de los Auditoris	The vegetation consists mainly of reeds and grasses hidden behind dunes, on the backs of which they grow. The most common trees are mulberries and junipers. There are also several Indian laurel trees.	1. This park is a large multi-purpose space, with open-air auditoriums that regularly play host to a large variety of events and places for taking a stroll. 2. The Auditori del Mar, popularly known as the auditori petit, or small auditorium, with a seating capacity for 3,500 people. Another terrace is the Gran Auditori, or large auditorium, with a seating capacity for 8,500 people	The various parts of the park are connected by diagonal ramps, with a design inspired by airport conveyor belts, allowing a gentle movement between levels. Five large, artificial dunes determine the layout of the park and its different parts. The dunes are covered in vegetation and, to a large extent, by pink-hued, crescent-shaped concrete pieces which pave the surface of the park's paths, giving a highly ornamental continuity to the area between the horizontal and sloping planes. Standing behind the end closest to the sea is one of the symbols of the 2004 Barcelona Forum.

Name	Biodiversity	Functions	Landscape plan and design
Jardines de Joan Brossa	There are large carpets of perennials and grasses of many different species. These gardens are rich in conifers, such as cedars, pine trees and cypresses. It has Atlas cedars, Himalayan cedars, Lebanon cedars, Aleppo pines, Monterey pines, Himalayan pines, maritime pines, cypresses, Arizona and Monterey cypresses. It also has olive trees, holm oaks and French tamarisk, and others with ornamental blossoms such as coojongs, pagoda trees, magnolias and acacias. There are large fan palms, chusan palms and Mediterranean dwarf palms.	Two of the buildings constructed in the old amusement park in 1965 have also been preserved. The first is the Damm kiosk, the brewery's bar restaurant, which became the amusement park's most popular and iconic circular building. It has been restored and is currently a venue for holding celebrations and conventions. The second is the amusement park's Bar Fanta, made of concrete and curiously shaped like an umbrella. Now it is a decorative feature of the gardens.	It is over 30 years, and now is a large green space covered with luxuriant and typically Mediterranean vegetation. It is an excellent example of how landscape and environmental reclamation can be achieved by consolidating the already existing vegetation and boosting its natural, slightly wild look. A cross between a woodland park and a city garden, they have features of both, especially the former. Their location means they form a link between a number of Montjuïc's gardens. There are three play and recreation areas with things for people of all ages. The path that crosses the park offers "musical cushions" that emit sounds when visitors step on them and there is an area with zip lines and climbing games.
Jadines de Frida Kahlo	There are several species of southern nettle trees, elms, cypresses, pines and poplars. The shrubs accompanying the trees are an example of a Mediterranean understorey with rosemary, common hawthorn, olive trees. A notable feature here are the sculpted cypresses. The parterres also boast magnolias and nettle trees intermingled with roses of Syria, glossy privets and Japanese mock oranges. A wooden platform is surrounded by specimens of cherry laurel and sweet bay, wide-branched cypresses, tipu trees.	It is part of a very wide green corridor that also includes other gardens and squares, and which crosses Barcelona from sea to mountain. The corridor that joins up the green spaces of Parc del Guinardó, Parc del Carmel and Park Güell with the green spaces of the Vall d'Hebron, Parc de les Heures and even the large green lung of Collserola through the Vall d'Hebron part.	It pays homage to Frida Kahlo (Mexican painter). It is dominated by Mediterranean trees and shrubs. The gardens are also known among the Vall d'Hebron neighbourhood residents as the jardins de l'estrella (star gardens), after the shape is outlined by the central and lateral parterres.

Name	Biodiversity	Functions	Landscape plan and design
Jadines de la Font dels Ocellets	There are plane trees, cypresses, palm trees, Canary Island date palms, ordinary date palms, fan palms. And some large eucalyptus and pine trees at the top of the garden. As for flowering trees, there are quite a few specimens of illawarra flame trees.	It is a leisure spot and meeting place for residents, with recreation area for people and dogs, a children' play area.	These long, narrow gardens form a pleasant link between Av Diagonal, Plaza de Pius XII and Av Pedralbes.
Jardines del Clot de la Mel	It has specimens of pata de vaca, golden weeping willow, lime trees and Indian bean trees, olive trees, poplars and palm trees. There are ombus and ash trees planted in the corner. In the children's play areas, there are rows of kurrajongs and a small group of holm oaks and horse chestnuts. It also has the most exotic species: a group of trees of heaven. These are also known as chouchun trees and Judas trees.	1. These gardens evoke the industrial era of Sant Martí's flour and textile mills. 2. The leisure and relax area for local residents, with Ping-Pong tables, the children's play area and recreation area for dogs.	It occupies a quadrangular area equivalent to a block in the Clot neighbourhood. Archaeological features, such as the tall chimney which acts as a landmark, remind us of the factory and industrial traditions of Sant Martí's flour and textile mills. The gardens are divided into four formally equal areas with a large number of flowering trees. These local spaces open to the whole neighbourhood, and extremely popular with older people, school children, teenagers and the general public.
Jardines de Rosa Luxemburg	They include a large number and variety of trees, many of them are fruit trees and floral ones. There is also a wood with full of shrubs and aromatic plants.	1. It offers a good view of El Carmel hill. 2. There is a large area for dogs and a children's play area. 3.This is a pleasant place for taking a stroll or having a good read in one of the shaded areas, especially in the spring, when the plants are at their peak.	The gardens are bounded on one side by school facilities, which use them as a second, first-class playground. These gardens are a green space with the lushness stands out and shines in the middle of the open spaces around them. It is homage to the neighbourhood's farming past, still present in its surroundings. The gardens are divided into terraces with a height difference of 15m.

Name	Biodiversity	Functions	Landscape plan and design
Parque de Diagonal Mar	There are the orange-flowered Hemerocallis sp., the yellow-flowered Hypericum sp., pink-flowered dwarf oleanders and red-flowered Callistemon speciosus, creeping rosemary, small white-flowered abelia, cotton lavender, sweet bay and prickly spider-flower Grevillea juniperina. The park has a large number of tipu trees. There are white poplars and black poplars around the lakes and numerous oaks. The park also has eucalyptus trees, Aleppo pine trees, stone pine trees, olive trees, French tamarisks, honey locusts, Chinese parasol trees, cockspur coral trees, pagoda trees and southern nettle trees and so on.	It has various uses, offering residential buildings, offices, a shopping centre, hotels and a park. Also it includes recreation areas for local residents, like the Ping-Pong tables, football field, municipal petanque tracks, several lakes, paly area for dogs, and the children's play area.	It is Barcelona's second largest park. It blends in with the city through a large open space that links to the sea. It is built round a series of paths which, like trees, stretch in all directions. There are very long concrete benches, separating and organising spaces, which are intended to conjure up the feeling of sea waves as they progressively adopt the shape of these paths and the contours of several squares.
Jardines de la Arboreda	There is a variety of trees, including common ash, a Lebanon cedar, poplars, river oaks, pink sirises, peppercorn trees, ombus, plane trees and honey locusts, grey poplars and pine trees, ash trees, jacarandas. Here the gardens continue with small parterres containing palm trees, dwarf palms, pagoda trees and black locusts.	1. Redeveloped the old seat flat. 2. The recreation area for residents with children's play area.	The Jardins de l'Arboreda and Jardins de Sant Cristòfol share a neighbourhood, and are parts of the old Seat flat redevelopment, to remind the area’s industrial past.
Parque de Carles I	It contains many of the plane trees, three large ombus, Seville orange trees and magnolias. Also noteworthy are the conifers there, as represented by Aleppo pines, stone pines and Himalayan cedars. There are also date and Canary Island date palms and fan palms, Siberian	The park has rest areas and a children’s play area. It also has one of the biggest dog recreation areas in Barcelona.	It is located in the vertex of the Parc de la Ciutadella, which makes up part of a long linear park area created to open Barcelona up to the sea for the Olympic Games in 1992. The park has a large grassland, along with the water from the canal flowing into the

Name	Biodiversity	Functions	Landscape plan and design
	elms, weeping willows, white mulberries and olive trees.		waterfall, along the route of the street, marking the end of the park's wide raised area. Other elements, such as rows of trees and gentle hills covered in grass, shape the landscape characters.
Parque de la Nova Icària	There are mulberries, Aleppo pines, stone pines, dwarf palms, ombu trees, a few olive trees and eucalyptuses, Chinese weeping willows. A large poplar stand out by the lake.	It is a hint of hills that turn into a large solarium on Sundays, locating between the Ronda del Litoral (coastal ring road) and the beaches.	It is one of five large, green parks that were built on Poblenou's old industrial land at the start of the 1990s. The others are Parc de les Cascades, Parc del Port Olímpic, Parc del Poblenou and Parc de Carles I. This is one of the green spaces built in 1992 around the Barcelona Olympic Games. The wooden bridges are attractive light structures and perfectly integrated into the landscape, giving the latter personality.
Parque del Pla de Fornells	The park is an extension of the Collserola range, dominated by holm oaks, Aleppo pines and stone pines. Its landings are shaded by plane trees, stone pines and peppercorn trees. There are also tipu trees, eucalyptus trees, cypresses, acacias and pagoda trees.	1. It links up and plan a large space between the last urban foothills of the Roquetes and Trinitat Nova neighbourhoods and the lower slope of the Collserola mountain range. 2. There are various facilities and rest area, like an amphitheatre where hold events, a small pool with aquatic plants to enjoy.	It combines an eminently forest character with a very modern layout. It starts in a small, paved square. It has a small pool with aquatic plants at the centre and parterres all around, with trees, shrubs and groups of flowers. The resting areas provides a good view of the city. A large slope at the top is covered by forest plants that occupy over half the park.
Jardins de Vil·la Cecília	There are stone pines, cypresses, Canary Island date palms, plane trees, lime trees, cedars, peppercorn trees, Siberian elms and trees of heaven. The civic centre is by a	1. There is a recreational area that designed for older people, where they can exercise and enrich their daily walks. 2. A	These gardens are a magnificent green space, with numerous hundred-year-old trees, they are one of the district's nerve centres. It was designed by the architects

Name	Biodiversity	Functions	Landscape plan and design
	jelly palm Butia capitata, a tree rarely found in Barcelona.	part of today's green spaces used to belong to the old Vil·la Amèlia Gardens, which are located right next to it and are now for public use.	Elías Torres and José Antonio Martínez. Two design elements that won a FAD decorative arts prize in 1986.
Parque de las Cascades	The park boasts hackberry trees and cypresses, jacarandas, poplars, olive trees, fan palms. Groups of dwarf palms and large shrubby scrubs surround the landscape below. Both sides of the park are delineated by the splendid, bright green of the wide and very long grass-covered parterres, where lush Aleppo pines, stone pines and tipu trees.	It devotes a part to the creation of new public green spaces. It is also part of the important urban renewal of city's coastline.	It is a part of the major facelift the city's coastal facade received for the 1992 Olympic Games and is one of the five large green spaces. This is the first space in a series of parks that follow one another almost until reaching Sant Adrià del Besòs. The pedestrian finds paths among the vegetation and, from time to time, there are streets that cross them.
Parque de Josep Maria Serra Martí	There are twenty fan palms and a group of eucalyptus trees, peppercorn trees, lime trees, jacarandas and tipu trees, and ombus, grey poplars, white poplars, pink sirises, kurrajongs and southern nettle trees and the blue plumbagos.	1. It is a multi-uses park, including holding the weekly Tuesday market in the neighbourhood: Canyelles. 2. It is a good example of restorative urban planning, as it improved the quality of the large area occupied by housing between Avinguda de la Guineueta Vella and Ronda de Dalt.	This green space, highly popular with local residents, is not just a park but also a thoroughfare and a square. It is designed with big banked flowerbeds between which run a number of serpentine ramps that create the various itineraries and leisure areas. The Font de Manuel de Falla, a fountain designed by Pedro Barragán (1994), has a set of light, water and sound that makes it a magic fountain.
Jardines de Joan Vinyoli	There are thin poplars, tipus, the poplars, golden rain trees, nettle trees, yellow bamboo reeds. As part of the events to mark Vinyoli Year, two trees were planted in the central part on 14 June 2014: a carob and a cork oak.	It provides a space for walking through an area with heavy traffic.	These gardens were designed in the 1990s and are located above the underground car park to mitigate the effects of heavy traffic. The designers of the garden used two artificial embankments to create a dune landscape to help the adjacent

Name	Biodiversity	Functions	Landscape plan and design
			streets mitigate and shield noise and pollution.
Parque de la Vall d'Hebron	There are slender fan palms, large Aleppo pines, reeds, cypresses, eucalyptuses, stone pines, olive trees, white poplars, poplars, Canary Island date palms. Its small squares abound in hackberry trees, tipu trees and jacarandas, while its slopes and parterres have oleanders, narrowleaf firethorns and ivy.	1. It is a link between the city and Collserola. 2. This area links together several green spaces in a zone that was totally redeveloped for the 1992 Olympic Games, and which includes several sports and residential facilities.	The park is a series of squares, some with pergola and attractive trees, and large roadside flower beds, mostly on slopes. This vast area is full of reeds, ivy climbs over the slopes, and there are plenty of palm trees and other trees. It has some famous and popular sculptures.
Parque de la Barceloneta	The park has an abundance of Aleppo pine trees, river oaks, tipu trees, tamarisks. The park also has an impressive group of ombu trees. As for palm trees, a constant feature of Barcelona's seafront, the park boasts numerous fan palms and date palms.	1. It preserved part of the factory, as a reminder of one of the industries Barceloneta, specialised in during the 19th century: gas. 2. Today it houses Fàbrica del Sol, literally the "Sun Factory" and actually the Barcelona Sustainable Resources Centre, whose facilities are dedicated to environmental education.	It is an open transitional space between Barceloneta and Vila Olímpica that extends to the sea. This wide, translucent green space, with lawn and gravel areas, is the communication link between the loop and the beach. The park is divided into three major areas: An open space was built around the remains of the old fuel tank; A large slope; The football field. Architects Jordi Henrich and Olga Tarrasó designed the park. They conserved the laminated steel structure of the gasometer, the water tower and the entrance of factory.
Parque del Poblenou	There are white poplars, bamboo, numerous privet, sweet bay, mastic tree hedges, Aleppo pines, a few carob trees, date palm trees, petticoat palms. The park also has several eucalyptuses and is full of aromatic species, such as thyme, rosemary and large scrubs consisting of French lavender and baby sage.	The recreation park for citizens, with recreation area for dogs, the Ping-Pong tables, the skateboarding area, and the children's play area.	This is one of the green spaces on the waterfront with direct access to the beach. Barcelona rebuilt the land and used part of it to build a new public green space, built in the 1992 Olympics. The park is located at the end of the Olympic Village and has a large pine forest and a space full of sand dunes. It is separated from the

Name	Biodiversity	Functions	Landscape plan and design
			traffic and leads to a long row of poplar trees and numerous tight rectangular hedges.
Parque del Port Olímpic	There are Aleppo pines, stone pines, ombu, tipu trees, plane trees, large groups of dwarf palms, date trees and Canary Island date trees. There are shrubs too, cheesewoods, abelias, oleanders and large ornamental expanses of juniper.	There is a resting area with benches, children's play area, and terracota plant pots displaying highly ornamental plants.	It is one of the five large green spaces and is redeveloped for the 1992 Olympic Games. Marc is a sculpture full of colour which the artist Robert Llimós dedicated to the memory of his son Marc who died in a car accident. At the centre of a small square pool, there is a bronze figure of Cobi, the mascot for the 1992 Olympic Games, by Xavier Mariscal.
Jardines del Palau Robert	It boasts aspidistras, umbrella sedges, ferns, a loquat and one of the large and hundred-year-old Canary Island palms, two enormous laurel-leaved snail trees, common ivy, cheesewood hedges, privets, butcher's broom, aspidistras. The parterres have numerous sago palms, African lilies. Besides, there are pagoda trees, cypresses, smooth American cypresses, plane trees, Judas trees, magnolias, large-leaved limes, Seville orange trees and Platycladus orientalis.	There is a resting area with peaceful atmosphere, there are some benches and the children's play area.	These gardens have amazing three large flower beds. They highlight a vivid green colour and become a thousand shades. The neoclassical building was designed by the French architect Henry Grandpierre and built with the stones of the Montgrí mountain (Baix Empordà). In the garden there is a sculpture called La lluna (the moon), which was carved in 2001 by Kiku Mistu. There is a stainless steel and iron moon with a red podium drawn by students at the Joan Amades School for the Blind.
Jardines de la Maternitat	There are 40 different species of trees, including eucalyptuses, mulberries, olive trees, peppercorn trees, cypresses and enormous pine trees from several species, acacias, tipus, pagoda trees, horse chestnuts, weeping willows, fig trees, umbus and poplars. Particularly notable are	The space for enjoying the tranquil ambience for health-care.	It was built in the late 19th century Can Cavaller estate, the original complex building and pavilion structure. After the original designer's death, the project was undertaken by other architects. The Prat de la Riba pavilion was designed. The Rosa i Goday Pavilion

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	the tall common date palms and Canary Island date palms and three magnolias of a more than exceptional height, one of which in particular, is a giant, probably the tallest in Barcelona, over 12 m high and more than 15 m wide.		and the blue pavilion were created. Manuel Baldrich i Tubau built the Cambó Pavilion towards the end of the 1950s. The buildings currently house a secondary school, IES Les Corts, the COM Ràdio station and several offices belonging to the Barcelona Provincial Council and the University of Barcelona.
Parque de la Font Florida	The yellow-flowering tipu trees may dominate the park's tree-lined square, and vivid-green-leafed hackberry trees, the stone pines, Aleppo pines, holm oaks, peppercorn trees, ombu trees, poplars and eucalyptuses. As well as Mediterranean shrubs, such as broom, and aromatic shrubs.	An area especially designed for pétanque players. There are plenty of courts to play on, as well as benches to sit on and watch the games.	This park is a good example of a city park created in the 1990s. At the heart of the park is a wide, slender paved esplanade. This is a very large tree-lined square with benches and children's play space on one side and a shaded area on the other. The bright yellow flowers form a delicate carpet on the ground, in stark contrast to the green of the opposite slope. The slope next to it is a grass-covered wall with a variety of trees and numerous shrubs. This reminds us the landscaping carried out by J. C. N. Forestier on Montjuïc for the International Exposition of 1929.
Jardines de las Tres Xemeneies	Grey poplars, the predominant feature of the gardens, are spread geometrically around the gravelled space. Specimens from several species bringing colour and diversity to the space have been planted in a corner next to the pétanque area.	1. It is for local residents to rest with a children's play area and the pétanque courts and table-tennis tables. 2. A large cube in the background provides a venue for celebrations and shows. 3.The three chimneys in these gardens are a homage to an excellent example	The gardens open up from one side of Avinguda del Paral·lel to the other in a large concrete esplanade with benches and trees planted in tree pits, a highly typical feature of Barcelona's urban planning in the 1990s.

Name	Biodiversity	Functions	Landscape plan and design
		of industrial architecture from the late 19th and early 20th centuries.	
Parque del Mirador del Poble Sec	The tree species in this park include jacarandas, hackberry trees, Mexican ash trees Fraxinus berlandieriana, holm oaks, acacias, Siberian elms, pagoda trees, cypresses, Aleppo pines, stone pines, peppercorn trees and numerous Judas trees, which have been given a shrubby appearance. The large resting area is dominated by golden rain trees and a pergola covered in Chinese wisteria and Virginia creepers.	It has pétanque courts, children's play areas, and recreational spaces shaded by trees and a pergola covered with climbing plants, and a pond full of aquatic plants.	It has the characteristics of a urban park and a forest park. Because it turned from the Montjuïc side into a urban garden, it became a bridge between the Montjuïc forest landscape and the Poble-sec community. It reproduces the rural forest landscape of Mediterranean vegetation. A huge stream of water erupted from one of the stone walls, supported by a small 28-meter-long iron pipe, and terminated in a small waterfall that descended from the waterfall.
Jardines de Ca l'Alena	It has trees, shrubs, creepers and grass.	1. It holds the events and activities of neighbourhood. 2. There is a fountain with drinking water. 3. It is also equipped with lighting and urban furniture: chairs, benches, litter bins, children's paly area and a fitness circuit.	The remodelling of the area and rationalisation of the pathways means it can help to improve neighbourhood activities. The park is designed by the yellow concrete paving and painted surrounding walls.
Jardines del Príncep de Girona	The gardens have Indian bead trees, several Canary Island date palms, oleanders, bougainvilleas, blue plumbago scrub, a group of dwarf palms and shrubs, such as firethorn and laurustinus. An evergreen fig tree Ficus elastica can be seen next to the table-tennis tables and plane trees by the lake.	There are various amenities, such as a children's play area, some table-tennis tables, a bar with tables shaded by pine trees, an area for dogs and a large lake.	The garden was built on the central courtyard of the old military camp. Some buildings remain on one side. This is a pleasant space. The Pinus pinea area offers a small picnic area; several seating areas and a large gravel central square provide good shade.

Name	Biodiversity	Functions	Landscape plan and design
Parque de la trinitat	There are numerous poplars, a large plantation of olive trees, many green-shaded privet, the scarlet of the purple-leaf cherry plums and Leyland cypresses. In the sports area, there are many ombu trees and acacias. The picnic area is shaded by the boughs of plane trees.	The space for enjoying the tranquil ambience for health-care. There is a multi-purpose amphitheatre that give access to the large resting area lying just before the sports courts and picnic area.	The long routine planting of trees was inspired by the trees that the drivers saw on the highway connecting Barcelona and Girona. The most beautiful part of the park is the wide path from the highest point of the park to its glory, a large balcony that provides a pleasant place to rest.
Jardines de Sant Pau del Camp	There are mulberries (Morus alba), tipus (Tipuana tipu) and poplars (Populus alba 'Pyramidalis'). It is bounded by a wall covered in bougainvillea.	There is a large gravelled space nearby, protected by the wide boughs of shady trees, where there are bowls courts and a children's play area.	These gardens surround the Romanesque Sant Pau del Camp monastery, one of Barcelona's architectural treasures. The wide grass parterres that form a small hill are the main attractions of these gardens. Although the building is at street level, the park's design allows it to be admired from the top of the small hill that crowns the grounds.
Jardines de Ca n'Altimira	The gardens have trees that are now a hundred years old, such as the Aleppo pines, river oaks, southern nettle trees, stone pines, Atlas cedars, Siberian elms and black locusts (Robinia pseudoacacia). Among the more recent plants, there are mountain laurels, purple-leaf cherry plum and kurrajong, the cat's claw creeper and so on.	The resting area with children's play area.	They are full of romantic and peaceful feel. Their plants create a rich atmosphere, enhanced by the play of light and shade. Their romantic nature comes from their architectural features. Besides the stone bridge and wooden-paved steel-suspension bridge, Can'Altimira, a former country mansion, is the most notable architecture.
Parque de Sant Martí	There are tipu trees, the cypresses, tall white poplars, orange trees and olive trees, and an immense Siberian elm stands out magnificently by the water,	1. There is a children's play area and a seating area with benches. 2. The Sant Martí parish church is a unique part of the park, the most	It is a large community park. The lush woods provide a quiet place surrounded by trees and large paved spaces. The largest part of the park is like an irregularly shaped triangle,

Name	Biodiversity	Functions	Landscape plan and design
	and a row of common alders at one end of the park.	prominent of which is the architectural features that have survived for many years: Can Cadena, Can Planas and Ca l'Arnó.3. Can Cardena has 16 plots of land grown by the elderly in the region. One area for farm animals, another for composting areas and classrooms for organic farming training.	completely covered by grass and trees.
Parque de Can Sabaté	There are maidenhair trees, nettle trees, weeping willows, river she-oaks, Canadian poplars, pepper trees, eucalyptuses, stone pines, holm oaks, ombus, sycamore maples and cypresses. The park also has fruit trees, such as persimmons, petticoat palms, date palms and Canary Island date palms; aromatic plants, such as rosemary; and shrubs such as sweet bays and glossy privet.	There is a small pathway full of nettle trees separates the large open and sunny space from the children's play areas, secluded and surrounded by hedges.	In the middle of the square there is a narrow canal with a small path on the small flowing water, turning from the spout of the pyramid into an original decorative fountain.
Parque de la Estació del Nord	There are stone pines, very high poplars, a lot of large white poplars, grey poplars. One particular grey poplar, remarkable for its hundred years and magnificent appearance, is listed in the Barcelona Trees of Local Interest Catalogue. It also includes lime trees, holm oaks, Monterey cypresses, white poplars, tamarisks, strawberry trees, cheesewood trees, laurustinuses, hackberry trees, pagoda trees and so on.	The recreation park for citizens, with recreation area for dogs, the Ping-Pong tables, and the children's play area.	This spacious and sunny park is built around a huge sculpture and is considered the only example of land art in Barcelona. Here it is represented by ceramics on the landscape, with two sculptures by Beverly Pepper: Cel caigut (Fallen Sky) and Espiral arbrada (Tree-lined Spiral). Small, wooden-beam paths make it easier for visitors to walk up.

Name	Biodiversity	Functions	Landscape plan and design
Parque del Les Corts	There are Common ash, grey poplars, holm oaks, Aleppo pines, tipu trees, pink siris, several magnolias. Notable too are the Himalayan and Atlas cedars and the stone pines.	The recreation park for citizens, with recreation area for dogs, the Ping-Pong tables, and the children's play area.	This little park is a treat for people living nearby, an unbeatable neighbourhood garden. A brick arcade near C/ Numància that recalls the industrial past of Les Corts. Long, sloping, grass-covered parterres adapt to the canal's curves on both sides.
Parque de la Creueta del Coll	There are the acacias in the resting areas, and the pine grove and Mediterranean shrubs in the picnic area, and some palm trees and two-stemmed date palm.	It is a sheltered park, with a big lake people can swim in during the summer, a huge square and numerous resting places, like a picnic area.	A large square, bounded in part by a pergola and protected at the back by the walls of what used to be a quarry. Paths climb upwards in the midst of a luxuriant vegetation of trees and shrubs. Right at the top, and the green of the plants that have steadily grown and add colour to the walls of the old El Coll quarry. One of the park's most highly prized features is a colossal sculpture by Eduardo Chillida entitled Elogi de l'aigua (In Praise of Water).
Parc del Clot	There are date palm trees, plane trees, ivy, stone pines, holm oaks, pagoda trees, blue-leafed acacias, hackberry trees, grey poplars, cypresses, Seville orange trees, shrubs, such as oleander, cheesewood, privet, sweet bay and wild sage, and so on.	It preserves some of the vestiges of the past that were integrated into the large square surrounded by the sports courts.	This is a good example of combining existing building features with green space design. The park was designed by Daniel Freixa and Vicent Miranda. They preserved some of the old factory structures and previously worked as part of the El Clot station and the railway repair shops. These structures are integrated into the park, giving it a unique look.

Name	Biodiversity	Functions	Landscape plan and design
Parque de La Pegaso	The are weeping willows, white poplars, Canadian poplars, umbrella sedge and bald cypress. Near the water, there are also specimens of French tamarisk, paper reed and large areas of bamboo. The park also boasts specimens of ombú, southern magnolias, chamaerops, Peruvian pepper, African hemp, Tasmanian bluegum, deodar cedar, jacaranda and ginkgo, alongside typically Mediterranean species like holm oaks and stone pines. The park has a variety of bushes, including abelias, oleander and California privet.	1. There is a sports centre, the children's play areas and a pond. 2. The pond's pipes are waterproof. The new machines for circulating water are installed. The water jets in the pond have been updated and low-energy lighting has been installed.	The park is a place of exuberant vegetation, with open spaces and other sheltered, shady areas with lots of trees. It is located on the site of the former ENASA (Empresa Nacional de Autocamiones) lorry factory. The park was designed by the architects Enric Batlle and Joan Roig. From the gate, the park is divided into two sectors: an esplanade under the shade of plane trees, and a series of small hills that pay architectural tribute to Fontserè's nineteenth century gardens.
Parque de la Espanya Industrial	There are several Chinese weeping willows, a couple of rows of purple-leaf cherry plum trees. A woody area that is full of holm oaks, Leyland cypresses, stone pines and plane trees.	1. There is the city's second largest lake. Water recirculation pumps were installed there, which enable it to connect with the groundwater grid that comes Parc del Joan Miró. That saves the city 26,000m_ of drinking water a year. 2. It became one of the main sports facilities in the Sants-Montjuïc district.	This is an example of land reclamation that began in Barcelona in the 1980s to recover land occupied by industry. It extends along a wide esplanade below hilly ground covered with long rows of steps. Nine lighthouse towers dominate the top of these steps. It also preserved the buildings of the old Espanya Industrial factory (now a children's centre, and the arcade of the entrance gate). There is an iron dragon with open wings and was by the Basque sculptor Andrés Nagel. Manuel Fluxà's 1881 sculpture Neptú (Neptune) stands in the water. Venus moderna (Modern Venus) sits on a rock near the lake.

Name	Biodiversity	Functions	Landscape plan and design
Jardines de Moragas	There are Aleppo pine trees, Himalayan cedars, horse chestnuts, cypresses, jacarandas and peppercorn trees. Notable palm trees include the fan palms, spectacular groups of dwarf palms and Canary Island date palms.	There is a children's play area in a wide open space. It is also a leisure and meeting point for older people.	It is a small green neighbourhood space, with a complex layout and variety of vegetation. The lush vegetation insulates visitors from the heavy urban environment that surrounds the park. A sculpture is Antoni Ramón González's homage to books and reading.
Parque de Joan Miró	There are Canary Island date palms, ordinary date palms,nthe stone and Aleppo pines, holm oaks, eucalyptuses, oleanders, cypress hedges, majestic white poplars, palm grove, cedars, Chinese wisterias and bougainvilleas.	1. There are several rest area and bars for local residents to meet up, and six children's play areas. The palm grove has pétanque courts and a large area for dogs. 2. The garden for biodiversity, is designed to improve the quality of the habitat for flora and fauna. 3. The public library is an extraordinary complement to this large urban green space for local residents.	The park occupies the location of the city's old slaughterhouse and is the size of four blocks in the Eixample district. It is also the first park to use outdated facilities. This park is organised into several areas: gardens for biodiversity; a 6,000_ expanse of grass that covers an underground car park and rain-water tank; the woods, a palm grove and a pine grove; a library surrounded by water. There is a 22-metre-high sculpture entitled Dona i Ocell (Woman and Bird), which is made from trencadís (a broken-tile mosaic) and has become one of the park's principal landmarks.
Parque del Turó de la Peira	There is a large pine grove, consisting of Aleppo pines, stone pines, olive trees, cypresses, Chinese parasol trees and groups of prickly pears.	It is a park for walking and admiring the view from any of its resting areas, for kids to have fun in any of the three children's play areas, for enjoying picnics and playing cards or dominoes on the tables all around.	Its height and privileged location make this park with views of Collserola and the sea. It was once part of an old quarry, and comprehensive restoration was carried out in 2007 to improve the park's general appearance and modernise the facilities.

Name	Biodiversity	Functions	Landscape plan and design
Parque de la Guineueta	There are a group of eight large petticoat palm trees, some Aleppo pines, acacias, yuccas, jacarandas, Judas trees, pata de vaca trees, peppercorn trees. Besides, there are date palms, fan palms, cedars, oriental and giant thujas, hackberry trees, stone pines, plane trees and several olive trees. A jujube tree planted there in 1999, to pay homage to Pere Fontàs i Puig.	1. It links the Guineueta and Verdum neighbourhoods. 2. A large square attracts large crowds throughout the year. Some other squares serve as resting places away from the activities, and there are also schools and sports facilities. 3. Andalusian associations in the Nou Barris district's hold Cruces de Mayo (May Cross) festivities for a fortnight every year.	It is an extraordinarily popular park. The park spreads out upwards and downwards from a large parterre with a pond. The two main paths lie on either side of this central parterre, parallel to each other and linked to the paths that cross the rest of the park, above and below.
Parque de las Aigües	It has a large variety of fruit trees, including orange and fig trees. Other trees that stand out include the groups of cypresses, Monterey cypresses and yuccas, as well as sweet bays and one of Barcelona's largest specimens of ombu tree.	The relax areas with plenty of benches. There are also three children's play areas, a small multisport court, a pétanque court and a properly marked out picnic area with guaranteed shade in the summer.	This park opened in 1978, it was built on the roof of two large water tanks that combine the gardens with agriculture. The location of this park makes it a mountainous island with staggered structures, separate terraces, versatile stone walls and paths.
Parque de Monterols	There are some large trees, like oaks, cypresses, holm oaks, pine trees. Other species include the enormous carob trees, large olive trees and several almond trees. There are numerous dwarf palm trees and a collection of aromatic plants: rosemary, thyme, lavender and sage, and the Mediterranean shrubs, such as broom, mastic, strawberry and hazelnut trees.	There are resting places with benches to sit and to enjoy some peace and quiet.	This is a secluded park on a slope of up to 121m. Several gravel paths take visitors to the top of the hill, where you can admire the stunning views of Barcelona. This route is round and usually connecting to different parts of the park. Tall trees and bushes on both sides ensure that it is completely isolated from the surrounding buildings.

Name	Biodiversity	Functions	Landscape plan and design
Parque del Turó del Putxet	It has a good portion of conifers and leafy plants and its sunnier flowerbeds contain very thick shrubs, as well as perennials and seasonal flowering plants. Such as the Aleppo pine trees, stone pines, Himalayan cedars, holm oaks and olive trees, Indian bead trees and acacias, peppercorn trees and a few oleasters. The small squares mainly contain tipu trees, pagoda trees, southern nettle trees, some plane trees and palm trees, etc.	The sheltered resting places have several terraces, interconnected by ramps skirting around the landscaped areas, to build a new children's play area, a picnic area with tables and a new dog area.	These gardens are one of Barcelona's most privileged viewing platform. The vegetation is not only abundant but also extremely varied species. Apart from the highest reaches of the hill, the gardens can be crossed without having to set foot on the steps. The gardens grew to 5.2 hectares of green space, adding new views of the city and the sea to the magnificent panoramic views already on offer.
Parque de la Font del Racó	There are hackberry trees, pine trees, carob trees, holm oaks, acacias, peppercorn trees, cypresses, Canary Island date palms, olive trees, eucalyptuses and ombu trees. The park also has an oak (Quercus cerrioides) listed in the Barcelona Trees of Local Interest Catalogue.	1. The special park for walking and relaxing. 2. This park led the way for a belt of parks around Barcelona and which was designed to add green spaces to the future urban network of the expanding city.	This green and luxuriant park is a small marvel, tucked between the bends of Av Tibidabo at the foot of the Collserola range. The first thing that stands out when visitors enter this park is its rustic, natural feel, as it was designed to respect the pre-existing landscape.
Parque del Castell de l'Oreneta	There are Aleppo pines, stone pines, oak trees and holm oaks, surrounded by an understorey packed with shrubs, such as broom, boxwood, laurustinus, strawberry tree and mastic tree. There are some hundred-year-old specimens of the latter two species, as well as numerous aromatic plants, such as thyme, sweet bay and lavender. Its orange trees, medlars, almond trees, olive trees and pomegranate trees bear testimony to the agricultural past of a good part of this place. New species planted in the park over the years, including	1. This is a large woody area that links Barcelona to the Collserola range. 2. The local authority has improved the network of paths, created resting areas and children's play areas, the table-tennis tables and the picnic areas. Besides, it is close to the Can Caralleu public swimming pools, which are ideal for taking a dip during the summer.	This is an excursion through a woody area inside the city. The woody area also has an ornamental fountain dating back to 1863, an old threshing yard, a garden pond and a half-buried irrigation system that recalls the agricultural past of this area. This location offers an exceptional panoramic view of Barcelona, from Sant Adrià de Besòs to Prat de Llobregat. The park has preserved almost all its original Mediterranean vegetation, with species that are very typical of Barcelona's mountain range. In fact, that vegetation is its main

Name	Biodiversity	Functions	Landscape plan and design
	eucalyptuses, cypresses, cedars and hackberry trees, contribute towards the luxuriance that characterises it. Two trees stand out for their exceptional beauty and are now listed in the Barcelona Trees of Local Interest Catalogue: an enormous eucalyptus, with the city beneath it, at one of the bends along the path named after this species of tree, and a St Lucie cherry tree, close to the pony stables.		attraction and makes it an amazing space to find in the city.
Jardines de Vil·la Amèlia	The gardens boast a wealthy range of plant species, nearly 50. There is pagoda tree, Styphnolobium japonicum, lime trees, cedars, cypresses, Jacarandas, tipus and Judas trees, and shrubs such as crape myrtle, Lagerstroemia indica. Particularly notable there are the magnolias, holm oaks, Judas trees, large specimens of stone and Aleppo pines, the Mediterranean dwarf palm. But the indisputable kings of the vegetation are a plane tree and a peppercorn tree close to 90 years old.	The resting area with a children's play area, the reecreation area for dogs and the Ping-Pong tables.	These traditionally designed gardens form a French-style green square. The pond and pine hills are prominent features of the garden. The pond is circular and located inside a large parterre with small, curiously sculpted myrtle hedges that form designs on the grass. Its water is dominated by aquatic plants, watched over by the figure of a protective nymph.The hill, slightly hidden from the bare ground and which can be reached by some wooden stairs, acts as a counterpoint to this peaceful, open space.
El parque de Cervantes	There are the oleanders, a row of Siberian elms, tipu trees, four magnificent lime trees, pink siris, large oaks, stone pines, very tall Aleppo pines, large Himalayan cedars, cypresses, smooth American cypresses, Monterey cypresses, Olive trees, black locusts, peppercorn trees, Indian bead trees and horse chestnuts and so on. Besides, the rose collection is the jewel in the	1. It is located on land once occupied by the Estela torrent, which collected water that flowed down from the summit of Sant Pere Màrtir. 2. Near the centre of the park there is an immense gravelled square with children’s games, a few table-tennis tables and	The park is a magnificent, open, green space distinguished by the large expanses of grass, wide paths and gentle slope of the land. This is the rose garden, which boasts an exceptional collection of over 10,000 rose bushes. There is a large, semicircular pergola overflowing with climbing rose bushes made up of 233

Name	Biodiversity	Functions	Landscape plan and design
	park's crown. The rose garden has close to 10,000 rose bushes made up of some 2,000 species and different varieties, which can produce at least 150,000 roses at the height of the flowering season between May and July. There are also fruit trees: cherry trees, common pear trees, persimmon trees, apple trees, quincetrees, cherry plum trees and jujube trees. There are also a large number of aromatic plants, grasses, perennials, irises and flowering shrubs.	a fountain, and a picnic area nearby.	different varieties. There is also a perfume garden that has 235 varieties of roses here.
Jardines del Mirador del Alcalde	Besides the large grass parterres, the large pine trees, especially the Aleppo pine trees are very important. Also, there are the palm trees, numerous dwarf palms, fan palms, Canary Island palms and the huge sago palms.	1. The great view point of Barcelona. 2. The resting area for walking and relaxing.	The garden is divided into different levels. The first floor is a great place to consider the city and the sea below. On the second floor, there is a swimming pool that collects water from the waterfall that falls from the third floor pool. At the very top of the fourth floor, the Mirador de l'Alcalde ends in a small square.
Parque del Mirador del Migdia	There are many Aleppo pines, stone pines, holm oaks and cypresses. It also boasts olive trees, acacias and eucalyptus trees, common ash trees, poplars, tipu trees and Judas trees. It also has lots of prickly pear trees and broom.	This a great park for walking and relaxing, with its large picnic area shaded by pine trees and a bar for contemplating some exceptional sunsets.	It is one of the best places for a magnificent panoramic view of Barcelona. The landscaping has made this park look more like a woody area than a garden. It lies at one end of a series of parks and gardens covering Montju_c, between the Zona Franca and the Marina del Port and Poble-sec neighbourhoods.
Parque de la Maquinista de Sant Andreu	There are holm oaks, olive trees, oaks, cypresses, white poplars. The resting areas is shaded by tipu trees, very tall specimens of Aleppo pine trees, the plane trees, a large tree of heaven. Two	1. The La Maquinista i Macosa Museum keeps historical documents, maps, photographs, models and historical items that belongs to	This is a large open plan boulevard with extremely diverse trees. It is located in the former site of 'La Maquinista Terrestre y Marítima'. This park is divided

Name	Biodiversity	Functions	Landscape plan and design
	huge groups of yuccas, a large Mediterranean dwarf palm and a few honey locusts dominate the setting by the lake.	the company. 2. Construction of the park pond, named after Narcís Monturiol, made the most of two old water galleries. It plays a role in the landscape but also supplies water for the irrigation system.	into two areas. These are separated by a spacious strip paved with reddish tiles, with large grass parterres full of trees on both sides.
Historic parks (12)			
Parque del Laberint d'Horta	A lime tree and a Himalayan cedar that are listed in the Barcelona Trees of Local Interest Catalogue. There are European yews, laurel-leaved snail trees, a Crape myrtle, a plantation of camellias, some rare alignment of holm oaks, a coast redwood tree, the hundred-year-old holm oaks and African lilies. Besides, there are climbing ivy, African lilies, sword fern, boxwood and butcher's broom. The largest trees here include European yews, sweet bays, oaks, manna ash trees and plane trees and so on.	1. It is a museum garden, with different landscaping and art style. 2. The magnificant garden for walking, relaxing, and rereation.	The park occupies the land of an estate once owned by the Marquis of Llupià, Poal and Alfarràs. It has the city's oldest conserved garden. Once Neoclassical, with a slightly Italian look, it later adopted a Romantic style. The Laberint d'Horta park is actually a museum garden.
Park Güell	The Gaudí area preserves the natural vegetation, today made up by an expanse of woodland that is home to abundant carob trees, oaks, pine trees and holm oaks, surrounded by a thick understorey. The Jardí d'_ustria, an old nursery where species were cultivated that would later be transferred to the park. There are olive trees, pine trees, oak trees, broom, laurustinus, magnolias and aromatic plants.	1. It is a place of interest and one of most popular place in Barcelona. It offers a guide service and facilities that help people with hearing or visual impairment to discover it, also make it an ideal recreation space, for local residents and all its visitors in general.	This park reflects the beauty of the curve everywhere. The columns are tilted like palm trees and have different shapes. Many decorative surfaces are made of ceramic or glass. This square is partially supported by the Sala de les Cent Columnes and is actually composed of eighty-six columns that look like giant stalagmites in the bay.

Name	Biodiversity	Functions	Landscape plan and design
		2. It was declared a Heritage of Humanity site by UNESCO in 1984.	The steps of the stairs at the main entrance of the park are symmetrically placed around the sculptures of the dragonfly, which has become a symbol of the garden. Architects really want to achieve the perfect symbiosis between stone and green.
Parque de la Ciutadella	There are abundant lime trees, magnolias, poplars, plane trees, nettle trees, foxglove trees, brown pine trees, Maidenhair, black locusts, cypresses, river oaks, ombus, horse chestnuts, three bald cypresses, Canary Island date palms, date palms, blue fan palms and spineless yuccas. It also holds several specimens featuring in the Catalogue of Trees of Local Interest in Barcelona: a pink siris, an osage orange, a river oak, a Mexican white oak and bald cypresses in the lake. A large number of birds (over 100 different species) live in this park.	1. This park is not only a big green area for local residents to have recreation acitivities but also an urban attraction for visitors. 2. This park has lots of historic and cultural heritage been perserved with high social, cultural and art value. 3. Ciutadella is a great place for bird lovers.	It was the first place to be specially designed as a public park. Ciutadella Park has a large number of century-old trees and the monumental waterfall, 19th-century buildings now used as museums, a lake for rowing boats, pathways and numerous sculptures, and the city zoo.
Jadines de Laribal	There are Aleppo pines, stone pines, sweet bays, Seville orange trees, cypresses, and eucalyptuses, Monterey cypresses, Himalayan cedars and three outstanding plane trees, aromatic plants, such as lavender and rosemary, and creepers such as common ivy. The Generalife stairs are surrounded by large acacias and shrubs such as privet, cheesewood, oleanders and Japanese spindle, while the elegant leaves of aspidistras and geraniums, wisterias and Lady	1. These gardens are one of the gems of Parc de Montju_c, and the first public rose garden in Barcelona. 2. A terrific palce for residents to recreation.	The water flowing down the waterfall flows gently between the wide side walls and the tiled benches and small squares. Forestier designed a series of steps with water flowing down the bannisters, pools with fountain jets on the landings and stone benches for resting on, enjoying the fresh air and sound of the water. Mirador pergolas lead from one garden to another, joined by ramps, steps and cascades that end up at the Font del Gat

Name	Biodiversity	Functions	Landscape plan and design
	Banks' roses (Rosa banksiae) shine from their terracotta flower pots.		or 'Cat Fountain', where visitors can admire magnificent views of Barcelona.
Jardines del Teatre Grec	There is lavender, Seville orange trees, African lilies and Natal lilies, boxwood hedges, ivy, pergola, jasmine and rose bushes, ash trees, the cypresses, holm oaks. Two trees are listed in Barcelona's Catalogue of Trees of Local Interest. There are also terracotta flower pots containing either small geraniums or ferns.	1. It is a magnificent park for community activities, like the amphitheatre that now hosts many of the Barcelona Grec Festival performances every summer. 2. Also it is a sunny spot, with geometric flowerbeds, pergolas and terraces, from where visitors can admire the landscaped mountain and the city.	This garden is one of several green spaces created on Montjuïc for the 1929 International Exposition. It was designed by Jean-Claude Nicolas Forestier. It is a highly geometric garden. The main features in this park are: the pergola, the old pavilion and the sloping trimmed hedges with tall trees behind them.
Jardines de Can Castelló	The vegetation here is important for the variety of its species and the quantity, age and size of its specimens. Prominent are the enormous Canary Island date palms, large yuccas, horse chestnuts and false pepper. There are also notable examples of date palms and, outstanding for their rarity, some succulent plants originating from California. As for shrubs, the huge cheesewoods and oleander stand out, along with the sweet bays surrounding the gardens and the laurustinus.	1. It is a romantic and peaceful place for citizens to rest and chat with the wall that encloses the gardens ensures peace and quiet. 2. The small channels dug either side of the paths that are covered with river rocks, which mark them out and allow rain water to pass through without eroding the paths. 3. The Castelló family house, a building with a country-house structure that was built in the 1930s. It is one of the few that are still preserved in Sant Gervasi.	These gardens, part of what was once the estate of Dr Josep Castelló i Galvany, are noted for their elegance and the variety of species they contain. The gardens are elegant and romantic. They are dominated by dense, rounded, very well-defined yet irregularly shaped flowerbeds of great landscape beauty.

Name	Biodiversity	Functions	Landscape plan and design
Jardines de Can Sentmenat	There are numerous hundred-year-old trees and palms. There are enormous lime trees, large acacias, a large Himalayan cedar, the Monterey cypress, Canary Island palms, date palms, livistonas, Mediterranean dwarf palms, Chusan palms, lots of fan palms, Bougainvillea, maidenhair vines, yellow bignonias, red bignonias, Aleppo pine trees, holm oaks, mastic trees, grey-leaved cistuses, etc.	They are one of the few left in Barcelona that bear witness to the stately gardens of the late 19th century. It is a notable piece of architectural and nature heritage.	These gardens on the sea-facing slope of the Collserola range. Romantic and French in character. They have maintained the original structure and typology. The enclosure walls around the building are covered in climbing plants and the entire terrace offers lovely views of Barcelona and Collserola which, together with the sky, provide an exceptional backdrop to the gardens.
Jardines de la Tamarita	There is myrtle, privet, sweet bay and large-sized cheesewood, black locusts, plane trees, European yews, Seville orange trees, boxwood, a jacaranda, cypresses, acanthuses, lily turfs, more cheesewood and privet, bamboo trees and large silver limes. The park has some curious species, such as araucaria, a silk oak that also comes from Australia, a purple-leaf European beech. Besides there is a highly valuable tree of local interest rarely found in Barcelona, an English oak.	1. These gardens are a good place for a rest and some peace and quiet, far from the madding crowd. 2. The garden's pavilions which is now put to social use as the centre of a residents' association and a service building.	It is a private garden and is now a public space and public heritage. It has two different areas, one is ordered and classical, and the other is natural. The garden is full of decorative features: small swimming pool, fountain fountain, terracotta pottery, stone, marble and ceramic cups into fountains, ornamental vases, etc.
Jardines Joan Maragall	There are lime trees and large conifers, such as Himalayan cedars, Lebanon cedars, stone pines, Aleppo pines, Austrian pines, cypresses, Arizona cypresses and Monterey cypresses. The gardens also have Mediterranean species, such as olive trees and holm oaks, palms. A jujube is listed in the Barcelona Catalogue of Trees of Local Interest. Several species of poplars, orange trees, elm trees	There are paths, cozy squares with fountains and fonds, and a large expanse of grass for residents to relax and exercise.	They were created for the Spanish kings in the early 20th century. These gardens are very elegant, with tree-lined avenues, wide meadows, stables, decorative fountains, numerous outdoor sculptures, and small palaces that used to be royal residences. Together with the building, the garden displays a total of 32 sculptures of various sculptors from different periods, some

Name	Biodiversity	Functions	Landscape plan and design
	and peppercorn trees are also found in these gardens.		of which are of excellent quality.
Parque del Guinardó	It is dominated by large Aleppo pines and tipu trees which overflow with yellow flowers in the summer. The historical area is full of large, well-trimmed hedges. There are abundant shrubs such as Japanese mock orange, butcher's broom, sweet bay and oleander. There are also numerous carob trees, cypresses, cedars and holm oaks, Sierra Madre lobelia, pagoda trees, rose bushes, coojongs and Seville orange trees and so on.	1. Given the park's steep rise and considerable height, it is a popular place for doing sports and physical exercise. 2. There are miradors at the top with offering magnificent views of Barcelona.	Water plays a central role in this park. The rustic atmosphere of the woodland and the well-kept bush garden coexist elegantly. It has three distinct areas: the urban part, the vestibule of this vast green space; the historical part; the top is made up of dense woodland vegetation.
Parque del Turó	Turó Park is rich in species and exceptional specimens of trees. It has a holm oak wood, with an understorey of shrubs and climbing plants. It also includes magnolias, peppercorn trees, Himalayan cedars, lime trees, plane trees and African lilies, date palms, Canary date palms, fan palms, sweet bay and oleander.	There are a large children's play area, stage for outdoor children's shows, and recreation area for dogs.	It is an elegant and welcoming park. A shady space with ivy flower beds, winding paths and beautiful sights. It has always been one of the most representative parks in Barcelona. There is a sculpture dedicated to the great cellist, Pau Casals, which is on an oval-shaped square. Two of the park's loveliest spots: the pond and the grass.
Jardines del Palacio de Pedralbes	One of the Himalayan cedars with hundred-year-old trees is listed in the Barcelona Catalogue of Trees of Local Interest, together with a stone pine on the grassy area next to the palace and a Cictus tree. There are conifers all around, including stone pines, Aleppo pines, cypresses, Monterrey cypresses and Arizona cypresses. The large sweet bays and boxwood, while bougainvillaea is the queen of the climber plants and ivory the queen of the creepers.	1. The City Council handed over the building and gardens to the Generalitat of Catalonia in 2004, and it is now used for official ceremonies and receptions. 2. The Kolonihaven, a little house for children's games with contemporary feature.	One of Barcelona's most majestic gardens, both French and English in style, a touch Romantic and very luxuriant. Behind a 250-metre-long wall covered to overflowing with bougainvilleas lie Barcelona's most majestic gardens: the Jardins del Palau Reial de Pedralbes.

Name	Biodiversity	Functions	Landscape plan and design
Thematic parks (6)			
Jardín Botánico	There are Kurrajong, eucalyptus, several varieties of acacias, shrubs such as soft tree fern. Also other species, such as boldo and false pepper, argans, oleanders, gum arabic trees, cedars and conifers.	The Botanical Garden is heir to a long tradition of gardens designed for studying, maintaining and preserving plant species. It has moved on from collecting exotic plants and botanical rarities, an activity typical of the natural science museums of the 18th and 19th centuries, and adopted a more scientific approach to meet sustainability criteria.	The core theme running through the garden is the Mediterranean region's botanical diversity, shown in eight phyto-episodes. The architects created these plant scenarios or phyto-episodes, and organised to make the most of the Montjuïc's slopes and combine the triangular plots of land. The triangles are distributed in a way that takes advantage of the various possible orientations towards the sun and in the light.
Jadines de Rodrigo Caro	These gardens have 80 different aromatics, perennial grass species and nineteen tree species. For example, there are varieties of rosemary, oleaster tree, sage scrub, cistus, scrubs and groups of santolina, curry plant, oregano, loquats, double-flower pomegranates, a quince tree and fig trees. The rare plants here include a lilac-coloured Australian flower, Tulbaghia violacia, popularly known as society garlic or South African wild garlic, of which there are two varieties in the gardens. The gardens' other notable resistant plants include a group of cistuses and phlomis, such as Jerusalem sage, Balearic Island sage and purple Jerusalem sage.	1. These are themed gardens specialising in Mediterranean-climate vegetation from the five continents. 2. Rodrigo Caro's landscaped slopes have helped to redevelop land which used to have a natural spring, in the heart of a rural area next to the Collserola mountain range and often visited by the residents of the Les Roquetes neighbourhood. 3. The locals plant geraniums from the adjacent houses to form the flowerpots, integrated into the gardens now,	The Gardens have a steep topography of 21m of height that suggests a transitional space between the city and the Collserola. The plant proposes a gently sloping path that allows Mediterranean landscapes to take place in the landscape, adapted to the climate of the city, which guide the journey towards three concrete platforms that are offered as leisure and resting spaces. The gardens carried out by the architects Imma Jansana, De la Villa and Robert De PAAUW together with Escofet.

Name	Biodiversity	Functions	Landscape plan and design
		which epitomise the entire neighbourhood's spirit and community.	
Jardines de Mossèn Costa i Llobera	There aer aloe and short-leaved aloe from South Africa; Hudson pears Cylindropuntia rosea from Mexico; African stone plants; Xanthorrhoea from Australia; Euphorbia resinifera from Morocco; large-sized Cereus jamacaru from Brazil and barrel cacti Ferocactus glaucescens from the Mexican State of Querétaro. The gardens offer an extensive collection of cacti from the Echinopsis genus, including Echinopsis santiaguensis. The gardens also have Echinopsis, specimens of Astrophytum miryostigma, Mammillaria. These are one of the most extensive genera, with over 350 recognised species. The gardens also offer an extensive variety of trees native to the Mediterranean climate, such as carob trees and olive trees, etc.	1. The Mossèn Costa i Llobera Gardens offer a spectacular panoramic view of the city's coastline and port. 2. The gardens are a privileged outdoor classroom that allows visitors to discover the evolutionary strategies of succulent plants, which have created varieties specialising in low water consumption.	These are one of Europe's biggest gardens that specialising in cacti and succulent plants. In 1987 a New York Times journalist ranked the Jardins de Mossèn Costa i Llobera among the top ten of the world's best gardens.
Vivero Municipal de Plantas Tres Pins	There is an enormous variety of plant species here since the nursery stores the species that are intended for Barcelona's greenery. The oldest part of the nursery boasts large specimens of Canary Island date palms, trees of heaven, white mulberries and sweet bays, etc. Two trees in particular stand out for their rarity: A Chinese elm and a staghorn sumac. Also, there are stone pines and Aleppo pines, holm oaks, tipu trees, pagoda trees, plane trees, purple-leaf cherry plums, etc.	1. It was an area for supplying Barcelona with plants for the International Exposition of 1929. It is the first municipal plant nursery producing plants for the city's green areas and is currently the only one left in Barcelona. 2. The nursery have sustainable irrigation systems. Water from the grid has been replaced with	This green space is on the north-west slope of Montjuïc's highest part, to cultivate and store plants intended for landscaping Barcelona. The oldest part has greenhouses, shade houses and spaces full of flower pots, while the new part has large terraces for plant stocks and plots used for experiments. It has an annual production of nearly 225,000 shrubs and perennials cultivated from cuttings and seeds. There are also two tunnels: one for producing

Name	Biodiversity	Functions	Landscape plan and design
		Barcelona's groundwater. This is pumped up to Tres Pins from the collection point below the Rambla and the nursery is also a groundwater storage and distribution point used for irrigating other parks and gardens on Montjuïc.	plants and the other for conserving stocks. A wide road zigzags between the successive terraces, which are very large and finished off with grass-covered slopes. The trees on the slopes and the plant pots which fill the terraces, especially those with flowers, offer visitors a colourful, vivacious and truly spectacular sight.
Jardines de Mossèn Cinto Verdaguer	There are the lilies, daylilies, tulips, Spanish bluebells, narcissuses, crocuses, anemones, buttercups and grape hyacinths, etc. About 80,000 bulbs are planted every year, distributed according to the colour, lifespan of the flowers and height of the plants.	1. The gardens on Montjuïc descends a gentle slope that offers visitors a good view of Barcelona and the sea, and the entire Montseny massif. They are parts of Montjuïc Park and one of its most outstanding theme gardens. 2. The gardens are a place for spending time and taking a stroll.	These are the most beautiful gardens in Barcelona. The combination of bulbs, rhizomes and aquatic plants provides them with a special range of colours. There are ivy-covered trails and short-stage stone steps around the garden. Bright green meadows contrast sharply with the colours of flowers in spring and summer, autumn in sharp contrast to the hues of deciduous plants.
Jadín de Aclimatación de Montjuïc	It boasts close to 230 different plant species. Especially notable is a golden rain tree, a large jujube. A white siris, which is listed in the Barcelona Trees of Local Interest Catalogue. It also includes a saffron tree, a willow myrtle, a picconia excelsa, a cockspur coral tree, a vachellia caven, a Japanese wax tree and a Natal plum. The garden also boasts eucalyptus species, such as Eucalyptus gomphocephala, and exotic conifers, such as Turkish or Cyprus pine. As for climbing plants, it includes giant Burmese honeysuckle, Coulter's	The memorial was a proposal made to Parks and Gardens by the NGO Project of Names, created in 1993 to promote awareness and public awareness of the AIDS disease.	The Garden is one of Barcelona's most interesting botanical spaces. Rows of stone columns rise up on the well-shaded upper level, part of the pergolas built for the climbing-plant species and still used for supporting them. There are gravel paths between the parterres, interspersed with the occasional resting bench. Most of the specimens, especially the trees, are identified by a sign that states their scientific name, their common name in Catalan (if

Name	Biodiversity	Functions	Landscape plan and design
	Matilija poppy and a large Pereskia aculeata.		they have one) and the area the species originates from.
Forest parks (2)			
Parque de Montjuïc	The area of the cliffs has a special relevance as a scrub space typical of arid soils, dry shrubs with a great ecological value due to the fact that it is a refuge for kennel colonies, peregrine falcons, prey and other species of birds such as the bluebird. It is a singular space, which concentrates a rupicolous habitat of great richness. Among the grasslands, up to sixty species find refuge as rabbits, shrews, bats, mice, owls, owls, owls, gulls, titmice, starlings, green frogs, frogs and toads, and reptiles such as pink dragons, lizards and white and green snakes.	1. The mountain park condenses a wide and extensive offer where nature coexists, from forest areas to thematic gardens, with recreational, sports, cultural and service areas. 2. Together with Collserola, it is one of the city's great urban lungs. therefore, the mountain is in the process to regulate and maintain the necessary balance between the protection of space and its richness and biodiversity, and citizen uses.	It is the great urban park of Barcelona, which can be reached by cable car to see the castle. Montjuïc is structured in large, well-differentiated planes. The southeast slope is the steepest of all, with a large cliff that offers a panoramic view of the port and the sea. The western slope drops to join the delta del Llobregat. The east slope offers views of Ciutat Vella and the sea, and the last one, the northern slope, merges with the urban layout of the city.
Parque de Collserola	There is a wide diversity of natural environments in the more than 8,000 hectares, much of which is occupied by Mediterranean forest. Almost all of the Mediterranean's fauna are found there, thanks to the combination of woodland, cultivated land, dry grassland and maquis scrubland. Despite the fires that cyclically afflict the Mediterranean woods, and the steady replacement of holm oaks with conifers such as pine trees, holm oaks are still the most typical tree found in the Collserola range. There are field and Montpellier maples, large stretches of riverbank woodland	1. It contains great valuable natural resources and benefits a lot for the huge population who lives around the Collserola. 2. There are many public facilities and services, like educational institutions, museums, observatories, animal protection centres, judicial schools; schools: learning camps, environmental education centres; horse farms; leisure areas: parking lots,	It is an invaluable natural heritage. This park's presence ensures quality of life for Barcelona's citizens but its maintenance poses a challenge. It is managed by the Collserola Park Consortium. Collserola offers a large diversity of landscapes. This is partly due to the heavy pressure of human life. Such pressure has given shape to a mosaic of spaces that combines woodland areas with agricultural spaces, meadows, maquis scrubland and so on. The lay of the land, which covers the city's entire northern edge, acts as a

Name	Biodiversity	Functions	Landscape plan and design
	alongside the gullies and fast-flowing streams, with a lots of white poplars, black poplars and narrow-leaved ash trees. The fruit trees include hazel, pomegranate and wild cherry. Shrubs there include chaste trees, common hawthorns, strawberry trees, laurustinuses, Mediterranean buckthorns, etc.	restaurants, cafes, drinking fountains, picnic restaurants, public Toilet etc.	frontier and marks out the city between two large, natural elements: the sea to the south and the mountain range to the north. This large, longitudinal park, which is what the range represents for Barcelona, has the potential to be a large, green space in contact with the urban network as well as the starting point for a whole series of green corridors that join the city to the sea.

Appendix C. Additional research achievements during the Ph.D. period

My research achievements during the PhD period (2015-2019) go beyond the completion of this PhD dissertation. During this period, I had the opportunities to participate in various scientific activities. All of these achievements are listed below.

- C.1. Articles in international peer reviewed journals (published / submitted)

Zhang Sining., Francesc Muñoz Ramíz., 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

(SSCI) (IF: 2.704)

Zhang Sining., 2019. The concept of landscape services towards landscape research: A review. *Landscape research.* (Revised)

(SSCI) (IF: 1.198)

- C.2. Articles and Oral presentations in conferences and seminars

Zhang Sining. [author and invited lecturer] International Master Course on "Landscape services towards urban green infrastructure" (1h). International Master Program of Intervention Landscape Heritage & Management, Universitat Autònoma de Barcelona, 17 January 2019.

Zhang Sining. [author and speaker] Ecosystem services assessment and mapping to support urban green infrastructure. The 9th International Conference of Ecosystem Services Partnership. Shenzhen, China, 11-15 December 2017.

Zhang Sining. [author and speaker] The research of sustainable development of regional ecological landscape based on landscape services. The Symposium of Young Researchers in Geography—Between diversity and integration: the resilience of the studies in Geography. Barcelona, Spain, 26-28 October 2016.

- C.3. Projects

03/2017-07/2017	'Identification and Evaluation of Metropolitan Voids in the Barcelona Region' project.	Developed by Observatori de la Urbanització (2018). Geography Department, Universitat Autònoma de Barcelona. Diputació de Barcelona.
05/2017-09/2017	'Blue Heritage Management—Urban heritage as a landscape catalyst' project.	Developed by European Union.

- C.4. Other research activities

Participation in the 9th International Biennial of Landscape Architecture & the Rosa Barba Landscape Architecture Prize (one of international team members; and the volunteer from 29th to 1st October 2016).

Participation in the 53rd IFLA (International Federation of Landscape Architects) Word Congress (from 20th to 22nd April 2016).

Participation in the International Conference 'Greening for change' (7th and 8th February 2019).

- C.5. International workshops

16/07/2017-26/07/2017	City limits at work: Urban planning facing metropolitan challenges.	Organised by UAB (Universitat Autònoma de Barcelona) and Ajuntament de Sabadell
08/05/2017-10/05/2017	Blue heritage at work: urban heritage as a landscape catalyst, Rubí.	Organised by UAB and MUHBA (History Museum of Barcelona)
23/04/2017-29/04/2017	Landscape planning in small town: cities in transition--Sant Esteved' en Bas.	Organised by UAB and MUHBA.

23/05/2016- 04/06/2016	Contemporary landscape in Baix Llobregat.	Organised by UAB and MUHBA.
29/02/2016- 03/03/2016	Mind the Gap.	Organised by ETSAB (Escuela Técnica Superior de Arquitectura de Barcelona) of Polytechnic University of Catalonia (UPC) and Harbin University of Science and Technology.
12/11/2015- 16/11/2015	The Market of Intangibles.	Organised by ETSAB of UPC and Tsinghua University.