Maria de Lurdes Chorro Simões Barrico

ECOLOGICAL PROCESSES RELATED TO URBAN DEVELOPMENT AND LAND USE CHANGE IN THE MUNICIPALITY OF COIMBRA

Tese de Doutoramento em Biologia, especialidade de Ecologia, orientada pela Professora Doutora Helena Freitas e pela Professora Doutora Paula Castro e apresentada ao Departamento de Ciências da Vida da Faculdade de Ciências e Tecnologia da Universidade de Coimbra

Junho de 2015

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Sumário

No início do século 21, três assinaláveis desafios ameaçam a Humanidade. Em primeiro lugar, cada vez mais pessoas habitam a Terra. Em segundo lugar, mais pessoas vivem em áreas urbanas. Em terceiro lugar, como resultado do crescimento da população e da urbanização, os ecossistemas estão a mudar a uma escala global. Por conseguinte, as atividades humanas estão a conduzir estas alterações e a ameaçar muitos dos serviços ecológicos que são essenciais para a sociedade.

Os padrões de urbanização controlam a dinâmica do ecossistema através de complexas interações e mecanismos de feedback, ligando as atividades urbanas e sua organização espacial ao uso do solo e às alterações ambientais. Tendo em conta que as cidades atuais estão a expandir-se rapidamente, de uma forma espacialmente complexa e não-linear, uma reflexão sobre a dinâmica espacial e temporal é crucial para entender os efeitos da urbanização no funcionamento do ecossistema nestas cidades tão rapidamente urbanizadas.

A fim de proporcionar a sustentabilidade local e global, a proteção e restauração do ambiente urbano, assim como, temas relacionados com a melhoria da qualidade de vida urbana têm um lugar importante no actual planeamento e programa político da Europa. Os espaços verdes urbanos são uma parte crucial da paisagem urbana, proporcionando serviços ambientais e o contacto com a vida selvagem. Eles podem desempenhar papéis importantes na promoção da qualidade ambiental através da melhoria da qualidade do ar, assim como, na redução dos custos energéticos na refrigeração de edifícios. Estes espaços verdes podem, também, promover a qualidade de vida dos residentes urbanos ao serem utilizados como áreas de lazer e da prática desportiva.

Este estudo propõe-se avaliar os processos ecológicos relacionados com o desenvolvimento urbano e alterações do uso do solo, ocorridos no concelho de Coimbra durante as últimas duas décadas (1990-2010).

A tese está dividida em sete capítulos. Cinco dos quais (**Capítulos 2-6**), estão estruturados como artigo já publicado (**Capítulo 4**), submetido (**Capítulo 3**) ou em

preparação (**Capítulos 2, 5 e 6**) para submeter para publicação em revistas científicas. Estes cinco capítulos são precedidos por um capítulo introdutório (**Capítulo 1**) e seguidos por um capítulo final, com as conclusões gerais (**Capítulo 7**).

O **Capítulo 1** corresponde a uma introdução geral sobre o tema da tese.

O **Capítulo 2** analisa a alteração do uso do solo no município de Coimbra no período de 1990 a 2010. Neste estudo caracterizou-se a dinâmica espacial e temporal do uso do solo neste município e discutiram-se os potenciais fatores que terão contribuído para essas alterações. Os resultados mostraram um padrão claro na alteração do uso do solo durante este período, caracterizado por uma contínua expansão da área urbana, principalmente à custa da perda de áreas agrícolas. A análise estatística indicou que os fatores físico, de distúrbio, demográfico e sócio-económico estão significativamente correlacionados com esta alteração do uso do solo.

O **Capítulo 3** avalia a expansão urbana espacial e temporal na cidade de Coimbra, durante um período de 20 anos (1990-2010). Os resultados revelaram uma expansão urbana durante esse período, seguida por um crescimento populacional, mas não tão brusco. Este padrão físico de expansão de baixa densidade em áreas urbanas contribuiu para uma evolução menos compacto da cidade, um indicador de "urban sprawl". Esta expansão urbana contribuiu para a perda de áreas agrícolas e para o aumento da impermeabilização do solo. A impermeabilização do solo pode conduzir a desastres naturais e humanos como as inundações, deslizamentos de terra, ondas de calor e incêndios.

No Capítulo 4, a composição e diversidade de plantas vasculares e fungos macromycetes são avaliados num espaço verde urbano, localizado na cidade de Coimbra, que compreende três tipos de habitats (Sobreiral, Eucaliptal e Olival). No total, foram registados 287 táxons de plantas, três delas com importante valor ecológico. Embora os índices de riqueza e de diversidade florística revelassem tendências semelhantes dentro dos três tipos de habitats, os valores mais elevados foram encontrados nos Olivais, devido à presença de herbáceas. A riqueza de herbáceas diminuiu com a densidade de cobertura arbórea. Os Sobreirais apresentaram maiores índices de riqueza e diversidade, especialmente nas comunidades de fungos simbióticos ectomicorrízicos. Apesar de não ser significativo, os Eucaliptais registaram maiores índices de riqueza e diversidade de fungos sapróbios.

O **Capítulo 5** avalia a diversidade de plantas vasculares e micro-organismos do solo em duas diferentes tipologias de espaços verdes urbanos (jardins públicos e florestas) na cidade de Coimbra. Nestes espaços verdes, foram registados 252 táxons de plantas vasculares. Os índices de diversidade mostraram tendências semelhantes entre as formas de crescimento, no entanto, foram significativamente diferentes apenas para os arbustos, com as florestas a apresentarem os valores mais elevados. Embora os padrões de bandas do DGGE não mostrarem diferenças significativas entre as comunidades bacteriana e fúngica do solo, o índice de riqueza bacteriana foi maior nas florestas do que nos jardins. Uma vez que as florestas abrigam táxons com elevados valores ecológicos e de conservação, a sua preservação deve ser fundamental nas decisões de gestão urbana nesta cidade.

O **Capítulo 6** caracteriza a perceção dos entrevistados sobre a qualidade dos recursos e serviços no município de Coimbra, através de um questionário. No total, participaram 382 cidadãos (249 mulheres e 133 homens) residentes no concelho de Coimbra. No geral, os participantes expressaram um elevado nível de satisfação com a qualidade de vida no seu município. Também expressaram satisfação com os recursos e serviços fornecidos pelas autoridades locais. A idade dos participantes foi o fator que mais influenciou as respostas, com o grupo mais jovem (18-25 anos) a expressar níveis de satisfação significativamente mais elevados na maioria das questões colocadas.

O **Capítulo 7** integra as considerações finais, resumindo as principais conclusões sobre os resultados obtidos neste estudo.

Summary

In the early 21st century three remarkable challenges hover over Humankind. First, increasingly people inhabit the Earth. Second, more people live in urban areas. Third, as a result of population growth and urbanization, ecosystems are changing on a global scale. Consequently, the human activities are driving these changes and threatening many of the ecological services that are essential to society.

The patterns of urbanization control the ecosystem dynamics through complex interactions and feedback mechanisms linking urban activities and their spatial organization to land use and environmental change. Given that contemporary cities are expanding rapidly in a spatially complex and non-linear manner, a consideration of the spatial and temporal dynamics is crucial in order to understand the effects of urbanization on ecosystem functioning in this rapidly urbanized cities.

Protection and restoration of urban environment and other subjects related to improvements in quality of urban life in order to provide local and global sustainability, take important place in Europe's current planning and political programme. Urban green spaces are a crucial part of the urban landscape, providing environmental services and contact with wildlife. They can play important roles on promoting the environmental quality through improving the air quality and reducing the energy costs of cooling buildings. These green spaces can also provide leisure and sport areas to urban residents improving the quality of life.

This study proposes to assess the ecological processes related to the urban development and land use change that has occurred in the municipality of Coimbra during the last two decades (1990-2010).

The thesis is divided into 7 chapters. Five out them (**Chapters 2 to 6**) are structured as a paper that have been either published (**Chapter 4**), submitted (**Chapter 3**) or are in preparation (**Chapters 2, 5 and 6**) to submit for publication in scientific journals. These five chapters are preceded by an introductory chapter (**Chapter 1**) and succeeded by a final chapter with the overall conclusions (**Chapter 7**).

Chapter 1 corresponds to a general introduction about the theme of the thesis.

Chapter 2 analyses the land use change from 1990 to 2010 in the municipality of Coimbra. It characterized the spatial and temporal land use dynamics in this municipality and discussed the potential driving factors that had contributed to these changes. The results showed a clear pattern in land use change during this period, characterized by a continuous built-up land expansion mostly at the expense of cropland loss. The statistical analysis suggested that the physical, disturbance, demographic, and socio-economic driving factors were significantly correlated with this land use change.

Chapter 3 evaluates the spatial and temporal urban expansion in the city of Coimbra during a 20-year period (1990-2010). The results revealed an urban expansion during this period, not followed by an equally rapid population growth. This physical pattern of low-density expansion in built-up areas contributed to a less compact city evolution, an indicator of urban sprawl. This urban sprawl contributed to the loss of cropland areas and increase of soil sealing. Soil sealing can facilitate the occurrence of natural and human hazards as floods, landslides, heat waves, and fires.

In **Chapter 4** the composition and diversity of vascular plants and macromycetes fungi are assessed in an urban green space located in the city of Coimbra, comprising three landscape types (Oak-, Eucalyptus-, and Olive-stands). In these landscape types, 287 taxa of plants were recorded, three of them with important ecological value. Although the plant richness and diversity indices revealed similar trends within the landscape types, the highest values were found in the Olive-stands due to the presence of herbaceous. The herbaceous' richness decreased with tree cover density. The Oak-stands showed higher richness and diversity indices, especially the symbiotic ectomycorrhizal fungal communities. Although not significant, the Eucalyptus-stands recorded the highest saprobic fungi richness and diversity values.

Chapter 5 evaluates the vascular plants and soil microorganisms' diversity in two different typologies of urban green spaces (public gardens and forests) in the city of Coimbra. In these green spaces, 252 taxa of vascular plants were recorded. The diversity indices showed similar tendencies among growth-forms, however they were only significantly different for shrubs, with the forests presenting the highest values. Although the DGGE banding patterns did not showed significant differences among the soil bacterial and fungal communities, the soil bacterial richness was higher in forests than in gardens.

Since forest systems harbour taxa with high conservation and ecological values, its preservation should be fundamental in urban management decisions in this city.

Chapter 6 characterizes the respondents' perception about the quality of resources and services in the municipality of Coimbra, using a questionnaire. A total of 382 respondents (249 females and 133 males) residing in the municipality were surveyed. Overall, the respondents expressed a high level of satisfaction with the quality of life in their municipality. They also expressed satisfaction with the resources and services provided by the local authorities. The age of the respondents was the factor that influenced the most their answers, with the younger group (18-25 years old) expressing significantly higher levels of satisfaction with the majority of the issues examined.

Chapter 7 integrates the final considerations, summarising the main conclusions about the results obtained in this study.

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Chapter 1

General introduction

1.1. Ecosystem's functions and services

Nowadays, is widely recognized that the nature conservation strategies do not necessarily cause a trade-off between the "environment" and "development". Investments in conservation, restoration, and sustainable ecosystem use are increasingly seen as a means which generates substantial ecological, social, and economic benefits (de Groot *et al*., 2010). The interest in the science of ecosystem and landscape functions and services has grown especially since the release of the Millennium Ecosystem Assessment (MEA, 2003).

The ecosystem services are essential for the human well-being. They include the provisioning services such as food, water, wool, fertile soils, timber, and medicines (Daily *et al*., 1997; de Groot *et al*., 2002; MEA, 2003). They play an important role in regulating the environments in which humans live by regulation of drought, land degradation, disease as well as by ensure the flow of clean water and protection from flooding or other hazards like soil erosion and landslides. They also are relevant in supporting services such as soil formation, nutrient cycling, and primary production. They can even contribute with cultural services such as aesthetic, recreational, educational, spiritual well-being, and other nonmaterial benefits (MEA, 2003, 2005a). Therefore, the human well-being depends on how ecosystems work (Haines-Young and Potschin, 2010).

The connection between the ecosystems and human well-being is well known (Figure 1.1) (de Groot *et al*., 2010). There is a distinction between ecological structures and processes created or generated by living organisms and the benefits that people eventually derive (Haines-Young and Potschin, 2010). Ecosystem services are generated by ecosystem's functions which in turn are sustained by biophysical structures and processes called "supporting services" (MEA, 2005a). Therefore, the ecosystem functions are intermediate between ecosystem processes and services and can be defined as the "capacity of ecosystems to provide goods and services that satisfy human needs, directly and indirectly" (de Groot, 1992). The use of a good or service provides benefits (*e.g.*, nutrition, health, safety) that can be valued in economic and monetary terms (de Groot *et al.*, 2010) (Figure 1.1).

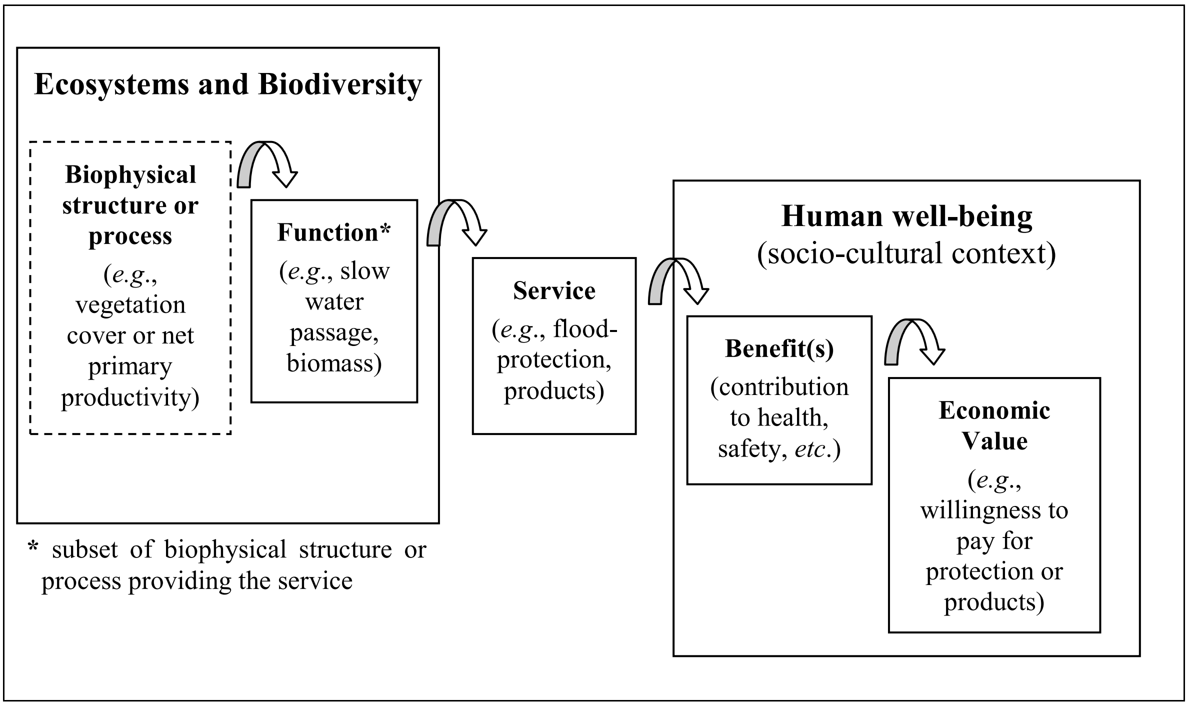


Figure 1.1 - The relationship between biodiversity, ecosystem function, and human well-being. (Adapted from de Groot *et al.*, 2010, after modified by Haines-Young and Potschin, 2010).

1.2. Urban areas

There are diverse definitions of what is "urban". Urban area (*i.e.*, a town, city, or metropolis) has been defined diversely by governmental agencies and individual researchers. In general, the urban areas share several common characteristics such as, high population density, abundant built structures, extensive impervious surfaces, altered climatic and hydrological conditions, air pollution, and modified ecosystem function and services (Pickett *et al.*, 2001; Grimm *et al.*, 2008). As it is neither feasible nor essential to encapsulate all these characteristics of urban areas into one definition, generally the high human population density and extensive impervious surface area are two principal factors that define what is urban (Pickett *et al*., 2011; Wu, 2014). Also, all major ecological and environmental characteristics of urban areas can be related to these two factors either directly or indirectly (Wu, 2014).

1.2.1. Urban development

The global human population has grown exponentially since the Industrial Revolution in the late 1700s, rising from 1 billion around 1800 to 2 billion in 1927, 4 billion in 1974, and is projected to grow from 7.2 billion in 2014 to 9.5 billion in 2050 (Wu, 2008a; United Nations, 2014). One of the most salient features that characterize human civilization during the past century is accelerating urban development (Wu, 2008a; Wu *et al*., 2014).

The world urban population has increased much faster than the rural population, rising from 14% in 1900 to 29.6% in 1950 and 46.6% in 2000 (Wu, 2010; United Nations, 2014). According to the United Nations (2014), the year 2007 was a historic moment in human civilization, where for the first time in history more than half of the world's population (50.1%) were living in urban areas. In Portugal, since 1994 that more than half of the population (50.4%) live in urban settlements. Furthermore, almost all future global population growth is expected to occur in urban areas, most of which will take place in developing countries (Wu, 2008a; Wu *et al*., 2014).

The global and particularly the Portuguese urban population will continue to grow until 2050 (United Nations, 2014) (Figure 1.2). Nowadays, 53.6% of the global population lives in cities and in 2050 is expected to reach a level of 66.4%. In Portugal, this value will reach a level of 76.8% in 2050 compared with 62.9% in 2014. While population is likely to stabilize in 2050 reaching around 9.5 billion, the urban population will continue to grow even after 2050 caused by continuing rural-to-urban migrations (United Nations, 2014).

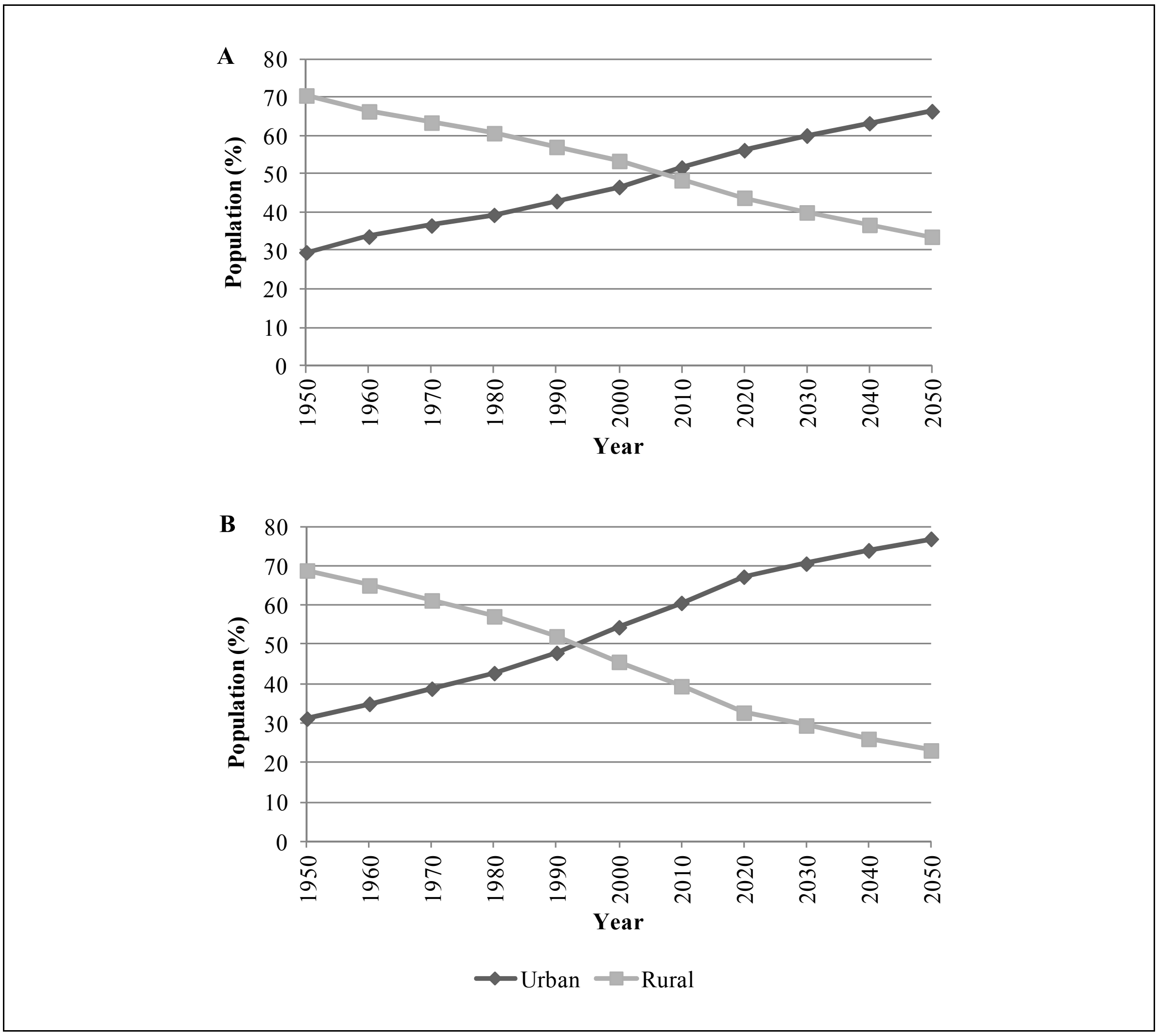


Figure 1.2 - The dynamics of urban and rural populations worldwide (A) and in Portugal (B) between 1950 and 2050. (Data from United Nations, 2014).

Although the urban development often corresponds to higher levels of economic and social development at the national and regional scales, the urban citizens usually have substantially greater and more diverse demands for resource consumption than those from rural areas. Therefore, this urban development adversely affects the ecosystems and landscapes at local and regional scales (Wu *et al*., 2014).

1.2.2. Urban patterns and processes

Cities are ecosystems, and thus, they are open and dynamic systems which consume, transform, and release material and energy. They also develop and adapt as well as interact with other ecosystems. Although cities are highly artificial and dominated by humans, they can only survive and deliver quality of life by using basic services provided by nature, such as regulating the water cycle and the climate, purifying the air, water and soil, and producing food and other goods (EEA, 2010a).

Urban ecosystems evolve over time and space as the outcome of dynamic interactions between socio-economic and biophysical processes (Alberti, 2008a). They consist of several interlinked subsystems, such as social, economic, institutional, and ecological, where each one represents a complex system of its own and affects all the others at various structural and functional levels (Figure 1.3) (Alberti and Marzluff, 2004).

To study the interactions between humans and ecological processes in urban ecosystems it is need to consider that many socio-economic and biophysical factors work simultaneously at various levels with important feedback mechanisms (Alberti, 2005). The ecological resilience of urban ecosystems *i.e.*, the degree to which they tolerate alteration before reorganizing around a new set of structures and processes, is influenced by these interactions (Alberti and Marzluff, 2004). For example, through direct and subtle changes in climatic, hydrological, geomorphic, and biogeochemical processes and biotic interactions, the urbanization affects primary productivity, nutrient cycling, hydrological function, and ecosystem dynamics (Alberti, 2008b).

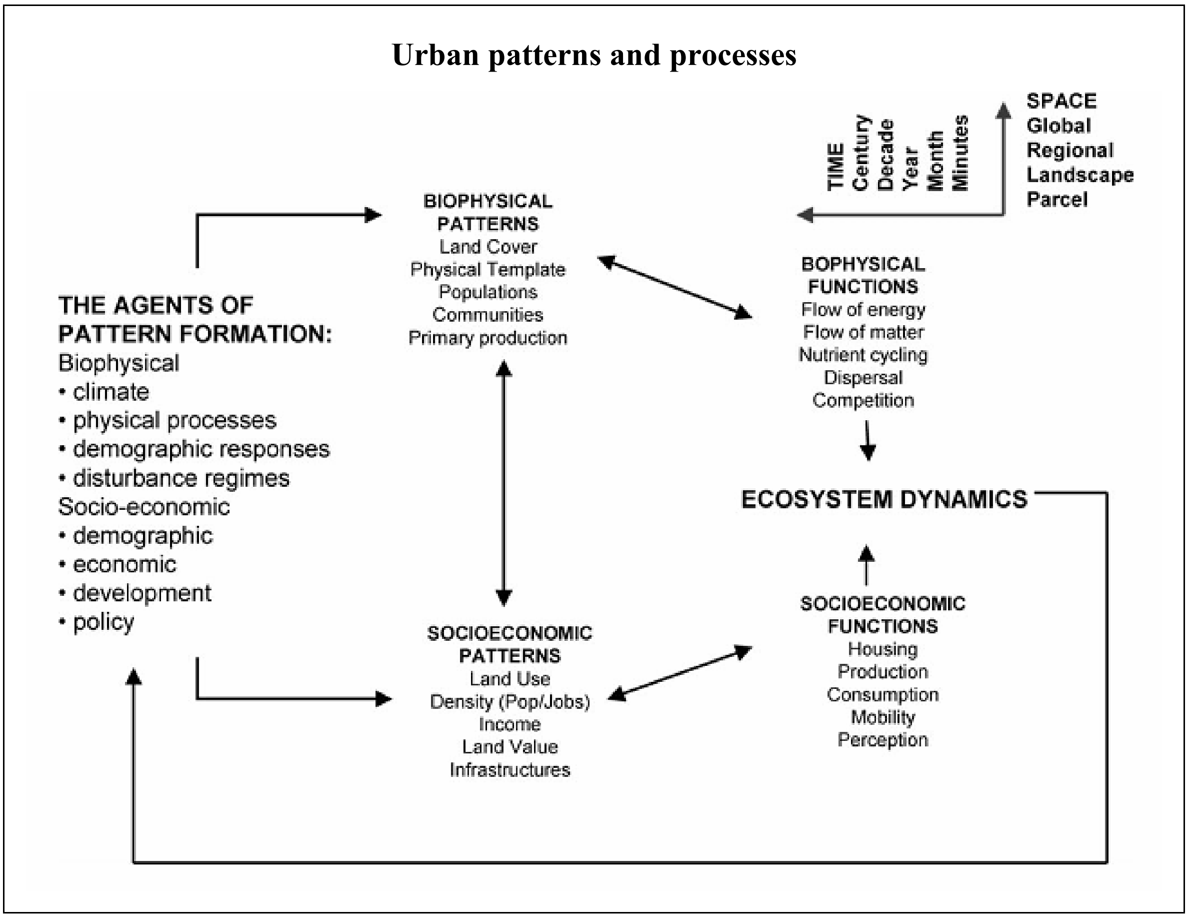


Figure 1.3 - Biophysical and socio-economic patterns are driven by the interactions of multiple biophysical and socio-economic agents and affect ecosystem dynamics through biophysical and socio-economic functions over multiple temporal and spatial scales. (From Alberti and Marzluff, 2004).

1.2.3. Urbanization and land use change

Urbanization is the spatial expansion of the built environment (human-constructed elements, such as buildings, roads, runways) that is densely packed by people and their socio-economic activities (Wu, 2010, 2014). Although the urbanized areas occupy a surprisingly tiny fraction (roughly 3%) of the Earth's surface, their impact has been global (Grimm *et al.*, 2008; Wu, 2008a; CIESIN *et al.*, 2011). In 2007, the humans modified more than half of the Earth's surface, a consequence of the increase in the human population and the resulting demand for more resources, such as minerals, soil, and water (Hooke *et al.*, 2012).

Changes in land use to yield goods and services represent the most substantial human alteration of the Earth system and the urbanization process is a major driver of this land conversion (Vitousek *et al*., 1997; Alberti, 2010). Land development and human activities in urban areas alter the land use type and the availability of nutrients and water, affecting population, community, and ecosystem dynamics, being responsible for drastic environmental problems, such as biodiversity loss, ecosystem degradation, landscape fragmentation, and climate change (Alberti, 2010; Wu, 2010). The urban areas account for 78% of carbon emissions, 60% of residential water use, and 76% of the wood used for industrial purposes (Brown 2001). Everyone in the world depends completely on Earth's ecosystems and the services they provide (MEA, 2005a). Therefore, the urbanization phenomenon is a dominant demographic trend and an important component of global land transformation (Pickett *et al*., 2011).

Land is an essential input for housing and food production. Land use is determined by the interaction in space and time of biophysical factors, such as soils, climate, topography and human factors like population, technology, or economic conditions (Veldkamp and Fresco, 1996). Consequently, although the land use change is necessary and essential for economic development and social progress, it has negative socio-economic and environmental impacts (Table 1.1) (Wu, 2008b).

During urbanization changes in land use to build cities and to support the demands of urban populations also drives environmental changes such as local and global alterations of biogeochemical cycles, climate, hydro-systems, and biodiversity (Figure 1.4), altering the structure and functioning of ecosystems (Vitousek *et al*., 1997; Grimm *et al*., 2008). Undoubtedly, the urbanization causes profound changes in all environmental components and the humans are the main drivers of these changes (Pickett *et al*., 2001; Alberti *et al*., 2003). Urbanization can significantly influence the local and regional climate by altering the land use patterns and consequently the surface radiation regimes and energy balance (Wu, 2008a).

Table 1.1 - Socio-economic and environmental impacts of land use changes. (Adapted from Wu, 2008b).

Socio-economic	**Environmental**
1. Conversion of cropland and forests to urban development reduces the amount of land available for food and timber production	1. Land use and land management practices have a major impact on natural resources including water, soil, air, nutrients, plants, and animals
2. Soil erosion, salinization, desertification, and other soil degradation associated with agricultural production and deforestation reduce land quality and agricultural productivity	2. Runoff from agriculture is a leading source of water pollution both in inland and coastal waters
3. Conversions of cropland and forests to urban development reduce the amount of open space and environmental amenities for local residents	3. Draining wetlands for crop production and irrigation water diversions has had a negative impact on many wildlife species
4. Urban development reduces the "critical mass" of cropland necessary for the economic survival of local agricultural economies	4. Irrigated agriculture has changed the water cycle and caused groundwater levels to decline in many parts of the world
5. Urban development patterns not only affect the lives of individuals, but also the ways in which society is organized	5. Intensive farming and deforestation may cause soil erosion, salinization, desertification, and other soil degradations
6. Urban development has encroached upon some rural communities to such an extent that the community's identity has been lost	6. Deforestation adds to the greenhouse effect, destroys habitats that support biodiversity, affects the hydrological cycle and increases soil erosion, runoff, flooding and landslides
7. Suburbanization intensifies income segregation and economic disparities among communities	7. Urban development causes air pollution, water pollution, and urban runoff and flooding
8. Excessive land use control, however, may hinder the function of market forces	8. Habitat destruction, fragmentation, and alteration associated with urban development are a leading cause of biodiversity decline and species extinctions
9. Land use regulations that aim at curbing land development will raise housing prices, making housing less affordable to middle-and low-income households	9. Urban development and intensive agriculture in coastal areas and further inland is a major threat to the health, productivity, and biodiversity of the marine environment throughout the world
10. Land use regulation must strike a balance between private property rights and the public interest	

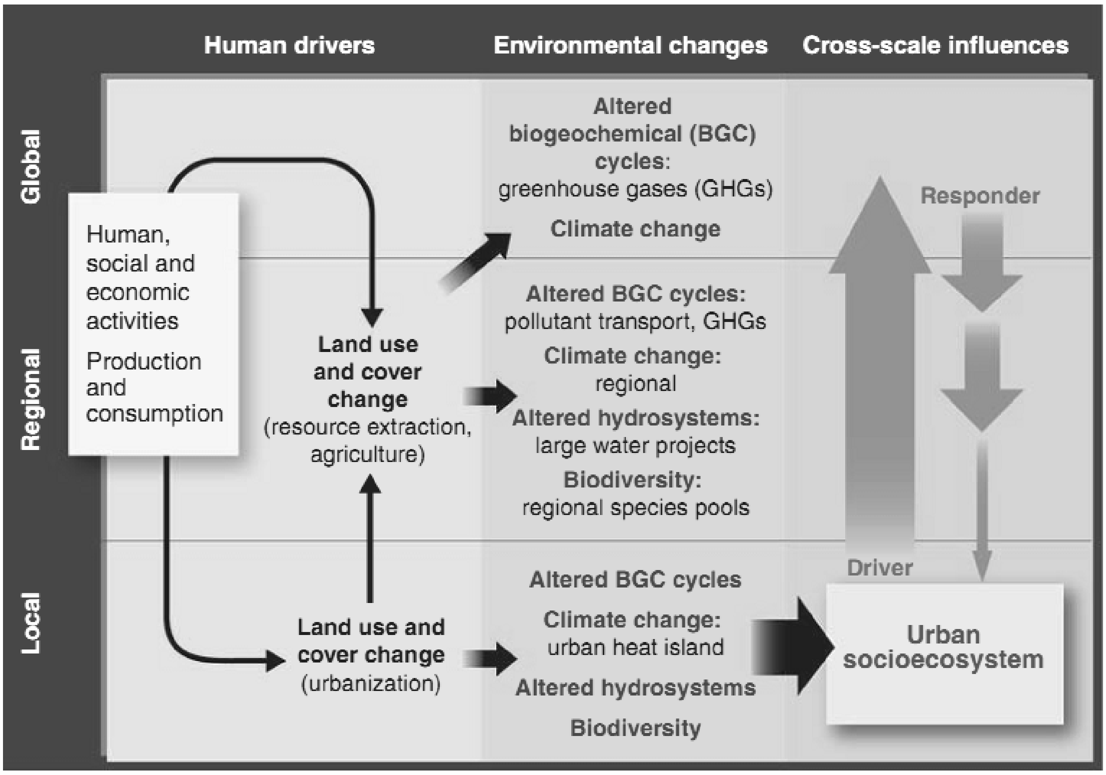


Figure 1.4 - Diagram showing urban socioecosystem (lower right) as a driver of (upward arrows) and responder to (downward and horizontal arrows) environmental change. Large local environmental changes are greater than those that filter down from global environmental change (horizontal black arrow). (From Grimm *et al*., 2008).

Urban areas' expansion implies an increase in impervious land area which affects both geomorphological and hydrological processes, thus causing changes in water and sediment fluxes (Grimm *et al*., 2008; Wu, 2008a). These impervious surfaces and the generation of heat from various combustion processes in urban areas modify the microclimate and air quality (Alberti, 2010). A best-known example of inadvertent climate modifications is the urban heat island effect once the urban areas tend to have higher air and surface temperatures than their surrounding suburban and rural areas (Arnfield, 2003; Rosenthal *et al*., 2008). This effect exists due to the greater heat retention of buildings and man-made surfaces, ever-present in cities, compared to the lesser heat retention and cooling properties of vegetation, which is more abundant in the countryside (Rosenthal *et al*., 2008; Winguth and Kelp, 2013). The urbanized areas usually have fewer trees and other vegetation to shade buildings and cool the air by evapotranspiration thus, tends to retain less surface water from precipitation than rural areas (Rosenthal *et al*., 2008).

Urbanization also affects biogeochemical processes by modifying the mechanisms that control the spatial and temporal variability of nutrient sources and sinks (Kaye *et al*., 2006; Grimm *et al*., 2008). Humans modify the ways in which nutrients are transported across the landscape and their cycles, for example, when nutrients are released from municipal wastewater and from combined sewer-storm water overflow systems in urban surface waters (Alberti, 2010).

Urbanization drastically affects the water resources due to increased *per capita* use of fresh water and contamination of water sources by sewage and wastes in cities (Wu, 2008a). In addition, the urban centers, especially those in the developed world, are the major producers of greenhouse gases and air pollutants that cause health problems for humans and the environment (Grimm *et al*., 2008; Wu, 2008a). Urbanization also alters the composition and spatial arrangement of the landscape elements (*e.g*., remnant natural areas, human-created or managed green spaces, waterways, agricultural fields, built structures, transportation corridors, and residential areas) (Wu, 2008a, 2014).

Change in land use associated with urbanization affects drastically the biodiversity, ecosystem functioning, and environmental quality, as well as human behavior, community structure, and social organization (Alberti, 2010; Wu, 2008a, 2014). Both the loss and fragmentation of natural habitats due to urbanization also have direct and indirect impacts on the diversity, structure, and distribution of vegetation leading to important consequences in the distribution, movement, and persistence of species (Alberti, 2010). Unquestionably, biodiversity plays a key role in maintaining ecosystem functions and the urbanization is associated with several changes in biotic interactions that affect the viability and distribution of species (Hansen *et al*., 2005).

1.3. Urban ecology

1.3.1. Emergence of the discipline of urban ecology

Humans are components of ecosystems but those dominated by humans provide a new and challenging field for inter- and trans-disciplinary studies involving the physical, ecological, and social sciences (Alberti, 2008a). The connotation of the term, urban ecology, has expanded and diversified during several decades by ecologists as well as urban geographers, planners, and social scientists (McDonnell, 2011; Wu, 2014). Urban ecology was originally developed as part of human ecology in the 1920s by an influential group of sociologists at University of Chicago (the Chicago school of sociology or human ecology). Four key players of the Chicago school were Robert E. Park, Ernest W. Burgess, Roderick D. McKenzie, and Amos H. Hawley (Wu, 2014). Park and Burgess elaborated a theory of urban ecology which proposed that cities were environments like those found in nature, governed by many of the same forces of Darwinian evolution that affected natural ecosystems. They defined urban ecology as "the study of the relationship between people and their urban environment" - which is essentially human ecology of the city (Park *et al.*, 1925).

In the late 1940s and early 1950s in Europe, North America, and Asia urban ecology was developed into a sub-discipline of ecology (Alberti, 2008b; Marzluff *et al.*, 2008). A number of European studies were carried out mainly by botanists and zoologists, representing a bio-ecology approach to urban ecology which has been sometimes called "the Berlin school" (Wu, 2008a; Weiland and Richter, 2011). Since the humans play a role as a source of disturbance and as users of urban ecosystems, a central motive for research is to transfer nature conservation to cities and urban areas in order to protect urban ecosystems for the humans (Weiland and Richter, 2011). By the late 1950s and early 1960s, it was becoming apparent to everyone on the planet that humans had significantly altered local and regional ecosystems (Berkes and Folke, 1998; MEA, 2005a).

Urban ecology as a sub-discipline of ecology only emerged in the 1970s in response to a growing awareness of human impact on the natural environment, and the role of cities in this regard (Cadenasso and Pickett, 2008; MacDonnell, 2011). In the 1970s, Herbert Sukopp and a group of colleagues developed a complex bio-ecological approach to urban ecology. This ecological approach considers a city as an ecosystem, characterized by its history, its structure and function, including both biotic and abiotic components, and the cycling and conversion of energy and materials (Sukopp, 2002). Unfortunately, these early urban ecology studies did not motivate a significant number of ecologists to continue to build the discipline in the 1970s and 1980s (McDonnell, 2011).

A renaissance in the development of the discipline of urban ecology occurred in the 1990s (McDonnell, 2011). McDonnell and Pickett (1990) introduced the well-established gradient analysis method in plant community ecology and vegetation science to the study of urban ecosystems - the urban-rural gradient approach. With the rapidly increasing availability of remote sensing data, geographic information systems (GIS), and spatial pattern analysis methods, the number of studies on the spatial and temporal patterns and socio-economic drivers of urbanization began to ascend (Wu *et al*., 2013a). The discipline of urban ecology was stimulated, in part, by the initiative of the US National Science to fund in 1997 two urban long-term ecological research (Urban LTERs) programmes: the Baltimore Ecosystem Study and the Central Arizona-Phoenix Long-term Ecological Research (Grimm *et al*., 2000).

During the past two decades urban ecology has developed into a highly interdisciplinary field of study, increasingly embraced by ecologists, geographers, and social scientists (Wu *et al*., 2013a). Presently, urban ecology usually consists of three kinds of research components that interact with each other in the study of cities, making urban ecology a truly inter-disciplinary science that integrates research with practice (Figure 1.5). Consequently, urban ecology can be defined as "the study of spatial and temporal patterns, environmental impacts, and sustainability of urbanization with emphasis on biodiversity, ecosystem processes, and ecosystem services" (Wu, 2014).

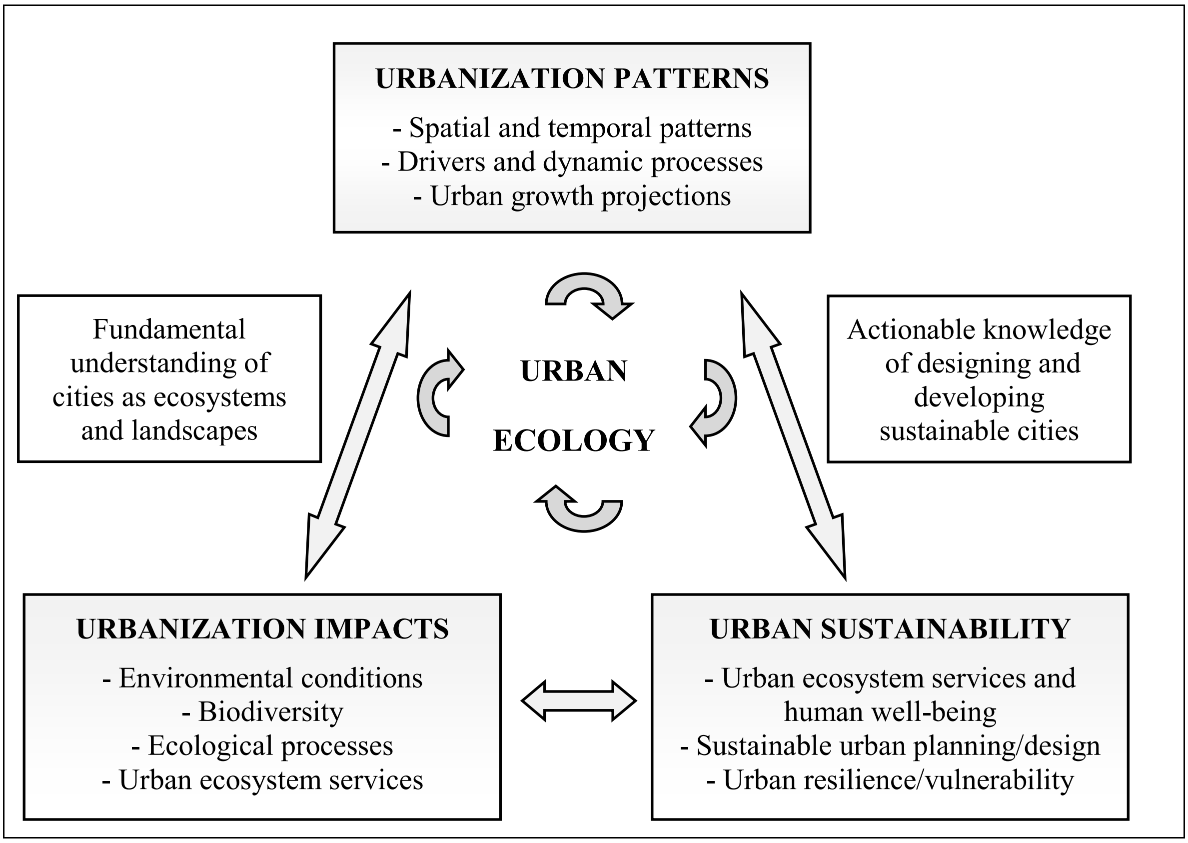


Figure 1.5 - The diagram of contemporary urban ecology: key components and their relationship. (Adapted from Wu, 2014).

1.3.2. Urban ecology perspectives

A major goal of urban ecology is to understand the relationship between the spatial and temporal patterns of urbanization and ecological processes (Wu, 2008a). In order to know and improve these relationships, many concepts and perspectives in urban ecology have been developed, reflecting different degrees of affinity to either natural sciences or humanities (Wu 2006, 2008a). These ecological perspectives have been categorized as either "ecology in cities", which focuses primarily on the non-human organisms in the urban environment, or "ecology of cities", which considers the whole city as an ecosystem or as a socio-economic system (Wu, 2008a). Considering the new developments in urban studies, Wu and its collaborators (2013) added a third category – "sustainability of cities". Based on this categorization, five distinct but related urban ecological approaches can be identified as illustrated in Figure 1.6 (Wu, 2008a, 2014; Wu *et al.*, 2013a).

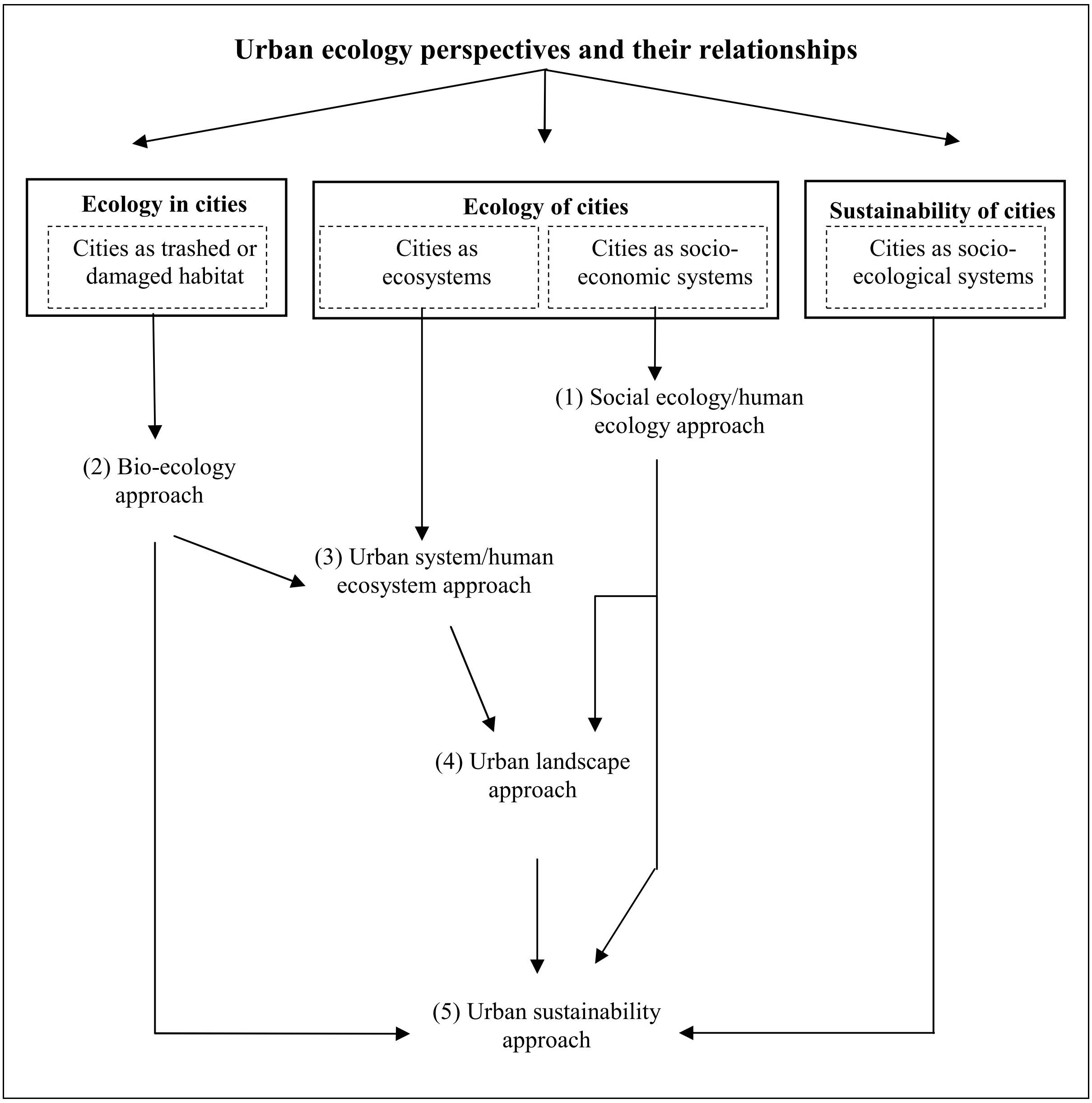


Figure 1.6 - Different perspectives in urban ecology and the rising prominence of the urban landscape ecology approach to the studies of cities and human-dominant areas. (Adapted from Wu 2008a, 2014, Wu *et al*., 2013a).

These five urban ecological approaches identified were (Wu, 2008a, 2014; Wu *et al*., 2013a):

1 - Social ecology approach or human ecology approach has followed the ecology of cities category that views cities as socio-economic systems and investigates human behaviour and social organization in cities based on borrowed ecological theory and concepts.

2 - Bio-ecology approach has followed the ecology in cities category that views cities as trashed or damaged habitat and has evolved with a focus on how urbanization affects the distribution and dynamics of plants and animals in cities.

3 - Urban systems approach or human ecosystem approach, both of which treat the city as a whole ecosystem consisting of both socio-economic and biological components.

4 - Urban landscape approach treats urban areas as spatially heterogeneous landscapes that are composed of multiple interacting patches. This approach focuses on the relationship between urbanization patterns and ecological processes.

5 - Emerging urban sustainability approach that treats cities as coupled human-environment systems or socio-ecological systems. This approach integrates the various urban ecology perspectives, and its scientific core develops around the structure, function, and services of the urban landscape, with an increasing emphasis on the relationship between ecosystem services and human well-being in urban areas.

1.4. Sustainability

1.4.1. Sustainable development and urban sustainability

According to UNESCO (2000), one of the greatest challenges facing the world community in the 21st century will be the attainment of sustainable development, calling for balanced policies aimed at economic growth, poverty reduction, human well-being, social equity, and the protection of the Earth's resources and life-support systems. The declaration on sustainable development by the World's Nations at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992 was most important for the commitment of researchers to tackling these problems of society in this century (United Nations, 1992). In this conference was adopted the definition of sustainable development that was put forward by the World Commission on Environment and Development (WCED) in 1987. The concept of sustainable development was officially defined as "a process of change in which the use of resources, the direction of investments, the orientation of technological developments and institutional changes are all in harmony with each other, with the aim of not only to meet present day needs, but also to ensure that future generations will be able to live as they would like to live" (WCED, 1987). This concept has encouraged policy-makers to formulate new strategies for achieving a balanced economic and technological pathway to safeguard the environment now and into the future *i.e.*, that the actual generation needs must be satisfied without compromising the capability of future generations satisfying their needs (Nijkamp and Vreeker, 2000; Hadorn *et al.*, 2006).

With the unprecedented growth of urbanization, now encompassing half of the world population (United Nations, 2014), global sustainability is increasingly an issue of urban sustainability, considering the impact of cities on the rest of the globe and of the sustainability of life in the cities themselves (Bugliarello, 2006). Therefore, Bugliarello (2006) defined urban sustainability as the intersection of urbanization and global sustainability (Figure 1.7).

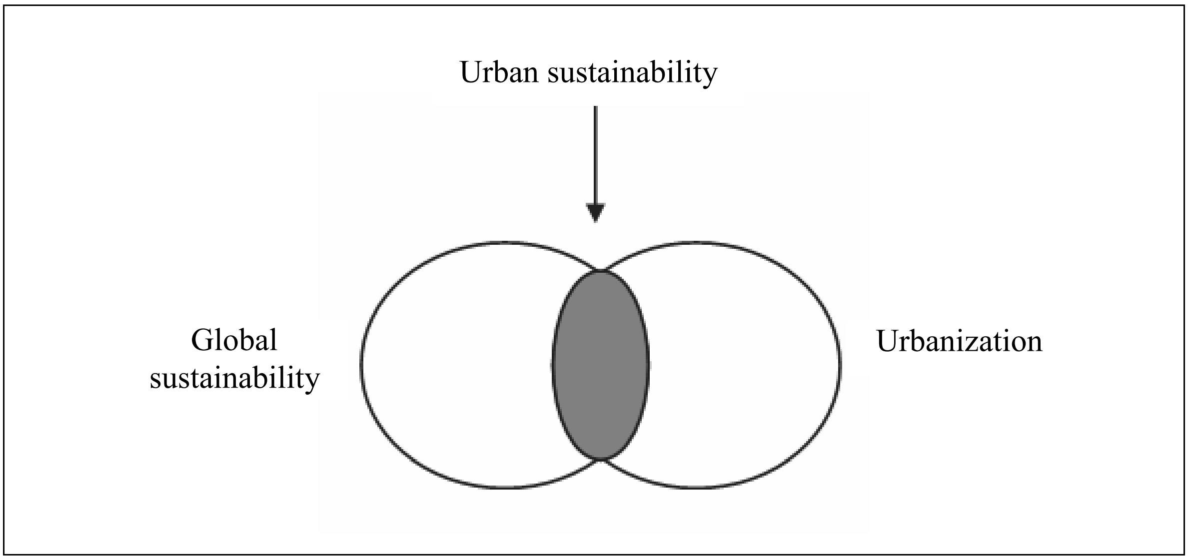


Figure 1.7 - Urban sustainability as the intersection of two phenomena (urbanization and global sustainability). (From Bugliarello, 2006).

The demand for more resources now exceeds what Earth can provide (Hooke *et al.*, 2012). The explosive growth of cities and resident population aspirations towards more quality of life make it an actual necessity of a conception and management of sustainable urban areas (Gomes and Panagopoulos, 2008). Therefore, understanding urban sustainability and improving the ability of policy makers to achieve sustainable management are pressing needs of the 21st century (Naess, 2001; Wu, 2010; Childers *et al*., 2014).

The concept of sustainability has become an important paradigm in urban planning, as the cities play a key role in our society. They are important generators of wealth, employment and productivity, and often serve as the engines of their national economies (EEA, 1995; Baycan-Leven *et al*., 2002). Consequently, strategies to make cities more sustainable have been formulated by governments and institutions all over the world. These strategies focus on the protection of environmental resources (*e.g*., air quality, biodiversity) as well as social and economic resources (*e.g*., livability, prosperity) (EEA, 1995; FEDENATUR, 2004; European Union, 2011).

1.4.2. Sustainable planning

Sustainable planning at the Municipal level is an opportunity for cities to address in a more innovative and effective way the challenges they are facing as well as to create a vision for the future they want to see in their city considering all aspects of economy, environment, and society (SCI, 2012).

The Agenda 21 (see at www.iisd.org/rio+5/agenda/default.htm) is a comprehensive plan of action to be followed globally, nationally, and locally by organizations of the United Nations System, governments, and other groups active in any area that has a human impact on the environment. The agenda was adopted by 178 governments at the United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil, 3-14 June 1992. Subsequently, the full implementation of the Agenda 21, the Programme for Further Implementation of Agenda 21, and the Commitments to the Rio principles were reaffirmed at the World Summit on Sustainable Development held in Johannesburg, South Africa from 26 August to 4 September 2002. Population, consumption, and technology are the primary driving forces of environmental change. Hence, Agenda 21 offers policies and programmes to achieve a sustainable balance between these forces of change and Earth's life-supporting capacity.

The "Charter" is the most successful European effort in sustainable urban development. The Aalborg Charter (1994) is an urban environment sustainability initiative approved by the participants at the first European Conference on Sustainable Cities and Towns in Aalborg, Denmark. It is inspired by the Rio Earth Summit's Local Agenda 21 plan and was developed to contribute to the European Union's Environmental Action Programme, "Towards Sustainability". The Charter is based on the consensus of individuals, municipalities, NGOs, national and international organizations, and scientific bodies. Nowadays, with more than 2 700 participants, the European Sustainable Cities and Towns Campaign remains the biggest bottom-up movement that had emerged following the Local Agenda 21 mandate from Rio. In 2004, during the 4th European Sustainable Cities and Towns Conference, also known as the Aalborg 10+, the Aalborg Commitments were established and adopted by 620 local governments in Europe. The objective of these ten commitments was to turn around sustainable urban development from words into real actions. After 20 years (2014), the spirit of the Aalborg Charter remains. Indeed, it prepared the ground for a variety of schemes and movements for local sustainability such as the Aalborg Commitments, the Covenant of the Mayors, the Green Capital Award, the EU Reference Framework for Sustainable Cities, and the Sustainable Cities website.

1.4.2.1. Urban green spaces

The world is facing unprecedented socio-demographic, technological, and environmental challenges which will have substantial consequences for cities and their development, and hence for the ecological functioning of urban areas (Niemelä, 2014). Humans modulate the urban ecosystems for a range of services including food, energy, water, and waste recycling, and thus threatening many of the ecological services that are essential to society (Carpenter and Folke, 2006; Rockström *et al.*, 2009; Raudsepp-Hearne *et al.*, 2010). This great pressure on natural resources caused by humans has upgraded the interest in urban green spaces. The ways in which these spaces can benefit cities and their residents have become key issues in urban planning (Sandström, 2002; Tzoulas *et al.*, 2007; Mazza *et al.*, 2011). The Municipal Master Plan of Coimbra, published in 1993, classifies green spaces as "spaces characterized by high expression of its vegetation cover and a core value in the landscape composition and contribute significantly as recreational and leisure elements, protection, and landscape composition for the environment quality" (CMC, 1993).

Urban citizens expect a high quality of life, a good public health, an unpolluted environment, and possibilities for recreation in green spaces (Botkin and Beveridge, 1997). Satisfying these aspects, along with economic and social well-being are the important components in the development of sustainable urban environment (Figure 1.8) (WCED, 1987; United Nations, 1992; Chiesura, 2004).

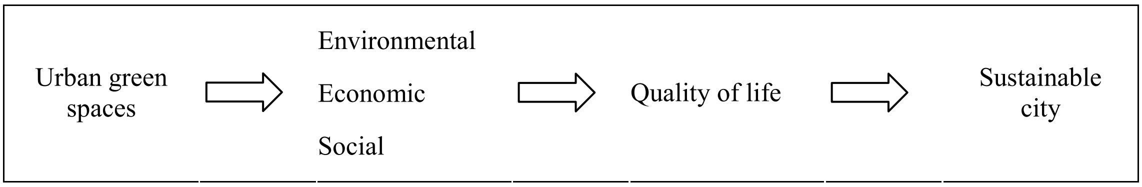


Figure 1.8 - Urban green spaces and city sustainability. (Adapted from Chiesura, 2004).

The urban green spaces promote the interaction between citizens and the environment within an urban context, promote human health, and provide environmental and recreational benefits to urban citizens (Cariñanos and Casares-Porcel, 2011). Consequently, their quality and aesthetics are important factors in making cities attractive and viable places to live in (Baycan-Leven *et al.*, 2002; European Union, 2011). The provision, design, management and protection of urban green spaces are at the main purposes of the plan of sustainability and liveability of modern cities (Baycan-Leven *et al.*, 2002; Haq, 2011). This requires large economic efforts and future commitment to their conservation by the government or similar entities. This should be followed with sensitivity actions and citizen awareness in their individual responsibility so that the urban environment can be protected and preserved (Gomes and Panagopoulos, 2008). Recently, the European Commission launched a strategy titled "Green Infrastructure - Enhancing Europe’s Natural Capital" basing on the principle that protecting and enhancing nature and natural processes, and the many benefits human society gets from nature, are consciously integrated into spatial planning and territorial development (European Commission, 2013a).

Urban green spaces supply to cities with ecosystem services ranging from maintenance of biodiversity to the regulation of urban climate (Haq, 2011). Biodiversity is essential for the functioning and sustainability of an ecosystem. Different species play specific functions and changes in species composition, species richness, and functional type affect the efficiency with which resources are processed within an ecosystem (Alberti, 2005). Biodiversity conservation emerged as a field of international policies in the 2nd half of the 20th century, culminating in the United Nations Convention on Biological Diversity which entered into force in 1992. The Convention on Biological Diversity (1992) defined biodiversity as "the variability among living organisms from all sources, including diversity within species, between species and of ecosystems". In short, the notion "urban biodiversity" can be interpreted as "the diversity of living things in an urban area" (Bezák and Lyytimäk, 2011). Biodiversity is considered to be a fundamental basis of goods and services needed for human well-being (MEA, 2003). In 2010, the tenth meeting of the Conference of Parties (COP 10) to the Convention on Biological Diversity led to the adoption of a global Strategic Plan for biodiversity for the period 2011–2020 to safeguard biodiversity and the benefits it provides to people (CBD, 2013). The European Commission has laid down a global commitment in a Biodiversity Strategy to 2020 which integrates ecosystem services as underpinning elements of Member States' economy to complement the conservation approach to biodiversity. This strategy aimed at reversing biodiversity loss and speeding up the Europe's transition towards a resource efficient and green economy (European Commission, 2011a). It is an integral part of the Europe 2020 Strategy (European Commission, 2010a), and in particular the resource efficient Europe flagship initiative (European Commission, 2011b).

1.5. Subject and scope of the thesis

1.5.1. Objectives

A inter-disciplinary approach integrating science with urban planning is essential and needed in order to manage the complexity of urban ecosystem services and promote quality of life in the context of global or local change (Bezák and Lyytimäk, 2011). Overall, this study aims to determine and evaluate some of the environmental implications of the dynamic of land use change in the municipality of Coimbra during the last two decades (1990-2010).

Specific goals:

1. Earth's ecosystems are increasingly influenced by the speed and patterns of urban expansion, and consequently the future of ecosystems will depend upon how the humanity will be able to make urban regions sustainable (Alberti, 2010). Given the magnitude of land use change and urban expansion worldwide, is important to

recognize its dynamic and driving factors at spatial and temporal scales, thus this study proposes:

↔ to identify land use changes that have occurred from 1990 to 2010 in the municipality of Coimbra (Chapter 2).

↔ to recognize the main driving factors of these changes and assess their impacts on the landscape patterns (Chapter 2).

↔ to identify the temporal and spatial dynamics of built-up land in the municipality of Coimbra during this two decades (Chapter 3).

↔ to identify and evaluate the characteristics of city expansion (Chapter 3).

2. Occurrence and quality of urban green spaces are important for the well-being of urban populations. Access to these spaces generally improves human well-being and if well planned they can play an important role in economic development as well (Bezák and Lyytimäk, 2011). Given that biodiversity is a fundamental basis of goods and services needed for human well-being, careful planning will be necessary in order to support the protection and enhancement of biodiversity and the needs of urban citizens (MEA, 2003). Therefore, since the urban green spaces are a vital part of the urban landscape, this study also proposes:

↔ to determine the composition and diversity of plants and macromycetes in three different landscape types (Oak-stands, Olive-stands and Eucalyptus-stands) of an urban green space located in the city of Coimbra (Chapter 4).

↔ to evaluate plant species and soil microorganisms diversity in two typologies of urban green spaces (public gardens and forests) in the city of Coimbra (Chapter 5).

3. The primary issue from the perspective of human well-being is whether the resources and services provided by municipal authorities offer a healthy and satisfying living environment for their citizens (Bezák and Lyytimäk, 2011). A good municipal service provides the citizens with what they need in order to best satisfy them and improve their quality of life (Duque *et al.*, 2013). Therefore, to characterize the level of citizens' satisfaction regarding its city, a perception survey, using a questionnaire, was developed aiming:

↔ to assess the residents' opinion about the resources of their municipality, the services provided by the local authorities, and to perceive what they value the most (Chapter 6).

↔ to relate the levels of satisfaction with the socio-demographic profile of respondents (Chapter 6).

1.5.2. Study area

The study was conducted in the municipality of Coimbra situated between latitudes 40º5'N and 40º19'N and longitudes 8º18'W and 8º35'W, in the Coastal Region of Centre Portugal (Figure 1.9), and thus in the Atlantic coast of the Iberian Peninsula and the European Union. Coimbra also performs an important function linking Portugal to Europe by two principal roadways (IP3 and A25) connected to the network of European motorways (CMC, 2008). The city of Coimbra is one of the country's main urban centres. Furthermore, due to its singular centrality, demography, and disturbance in land use patterns, this municipality becomes an interesting case study. Since the 1970s, an urban expansion has taken place, together with the construction of important road infrastructures and facilities (Tavares, 2004). This development caused a marked change between human occupation and physical factors namely: (1) progressive development and building in areas with severe slope, (2) urban growth in areas intermittently inundated or with superficial water tables, and (3) a move into areas with evidence of instability associated with geomorphic processes (Tavares and Soares, 2002). These features have created evident changes in landscape, with an increase in the magnitude and frequency of geomorphic processes and a surface extension of disturbance, reflecting a general state of disequilibrium. The active disturbance has special relevance in the outer urban areas in the north, southwest and east of the city of Coimbra (Tavares, 2004).

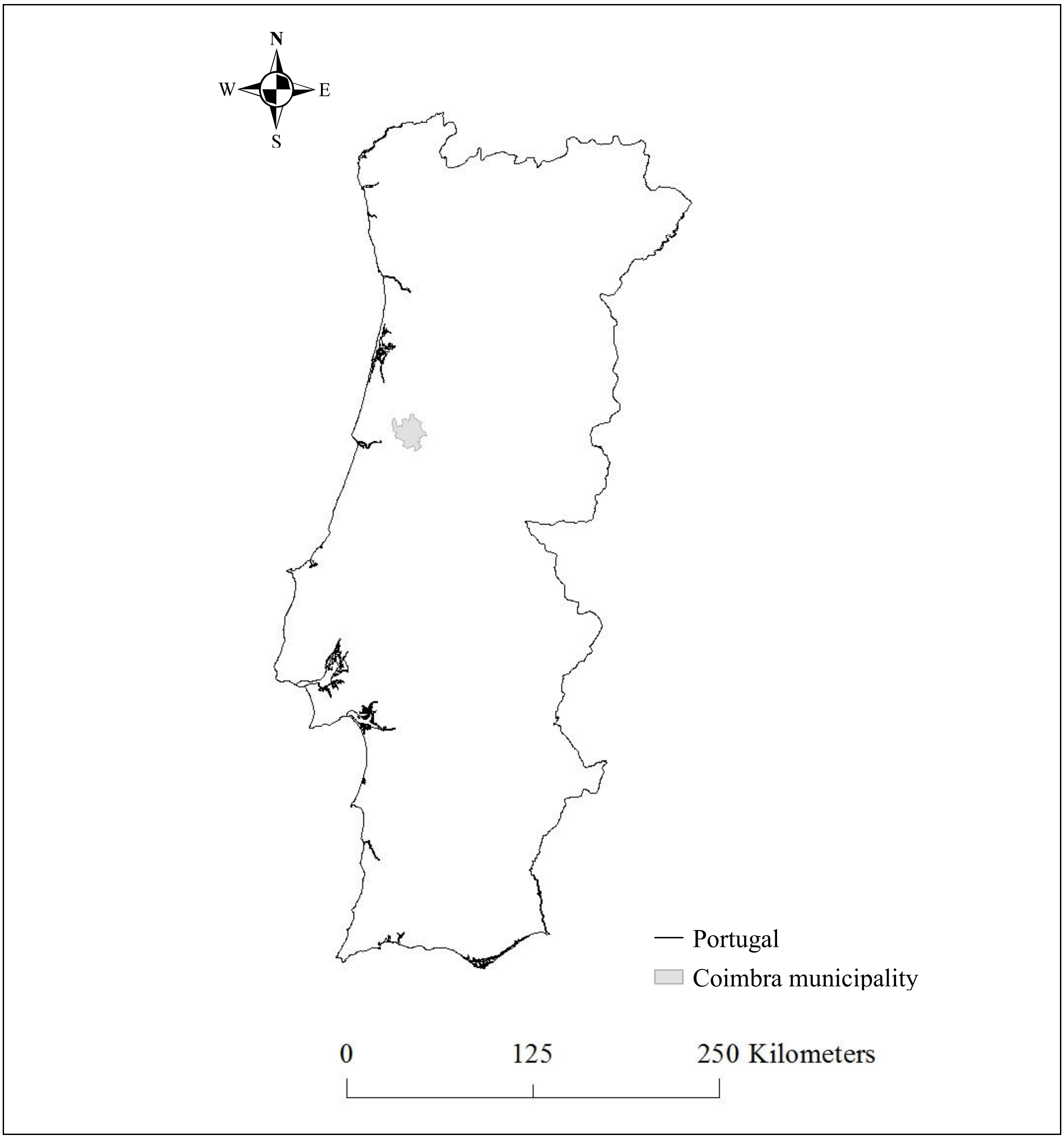


Figure 1.9 - Location of the study area.

On the other hand, the extreme fertility of the Mondego Fields (Baixo Mondego) always promoted a great attraction to human occupation. This occupation has benefited in particular the agriculture and has discouraged the construction near river banks due to periodic flooding. The open valley created an extensive alluvial surface generally occupied for agricultural production. In recent decades, urban river banks have been gradually converted into green recreational spaces playing a key role for leisure and water sports activities (Figure 1.10) (CMC, 2012).

Figure 1.10 - The green recreational spaces in the banks of the Mondego river.

Coimbra is a reference centre of Portuguese education and culture (CMC, 2012). In 2013 the University of Coimbra (Figure 1.11) – Alta and Sofia were included in the UNESCO World Heritage List. According to UNESCO, Coimbra offers an outstanding example of an integrated university city with a specific urban typology as well as its own ceremonial and cultural traditions that have been kept alive through the ages (Portuguese Commission for UNESCO, 2014).

Figure 1.11 - The University of Coimbra, included in the UNESCO World Heritage List.

The municipality of Coimbra has about 320 km² and 143 396 inhabitants, divided into 31 parishes (INE, 2011). In 2013, with the administrative reorganization of parishes in Portugal and respective union of parishes, Coimbra was divided into 18 parishes (Table 1.2) (see at www.cm-coimbra.pt). This study was conducted before the spatial reorganization of the municipality and for that it was considered the division in 31 parishes.

Table 1.2 - Administrative organization of Coimbra parishes until and after 2013.

Administrative organization of parishes	
Parishes until 2013	**Parishes after 2013**
1. Almalaguês	1. Almalaguês
2. Brasfemes	2. Brasfemes
3. Ceira	3. Ceira
4. Antuzede	4. Union of Antuzede and
5. Vil de Matos	Vil de Matos
6. Assafarge	5. Union of Assafarge and
7. Antanhol	Antanhol
8. Eiras	6. Union of Eiras and
9. São Paulo de Frades	São Paulo de Frades
10. Cernache	7. Cernache
11. Santo António dos Olivais	8. Santo António dos Olivais
12. São João do Campo	9. São João do Campo
13. São Silvestre	10. São Silvestre
14. Torres do Mondego	11. Torres do Mondego
15. Almedina	12. Union of Almedina,
16. Santa Cruz	Santa Cruz,
17. São Bartolomeu	São Bartolomeu, and
18. Sé Nova	Sé Nova
19. Lamarosa	13. Union of Lamarosa and
20. São Martinho de Árvore	São Martinho de Árvore
21. Ribeira de Frades	14. Union of Ribeira de Frades and
22. São Martinho do Bispo	São Martinho do Bispo
23. Santa Clara	15. Union of Santa Clara and
24. Castelo Viegas	Castelo Viegas
25. Botão	16. Union of Botão and
26. Souselas	Souselas
27. Ameal	17. Union of Ameal,
28. Arzila	Arzila, and
29. Taveiro	Taveiro
30. Trouxemil	18. Union of Trouxemil and
31. Torre de Vilela	Torre de Vilela

Chapter 2

Analysis of land use change and its driving factors in the municipality of Coimbra from 1990 to 2010

2.1. Abstract

Land use change is a major issue in global environmental change, especially in developing countries. Human impacts upon the land are very pronounced and still increasing. This study analysed the land use change during the last two decades in the municipality of Coimbra using three land use maps corresponding to the years 1990, 1999, and 2010. The main objective of the study was to characterize the spatial and temporal land use changes in the municipality and discuss how potential driving factors have contributed to this alteration. With its economic development, population growth, and urbanization the municipality of Coimbra has experienced a clear pattern in land use change from 1990 to 2010. The change was mainly characterized by a continuous built-up land expansion, mostly at the expense of cropland loss. The bivariate statistical analysis suggested that physical, disturbance, demographic, and socio-economic factors were significantly correlated with this land use change. This study also revealed an increase of built-up land on lands with slopes above 15° which may increase the risk levels for landslides. Coimbra is a municipality where older population and people with higher school degrees live in the centre urban area. However, despite this higher population density, the unemployment rate is also superior when compared with more periurban areas of the municipality. More urbanized areas comprised older buildings, a clear indicator of urban degradation. The knowledge about land use change and its driving factors are urgently needed, particularly at local/regional level, in order to obtain reliable data for a sustainable land use planning and management.

Keywords
land use change; driving factors; urbanization; Coimbra municipality; GIS

2.2. Introduction

The speed, magnitude, and spatial reach of human alterations on the Earth's land surface are unequalled (Lambin *et al.*, 2001). The interactions between environmental change and human societies' activities have a long and complex history and have varied greatly through time and space (Steffen *et al.*, 2004). In developing countries where a large proportion of the human population depends almost entirely on natural resources for their subsistence there are increasing competing demands for the utilization, development, and sustainable management of these resources, resulting in profound land use changes (Mwavu and Witkowski, 2008).

The land is an important and finite resource for essential human activities such as lodging, agriculture, forestry, industry, transportation, and recreation and therefore is tightly coupled with economic growth (Xie *et al.*, 2005; Zhan *et al.*, 2010). Land use activities have transformed a large proportion of the planet's land surface exerting important impacts on the regional's ecosystems, and consequently influencing the global environment (Foley *et al.*, 2005, Grimm *et al.*, 2008). Nearly 50% of the land surface has been transformed by direct human action during the second half of the 20th century (Steffen *et al.*, 2004) with significant consequences for biodiversity, nutrient cycling, soil structure, soil biology, and climate (Vitousek *et al.*, 1997; EEA, 2010b; Niemelä, 2014).

Land use change patterns are the result of complex interactions between numerous driving factors, such as agricultural technology, geography, demography, economy, or political and planning frameworks (Wu *et al.*, 2008; Jones *et al.*, 2011; Du *et al.*, 2014), operating at different spatial scales (Lambin *et al.*, 2001). The human population and the socio-economic development of the world have grown rapidly, significantly increasing the resource consumption (Steffen *et al.*, 2004). The second half of the 20th century has, without doubt, seen the most rapid transformation of the human relationship with the natural world in the history of humanity. During this period, the global population more than doubled, grain production tripled, energy consumption quadrupled, and economic activity quintupled (Steffen *et al.*, 2004, United Nations, 2014). The consecutives economic policies designed to promote growth and liberalization have been encouraged with little regard to their environmental consequences (Arrow *et al.*, 1995).

Population density and socio-economic expansion are considered as the major drivers of land use change worldwide, especially in developing countries with high economic development (Li *et al.*, 2009). Humans require a secure and renewable natural resource base to sustain their basic needs such as residential spaces, roads' networks, food and even leisure areas, and economic activities as well (Steffen *et al.*, 2004; Xie *et al.*, 2005). Increasing human population has undoubtedly driven global changes in land use (Ramankutty *et al.*, 2002). Consequently, this fast development brought serious consequences leading to dangerous levels of habitat's destruction, deforestation, and loss of agricultural land since the natural resources are replaced directly by artificial features such as roads and buildings (Xie *et al.*, 2005; EEA, 2010b), consequently affecting ecosystem services.

In Europe, with its long and complex history and great cultural diversity, a rich variety of traditional land uses emerged which form an integral part of our cultural heritage (Antrop, 2005; Plieninger *et al.*, 2006). The introduction of new modes of transportation, in particular those that allowed the mobility of the masses such as the railroad and road crossings, and their consequent urban and industrial expansion greatly influenced land use change (Antrop, 2004, 2005, 2008). Gradually, the economy became more international and is now dominated by global processes that attempt to increase productivity, reduce time-cost distance, develop networking, and if necessary, replace and displace the economic activities (Antrop, 2008).

Similar to the trend seen across European countries (EEA, 2010b), the land use in Portugal has also been suffering great changes. Between 1990 and 2000, Portugal had the highest percentage of land use change (about 9.9%) among 24 European countries and presented simultaneously the highest rates of deforestation (about 3.5%) and forestation (about 4%) (Feranec *et al.*, 2010). According to the Institute for Nature Conservation and Forestry similar results were recorded in 2005 and 2010 (ICNF, 2013a). This means that the regeneration of forests by natural and man-induced developments (plantations or regeneration after natural calamities) as well as the processes leading to deforestation by cut or due to various natural catastrophic situations (*e.g.*, fire, strong winds, disease) are the prominent land use change patterns observed in Portugal (Feranec *et al.*, 2010; ICNF, 2013a). The occurrence of diseases such as the "Pine Wood Nematode" has severely affected the *Pinus pinaster* Aiton plantations forcing the realization of exceptional cuts for enforcement of plant health regulations. No other country in Europe has been subject to this level of disturbance (ICNF, 2013a). The evolution of the agricultural and forestry sectors and associated industries were generally positive influenced by Portugal's adhesion to the European Union in 1986 with a significant progress at economic, environmental, and social levels (MAMAOT, 2012).

The development of any community together with its political and economic power depends in a large extent of its geographical situation and accessibilities (Rodrigue *et al.*, 2006). This case study, the municipality of Coimbra and its city centre possess major axes of transportation and telecommunications, key structuring factors for the economic-enterprise sector and demographic dynamism at regional and national levels, and is considered an important connecting corridor system to Europe (CMC, 2008, 2012). Due to its singular centrality between Lisboa and Porto (the two major Portuguese cities), Coimbra became an important asset to the development of the Central Region as well as to the country.

Scientific knowledge about the characteristics of land use is gaining increasing attention from researchers, planners, and policy makers because such changes cause serious environmental impacts devastating many heritage values and natural resources become irreversibly lost (Council of Europe, 2000; Antrop, 2004). Natural resource management is a complex task to undertake influenced by environmental, demographic, socio-economic, and political factors (Rao and Pant, 2001; Zhan *et al.*, 2010).

There are several approaches to detect land change which enable to recognize the variation among different land use patterns and to identify temporal land use changes based on its driving factors (Verburg *et al.*, 1999; Krausmann *et al.*, 2003; Hietel *et al.*, 2004). These procedures can provide relevant information for the sustainable management of land resources and regional development (Alig *et al.*, 2004; Long *et al.*, 2007). Thus, it is important to recognize the complex relationships between driving factors and the changes in land use patterns at several spatial scales.

The present study aimed to: (a) identify the land use changes occurring from 1990 to 1999 and from 1999 to 2010 in the municipality of Coimbra; (b) recognize the main driving factors of these changes; and (c) assess the impacts of such changes on landscape in a local perspective. This work hoped to contribute with valuable information to help planners to design more suitable and sustainable strategies for the development of the municipality.

2.3. Material and Methods

2.3.1. Study area

The study was conducted in the municipality of Coimbra (see Figure 1.9). This municipality comprises diverse landscape units determined by factors of lytic, morphological, and structural nature as well as by the dynamics and evolution of the Mondego river (CMC, 2008). Coimbra is an historic city with an important cultural heritage centre and hold educational and health facilities of national importance placing it in a privileged position in the network of urban national centers (Tavares *et al.*, 2012). The economy of the municipality is mainly characterized by tertiary activities being the productive structure dominated by services and commerce. The health, educational, and commercial facilities explain the importance of the tertiary sector in this region (Tavares *et al.*, 2010).

Coimbra is a hilly area (Figure 2.1-A) ranging from 6 meters (in the farm fields of the Mondego river) to 495 meters (in the east side, on the limit of the municipality), highlighting several contrasts in the municipality. The areas exceeding a slope of 15º occupy less territory and are particularly located in the east side of the municipality (Figure 2.1-B). Though not decisive, the relief contributes to the instability of the territory associated with landslides (20% of the municipality contain areas classified from moderate to high instability) (CMC, 2008). One of the main morphological and hidrological marks is the Mondego river which flows from an upstream-incised valley to a large downstream valley floor (Tavares *et al.*, 2010) (Figure 2.1-C). Therefore, these conditions make Coimbra an appropriate site to study the dynamics of land use and the factors triggering land change.

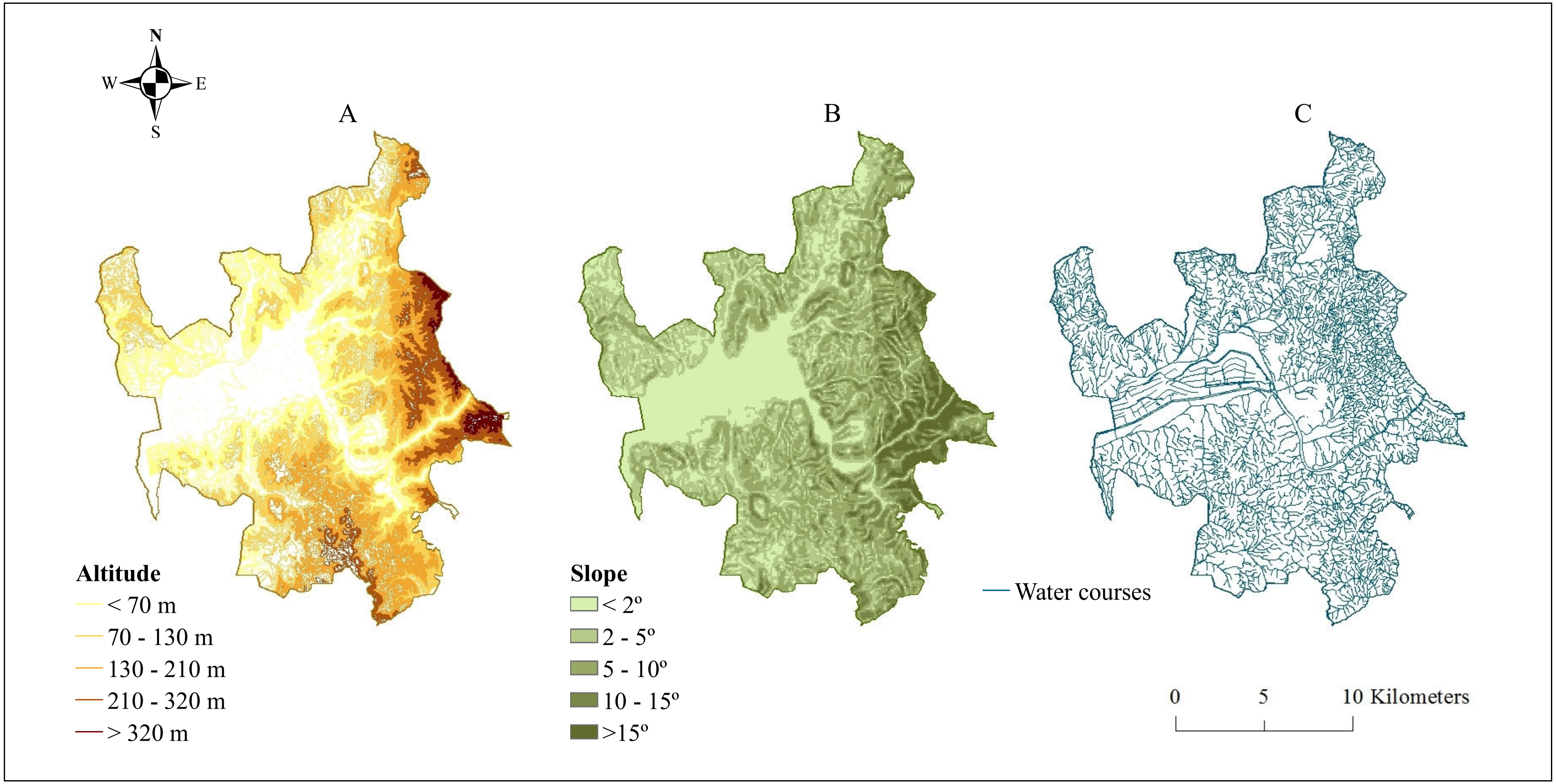


Figure 2.1 - The hypsometric (A), slope (B), and hydrological (C) maps of the study area.

2.3.2. Land use data

The Portuguese Official Administrative Cartography of 2010 (CAOP, 2010), a shapefile version with a classification of polygons at the scale of 1:25 000 with administrative boundaries (municipality and parish boundaries) developed by the Portuguese Geographic Institute (IGP) was used to identify the extent of the municipality of Coimbra.

The analysis of spatial and temporal land use changes in the study area during a 20-year period (1990-2010) was conducted for three different years (1990, 1999, and 2010) based on the interpretation of an existing land use map (COS90) and digital aerial photographs. The COS90 is a detailed land use map of Portugal for the year 1990, produced in the shapefile version with a classification of polygons at a scale of 1:25 000 and developed by IGP (1990). The 1999 and 2010 aerial photographs were ceded by IGP at a scale of 1:15 000 and 1:10 000, respectively, in a raster format. The 2010 aerial photographs were previously georeferenced by IGP which helped georreferencing the 1999 aerial photographs. The land use maps for the years 1999 and 2010 were derived from visual interpretation of these two sets of aerial photographs. The adopted nomenclature was consistent with that of the Corine Land Cover classes which is a reference product in land use/cover in Europe. Therefore, the land use categories of all maps were adapted from Caetano *et al.* (2009) and grouped into eight aggregated categories considered adequate for the purposes of this study: built-up land, construction site, cropland, forest, leisure area, inland waters, inland wetlands, and unused land (Table 2.1). To minimize errors, the same person carried out the interpretation and mapping of land use.

2.3.3. Driving factors of land use change

In order to assess the main driving factors of land use change, 13 variables (Table 2.2) reflecting physical characteristics and human activities where two physical factors (altitude and slope) and ten human factors (demographic and socio-economic conditions) were selected. The fire, an important disturbance factor of landscape patterns in the municipality of Coimbra, was also chosen (Table 2.2).

Table 2.1 - Land use categories used in this study.

Land use	Description
Built-up land	Land used for urban and rural settlements, industrial and commercial units, road and rail networks, aerodrome, quarries, mining and dumping
Construction site	Abandoned areas in artificialized territories, areas under/for construction and included in the Municipal Master Plan of Coimbra
Cropland	Areas currently under crop (annual or permanent), orchards and fallow, dry farming land, land under irrigation, cultivated land or land being prepared for raising crop, pastures areas
Forest	All wooded areas, natural or planted forests, riverine vegetation, shrubs and bushes, sclerophyllous vegetation, transitional woodland-shrub
Inland waters	Natural water courses, artificial canals
Inland wetlands	Inland marshes
Leisure area	Gardens, parks, sport and leisure facilities, cemeteries
Unused land	Open spaces with little or no vegetation, bare soils, burnt areas

Table 2.2 - List of the selected 13 driving factors.

Driving factors	Description
Physical	Altitude
	Slope
Disturbance	Fire
Demographic	Population density (persons/km^2)
	Ageing index (% of persons >65 year-olds/persons <14 year-olds)
	Working-age population (% of population >15 year-olds)
	Number of families/km^2
	Household composition (number of persons per family)
Socio-economic	Illiteracy rate (%)
	Population with higher education degree (%)
	Unemployment rate (%)
	Number of buildings/km^2
	New buildings (percentage of buildings constructed in the last 10 years)

The hypsometric map and slope data were obtained from a digital topographic and cartographic information system provided by the Army Geographic Institute, series M888, on a scale of 1:25 000 (IGeoE, 2002). The hypsometric map was used to classify the altitude into 5 levels (Figure 2.1-A) considered adequate for the characterization of this study area: <70 m, 70-130 m, 130-210 m, 210-320 m, and >320 m. The slope map (Figure 2.1-B) was classified into five categories: <2º, 2-5º, 5-10º, 10-15º, and >15º according to the critical gradients for land use and land cover soil (adapted from

Cox, 1981). The hydrological map (Figure 2.1-C) was obtained from the former ARH-Centro (now included in the Environment Portuguese Agency - APA).

The burnt area maps (Figure 2.2) for the period of 1990-2009 were obtained from the National Forest Authority (ICNF, 2013b). The demographic and socio-economic data (Table 2.2) for the years 1991, 2001, and 2011 were acquired from the National Institute of Statistics (INE, 2011) and used to evaluate their potential role as driving factors of land use change. These three years comprise de national census data and serve as proxy for the years used to evaluate land use evolution in this study.

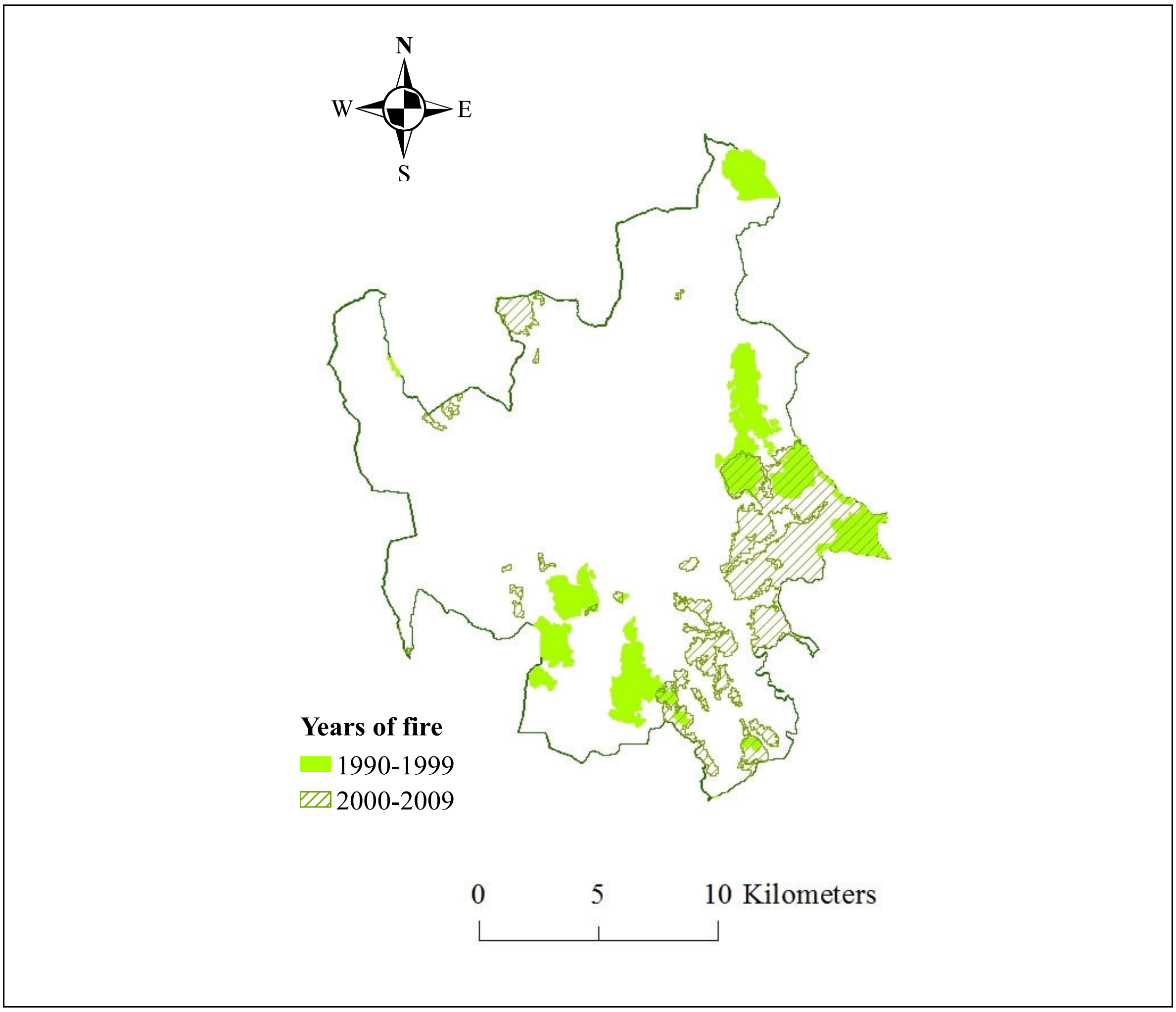


Figure 2.2 - The burnt area maps for the period of 1990-2009 in the municipality of Coimbra.

2.3.4. Land use and internal conversions analysis

To evaluate temporal land use and trajectories' trends, two periods of analysis were considered: first period (1990-1999) and second period (1999-2010) providing information on land use change for these two decades in the municipality of Coimbra. The land change was assessed by overlaying the land use maps of 1990 with 1999 and 1999 with 2010. Then, the magnitude and direction of land use were determined based on the transition matrix.

Internal conversions between the eight land use categories that took place between the two compared periods were determined through the analysis of the area (in hectares) gain or lost by each land use category in relation to the total loss or gain of the other land use categories.

All maps were projected to the same national coordinate system (PT-TM06/ETRS89) using ArcGIS® version 10.2 (ESRI, Redlands, CA, USA).

2.3.5. Driving factors' analysis

To relate land use change with physical factors of the landscape, land use maps of each year (1990, 1999, and 2010) were overlaid with the altitude and slope maps and the percentage of each land use category included in each physical class was then calculated.

For exploring the impact of fire events on land change that took place during the two periods (1990-1999 and 1999-2010), land use maps and the maps with the areas affected by fire were also overlaid. This way, the magnitude and impact of fire on land use change were determined based on the transition matrix.

To explore the correlations between land use change and demographic and socio-economic variables, bivariate statistical analyses were performed using SPSS® version 21 for Windows (SPSS Inc., IL, USA). All the data were checked for normality and homogeneity of variance and transformed if necessary to meet parametric requirements (Zar, 1996). The Pearson correlations analysis was performed to check the linear relationships among these variables.

2.4. Results

2.4.1. Land use change

The cartographic results for 1990, 1999, and 2010 are presented in Figure 2.3 and the transition matrices (Table 2.3 and Table 2.4) highlight the dominant dynamic events during the study period. While in 1990 and 1999 the cropland was the dominant land use category occupying 13 192.5 ha and 14 746.7 ha, respectively, the forest was the land use category prevailing in 2010 occupying 12 689.6 ha (Table 2.3 and Table 2.4). As a result, the cropland and forest were the two largest land use categories in this region accounting jointly more than 70% of the total area in the three studied dates.

The next two dominant land use categories were the built-up land and unused land occupying both 5 913.8 ha, 6 065.4 ha, and 6 732.3 ha in 1990, 1999, and 2010, respectively (Table 2.3 and Table 2.4).

In all studied dates the forest areas were mainly located east, southwest, and around the limits of the municipality (Figure 2.3) coincident with the steeper and hilly areas (Figure 2.1-B). On the other hand, the cropland areas were mostly situated northwest along the Mondego river (Figure 2.3) as well as in flatter areas - the called farm fields of the Mondego river (Figure 2.1-B).

In 1990 the built-up and unused land were mostly located in the centre and northeast of the municipality, respectively (Figure 2.3). Relatively to 1999 and 2010, the built-up land was mainly sited in the centre, northeast, and southwest of the municipality. In both dates, the unused land was predominantly located south of the municipality (Figure 2.3). The built-up land expansion occurred principally close to existent infrastructures (roads, buildings, and leisure facilities) but also close to water courses (Figure 2.3).

The land use has changed greatly over the period from 1990 to 2010 in the municipality of Coimbra (Figure 2.4). Furthermore, the transition matrices (Table 2.3 and Table 2.4) showed general trends of land use dynamics for the same period, and revealed two distinct phases.

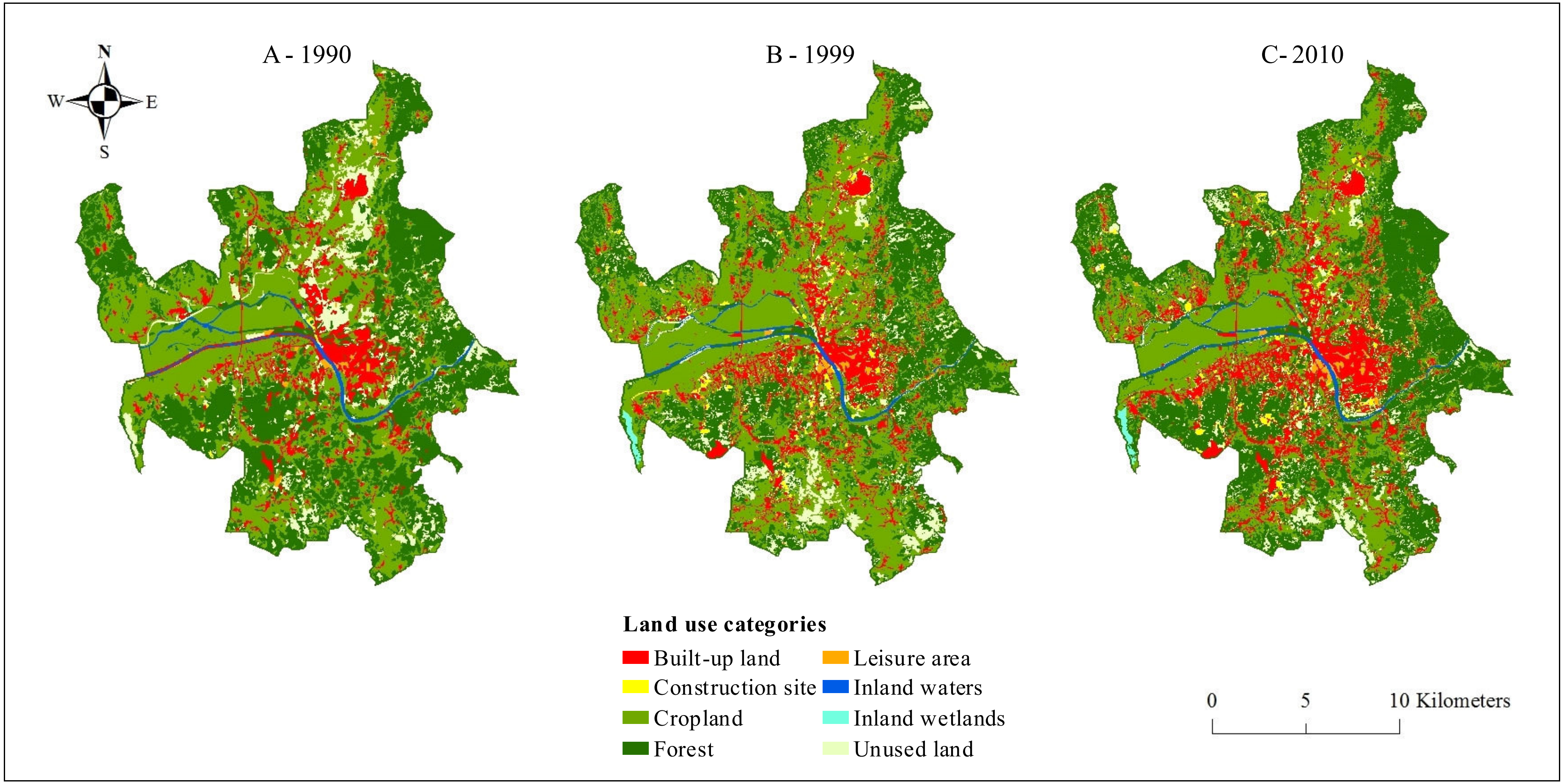


Figure 2.3 - Land use in the municipality of Coimbra in 1990 (A), 1999 (B), and 2010 (C).

Table 2.3 - The conversion matrix of land use change from 1990 to 1999 (unit: hectare) in the municipality of Coimbra.

Land use in 1990	Land use in 1999								
	BL	CS	CL	F	IW	IWL	LA	UL	Total
BL	**2 240.2**	157.7	453.3	108.2	36.1	0.1	31.5	58.5	3 085.4
CS	9.5	**12.0**	6.2	2.4	2.4	0.0	0.0	5.1	37.8
CL	1 156.5	260.6	**10 614.6**	929.3	28.4	26.7	16.7	159.7	13 192.5
F	220.9	128.6	2 423.3	**8 010.1**	47.2	2.3	5.1	1 421.4	12 258.7
IW	1.7	1.7	42.1	52.7	**253.2**	0.0	4.5	30.5	386.4
IWL	0.0	1.0	2.3	0.4	0.0	**0.0**	0.0	0.0	3.8
LA	38.7	5.8	16.7	16.4	4.0	0.0	**63.2**	2.1	146.9
UL	222.7	167.2	1 188.2	663.0	9.5	68.0	11.9	**497.9**	2 828.4
Total	3 890.2	734.6	14 746.7	9 782.6	380.8	97.1	132.9	2 175.2	
Change	+804.8	+696.8	+1 554.2	-2 476.2	-5.6	+93.3	-14.0	-653.3	

BL - Built-up land, CS - Construction site, CL - Cropland, Forest - F, IW - Inland waters, IWL - Inland wetlands, LA - Leisure area, UL - Unused land. The unchanged area of each land use category was marked in bold. The rows and columns contain data of 1990 and 1999, respectively.

Table 2.4 - The conversion matrix of land use change from 1999 to 2010 (unit: hectare) in the municipality of Coimbra.

Land use in 1999	Land use in 2010								
	BL	CS	CL	F	IW	IWL	LA	UL	Total
BL	**3 846.8**	21.0	9.0	3.6	0.0	0.0	4.8	5.1	3 890.2
CS	330.1	**258.5**	28.7	43.2	0.0	0.0	28.0	46.2	734.6
CL	618.5	320.1	**10 628.2**	2 715.0	2.4	8.9	24.5	429.1	14 746.7
F	106.9	153.5	354.6	**8 530.2**	7.5	0.4	1.3	628.3	9 782.6
IW	0.1	0.1	2.7	17.1	**359.3**	0.0	0.2	1.2	380.8
IWL	0.0	0.0	0.1	8.5	0.0	**88.4**	0.0	0.0	97.1
LA	0.0	0.0	0.0	0.2	1.0	0.0	**131.7**	0.0	132.9
UL	47.8	52.2	21.4	1 371.8	1.8	0.0	7.9	**672.3**	2 175.2
Total	4 950.2	805.3	11 044.7	12 689.6	372.0	97.8	198.3	1 782.1	
Change	+1 059.9	+70.7	-3 702.0	+2 907.0	-8.7	+0.7	+65.4	-393.1	

BL - Built-up land, CS - Construction site, CL - Cropland, Forest - F, IW - Inland waters, IWL - Inland wetlands, LA - Leisure area, UL - Unused land. The unchanged area of each land use category was marked in bold. The rows and columns contain data of 1999 and 2010, respectively.

During the first period (1990-1999) the cropland increased by 11.8%, principally towards the south while forest areas decreased by 20.2% (Table 2.3 and Figure 2.3). During the second period (1999-2010) the cropland continued to decrease (25.1%) but in contrast, the forest increased by 29.7%, mostly towards the east and southwest (Table 2.4

and Figure 2.3). The inland waters and unused land decreased during the two study periods. An opposite pattern was observed for the built-up land, construction site, and inland wetlands that increased in the same periods (Table 2.3, Table 2.4, and Figure 2.4). The built-up land and construction site expanded to northeast and southwest areas of the municipality. The inland wetlands increased its area on the southwest side (Figure 2.3).

From 1990 to 2010 the built-up land was the land use category with more expansion, increasing 1 864.7 ha. In contrast, the cropland and unused land were the land use categories that lost more area in the same period, decreasing in 2 147.8 ha and 1 046.3 ha, respectively (Table 2.3, Table 2.4 and Figure 2.4).

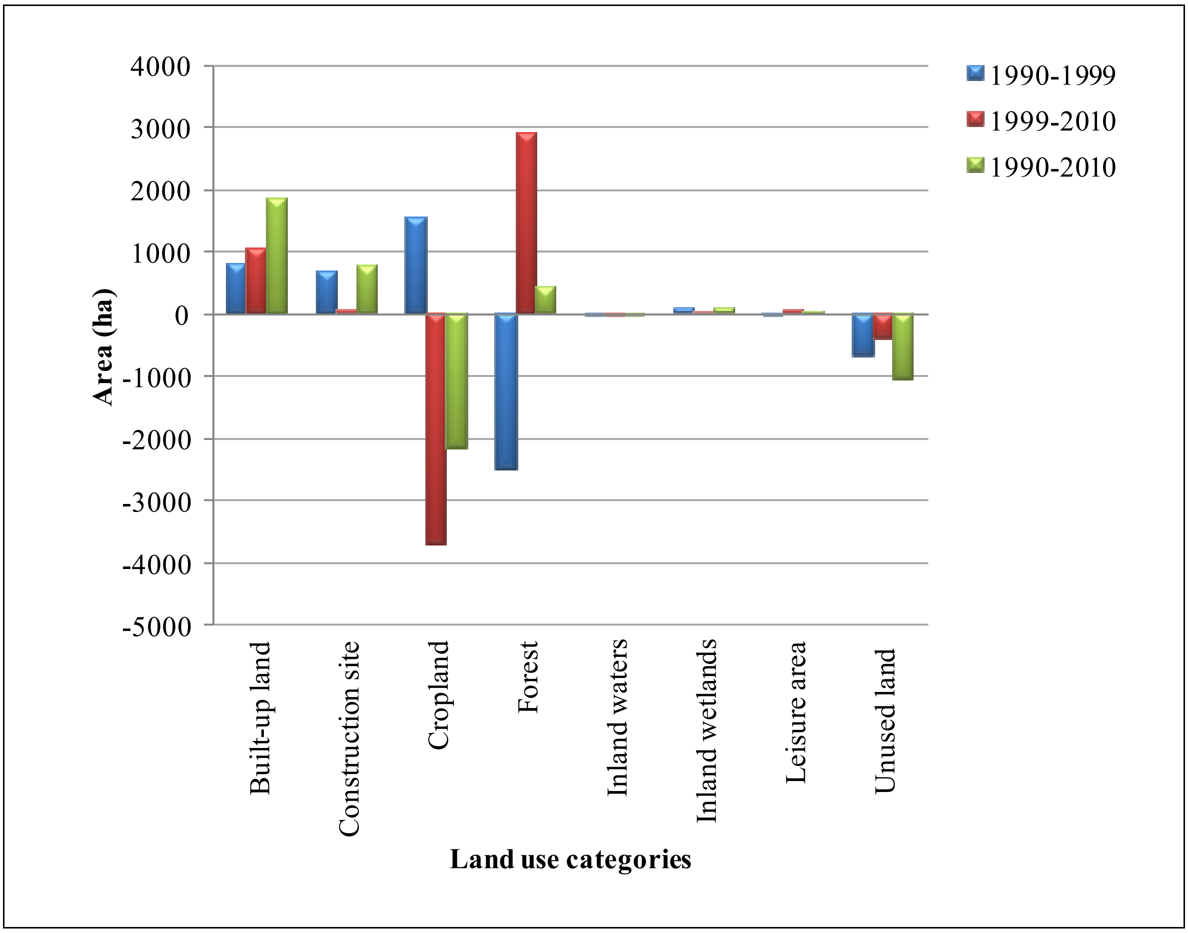


Figure 2.4 - Periodic change of each land use category that took place from 1990 to 2010 in the municipality of Coimbra.

Almost one third of the municipality of Coimbra territory suffered land use change from 1990 to 1999, decreasing to 23.2% from 1999 to 2010 (Figure 2.5). Although changes have occurred throughout the municipality, during the first period this change was most prominent northeast, centre, and southwest of the municipality, and during the second period this change occurred mostly southwest of the studied territory (Figure 2.5).

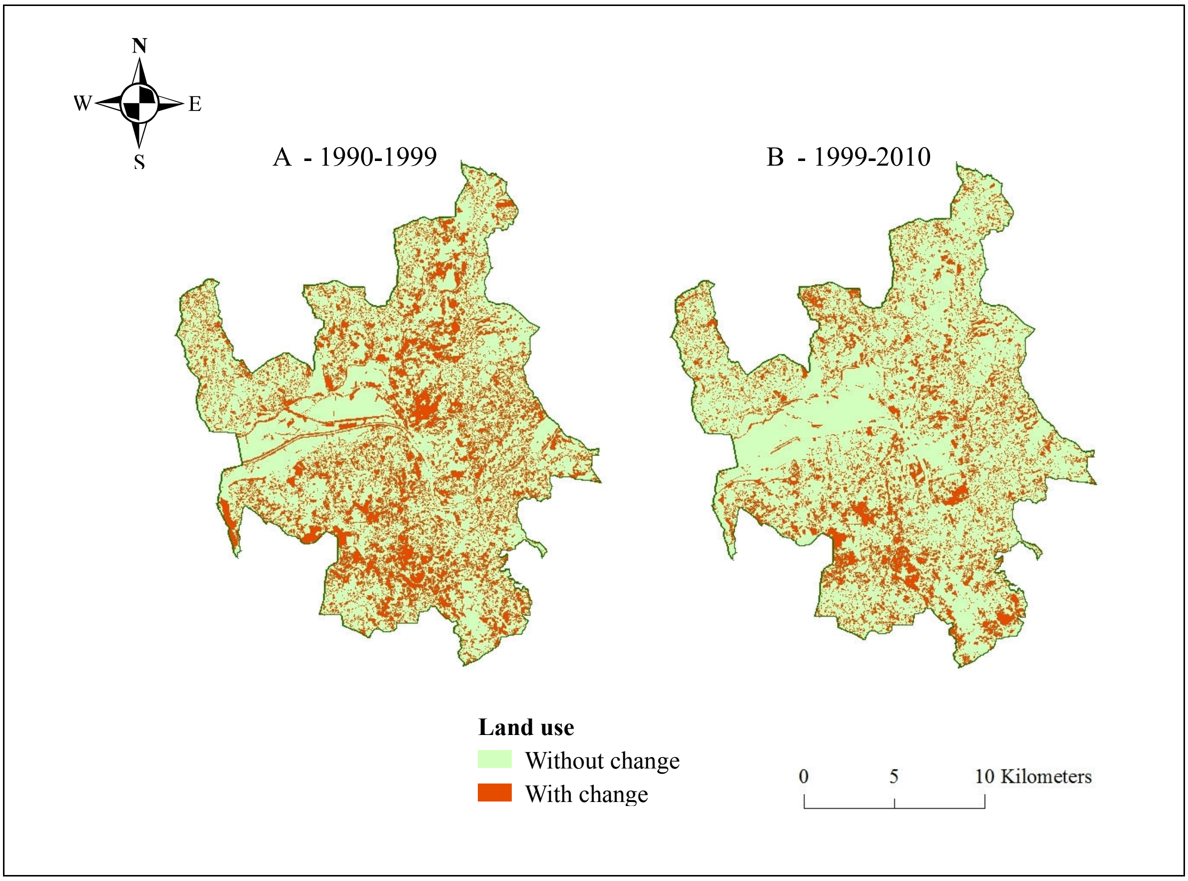


Figure 2.5 - Spatial distribution of land use without/with change in the municipality of Coimbra from 1990 to 1999 (A) and from 1999 to 2010 (B).

2.4.2. Internal conversions

The results regarding the internal conversions between land use categories that have occurred in each temporal analysis may also be detected on Figure 2.6. During the first period (Figure 2.6-A and Table 2.3) the increase of built-up land and construction sites occurred mainly at the expense of cropland which contributed with 703.2 ha and 254.4 ha, respectively. The increase of cropland area was achieved through the conversion of 1 494.0 ha of forest and 1 028.5 ha of unused land (Figure 2.6-A and Table 2.3).

Over the second period (Figure 2.6-B and Table 2.4), and similarly to the period before, occurred an expansion on built-up land and construction site, predominantly resulting from the conversion of cropland areas, both totalizing an expansion of 900.9 ha. The patterns found for the internal conversions of cropland and forest areas differed from that of the previous decade (Figure 2.6-B). During this time the increase of forest area was mainly due to the change of cropland (2 360.4 ha) and unused land (743.5 ha) (Figure 2.6-B and Table 2.4).

Clearly, the land use change from 1990 to 2010 was characterized by an obvious replacement of cropland by built-up land and construction site showing a considerable increase in both periods (Figure 2.6).

2.4.3. Driving factors and land use change

2.4.3.1. Physical and disturbance driving factors

More than half of the municipality of Coimbra comprises altitudes of less than 130 m and only 3.2% of the territory occurs at altitudes of more than 320 m (Figure 2.1-A). Furthermore, more than half of the municipality has slopes of less than 5° and higher reliefs (slopes with more than 15º) can only be are find in 4.3% of the total area, mainly in the east portion of the municipality (Figure 2.1-B).

The percentages of each land use category distributed per each altitude and slope classes from 1990 to 2010 are indicated in Figure 2.7. Whereas at lower altitudes ranges (<70 m) all land use categories were found, at high altitudes (>320 m) only four land use categories were observed (Figure 2.7-A). The forest was the land use category more abundant in all altitude ranges, except in areas lower than 70 m where cropland was the dominant category. At higher altitudes (>320 m) more than 75% of the area was covered by forest, but a considerable proportion of cropland could also be encountered (Figure 2.7-A).

Similarly, all land use categories were found in the flatter regions. The cropland was the land use category dominant in slopes lower than 5º, whilst in higher slopes (>5º) the forest covered more than 70% of the area. In steeper areas (10-15° and even above 15°) cropland and built-up land were also present (Figure 2.7-B).

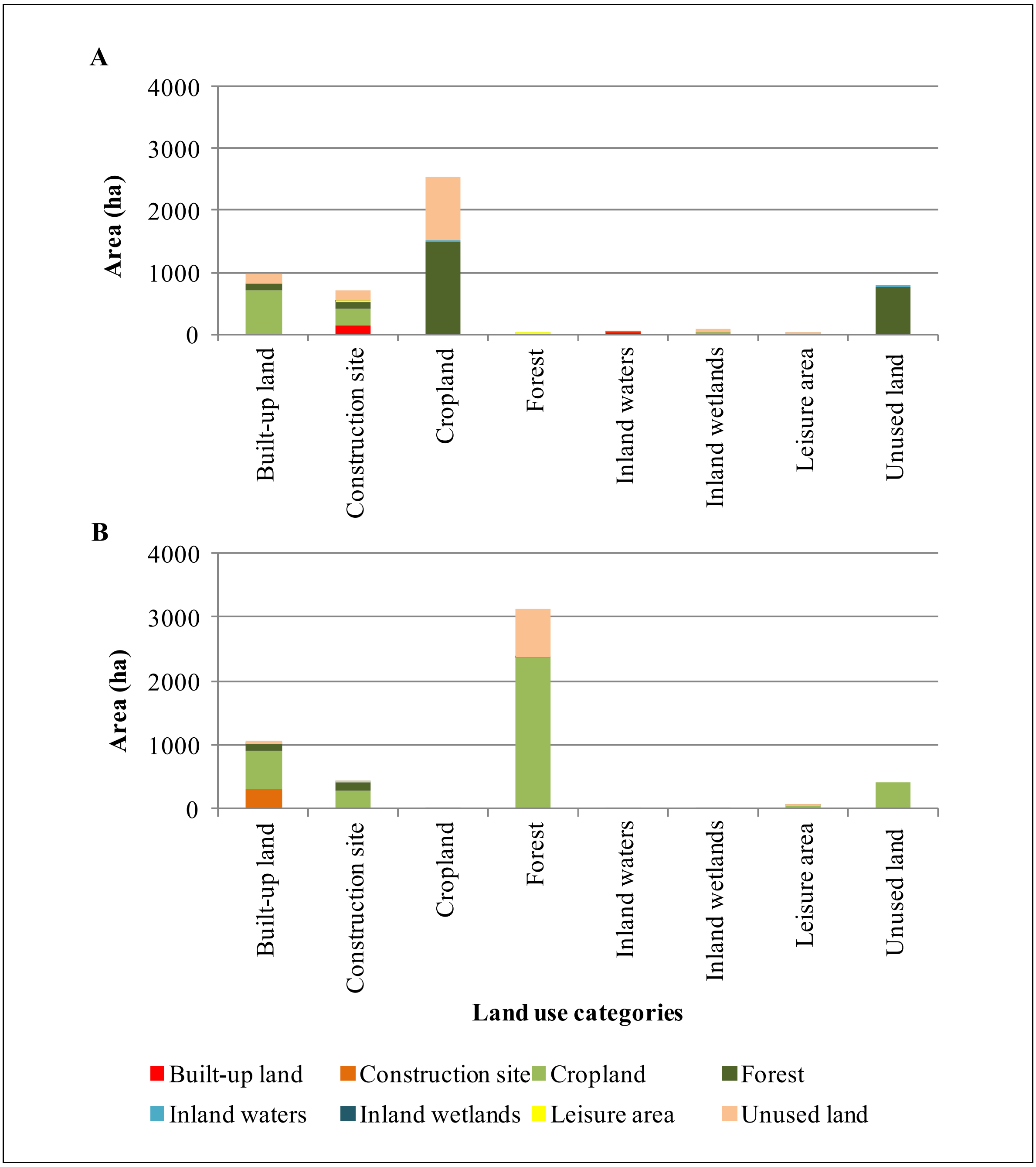


Figure 2.6 - Internal conversions between land use categories from 1990 to 1999 (A) and from 1999 to 2010 (B) in the municipality of Coimbra.

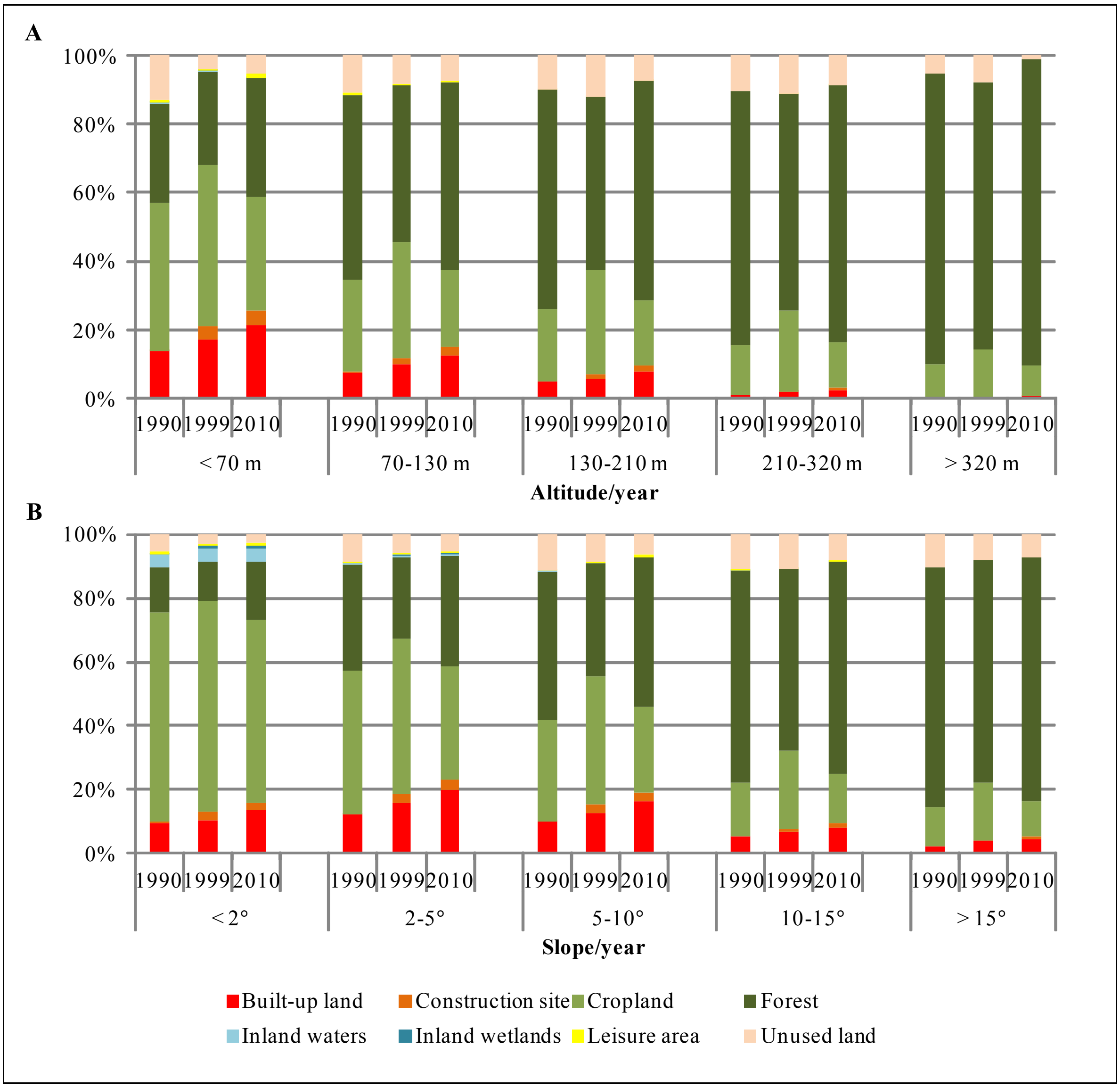


Figure 2.7 - Percentage of each land use category in different altitude (A) and slope (B) ranges from 1990 to 2010.

The occurrence of several fire events that reached or occurred within Coimbra also are constrain the use of the land and thus must be considered an important driving factor of land use change in this region (Figure 2.2). Between 1990 and 2009 fires affected about 22% of the total land area, mostly forest and cropland areas (Table 2.5 and Table 2.6).

Between 1990 and 1999 five fires occurred (1990, 1991, 1992, 1995, and 1996) affecting 9.1% of the total land area (Figure 2.8-A), where 781.5 ha was forest land (Table 2.5). Of these, the fire event in 1995 stands out since it affected 7.1% of municipality (Figure 2.8-A). This was clearly reflected in the observed land use changes with the increase of cropland (387.0 ha) and unused land (381.6 ha) at the expense of forest (Figure 2.8-A and Table 2.5).

Table 2.5 - The conversion matrix of land use change within the areas affected by fire from 1990 to 1999 (unit: hectare) in the municipality of Coimbra.

Land use in 1990	Land use in 1999								
	BL	**CS**	**CL**	**F**	**IW**	**IWL**	**LA**	**UL**	**Total**
BL	**12.7**	0.2	2.0	0.9				0.1	15.9
CS									0.0
CL	9.8	1.1	**204.9**	43.9				12.8	272.5
F	7.9	6.0	430.9	**1 328.3**				503.6	2 276.7
IW									
IWL									
LA		0.2	0.2						0.4
UL	0.8	0.4	88.8	122.1				**139.8**	351.8
Total	31.1	7.9	726.8	1 495.2	0.0	656.3	31.1	7.9	2 917.3
Change	15.2	7.9	454.3	-781.5	-0.4	304.5	15.2	7.9	

BL - Built-up land, CS - Construction site, CL - Cropland, Forest - F, IW - Inland waters, IWL - Inland wetlands, LA - Leisure area, UL - Unused land. The unchanged area of each land use category was marked in bold. The rows and columns contain data of 1990 and 1999, respectively.

Table 2.6 - The conversion matrix of land use change within the areas affected by fire from 1999 to 2010 (unit: hectare) in the municipality of Coimbra.

Land use in 1999	Land use in 2010								
	BL	**CS**	**CL**	**F**	**IW**	**IWL**	**LA**	**UL**	**Total**
BL	**88.1**	0.1	0.5	0.1				0.1	88.8
CS	2.9	**4.9**	0.8	2.2				0.8	11.6
CL	13.4	8.3	**545.3**	320.1	0.4			119.5	1 007.0
F	6.3	13.7	66.2	**2 102.3**	1.6		0.2	244.6	2 434.8
IW			1.0	3.0	**7.0**			0.2	11.2
IWL						**1.6**			1.6
LA							**0.3**		0.3
UL	0.9	2.6	0.4	288.1	0.6			**160.3**	452.9
Total	111.5	29.5	614.2	2 715.8	9.6	1.6	0.5	525.5	4 008.2
Change	22.7	17.9	-392.8	281.0	-1.6	0.0	0.2	72.6	

BL - Built-up land, CS - Construction site, CL - Cropland, Forest - F, IW - Inland waters, IWL - Inland wetlands, LA - Leisure area, UL - Unused land. The unchanged area of each land use category was marked in bold. The rows and columns contain data of 1999 and 2010, respectively.

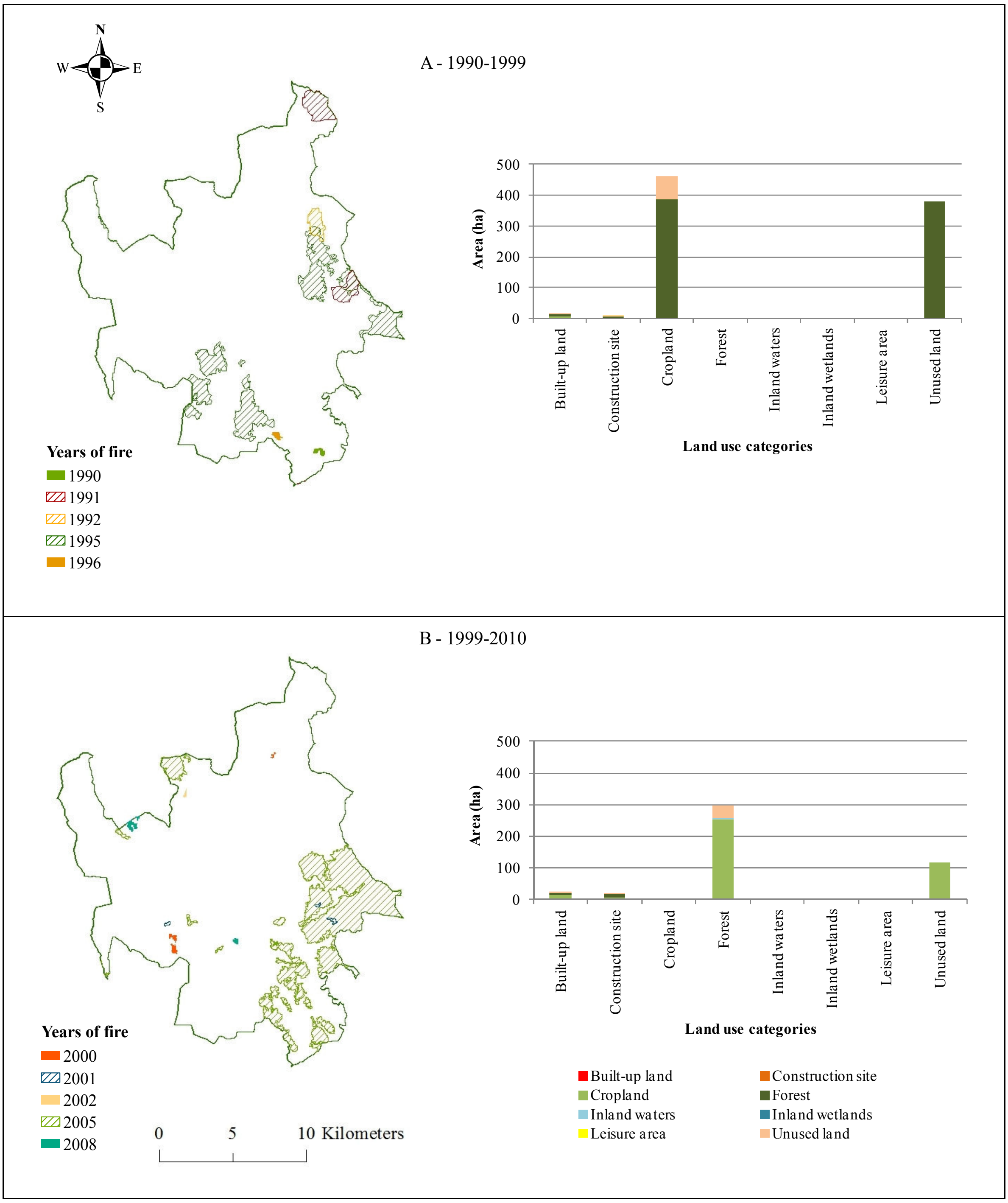


Figure 2.8 - Burned area (left) and internal conversions (right) between land use categories from 1990 to 1999 (A) and from 1999 to 2010 (B).

Between 2000 and 2009 five fires also occurred (2000, 2001, 2002, 2005, and 2008) consuming 12.5% of the total land area (Figure 2.8-B), where the cropland area loss reached the 392.8 ha (Table 2.6). The area affected by fire in 2005 was the largest in this period (Figure 2.8-B), reaching 12.2% of the total area. The consequences of these fires were clearly reflected in the observed land use changes with the increase of forest area (253.9 ha) and unused land (119.1 ha) at the expense of cropland (Figure 2.8-B and Table 2.6).

2.4.3.2. Demographic driving factors

The changes in land use that have occurred over the period from 1990 to 2010 showed interesting correlations with the Coimbra's demographic factors (Table 2.7). Urbanized area increased from 1990 to 2010 as evidenced by the fast increase in the total built-up land values (Table 2.3 and Table 2.4). It seemed that population growth and consequent urbanization in Coimbra were very significant factors of land use change. A strong positive correlation was found between the expansion of built-up land and population growth (Table 2.7). Furthermore, the increase in population density probably caused great losses of cropland and forest areas that have been transformed in urban settlements and infrastructures required for human activities. The population density factor also showed a positive correlation with inland waters and leisure area, but a negative correlation with cropland, forest, and unused land was obtained (Table 2.7).

Land use changes were also somehow related to age and family structure of Coimbra population (Table 2.7). Relatively to the age structure, the results showed that the ageing index was positively correlated with built-up land and inland waters. By contrast, it was negatively correlated with cropland and unused land. Another interesting result corresponded to the positive correlation found between the number of families with built-up land, inland waters, and leisure area. An opposite pattern in the correlation was observed with cropland, forest, and unused land. Also, there was a negative correlation between the household composition and built-up land, construction site, inland waters, and leisure area. On the other hand, the household composition showed a positive correlation with cropland, forest, and unused land (Table 2.7) which means that bigger families live in the periurban areas.

Table 2.7 - Correlation coefficients among land use categories and demographic variables.

	BL	CS	CL	F	IW	IWL	LA	UL	PD	AI	WP	NF
BL												
CS	0.31**											
CL	-0.43**	0.02										
F	-0.63**	-0.14	-0.22*									
IW	0.52**	-0.12	-0.40**	-0.44**								
IWL	-0.13	-0.10	0.004	-0.04	-0.07							
LA	0.43**	0.001	-0.39**	-0.35**	0.38**	0.09						
UL	-0.31**	0.08	-0.07	0.36**	-0.28**	-0.28**	-0.18					
PD	0.73**	-0.02	-0.58**	-0.49**	0.62**	-0.06	0.43**	-027**				
AI	0.42**	0.15	-0.48**	-0.11	0.46**	0.12	0.09	-0.28**	0.36**			
WP	0.16	0.49**	0.16	-0.04	-0.32**	-0.04	-0.05	0.01	-0.06	-021*		
NF	0.73**	-0.02	-0.60**	-0.49**	0.64**	-0.06	0.42**	-0.28**	1.00**	0.40**	-0.08	
HC	-0.66**	-034**	0.59**	0.24*	-0.46**	-0.07	-0.29**	0.25*	-0.55**	-0.80**	-0.09	-0.58**

BL - Built-up land/km^2, CS - Construction site/km^2, CL - Cropland/km^2, F - Forest/km^2, IW - Inland waters/km^2, IWL - Inland wetlands/km^2, LA - Leisure area/km^2, UL - Unused land/km^2, PD - Population density, AI - Ageing index, WP - Working-age population, NF - Number of families, HC - Household composition.

* Significant correlation at $p \leq 0.05$

** Significant correlation at $p \leq 0.01$.

2.4.3.3. Socio-economic driving factors

The socio-economic conditions of the population also exhibited high correlation values with land use change from 1990 to 2010 (Table 2.8). These results showed that land use patterns were significantly correlated with the school degree of the population. The built-up land was positively correlated with the increase of population with higher school degrees (Table 2.8). The population with higher school degrees also showed a positive correlation with construction site and leisure area, and a negative correlation with cropland (Table 2.8). Opposite results were found for the variable illiteracy rate.

The economic structure is an important factor influencing land use (Table 2.8). This can be showed by the positive correlation of the unemployment rate with built-up land and inland waters. By contrast, there was a negative correlation between unemployment rate and cropland. On the other hand, the unemployment rate was significantly correlated with the school degree of the Coimbra population. This is shown by the positive correlation between unemployment rate and population with higher education degree and by the negative correlation between unemployment rate and illiteracy rate (Table 2.8).

The expansion of built-up land is largely a result of buildings' construction which can be illustrated by the strong positive correlation between built-up land and the number of buildings (Table 2.8). Also, there was a positive correlation between the number of buildings and inland waters and leisure area. In contrast, the number of buildings was negatively correlated with cropland, forest, and unused land. The recent built-up land expansion can be illustrated by the number of buildings constructed in the last 10 years. The results showed that recent buildings were negatively correlated with built-up land, inland waters, and leisure area. A positive correlation between recent buildings and cropland, forest, and unused land was found (Table 2.8).

Table 2.8 - Correlation coefficients among socio-economic variables and land use categories.

	BL	**CS**	**CL**	**F**	**IW**	**IWL**	**LA**	**UL**	**IR**	**PHSD**	**UR**	**NB**
IR	-0.55**	-0.39**	0.36**	0.10	0.004	0.19	-0.25*	-0.03				
PHSD	0.65**	0.49**	-0.41**	-0.18	0.13	-0.03	0.24*	-0.17	-0.81**			
UR	0.49**	0.17	-039**	-0.16	0.47**	-0.11	0.14	-0.19	-0.37**	0.48**		
NB	0.69**	-0.09	-0.57**	-0.48**	0.81**	-0.05	0.37**	-0.30**	-0.14	0.25*	0.42**	
RB	-0.58**	-0.13	0.48**	0.29**	-0.54**	0.02	-0.40**	0.27**	0.28**	-0.49**	-0.47**	-0.53**

BL - Built-up land/km^2, CS - Construction site/km^2, CL - Cropland/km^2, F - Forest/km^2, IW - Inland waters/km^2, IWL - Inland wetlands/km^2, LA - Leisure area/km^2, UL - Unused land/km^2, IR - Illiteracy rate, PED - Population with higher school degree, UR - Unemployment rate, NB - Number of buildings, RB - Recent buildings.

* Significant correlation at $p \leq 0.05$
** Significant correlation at $p \leq 0.01$.

2.5. Discussion

The land use dynamics in the municipality of Coimbra during the two decades (1990-2010) underline the interconnecting effects of physical, disturbance, demographic, and socio-economic driver factors on the land use change (Figure 2.3 and Figure 2.5). Major changes have occurred in forest and cropland areas albeit involving opposite trends between the two study periods (Table 2.3 and Table 2.4). The cropland increased during the first period (1990-1999) 1 554.2 ha, of which 1 494.0 ha were gained from forest areas (Table 2.3 and Figure 2.6-A) probably as a response to the European Union policies and market incentives. These changes possibly were also strongly driven by institutional and political factors given that the government land management strategies tend to influence the decisions of individual farmers on how natural resource are used (Wu *et al.*, 2008). Since entering the European Union in 1986, agricultural practices in Portugal have been increasingly determined by subsidies and regulations associated to the Common Agricultural Policy (Diogo and Koomen, 2010).

The forest loss of 2 476.2 ha (Table 2.3 and Figure 2.6-A) during the first period was probably due to cutting practices, abandonment which overtime resulted in unused land, but also due to various catastrophic situations (*e.g.*, fire, strong winds, disease) frequently observed in Coimbra as well as in Portugal (Feranec *et al.*, 2010; Tavares *et al*., 2010; ICNF, 2013a). An opposite evolution pattern was observed during the second period (1999-2010) where forest increased 2 907.0 ha mainly at the expense of cropland areas (Table 2.4 and Figure 2.6-B). This can be in part the result of the forestation policy implemented by the Rural Development Programme - Forestation of Agricultural Land. This was a forestation programme especially focused on marginal and abandoned agricultural land that proposed to contribute to the rehabilitation of degraded areas and to the mitigation of the effects of desertification by favouring soil fertility recovery and ultimately for the diversification of farming activity (European Commission, 2014).

This study also demonstrated a strong impact of the physical parameters (altitude and slope) on land use changes (Figure 2.7). The land use categories classified as built-up land, construction site, cropland, inland waters, and leisure area mainly occupied lower altitude and flatter areas. By contrast, the forest area showed an increasing with the altitude

(Figure 2.7-A) and also occurred in steeper slopes (Figure 2.7-B). This seems to indicate that population pressure caused the expansion of the areas needed for human activities in areas with low altitudes and forced forests to be located in higher altitude ranges where the human intervention was small and where built-up land and cropland areas are less feasible to take place. This clear pressure to expand built up land and other soil uses related to human activities to other less suitable areas was demonstrated by the increase (almost double) from 1990 to 2010 of this land use category in steeper slopes (above 15°) (Figure 2.7-B). Coimbra is, historically, a municipality with geomorphological hazardous events and this dynamic of built-up growth in areas with higher slopes may have contributed to these dangerous events, mainly the landslides occurred in 2006 (Tavares *et al*., 2010). The influence of slope in building construction and the choice of areas for agriculture or forest practices were also demonstrated by Diogo and Koomen (2010) and Carmo *et al*. (2011) where steeper areas are more suitable for forestry activity and less suitable for housing construction and agricultural practices. Urbanization was also related to the existence of accessibilities and the cropland areas were located close to urban centres (Diogo and Koomen, 2010).

The observed pattern of forest distribution and expansion (<70 m and >320 m; <2º and >15º) (Figure 2.7) may be a consequence of forestation (plantations) due to the action of forest owners, who have continued to invest in the forest with shares forestation and reforestation (Feranec *et al*., 2010; ICNF, 2013a). Another possible cause may be related with the occurrence of natural processes in the unused land such as the natural succession where the pioneer vegetation developed over time into forest vegetation, demonstrating the natural fitness of Portuguese soil to the forest (ICNF, 2013a). The lands are inherently dynamic and they can change even without being subject to extrinsic driving factors. The most obvious example of inherent dynamics is the natural succession (Bürgi, 2004).

Fire events also contributed to the dynamics of land use change in this studied area during these two decades (Figure 2.8, Table 2.5 and Table 2.6) where patterns in land use shifted after fire occurrence. As showed in Figure 2.1-B and Figure 2.2 the fires occurred, principally in steeper slopes where were relatively inaccessible and received limited management. Carmo *et al.* (2011) confirmed the importance of slope in determining fire selectivity, not only because of more fire-prone land uses being associated to steeper slopes, but also because of the physical effect of slope on fire behaviour. Topography directly affects fire behaviour by promoting the radiant energy transfer from the fire line in the direction of the higher slopes (Rothermel, 1983) and indirectly by creating different microclimates which influence the moisture content of fuels, the air temperature as well as the biogeographic distribution of plant species (Heyerdahl *et al.*, 2001; Mermoz *et al.*, 2005). Additionally, in Portugal a set of environmental, socio-economic, and demographic conditions makes this country quite prone to wild land fires (Nunes *et al.*, 2005; Carmo *et al.*, 2011). The climate is a warm temperate climate, mostly Mediterranean, characterized by dry summers. The natural vegetation is typically evergreen, resistant to drought and pyrophytic and generally sited in steeper areas (Nunes *et al.*, 2005). Socio-economic and demographic trends led to agricultural land abandonment and subsequent shrubland encroachment as well as the forestation of former agriculture fields (Carmo *et al.*, 2011; Tomaz *et al.*, 2013). Therefore, the reduction in the consumption of forest fuels by grazing and by harvesting for fuel wood led to the higher accumulation of fuels, and consequently to a higher risk of fire (Moreira *et al.*, 2001, 2009).

Within the burnt area, during the first period (Figure 2.8-A and Table 2.5) some forest land was transformed into cropland and unused land. However, during the second period (Figure 2.8-B and Table 2.6) it was the cropland the land use category that lost most of its area to forest and unused land. Jones *et al.* (2011) demonstrated that disturbance by fire was the most important driving factor of land use change in three municipalities: Mação, Proença-a-Nova, and Vila Velha de Rodão, also localized in the Centre of Portugal. In these three municipalities the magnitude of the fire damage was clearly reflected in the observed land use changes, with the increase of unused land at the expense of forest area (62% of total change in 1990-2000, against 80% in 2000-2006) but where an area transfer from unused land to forest was also found (19% of total change in 1990-2000, against 16% in 2000-2006) (Jones *et al.*, 2011).

The results also showed a strong positive correlation of the built-up land with population density and number of buildings (Table 2.7 and Table 2.8). The fast economic growth possibly brought an increasing of wealthy rural residents who allowed the conversion of much of the cropland for residences and services. Additionally, the opportunities for better jobs, future improvements, and better quality of life in the cities encourages more rural people to leave cropland areas attracting them to the urban environment (Xie *et al.*, 2005). Consequently, the growth of the urban population presses urbanization growth. Along with the economic growth more land is required for infrastructures and residential purposes. The growing demand on land for building construction observed in Coimbra, probably forced the abandonment and degradation of cropland areas which were then converted into this expanding land use category. Ascione *et al.* (2009) recognized the importance of the driving factors in urban growth and development, and expressed concerns about their environmental and social consequences.

The built-up land expansion verified close to existent infrastructures and water courses can be illustrated by the cartographic maps in the Figure 2.3 as well as by the positive correlation of the built-up land with inland waters and leisure area (Table 2.7). The main hydrological marks in the municipality is the Mondego river which flows close to the urban area and along of the alluvial plains where the main activity is the agricultural production (Tavares *et al.*, 2010). The land use change driven by urbanization modifies the hydrological response of watersheds and affects landforms, water quality and habitat, and increases the flood hazard (WMO, 2009). The urbanization expansion also increases the human pressure in the riparian zone often leading to significant modifications of their structure and functioning (Steiger *et al.*, 2005). Furthermore, the increase in artificial surfaces due to urbanization causes an increase in the flooding frequency owing to poor infiltration and reduction of flow resistance (Huong and Pathirana, 2013; Du *et al.*, 2014). In Coimbra, one of the most relevant and frequent hazardous events derive from flooding caused by the Mondego river and its tributaries, and also by difficulties of runoff in areas with anthropogenic disturbance (Tavares *et al*., 2010).

The results also demonstrated that age, family structure, and school degree of the Coimbra population influenced the land use dynamics (Table 2.7 and Table 2.8) revealing that the older population and those with higher school degree lived in the most densely populated urban area. On the other hand, in more urbanized areas the number of families was greater but the number of person per family was lower. This was illustrated in the positive correlation between number of families and built-up land and in the negative correlation between household composition and built-up land. In cropland areas the population was younger, with lower school degree, and existed fewer families, but with a bigger household composition *i.e.*, with more persons per family. This was showed by the negative correlation between cropland and these driving factors, except with the last (household composition) where a positive correlation was established. Cities concentrate the largest proportion of the population with higher education (European Union, 2011). Lack of opportunities among young people in rural areas could be one of the causes of the lower school degree leading people to migrate to other regions or countries (European Commission, 2011c). On the other hand, rural areas tend to gain population through the immigration of young families with children (McGranahan *et al*., 2010). This corresponded with the results of other studies emphasising the role of socio-economic factors on land use change (Kristensen *et al*., 2001; Hietel *et al*., 2007; Wu *et al*., 2013b). Furthermore, the unemployment rate was higher in the areas more urbanized. This was illustrated by the positive correlation between built-up land and unemployment rate and by negative correlation between cropland and unemployment rate (Table 2.8). Although the cities are generators of growth, they are also places where problems such as unemployment and poverty are concentrated. Globalization has led to a loss of jobs, especially in the industrial and commercial sectors, and this has been amplified by the economic crisis (European Union, 2011).

More urbanized areas have also older buildings, contrary to cropland and forest areas where the percentage of buildings constructed in the last 10 years was greater. This was showed by the negative correlation between built-up land and recent buildings and by the positive correlation of cropland and forest areas with recent buildings (Table 2.8). The ageing population and the increase of the unemployment rate verified in the municipality of Coimbra (INE, 2011) probably were responsible for the degradation of buildings recorded in the last years, especially in their urban centre (CMC, 2012). Therefore, it was evident a strong need for the rehabilitation of buildings and for the urban regeneration of the municipality. Nowadays, the younger people tend to build their houses outside of urban centres causing a typical model of urban sprawl expansion (EEA, 2006). Additionally, during the first period 148.2 ha of built-up land was converted in construction site (Table 2.3 and Figure 2.6-A) however, during the second period the built-up land gained 309.1 ha ha at the expense of construction site (Table 2.4 and Figure 2.6-B). Probably, some of the redevelopments were residential and commercial buildings involving the demolition of old houses.

This study demonstrated that land use change resulted from the interconnected effects between the physical, disturbance, demographic, and socio-economic factors as supported by several authors (Hietel *et al.*, 2007; Long *et al.*, 2007; Wu *et al.*, 2008; Jones *et al.*, 2011). Therefore, it is important to know how these factors interact with each other to drive land use changes. Comprehensive knowledge of these dynamics may help to elaborate sustainable management plans aimed at preserving essential land functions in this municipality.

2.6. Conclusions

This study explored the spatial and temporal pattern of land use in the municipality of Coimbra from 1990 to 2010. The results indicated that the study area was mainly dominated by cropland and forest. The analysis also showed that the overall land use change was significant and characterized by continuous built-up land expansion, mostly at the expense of cropland loss. Physical, disturbance, demographic, and socio-economic factors were significantly correlated with this land use change, but in some cases it was difficult to accurately evaluate the contribution of each factor.

The physical factors such as altitude and slope strongly affected the distribution of different land use categories. Although a substantial proportion of built-up land occurred on lands with low altitude and slopes, it was still encountered on the slopes above 15° and even expanded in these less suitable areas for construction. This pattern also contributes to increase risk levels of landslides. On the other hand, the increase of built-up land closer to the water bodies may increase the environmental impacts consequent of flooding events. Fire events are known to be important disturbance factors affecting land use and its change. In this municipality they were responsible for the decrease of a substantial forest area during the first period studied but, in contrast, in the second time period burnt areas supported forest growth probably due to the reforestation and natural succession.

Relatively to the demographic and socio-economic factors the results showed that Coimbra was a municipality where its urban area was populated by older people and by a population with higher school degrees. Although the number of families was higher in the urban area the household composition was smaller. The ageing of the population and buildings can lead to degradation of the urban area. Thus, is important to develop effective management strategies and policies for the rational land use and environmental protection to mitigate the risks and provide a basis for the development of sustainable land use management systems.

Chapter 3

Spatial and temporal dynamics of urban sprawl in Coimbra and its impacts on cropland loss and soil sealing, during a 20-year period (1990-2010)

3.1. Abstract

The urban expansion will be the largest influence on development in the 21st century. The concentration of people in densely populated urban areas, especially in developing countries, will undoubtedly continue to increase as the majority of the world's population will live in urban settlements. This study analysed the spatial and temporal urban expansion in the city of Coimbra during a 20-year period (1990-2010). Coimbra was chosen as the study area due to its drastic changes in land use patterns and demographic dimension at the country scale. The results revealed an urban expansion of 1 142.3 ha during these last two decades corresponding to a mean growth value of 57 ha/year, land that was taken mostly of at expense of cropland areas. This expansion, however, has not been followed by an equally rapid population growth. This physical pattern of low-density expansion in built-up areas contributed to a less compact city evolution, clearly an indicator of urban sprawl. Urban sprawl contributed mostly to the loss of cropland areas and to a concerning increase of soil sealing contributing to increase the probability of natural and human hazards as floods, landslides, heat waves, and fires. Therefore, it is important to design and implement suitable strategies that are able to reduce these harmful impacts. A better understanding of the spatial and temporal dynamics of the city's expansion, provided by this study, may be a helpful input for a better planning and spatial organization of local human activities for future sustainable urban development of Coimbra.

Keywords
urban sprawl; urbanization; city area; cropland loss; soil sealing; GIS

3.2. Introduction

Today, the world population surpasses 7 billion, of which over 53% lives in cities although urban areas occupy a relatively small portion of the earth's surface (roughly 3%) (CIESIN *et al*., 2011; United Nations, 2014). According to an estimate by the United Nations (2014), in 2020 75% of Europe's population will inhabit cities and in Portugal this number will reach that over 66%. In developing countries the lack of job opportunities in rural areas, the decline in subsistence economies, and hope for a better life has resulted in the urban expansion (Torres-Vera *et al.*, 2009). This human population growth and expansion of urban areas inevitably affects the natural environment by diminishing the vital natural resources and increases the conflicts over land use (Van, 2008; Beardsley *et al.*, 2009). A major problem of rapid urban growth and consequent urbanization is the change of land use patterns as urban areas expand into the surrounding croplands, pastures, forests, and other land use areas (Henderson and Xia, 1997; Naab *et al.*, 2013). The land use change represents the most significant human alteration of the Earth system being the greatest threat to ecological landscapes, altering the structure and functioning of ecosystems, the interaction between ecosystems and the atmosphere, the aquatic systems, and surrounding land (Vitousek *et al.*, 1997; DeFries *et al.*, 2004).

Human activities both modify and model landscapes by change the land use pattern to produce more and more goods and services (Vitousek *et al.*, 1997; Hietel *et al.*, 2004). The conversion of natural landscapes for artificial uses or the change of land management practices have transformed, either directly or indirectly, a large proportion of the planet's land surface (Foley *et al.*, 2005). Although these changes vary greatly across the world the final purpose is generally the acquisition of natural resources for immediate human needs, often at the expense of degrading environmental conditions (Antrop, 2000; Foley *et al.*, 2005). The poorly planned human interference and limited access to adequate information and appropriate technology are responsible by the continuous deterioration of living conditions, particularly in cities of the developing countries (Fanan *et al.*, 2011).

Europes's population and economic growth increased after World War II and contributed to the drastic urban expansion which is still ongoing (Kasanko *et al*., 2006; Schneider and Woodcock, 2008). In southern Europe the informal action of private agents and the deregulated planning system promoted the spontaneous 'compact growth' observed until the early 1990s and the subsequent urban expansion (Giannakourou, 2005). Currently, the cities are spreading, minimising the time and distances between the cities (in and out). This expansion is occurring in a scattered way throughout Europe's countryside, denominated by urban sprawl (EEA, 2006). The European Environment Agency (EEA, 2006) has described sprawl "as the physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas".

Urban sprawl is generally believed to result from an uncontrolled and inefficient urban dispersion accompanied by low building and population density, over rural or semi-rural areas, likely to be mainly found in peripheral areas, and occurs when urban planning is not well managed and turns open spaces into built spaces (Zhang, 2001; Altieri *et al*., 2014). As a consequence, the urban sprawl leads to negative effects on the environment. This model of development also dramatically transforms the properties of soil reducing its capacity to perform its essential functions (EEA, 2006). The land take for the urban development results in soil sealing *i.e.*, the loss of soil resources due to the covering of land for housing, roads, and other construction work, which is generally irreversible (EEA, 2010b). The growth of impervious areas can be thus regarded as an indicator of land degradation (Salvati *et al*., 2011).

Although its importance first became obvious in the second half of the 20th century, urban sprawl is still considered to be a major problem today (Coisnon *et al*., 2014). Successive European Union Council Presidencies have recognized the relevance of urban issues and urban development policies at all levels of governance. In particular, a series of informal ministerial meetings on urban development - in Lille 2000, Rotterdam 2004, Bristol 2005, Leipzig 2007, Marseille 2008, and Toledo 2010 - have shaped common European objectives and principles for urban development (European Union, 2011).

Coimbra is an interesting case study as its demographic dimension and drastic changes in land use patterns have occurred during the last half century, making it an appropriate site to study the urban expansion pattern of a Portuguese medium-size municipality. In the 1950s the centre of urban occupation was surrounded by outer small urban and rural areas, evidencing a very rural nature of the municipality. Since the 1970s a large expansion of the artificialization of the territory has taken place with the construction of important road infrastructures and facilities leading to the definition of new building areas. Thus, it was verified an urban growth either by congregation of existing periurban spots or by expansion to non-occupied areas (CMC, 2008; Tavares *et al.*, 2012). All these changes must be considered in order to effectively plan and manage ecologically sustainable cities. Without it, the policy decisions will be made without the full benefit of relevant scientific information, and cities will continue to grow in increasingly unsustainable ways (Alberti *et al.*, 2003). Thus, to make cities sustainable over the long term is required an understanding of the mechanisms that link human to ecological processes and control their dynamics and evolution (Alberti and Marzluff, 2004). Then, monitoring and mapping the trend of changes in urban areas in time is extremely valuable to urban planners who can use this information to monitor the impact of urban growth, to evaluate and modify existing urban policies, and also to develop appropriate responses or strategies.

By analysing the land use change and urban expansion in Coimbra over 20 years (1990-2010) may provide useful indications on changes in city's form and urbanization patterns at the local scale. The objectives of this study were: (1) to identify the temporal and spatial dynamics of built-up land in the municipality of Coimbra during the periods from 1990 to 1999 and from 1999 to 2010; (2) to identify and evaluate the spatial and temporal characteristics of the city area expansion (urban expansion) in these two decades as indicators of land degradation; and (3) given that this kind of analysis has never been done for the municipality of Coimbra before, this study can provide useful information for managers and planners to draw up more effective strategies for land resource management and urban planning in this region.

3.3. Materials and Methods

3.3.1. Study area

The study was conducted in the municipality of Coimbra which includes thirty-one parishes and occupies about 320 km^2 (Figure 3.1). According to the latest census Coimbra has a resident population of 143 396 inhabitants which highlights the municipality by its demographic dimension. It is the only municipality that, in the Centre Region of Portugal, has exceeded the 140 000 inhabitants. More than three-fourth (78%) of these inhabitants lives in the city, a worrying fact given that the city area represents only about one-fourth (26%) of the total area of the municipality (INE, 2011).

Figure 3.1 - The municipality of Coimbra with the thirty-one parishes.

The municipality of Coimbra is almost fully inserted in the Mondego river basin. What emerges from the hydrographic basin of Coimbra is the direction from east to west of the Mondego river with its inflections, and particularly the amplitude of its alluvial plain. The presence of the Mondego river and some of its tributaries, the proximity to the Atlantic Ocean (45 km), and the weak resistance of lytic units help created a vast alluvial plain - the Mondego Fields (Baixo Mondego), an agricultural area of excellence (CMC, 2008).

Throughout the municipality we may still visualize signs of a recent landscape dominated by agro-forestry systems. In todays landscape the country and city are intertwined and the agriculture and forest are diluted in a more urban landscape. The peculiar geomorphology, geographical richness, and diversity of the sites, make Coimbra a municipality characterized by distinct landscape unities (CMC, 2008).

3.3.2. Land use and city data

The analysis of spatial and temporal land use changes in the study area during a 20-year period (1990-2010) was based in the land use maps used in Chapter 2. The land use categories were classified as: built-up land, construction site, cropland, forest, leisure area, inland waters, inland wetlands, and unused land as explained in Chapter 2 (see Table 2.1).

Changes in city area, population density, and number of buildings were examined using 1991, 2001, and 2011 data acquired on-line from the National Institute of Statistics (INE). These three years were considered because they were the closest available data to the years used for the land use study.

3.3.3. Urban expansion analysis

In order to evaluate the urban expansion the spatial and temporal distribution of different land use categories in each parish were assessed by comparing the area (in hectares) of each land use category for the three study years (1990, 1999, and 2010). The years between 1990 and 1999 were considered as the first period, and those between 1999 and 2010 as the second period. A special emphasis was given to the built-up area. Then, the land change was assessed by overlaying the land use maps (1990-1999 and 1999-2010), and the change of built-up land between both periods was calculated. The magnitude and direction of land use in the city of Coimbra were also determined based on the transition matrix. The transition matrix and internal conversions between the eight land use categories were determined as explained in Chapter 2.

All maps were projected to the same national coordinate system (PT-TM06/ETRS89) using ArcGIS® version 10.2 (ESRI, Redlands, CA, USA).

3.4. Results

3.4.1. Built-up land change and population growth in the municipality of Coimbra

The cartographic results for the built-up land in 1990, 1999, and 2010 as well as their dynamics during the study period are presented in Figure 3.2 and Table 3.1. Although the built-up land occupies only 9.7%, 12.2%, and 15.5% of the total area in 1990, 1999, and 2010, respectively, this land use type was largely broadened, expanding more than 20% in each period. Throughout these 20 years, the built-up land grew by 60%, corresponding to an expansion nearly 2 000 ha (from 3 085.4 ha to 4 950.1 ha) all over the municipality. Despite all parishes presented an increase in built-up land (except São Bartolomeu) more than half of this growth took place in only seven parishes: Almalaguês, Cernache, Eiras, Santa Clara, Santo António dos Olivais, São Martinho do Bispo, and Taveiro each one expanding more than 100 ha during these two decades. The lowest built-up land expansion was verified in the parishes of Sé Nova (6.3 ha) and Almedina (6.7 ha) (Table 3.1).

Figure 3.2 - Built-up land dynamics in the municipality of Coimbra in 1990 (A), 1999 (B), and 2010 (C).

Table 3.1 - Built-up land dynamics and changes from 1990 to 2010 (unit: hectare).

Parishes	Built-up land			Built-up land change		
	1990	1999	2010	1990 1999	1999 2010	1990 2010
Almalaguês	68.3	157.5	185.7	+89.2	+28.2	+117.4
Almedina	36.4	36.4	43.1	0.0	+6.7	+6.7
Ameal	52.6	91.8	126.9	+39.2	+35.1	+74.3
Antanhol	123.4	150.8	191.3	+27.5	+40.5	+67.9
Antuzede	65.0	104.6	119.2	+39.6	+14.6	+54.2
Arzila	11.8	18.7	22.5	+7.0	+3.8	+10.7
Assafarge	65.1	100.0	136.7	+34.9	+36.7	+71.6
Botão	49.6	84.9	108.2	+35.4	+23.3	+58.7
Brasfemes	37.0	60.2	77.9	+23.2	+17.7	+41.0
Castelo Viegas	68.9	91.5	110.4	+22.6	+18.9	+41.5
Ceira	101.1	120.7	136.3	+19.6	+15.6	+35.2
Cernache	102.0	171.9	234.5	+69.9	+62.6	+132.5
Eiras	193.8	233.7	307.2	+39.9	+73.5	+113.4
Lamarosa	53.8	71.7	95.9	+17.9	+24.2	+42.1
Ribeira de Frades	68.9	93.0	121.5	+24.1	+28.5	+52.6
Santa Clara	173.1	201.7	289.7	+28.6	+88.0	+116.6
Santa Cruz	164.2	167.2	186.2	+2.9	+19.0	+22.0
Santo António dos Olivais	482.1	524.2	687.9	+42.1	+163.7	+205.8
São Bartolomeu	12.2	12.1	12.1	-0.2	0.0	-0.2
São João do Campo	47.1	68.0	85.1	+20.9	+17.1	+38.0
São Martinho de Árvore	30.9	34.5	50.0	+3.5	+15.5	+19.1
São Martinho do Bispo	267.4	317.4	406.7	+50.0	+89.3	+139.3
São Paulo de Frades	88.4	109.5	138.1	+21.1	+28.6	+49.7
São Silvestre	57.7	72.9	97.6	+15.2	+24.6	+39.8
Sé Nova	133.9	138.7	140.3	+4.8	+1.5	+6.3
Souselas	205.0	224.7	256.5	+19.7	+31.7	+51.5
Taveiro	74.1	146.5	207.1	+72.4	+60.6	+133.0
Torre de Vilela	48.9	67.9	84.5	+19.1	+16.5	+35.6
Torres do Mondego	39.6	58.4	74.7	+18.8	+16.2	+35.1
Trouxemil	94.8	106.3	135.0	+11.5	+28.7	+40.2
Vil de Matos	68.4	52.8	81.3	-15.6	+28.5	+12.9
Municipality	**3 085.4**	**3 890.2**	**4 950.1**	**+804.7**	**+1 059.9**	**+1 864.6**

The spatial distribution of built-up land showed that during the two study periods (1990-1999 and 1999-2010) more built-up land was gained than lost (Figure 3.3). Table 3.2 and Table 3.3 also illustrate the built-up land change within the same periods. The results show that during the first period (1990-1999) the built-up land gained 1 650 ha, of which 1 156.5 ha were obtained from cropland. The largest gain on built-up land occurred in the parishes of Santo António dos Olivais and São Martinho do Bispo, where almost

58% and more than 80%, respectively, were converted from cropland (Table 3.2). It was also observed a loss about of 845 ha on built-up land where about half were transformed into cropland, in the same period. The largest loss of built-up land also occurred in Santo António dos Olivais and São Martinho do Bispo where mostly was converted to cropland, about 46% in both parishes (Table 3.3).

Relatively to the second period of analysis (1999-2010) the built-up land also expanded, gaining 1 103.6 ha among which about 619 ha were converted from cropland. The largest gain on built-up land occurred in Santo António dos Olivais mostly through the conversion of cropland (74.2 ha) (Table 3.2). The loss of built-up land was only 43.6 ha with half of this areas changed for construction purposes. The largest loss of built-up land also occurred in Santo António dos Olivais mostly converted to construction sites and unused land (Table 3.3).

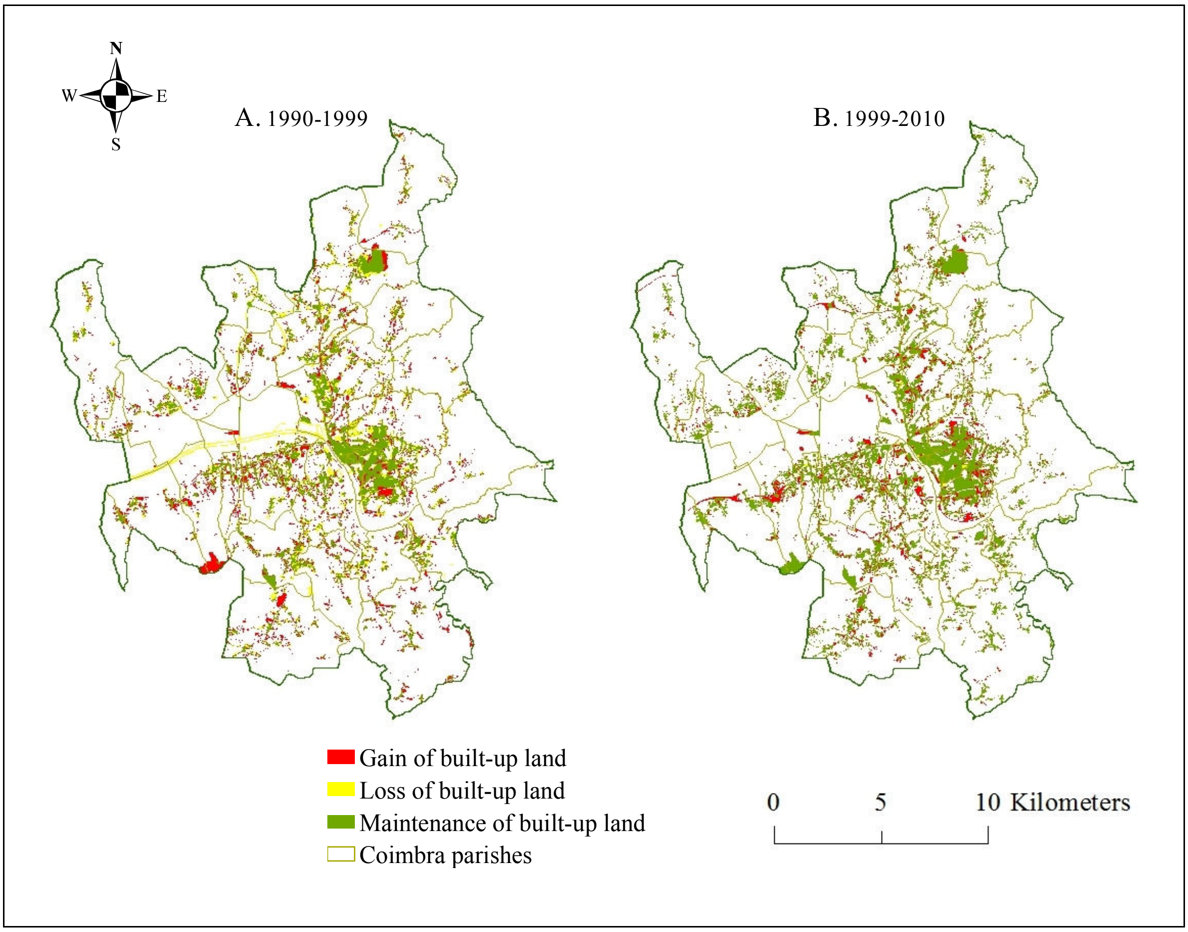


Figure 3.3 - Spatial distribution of built-up land change (gain and loss) and maintenance from 1990 to 1999 (A) and from 1999 to 2010 (B).

Table 3.2 - Area converted from each land use category to built-up land in each parish from 1990-1999 and 1999-2010 (unit: hectare).

	Gain in built-up land from															
	construction site		cropland		forest		inland waters		inland wetlands		leisure area		unused land		Total gain	
Parishes	1990 1999	1999 2010	1990 1999	1999 2010	1990 1999	1999 2010	1990 1999	1999 2010	1990 1999	1999 2010	1990 1999	1999 2010	1990 1999	1999 2010	1990 1999	1999 2010
Almalaguês	0.0	2.7	80.8	23.8	18.5	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.2	99.7	28.5
Almedina	0.0	0.6	3.3	2.9	0.5	1.4	0.0	0.0	0.0	0.0	2.1	0.0	0.0	2.0	5.9	6.9
Ameal	7.0	17.8	39.7	18.1	11.5	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	58.6	37.1
Antanhol	0.0	5.4	33.3	27.2	15.2	3.7	0.0	0.0	0.0	0.0	0.0	0.0	5.4	4.7	54.0	41.0
Antuzede	0.0	0.9	39.6	11.9	4.9	2.1	0.0	0.0	0.0	0.0	0.1	0.0	10.9	0.0	55.4	14.9
Arzila	0.0	0.5	7.8	3.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.7	4.0
Assafarge	0.0	7.5	36.2	24.8	13.4	3.5	0.0	0.0	0.0	0.0	0.0	0.0	2.3	1.4	52.0	37.1
Botão	0.0	3.4	29.5	16.4	1.0	1.6	0.0	0.0	0.0	0.0	0.1	0.0	18.9	2.4	49.5	23.8
Brasfemes	0.0	1.0	25.6	15.1	2.8	1.7	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	31.1	17.8
Castelo Viegas	0.0	2.5	30.2	15.1	11.1	1.6	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.1	43.7	19.3
Ceira	0.0	2.9	32.7	10.1	11.5	3.0	0.1	0.1	0.0	0.0	0.1	0.0	2.4	0.0	46.8	16.0
Cernache	0.0	17.4	71.3	39.7	9.2	5.7	0.0	0.0	0.0	0.0	14.3	0.0	4.3	1.3	99.1	64.2
Eiras	0.0	40.4	35.5	32.9	5.7	0.7	0.0	0.0	0.0	0.0	2.1	0.0	42.4	2.5	85.7	76.5
Lamarosa	0.0	3.1	35.7	16.9	1.7	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	37.4	24.9
Ribeira de Frades	0.0	5.2	37.4	24.2	7.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.4	48.2	30.5
Santa Clara	0.0	43.3	56.4	36.0	17.5	8.6	0.9	0.0	0.0	0.0	3.2	0.0	6.5	4.8	84.6	92.8
Santa Cruz	2.3	9.9	25.7	10.1	6.2	1.2	0.4	0.0	0.0	0.0	0.0	0.0	12.1	0.2	46.7	21.5
Santo António dos Olivais	0.0	57.9	92.6	74.2	31.7	22.8	0.0	0.0	0.0	0.0	2.8	0.0	33.0	17.9	160.1	172.8
São Bartolomeu	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
São João Campo	0.0	2.2	31.7	15.9	1.2	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	33.1	18.4
São Martinho Árvore	0.0	3.1	18.6	12.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.8	15.6
São Martinho Bispo	0.0	21.8	107.4	54.7	11.7	13.0	0.1	0.0	0.0	0.0	8.3	0.0	6.4	1.8	133.9	91.4
São Paulo Frades	0.0	8.1	32.9	15.1	6.6	4.8	0.0	0.0	0.0	0.0	0.0	0.0	11.1	1.8	50.6	29.8
São Silvestre	0.0	11.3	28.6	12.9	2.1	0.8	0.1	0.0	0.0	0.0	0.1	0.0	0.9	1.0	31.8	26.1
Sé Nova	0.0	2.6	5.9	0.0	5.6	0.1	0.0	0.0	0.0	0.0	4.8	0.0	0.0	1.0	16.3	3.7
Souselas	0.0	12.2	36.5	17.9	1.2	1.9	0.0	0.0	0.0	0.0	0.1	0.0	35.6	1.9	73.5	33.8
Taveiro	0.3	29.9	83.2	30.1	14.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0	5.7	0.7	103.7	63.2
Torre de Vilela	0.0	6.3	22.9	10.0	0.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	31.8	16.6
Torres do Mondego	0.0	1.6	28.2	11.2	5.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.4	34.0	16.7
Trouxemil	0.0	7.1	34.4	19.8	1.2	1.7	0.0	0.0	0.0	0.0	0.0	0.0	6.2	0.3	41.9	29.0
Vil de Matos	0.0	1.5	12.5	15.8	0.7	11.5	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	13.5	29.5
Municipality	**9.5**	**330.1**	**1 156.5**	**618.7**	**220.9**	**106.9**	**1.7**	**0.1**	**0.0**	**0.0**	**38.7**	**0.0**	**222.7**	**47.8**	**1 650.0**	**1 103.6**

Table 3.3 - Area converted from built-up land to other land use categories in each parish from 1990-1999 and 1999-2010 (unit: hectare).

	Loss in built-up land to															
	construction site		**cropland**		**forest**		**inland waters**		**inland wetlands**		**leisure area**		**unused land**		**Total Loss**	
Parishes	**1990 1999**	**1999 2010**	**1990 1999**	**1999 2010**	**1990 1999**	**1999 2010**	**1990 1999**	**1999 2010**	**1990 1999**	**1999 2010**	**1990 1999**	**1999 2010**	**1990 1999**	**1999 2010**	**1990 1999**	**1999 2010**
Almalaguês	0.5	0.0	9.5	0.1	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	0.2
Almedina	1.6	0.0	0.9	0.0	0.1	0.2	0.1	0.0	0.0	0.0	3.3	0.0	0.0	0.0	6.0	0.2
Ameal	0.2	0.0	6.6	0.8	10.4	1.2	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.4	2.0
Antanhol	8.5	0.1	13.6	0.1	3.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	26.5	0.5
Antuzede	0.3	0.0	14.1	0.1	1.3	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	15.8	0.3
Arzila	0.2	0.0	1.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.2
Assafarge	1.3	0.1	14.4	0.2	0.9	0.1	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.0	17.1	0.4
Botão	0.6	0.1	11.8	0.3	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	14.1	0.5
Brasfemes	0.1	0.0	7.2	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	7.8	0.1
Castelo Viegas	0.5	0.0	17.1	0.3	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	21.2	0.4
Ceira	1.4	0.2	20.8	0.1	4.1	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.3	0.0	27.2	0.4
Cernache	5.2	0.6	20.7	0.6	1.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.2	29.2	1.6
Eiras	23.1	2.5	20.1	0.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	45.8	3.0
Lamarosa	1.4	0.2	16.3	0.4	1.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	19.5	0.7
Ribeira de Frades	2.2	1.2	10.1	0.5	7.0	0.1	4.0	0.0	0.0	0.0	0.0	0.0	0.8	0.3	24.2	2.0
Santa Clara	14.6	3.6	26.0	0.3	3.8	0.3	0.0	0.0	0.0	0.0	8.4	0.0	3.2	0.6	56.0	4.7
Santa Cruz	5.8	2.1	13.6	0.2	11.3	0.2	4.5	0.0	0.0	0.0	3.7	0.0	4.8	0.0	43.8	2.5
Santo António dos Olivais	29.7	2.9	54.3	0.6	14.3	0.4	0.0	0.0	0.0	0.0	6.6	2.5	13.1	2.9	118.0	9.1
São Bartolomeu	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	0.2	0.0
São João Campo	1.8	0.9	9.7	0.2	0.4	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	12.2	1.3
São Martinho Árvore	0.2	0.0	3.9	0.1	1.8	0.0	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.3	0.1
São Martinho Bispo	9.6	1.4	39.2	0.3	15.9	0.1	8.4	0.0	0.0	0.0	1.2	0.0	9.6	0.3	83.9	2.1
São Paulo Frades	4.5	0.8	21.4	0.4	2.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.9	0.0	29.5	1.2
São Silvestre	4.2	0.4	9.5	1.0	1.4	0.0	1.1	0.0	0.0	0.0	0.2	0.0	0.1	0.0	16.6	1.4
Sé Nova	2.9	0.3	0.8	0.2	0.2	0.0	0.0	0.0	0.0	0.0	7.2	1.7	0.4	0.0	11.5	2.2
Souselas	20.6	1.6	26.7	0.3	3.8	0.1	0.0	0.0	0.0	0.0	0.1	0.0	2.4	0.1	53.7	2.1
Taveiro	3.3	1.5	7.7	0.2	1.2	0.1	5.8	0.0	0.0	0.0	0.0	0.6	13.4	0.2	31.4	2.6
Torre de Vilela	5.4	0.1	6.8	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	12.8	0.1
Torres do Mondego	0.2	0.0	13.0	0.3	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	15.1	0.5
Trouxemil	4.2	0.0	18.1	0.1	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.2	30.4	0.3
Vil de Matos	3.6	0.3	17.6	0.5	6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.3	29.1	1.0
Municipality	**157.7**	**21.0**	**453.3**	**9.0**	**108.2**	**3.6**	**36.1**	**0.0**	**0.1**	**0.0**	**31.5**	**4.8**	**58.5**	**5.1**	**845.3**	**43.6**

From 1991 to 2011 the mean population density of the municipality of Coimbra increased by 3.1%, but with different trends when comparing the two periods of analysis (Table 3.4). From 1991 to 2001 population grew 6.8% and an opposite pattern occurred between 2001 and 2011, where it decreased 3.4% (Table 3.4). In the three study years, four of the thirty-one parishes (São Bartolomeu, Sé Nova, Santo António dos Olivais, and Santa Cruz) showed a population density above 1 000 persons/km^2. In contrast, the lowest density was found in Botão and Vil de Matos, both with less than 100 persons/km^2. Between 1991 and 2011 the greatest percentage of population growth was verified in Assafarge (47.2%) followed by Eiras (25.3%), São Paulo de Frades (23.1%), São Silvestre (22.7%), and Antanhol (20.2%). From these five parishes, four experienced positive growth rates in the two periods. São Paulo de Frades, in turn, presented a negative rate in the second period. Of the thirty-one parishes, fifteen presented negative population growth rates during 1991-2011, with São Bartolomeu (-55.1%), Almedina (-53.7%), Santa Cruz (-30.8%), and Sé Nova (-21.7%) showing the lowest values. These four parishes showed negatives values in the two study periods (Table 3.4).

The number of buildings in the municipality of Coimbra grew 23.5% from 1991 to 2011, increasing 8.8% in the first period and 13.5% in the second period (Table 3.4). São Bartolomeu and Sé Nova were the parishes with more buildings per km^2, both with more than 800 buildings/km^2, in all analysed years. By contrast, Botão and Vil de Matos were the parishes with less buildings/km^2 (less than 50 buildings/km^2) in the three study years. From 1991 to 2011 the number of buildings increased more than 40% in four parishes, Assafarge, Torre de Vilela, Brasfemes, and São Martinho de Árvore, and three others, during the same period, presented negatives values: São Bartolomeu (-9.7%), Santa Cruz (-8.3%), and Almedina (-3.5%) (Table 3.4).

Table 3.4 - Population density and number of buildings in 1991, 2001, and 2011 in each parish, and its change between different periods.

Parishes	Area (km²)	Population density			Change (%)			Number of Buildings/km²			Change (%)		
		1991	2001	2011	1991 2001	2001 2011	1991 2011	1991	2001	2011	1991 2001	2001 2011	1991 2011
Almalaguês	23.2	151.4	148.3	134.1	-2.1	-9.6	-11.4	55.4	58.6	64.7	5.7	10.4	16.7
Almedina	1.0	1 953.0	1 521.0	904.0	-22.1	-40.6	-53.7	460.0	389.0	444.0	-15.4	14.1	-3.5
Ameal	11.3	155.4	148.5	148.8	-4.4	0.2	-4.2	47.8	47.5	61.4	-0.6	29.2	28.5
Antanhol	9.8	217.0	249.7	260.8	15.0	4.5	20.2	66.8	73.8	92.2	10.4	25.0	38.0
Antuzede	8.1	247.2	279.6	281.0	13.1	0.5	13.7	80.0	100.6	111.7	25.8	11.0	39.7
Arzila	3.4	209.1	214.1	192.6	2.4	-10.0	-7.9	70.9	72.1	80.6	1.7	11.8	13.7
Assafarge	9.7	192.4	233.8	283.1	21.5	21.1	47.2	63.3	85.4	115.4	34.9	35.1	82.2
Botão	17.3	93.9	97.3	91.8	3.6	-5.6	-2.3	38.3	40.4	41.6	5.4	3.0	8.6
Brasfemes	9.2	184.2	200.8	214.0	9.0	6.6	16.2	58.2	66.0	86.1	13.5	30.5	48.0
Castelo Viegas	7.5	244.4	236.1	226.0	-3.4	-4.3	-7.5	63.9	77.9	87.9	21.9	12.8	37.6
Ceira	12.4	361.7	339.3	298.5	-6.2	-12.0	-17.5	111.7	124.0	133.5	11.0	7.7	19.6
Cernache	19.2	190.1	201.6	210.8	6.1	4.6	10.9	71.3	75.1	91.3	5.3	21.6	28.1
Eiras	9.8	985.2	1 229.8	1 234.4	24.8	0.4	25.3	144.2	176.3	190.5	22.3	8.0	32.1
Lamarosa	16.3	122.0	134.3	126.9	10.1	-5.5	4.0	50.4	51.6	58.7	2.4	13.8	16.6
Ribeira de Frades	5.9	329.7	349.8	322.4	6.1	-7.8	-2.2	122.0	124.1	133.1	1.7	7.2	9.0
Santa Clara	10.2	844.0	944.8	973.4	11.9	3.0	15.3	214.9	218.8	241.2	1.8	10.2	12.2
Santa Cruz	5.6	1 471.3	1 226.1	1 017.7	-16.7	-17.0	-30.8	258.6	254.3	237.1	-1.7	-6.7	-8.3
Santo António dos Olivais	19.3	1 855.3	2 047.5	2 017.4	10.4	-1.5	8.7	265.5	296.3	338.1	11.6	14.1	27.3
São Bartolomeu	0.2	6 975.0	4 280.0	3 135.0	-38.6	-26.8	-55.1	1 655.0	1 525.0	1 495.0	-7.9	-2.0	-9.7
São João Campo	7.9	286.2	292.3	262.4	2.1	-10.2	-8.3	80.1	95.9	102.3	19.7	6.6	27.6
São Martinho Árvore	4.6	212.6	218.0	224.6	2.6	3.0	5.6	64.1	72.6	90.0	13.2	24.0	40.3
São Martinho Bispo	18.7	667.6	761.8	756.5	14.1	-0.7	13.3	184.0	207.9	237.7	13.0	14.4	29.2
São Paulo Frades	15.0	315.5	394.1	388.3	24.9	-1.5	23.1	81.0	92.5	106.3	14.2	15.0	31.3
São Silvestre	10.3	247.0	300.2	303.1	21.5	1.0	22.7	78.2	91.8	105.1	17.5	14.5	34.5
Sé Nova	1.6	5 380.6	5 184.4	4 213.1	-3.6	-18.7	-21.7	908.1	831.9	961.3	-8.4	15.6	5.8
Souselas	15.7	201.2	200.4	196.9	-0.4	-1.7	-2.1	61.4	70.7	83.6	15.1	18.3	36.2
Taveiro	9.6	200.4	215.0	202.9	7.3	-5.6	1.2	77.0	72.0	78.3	-6.5	8.8	1.8
Torre de Vilela	3.3	328.8	347.3	376.4	5.6	8.4	14.5	91.8	120.9	141.2	31.7	16.8	53.8
Torres do Mondego	16.7	164.0	152.7	143.8	-6.9	-5.8	-12.3	55.8	57.5	68.8	3.1	19.6	23.3
Trouxemil	7.2	410.0	416.5	376.7	1.6	-9.6	-8.1	130.4	133.8	148.8	2.6	11.2	14.1
Vil de Matos	9.6	76.1	80.7	90.6	6.0	12.3	19.0	28.2	30.7	38.1	8.9	24.1	35.1
Coimbra municipality	**319.4**	**435.4**	**464.8**	**449.0**	**6.8**	**-3.4**	**3.1**	**103.0**	**112.1**	**127.2**	**8.8**	**13.5**	**23.5**
Coimbra city		**1 284.8**	**1 903.5**	**1 343.9**	**48.1**	**-29.4**	**4.6**	**242.7**	**388.9**	**327.4**	**60.3**	**-15.8**	**34.9**

3.4.2. Urban expansion and population growth in the city of Coimbra

The area of the city of Coimbra, here considered the main urban centre by INE (Figure 3.4), expanded from 7 175.7 ha in 1991 to 8 318.0 ha in 2011 which corresponded to a mean growth value of 57 ha/year. The results showed that during the first period (1991-2001) the city area has decreased 1 302.1 ha. On the other hand, in the second period (2001-2011) the city area grew 2 444.4 ha reaching an average rate of 244.4 ha/year (Table 3.4).

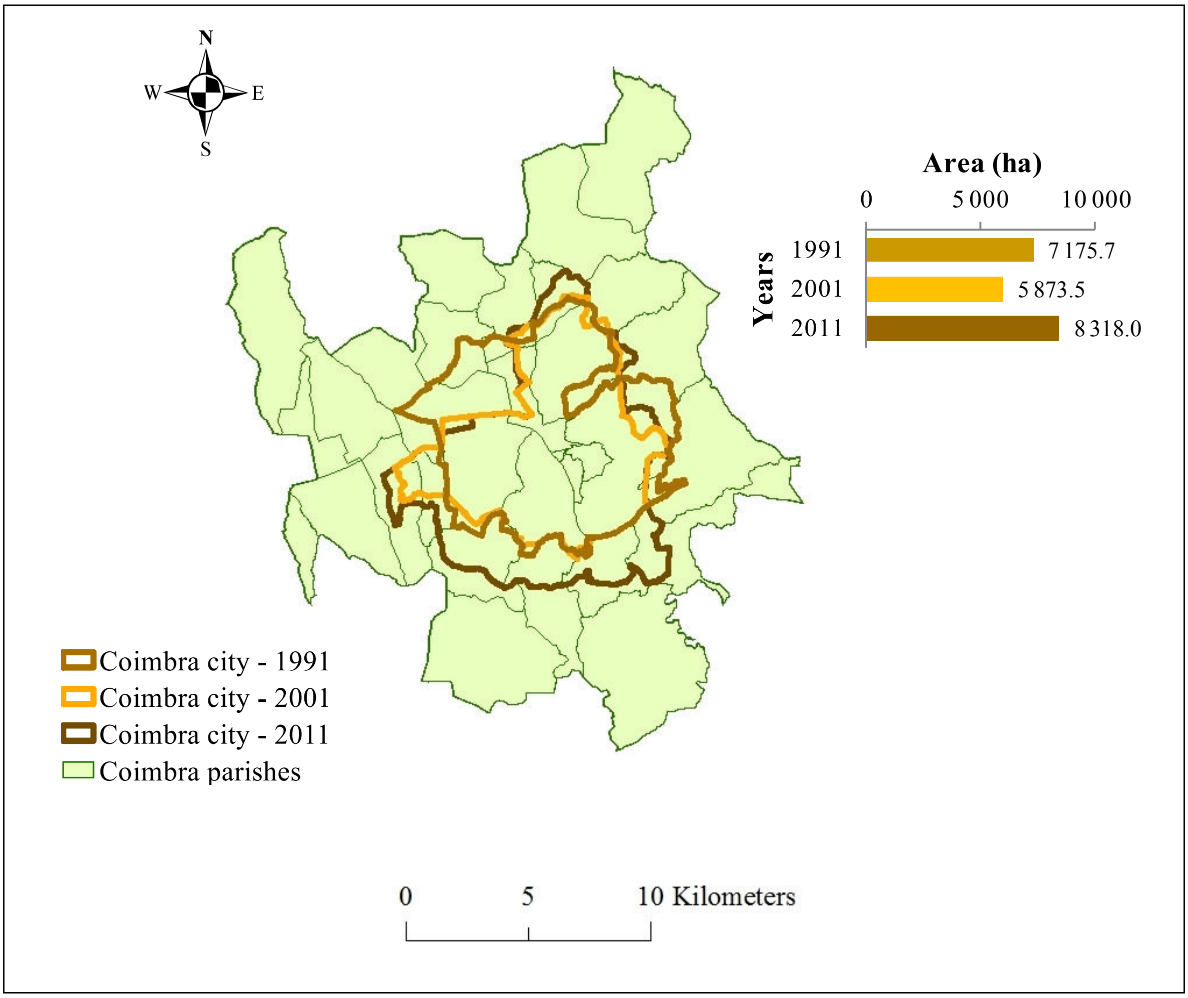
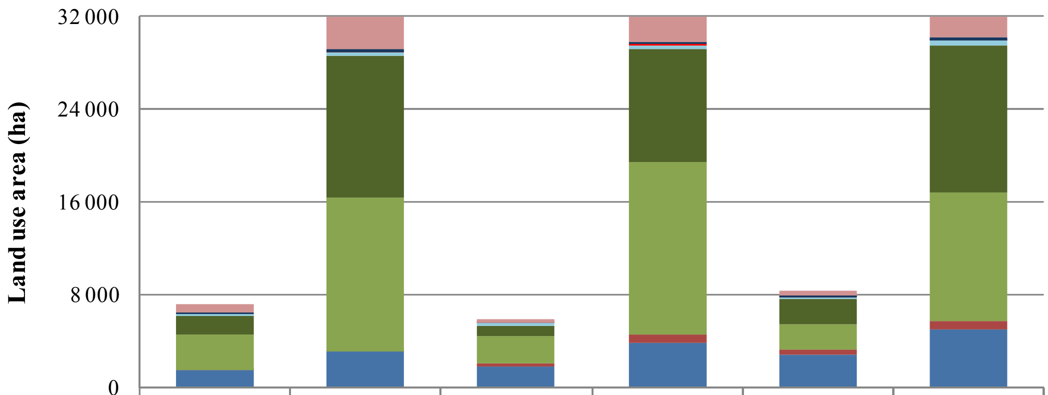


Figure 3.4 - Map with the area of the city of Coimbra in different years considered by INE.

Although the city area occupies a relatively small area of the municipality i.*e.*, 22.5%, 18.4%, and 26% in 1991, 2001, and 2011, respectively, more than 45% of the built-up land was found here (Figure 3.5). From 1990 to 2010 a high percentage (67.4%) of the built-up expansion was also found in the city area. This expansion was more pronounced in the second period (94.1%) than in the first one (32.3%). Moreover, about 50% of the construction sites and inland waters as well as more than 60% of the leisure were also found in the city area (Figure 3.5).



	1990 City	1990 Municipality	1999 City	1999 Municipality	2010 City	2010 Municipality
Unused land	759.9	2 828.4	228.3	2 175.1	406.8	1 782.1
Leisure area	94.0	146.9	105.7	132.9	172.2	198.3
Inland wetlands	0.0	3.8	1.8	97.1	1.8	97.8
Inland waters	196.8	386.4	177.0	380.8	183.5	372.1
Forest	1 629.3	12 258.7	933.2	9 782.6	2 125.1	12 689.6
Cropland	2 964.7	13 192.5	2 300.6	14 746.8	2 224.1	11 044.6
Construction site	19.1	37.8	355.4	734.6	436.2	805.3
Built-up land	1 511.8	3 085.4	1 771.5	3 890.2	2 768.4	4 950.1

Figure 3.5 - Area occupied by each land use category in the city and municipality of Coimbra from 1990 to 2010.

The city's population and the number of buildings have changed during the study period (Table 3.4). This population increased greatly between 1991 and 2001 (+19 605 inhabitants), while the period between 2001 and 2011 witnessed a very small drop in population growth (-13 inhabitants), similarly to the patterns found for the municipality. These results showed that more than 65% of the inhabitants lived in the city in 1991, whereas in 2001 and 2011 more than 75% of the population inhabited in the main urban centre. The population density in the city varied between approximately 1 300 persons/km^2 in 1991, 1 900 persons/km^2 in 2001, and again 1 300 persons/km^2 in 2011 (Table 3.4).

From 1991 to 2011 the number of buildings increased in total 34.9%, experiencing a more aggressive expansion in the first period (60.3%). In the second period a slight decreased in its numbers (15.8%) was observed (Table 3.4).

3.4.3. Land use change and soil sealing in the city of Coimbra

The land use changed greatly over the period from 1990 to 2010 in the city of Coimbra (Figure 3.6). Furthermore, the transition matrices (Table 3.5 and Table 3.6) showed clear trends of land use dynamics for the same periods. The cropland and built-up areas were the two major land use categories in the city, accounting jointly more than 60% of the total area in the three years. However, during the first period (1990-1999) the cropland increased 130.3 ha and the forest area decreased 236.7 ha (Table 3.5). In contrast, during the second period (1999-2010) the cropland decreased 1 173.2 ha and the forests increased 460.9 ha (Table 3.6).

During the first period the construction sites followed by the built-up land were the land use categories with more expansion, increasing 336.4 ha and 203.6 ha, respectively. By contrast, the unused land (482.2 ha) followed by forest (236.7 ha) showed the higher decline (Table 3.5). On the other hand, during the second period the built-up land (601.4 ha) and forest (460.9 ha) were the land use categories that more increased, while cropland and inland waters were the land uses that lost more importance, decreasing 1 173.2 ha and 7.3 ha, respectively (Table 3.6). Thus, from 1990 to 2010 the built-up land was the land use category with more expansion (805.0 ha) and the cropland was the land use category that lost more area (1 042.9 ha) (Table 3.5 and Table 3.6). By 2010, 2 768.4 ha of the land in the city was being used for built-up areas compared with 1 771.5 ha and 1 511.8 ha in 1999 and 1990, respectively (Figure 3.5). As a result, large areas of land are being covered in impenetrable or impervious artificial surfaces, such as roads, buildings, and pavements sealing off the soil beneath.

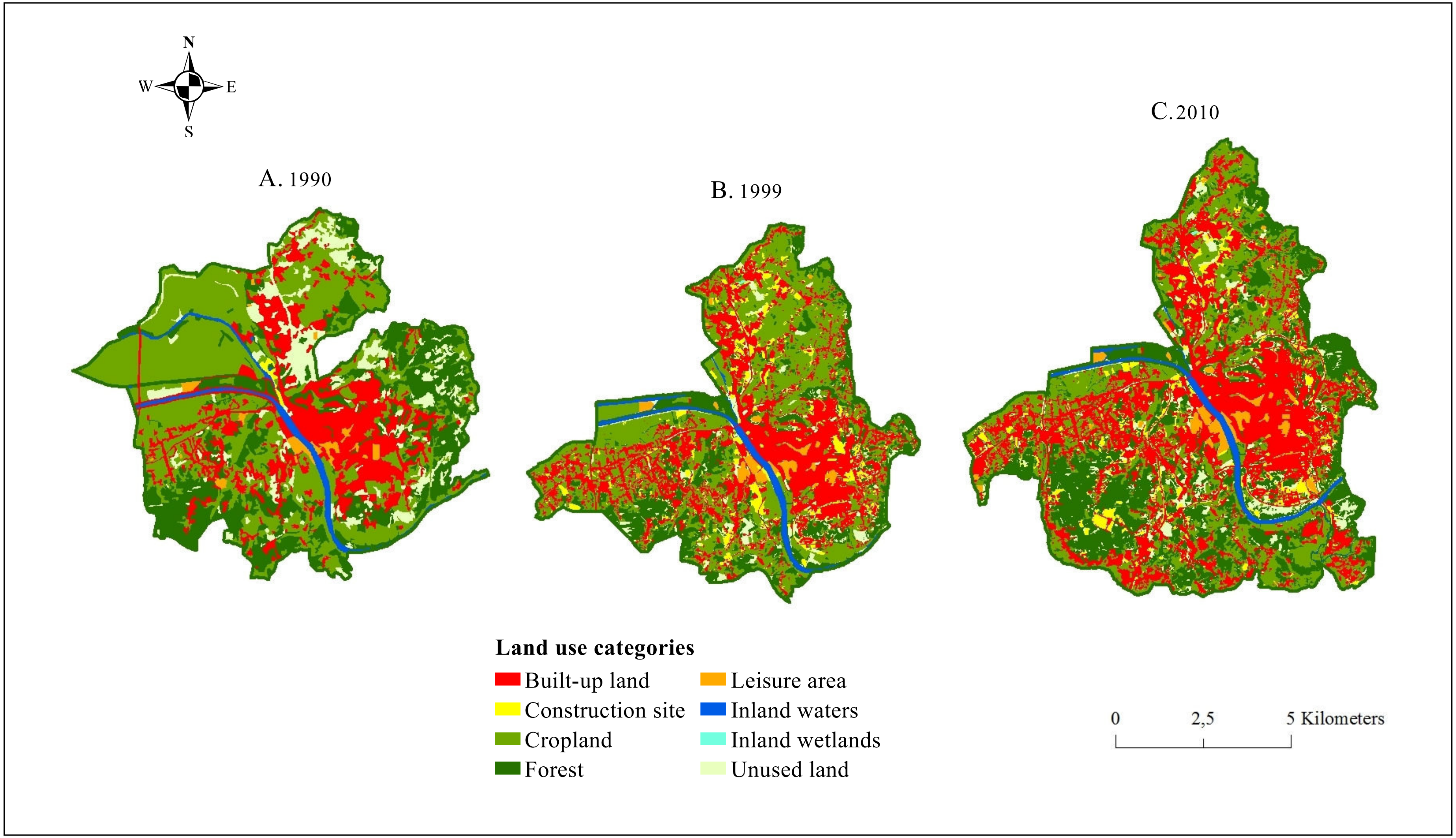


Figure 3.6 - Land use in the city of Coimbra in 1990 (A), 1999 (B), and 2010 (C).

Table 3.5 - The conversion matrix of land use change in the city of Coimbra from 1990 to 1999 (unit: hectare).

Land use in 1990	Land use in 1999								
	BL	CS	CL	F	IW	IWL	LA	UL	Total
BL	**1 184.1**	92.8	170.8	45.8	11.8	0.1	30.5	31.8	1 567.8
CS	2.3	**3.5**	6.1	0.4	2.4	0.0	0.0	4.4	19.1
CL	362.2	121.4	**1 499.2**	118.2	5.6	0.2	9.4	54.1	2 170.3
F	80.2	47.0	246.2	**685.5**	27.5	0.0	6.5	77.1	1 169.9
IW	1.2	0.8	2.1	10.0	**125.7**	0.0	0.0	3.8	143.7
IWL	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0
LA	23.4	5.0	2.4	4.1	2.3	0.0	**53.6**	1.3	92.1
UL	118.1	84.8	373.7	69.1	1.9	1.5	5.7	**55.7**	710.5
Total	1 771.5	355.4	2 300.6	933.2	177.0	1.8	105.7	228.3	
Change	203.6	336.4	130.3	-236.7	33.3	1.8	13.7	-482.2	

BL - Built-up land, CS - Construction site, CL - Cropland, F - Forest, IW - Inland waters, IWL - Inland wetlands, LA - Leisure area, UL - Unused land. The unchanged area of each land use category was marked in bold. The rows and columns contain data of 1990 and 1999, respectively.

Table 3.6 - The conversion matrix of land use change in the city of Coimbra from 1999 to 2010 (unit: hectare).

Land use in 1999	Land use in 2010								
	BL	CS	CL	F	IW	IWL	LA	UL	Total
BL	**2 136.6**	16.4	3.7	1.4	0.0	0.0	4.7	4.1	2 167.0
CS	221.3	**125.5**	8.8	20.7	0.0	0.0	24.0	23.2	423.6
CL	314.6	183.6	**2 159.7**	572.0	1.6	0.0	24.3	141.6	3 397.3
F	59.4	79.6	49.7	**1 367.3**	2.3	0.0	1.1	104.9	1 664.2
IW	0.1	0.1	1.5	9.1	**179.7**	0.0	0.0	0.4	190.8
IWL	0.0	0.0	0.0	0.0	0.0	**1.8**	0.0	0.0	1.8
LA	0.0	0.0	0.0	0.0	0.0	0.0	**110.3**	0.0	110.3
UL	36.3	30.9	0.7	154.7	0.0	0.0	7.7	**132.7**	363.0
Total	2 768.4	436.2	2 224.1	2 125.1	183.5	1.8	172.2	406.8	
Change	601.4	12.6	-1 173.2	460.9	-7.3	0.0	61.8	43.8	

BL - Built-up land, CS - Construction site, CL - Cropland, F - Forest, IW - Inland waters, IWL - Inland wetlands, LA - Leisure area, UL - Unused land. The unchanged area of each land use category was marked in bold. The rows and columns contain data of 1999 and 2010, respectively.

The internal conversions between land use categories in the city from 1990 to 2010 were presented in Figure 3.7. During the first period the increase of cropland occurred at the expense of unused land and forest, which contributed with 319.6 ha and 128 ha, respectively. The expansion of built-up land and construction sites occurred mainly at the expense of croplands, which have contributed with 191.3 ha and 115.3 ha, respectively. Also, 90.6 ha of built-up land contributed to the increase of the construction sites (Figure 3.7-A). Relatively to the second period the increase of forest, built-up land, construction site, and unused land occurred mainly due to the transformation of cropland. The construction site also contributed with 204.9 ha to expand the area of the built-up land (Figure 3.7-B). As can be seen from Figure 3.7-A, during the first period, 311.9 ha of unsealed surfaces (cropland, forest, and unused land) contributed to the increase of the built-up land. From 1999 to 2010 the expansion of built-up land also occurred at the expense of these unsealed surfaces which contributed with 401.1 ha (Figure 3.7-B).

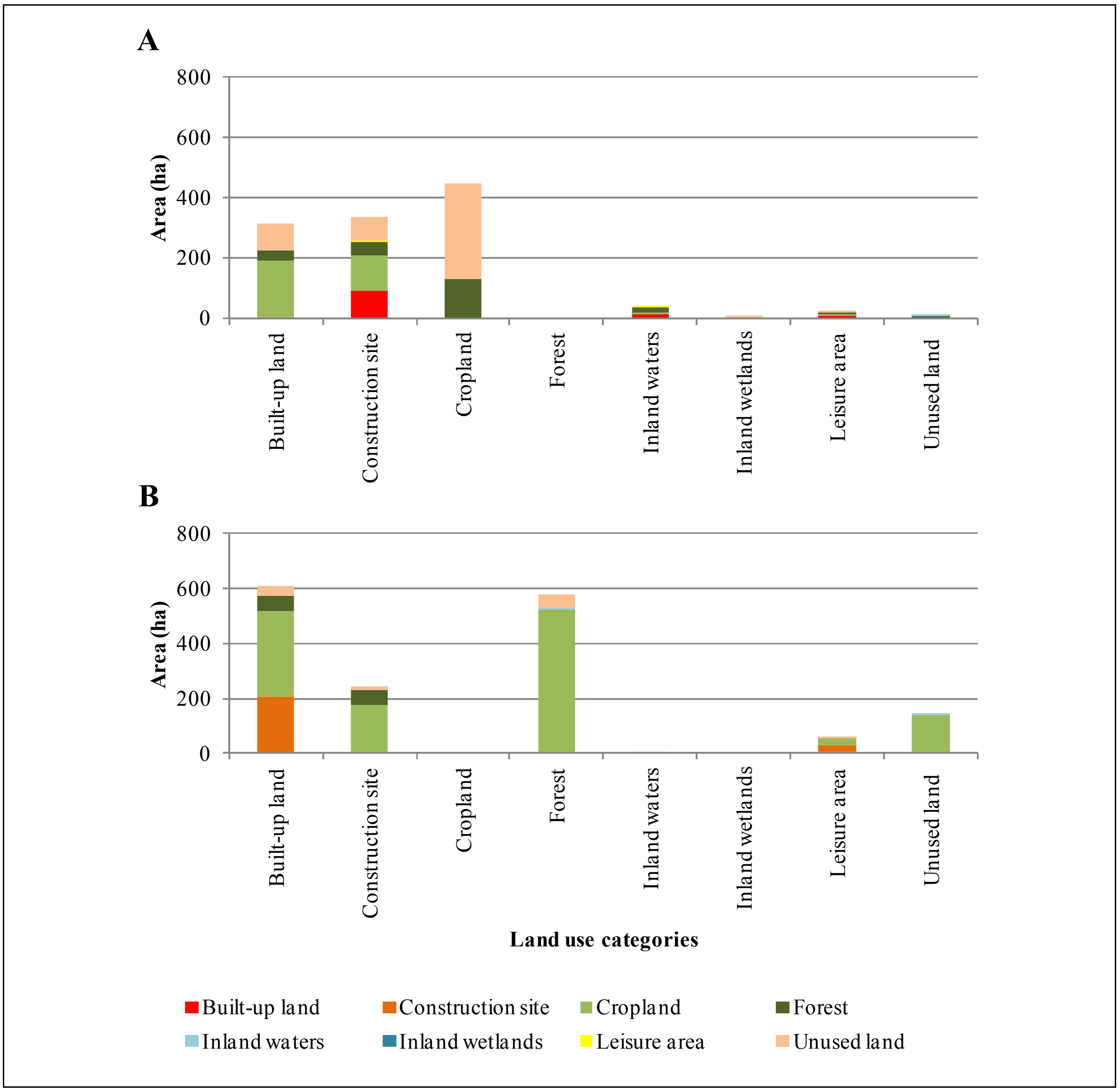


Figure 3.7 - Internal conversions between land use categories in the city of Coimbra from 1990 to 1999 (A) and from 1999 to 2010 (B) and the area taken by corresponding categories in such loss or gain conversions.

3.5. Discussion

The land use maps showed a significant built-up land expansion in the municipality of Coimbra from 1990 to 2010 (Figure 3.2). Over this period the built-up land expanded more than 60% showing an increase in all parishes, except in São Bartolomeu (Table 3.1). Most of this expansion was due to the artificialization of the land, especially through the construction of residential and commercial buildings and roads networks. It should be noted that 20% of the households in the municipality were built between 1991-2001 (CMC, 2008). The construction of commercial areas and roads networks contributed significantly to the built-up development verified in the second period (1999-2010). Between 2002 and 2006 three big commercial areas were built in the municipality, being the Mondego Retail Park one of the largest investments made in Taveiro (Figure 3.8). It is an infrastructure of high commercial relevance which consists of more than a dozen commercial units of medium and large dimension, and catering units. The Dolce Vita is a commercial space in the city centre (Santo António dos Olivais) resulting from the remodeling of the stadium for the European Football Cup in 2004 (Figure 3.8). This commercial area is one component of the complex Eurostadium annexed to the new Stadium of Coimbra which also includes a multipurpose pavilion, an Olympic pool, and a Studio Residence - a set of 200 apartments. The Forum Coimbra, the largest shopping center in the region, was built in the parish of Santa Clara (Figure 3.8). Associated to this commercial development, new roads networks, including a new bridge (Ponte Rainha Santa Isabel) over the Mondego river between Santa Clara and Almedina, were built. The road's networks greatly influenced the structure and spatial location of urban development which assumed a meaningful growth along the major roads. A similar growth pattern associated to the amelioration of the road network was verified in Nairobi city by Mundia and Aniya (2005).

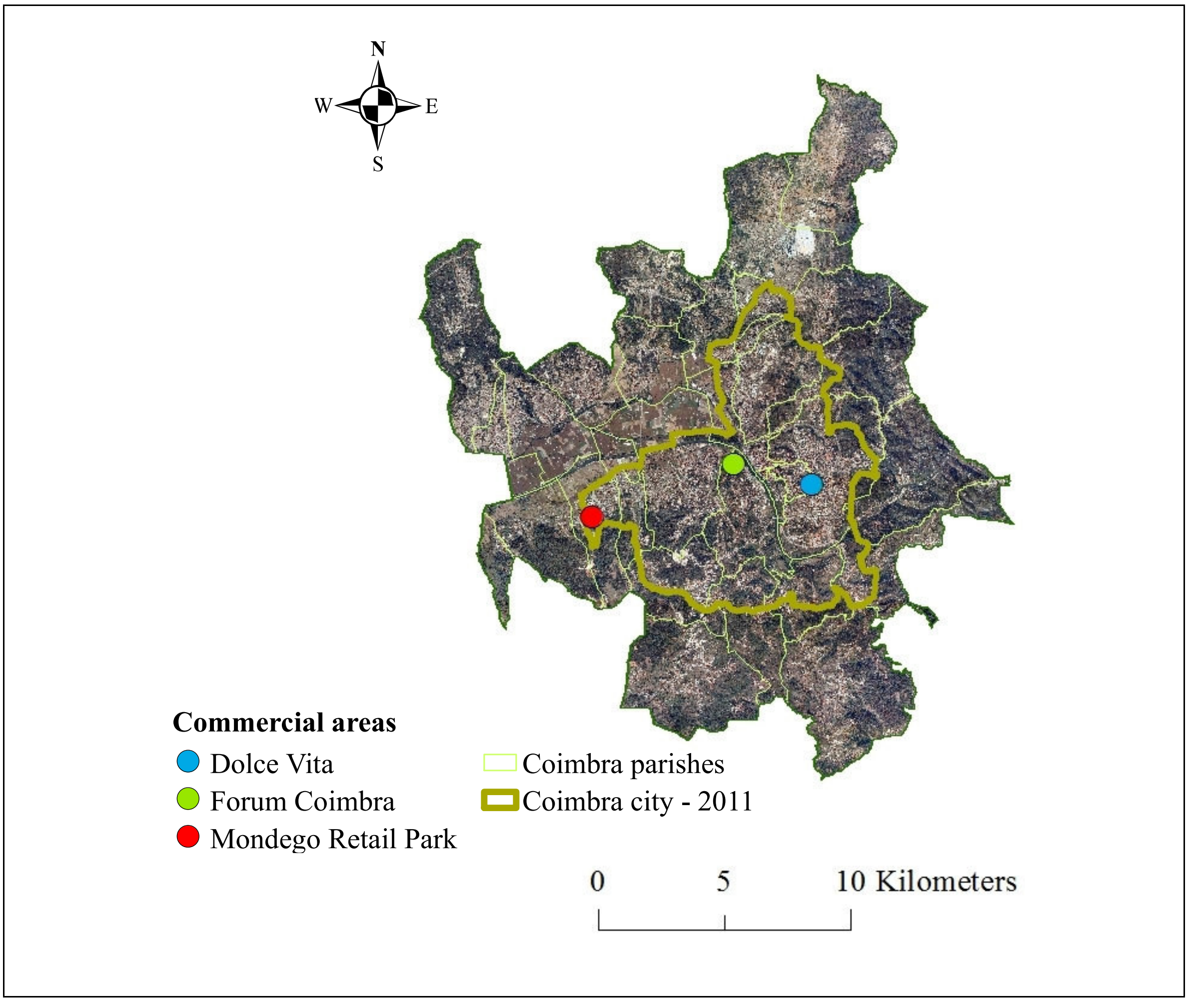


Figure 3.8 - Location of the three big commercial areas built between 2002-2006 in the municipality of Coimbra.

During the study period, in the city of Coimbra, it was verified an urban expansion and population growth associated to the building development (Table 3.4). Although the city occupies a relatively small area of the municipality (about 20%) (Figure 3.4), more than 45% of the built-up land was found in the city area (Figure 3.5). There was an obvious progression of urban areas during the second period more directed to the south of the city, reaching the four surrounding parishes of Ceira, Castelo Viegas, Assafarge, and Antanhol (Figure 3.4). Although population and building densities were mainly in the city centre, the parishes within the city showed lower values in population growth and building development when compared to the surrounding parishes during these last two decades. Thus, a part of the periurban area was urbanized principally replacing cropland areas. The periurban areas suffered, in turn, must faster rates of urban expansion than population growth, a common feature observed in several European cities (Kasanko *et al.*, 2006; EEA, 2010b). Also the important infrastructures to serve human purposes, as leisure areas, are localized in the city area (Figure 3.5).

Europe's population, in particular urban population, has increased over recent decades but built-up areas increased even more, in particular commercial and industrial areas (EEA, 2010b). The development of commercial areas which require more buildings and more space, together with the preferences of single houses over blocks of flats, can explain these faster rates of building development than population growth on the periurban areas, which occurred during the two decades of the study. Furthermore, the progressive construction of commercial areas and road networks outside the city centre also point to a horizontal development in line with a tendency shown by other European cities (Catalán *et al.*, 2008). In Europe, the wish of humans to live in a green surrounding, life styles with higher demands regarding dwelling, and the search for inexpensive building lots contributed to a highly dispersed urban development (EEA, 2010b; Jaeger *et al*., 2010; Sung *et al*., 2013).

During the first period of study the city of Coimbra showed a great increase in population density and number of buildings (48.1% and 60.3%, respectively) nevertheless, a significant decrease occurred in the second period (29.4% and 15.8%, respectively) (Table 3.4). The built-up land increased in both study periods (Table 3.5 and Table 3.6). On the other hand, the urban area decreased during the first period but showed a great increase during the second period (Figure 3.4). This result suggests that the city of Coimbra (main urban centre) has become less compact, with a larger area but with less population density and number of buildings, a clear indicator of urban sprawl.

The urban sprawl has become a very remarkable characteristic of European urban development (Kasanko *et al.*, 2006; Arribas-Bel *et al*., 2011). Examples of this trend can be found in Porto (EEA, 2006), Madrid (López de Lucio, 2003), Barcelona (Catalán *et al.*, 2008), Rome (Frondoni *et al.*, 2011), and Milan (Camagni *et al.*, 2002). The research of Kasanko *et al.* (2006) confirmed that Southern European cities have started to experience rapid urban expansion but remain very compact if compared to other European cities, in particular to those in Northern Europe. The urban sprawl produces many adverse environmental effects that have direct impacts on the quality of life and human health in cities (EEA, 2006, 2010a). The impacts of urban sprawl are evident in the extent of compaction of soil leading to impairment of soil functions such as loss of water permeability (soil sealing) (EEA, 2006; Munafò *et al*., 2013). The increase in impervious surface leads to a decrease in infiltration and an increase in surface runoff (Braimoh and Onishi, 2007).

Driven by an increasing population and a shift towards greater urbanization verified in the city of Coimbra more unsealed surfaces are being replaced by impervious surface, thus built-up lands (housing, road infrastructures, and industrial and commercial development) are being laid down over what was once cropland, forest or unused land. One consequence of this is that large impervious surfaces are connected together, increasing the risk of urban flooding (European Commission, 2012). Soil sealing also contributes to the urban heat island effect that increase the temperature of the air close to the sealed soil relative to the air temperature outside the city (Scalenghe and Marsan, 2009; Depietri *et al*., 2012). This urban heat island effect contributes to heat waves as the heat wave that hit Europe in the summer of 2003 (European Commission, 2012). The area of Coimbra is, historically, an area with geomorphological and meteorological hazardous events. Of special importance are the recent flood and landslide events that took place in the 2000/2001 winter and 2006, the heat waves in 2003 and 2005, and the fires in 2005 (Tavares *et al*., 2010).

The built-up land expansion was the most important process in terms of extent and impact on land composition and pattern as showed by the internal conversions between land use categories in the city of Coimbra (Figure 3.7). The results showed that built-up land was developed mainly at the expense of cropland areas and their expansion was the most important process in terms of extent and impact on land composition and pattern. In many European cities such as Brussels, Dublin, Copenhagen, Milan, Porto, Bilbao, and Bratislava there is a clear dominance of new building development in previous cropland areas (Kasanko *et al*., 2006; Baus *et al*., 2014). Due to its abandonment or by planning decision, cropland areas are generally available for urban growth, and in most cases, both topographically and in economic terms these areas are technically more suitable for construction (Kasanko *et al.*, 2006). Despite the loss of cropland area to built-up land still a great area of cropland was maintained over time, both in the municipality and city (Figure 3.5). Its spatial dominance is very important for preserving soil resources and for the potential recovery of vegetation, and can be regarded as an ecologically positive event (Frondoni *et al.*, 2011). The unsealed surfaces, as cropland areas, allow water to filter into the ground, prevent excessive rainfall run-off, enhance sensitive flows of evapotranspiration, and improve the health of urban citizens by increasing cooling (European Commission, 2012).

Insights into the relationships between spatial changes in municipal land use and urban sprawl illustrate the kind of scientific approach that will support decision-making to increase the likelihood of sustainable urban development (Li *et al.*, 2014). Both the impact of urbanization (through an increase in impervious surfaces) and climate change (through higher temperatures and precipitation values) are expected to affect future watershed run-off and streamflow. Therefore, understanding the different effects of increased impervious surfaces and climate change on surface run-off can help urban planners to design suitable policies in response to the challenges of greater sealing of urban areas and climate change impacts (European Commission, 2012).

This study can help urban planners to incorporate climate adaptation measures in their planning processes in order to minimise the negative impact of urban development and climate change in the city of Coimbra. We hope, with this study, to contribute with important indicators and findings management planning as well as to raise awareness to this issue so crucial to Coimbra's sustainable development.

3.6. Conclusions

This study examined the dynamics of urban expansion in the city of Coimbra from 1990 to 2010. The growth of built-up land and the existence of a high urban population density in the city were responsible for the urban expansion rate verified in these periods. The city area expanded from 7 175.7 ha in 1991 to 8 318.0 ha in 2011 at an average rate of 57 ha/year. This urban expansion was taken mostly of at expense of cropland areas. This study also showed that the growth of urban population and a much faster growth of urban area resulted in the artificialization of the land. Consequently, the population density in built-up areas decreased and the structure of the city of Coimbra has become less compact, a signal of urban sprawl *i.e.*, low-density urban expansion (EEA, 2006). Driven by an increasing population and urbanization more cropland areas were converted to urban uses, and thus more unsealed surfaces were sealed by impervious surfaces. The consequences of this soil sealing can be considerable and policies are needed to address the problems and minimise further impacts caused by the sealing of soils such as floods and heat waves. The information collected from this work is important for urban planning purposes and for the appropriate and balanced allocation of services and infrastructures. Understanding urbanization trends and their impacts in the social, economic, and natural resources is therefore crucial for sustainable development. This study is a contribution to the understanding of spatial and temporal dynamics of urban expansion in the city of Coimbra, and may bring important information to be used for better planning and effective spatial organization of urban activities, which is crucial for future development of this city, and thus improving the quality of life for current and future generations to come.

Chapter 4

Biodiversity in urban ecosystems: plants and macromycetes as indicators for conservation planning in the city of Coimbra

4.1. Abstract

Urban landscapes support a high and rich diversity often occurring as unusual or unique communities. Urban green spaces are a vital part of the urban landscape, providing contact with wildlife and environmental services with additional socio-ecological benefits to the overall quality of life. The composition and diversity of vascular plants and macromycetes were assessed in an urban green space of the city of Coimbra comprising three landscape types (Oak-, Eucalyptus-, and Olive-stands), with historical periurban agriculture and forest uses. We recorded 287 taxa of plants, including three taxa with important ecological value (*Quercus suber*, *Quercus faginea* subsp. *broteroi* and *Ruscus aculeatus*) and 96 taxa of macromycetes. The pattern of land use resulted in the establishment of different plant and soil fungal communities' composition and diversity among these landscapes. The plant richness and diversity indices revealed similar trends within the landscape types, with the highest values found in the Olive-stands due to the presence of herbaceous that decreased with tree cover density. Richness and diversity of macromycetes were higher in Oak-stands especially the symbiotic ectomycorrhizal fungal communities. Although not significant, higher saprobic fungi richness and diversity values were found in the Eucalyptus-stands. Given the undoubted ecological complexity of urban green spaces and the value of these ecosystems for society in terms of goods and services, it is imperative to select bioindicators that are readily accessible and reliable to design

balanced urban ecosystems by linking wildlife and biological parameters to human well-being.

Keywords
biodiversity; urban green space; vascular plants; macromycetes; land use; bioindicators

4.2. Introduction

Landscapes across the world have been severely affected by human activities since the second half of the 20th century (EEA, 2006). A major concern involving human impact is a rise in urbanization, associated with the rapid growth of the world's population and the consequent transformation of rural and natural landscapes (Keleş *et al.*, 2008). Although urban landscapes occupy only approximately 3% of the earth's surface (CIESIN *et al.*, 2011), 78% of the population in developed countries lives in urban settlements with a corresponding 48.4% of the population in less developed countries (United Nations, 2014). In Portugal, 62.9% of the total population inhabits urban areas (United Nations, 2014).

Urban landscapes are complex ecological systems, affected by human practices that have increasingly altered biogeochemical cycles and contributed to the deterioration of natural habitats and loss of biodiversity by promoting the replacement of native species with non-native counterparts, leading to the extinction of some species and to biotic homogenization (Chapin *et al.*, 2000; McKinney, 2006; Kowarik, 2011).

In the past decade, studies and discussions focusing on biological diversity have become one of the most pressing and important topics for the scientific community, environmental policy makers and forestry planners (Dana *et al.*, 2002; Gustafsson *et al.*, 2005; Jooss *et al.*, 2009). Biodiversity is an important component of any ecological system that promotes functional diversity and improves ecological stability by influencing the resistance and resilience to environmental change (Peterson *et al.*, 1998; Chapin *et al.*, 2000) and is therefore crucial to the overall quality of life. In this context, urban green spaces have gradually become recognized as important local habitats in urban systems.

In Portugal, urban green spaces have also been identified for a long time as major contributors to the physical and aesthetic quality of surroundings (Loures *et al.*, 2007). In the 1940s, city managers determined that urban growth in Coimbra should follow the "garden-city" concept in which the urban area would be bounded by a rural landscape - the green belt - containing no urban development (Santos, 1983). This green belt would serve as a reservoir of clean air, as protection against the encroachment of other urban centres, and as a supplier of agricultural products. This type of agriculture, within the city boundaries or in the immediate surroundings, is generally defined as periurban agriculture (FAO, 2007). These areas are of extreme importance due to the services they may provide to cities, and should be taken into consideration in any territorial development policies.

The Santa Clara Plateau represents one example of Coimbra's periurban agriculture area where no urban infrastructures were allowed until the 1990s. Soil management associated with agriculture and forest uses over several decades resulted in three distinct landscape types in the Santa Clara Plateau. This mosaic within Santa Clara Plateau offers an excellent case study, not only because of the historical periurban use, but also due to two potential environmental risks in the area: i) fire, associated with the forest-urban interface, and ii) pressures associated with urban and commercial growth, particularly in the last twenty years. Moreover, the Santa Clara Plateau evaluation of biodiversity parameters represents a unique example to explore biological conservation and include collaborative reflections on urban design strategies and planning decisions.

The value of wildlife and native biota in urban green spaces is often underestimated and its socio-ecological functions have not been comprehensively studied (EEA, 2010a). Assessing, understanding, and improving urban biodiversity is of great importance from both conservation and social point of views (Kowarik, 2011). Two important biological and ecological components in these systems include vegetation and soil fungi (in particular, the symbiotic and the saprobic).

The vegetation component provides important environmental services, such as stabilization of stream banks, moderation and improvement of storm water flow, and conversion of nitrate pollution to harmless gaseous nitrogen, in addition to contributing towards the sustainability of urban areas and helping to recharge water tables (Chiesura, 2004; Grove *et al.*, 2006). Furthermore, vegetation can improve climatic conditions within urban areas, provide a recreational resource for local residents (van Herzele and Wiedemann, 2003; Chiesura, 2004), contribute towards carbon sequestration, and generate both food and habitats for other organisms (Mathieu *et al.*, 2007; Davies *et al.*, 2011).

Soil fungi play a pivotal role in decomposition and nutrient cycling in terrestrial ecosystems and influence the establishment and dynamic succession of plant communities (Smith and Read, 2008). Certain soil fungi establish a symbiotic relationship with roots of plants, called mycorrhizas, that is widely recognized as mediators between soil processes and plant community, by enhancing nutrient acquisition, drought tolerance, and pathogen resistance of their hosts, whereas saprobic fungi have been shown to remobilize and translocate biomass and store mineral nutrients (Smith and Read, 2008). Several ectomycorrhizal fungal species, predominantly Basidiomycetes and some Ascomycetes, likely have similar functions in nutrient cycling (Finlay, 2008). In Mediterranean Basin ecosystems all major types of mycorrhiza can co-exist, depending on the plant community structure and the stage of ecological succession.

We hypothesized that the pattern of land use in the Santa Clara Plateau has influenced the establishment of the floristic and macromycete communities, resulting in different plant and soil fungal community composition and diversity among landscapes. In order to evaluate these differences, the composition and diversity of flora and macromycetes were determined in the three different landscape types that currently characterize this green space. The study also aims to provide relevant information for policy makers to design balanced urban ecosystems by linking biological indicators to human well-being.

4.3. Material and Methods

4.3.1. Study area

The study was conducted in the Santa Clara Plateau (40º21’ N, 8º45’ W), an urban green space (54.2 ha) in the centre of Coimbra (Figure 4.1). The Santa Clara Plateau is influenced by a Mediterranean climate, characterized by warm, dry summers and mild, humid winters. The average annual temperature and total annual precipitation is around 15ºC and 900 mm, respectively (CMC, 2008). The geological formation is composed of dolomite and calcareous rock, and a soil type consisting of Podzols, associated with Eutric Cambisols (APA, 1971). The Santa Clara Plateau stands on the left bank of the Mondego river and is surrounded by two growing urban areas: Santa Clara in the south and São

Martinho do Bispo in the northwest, both of which put pressure on land natural resources at local and regional levels.

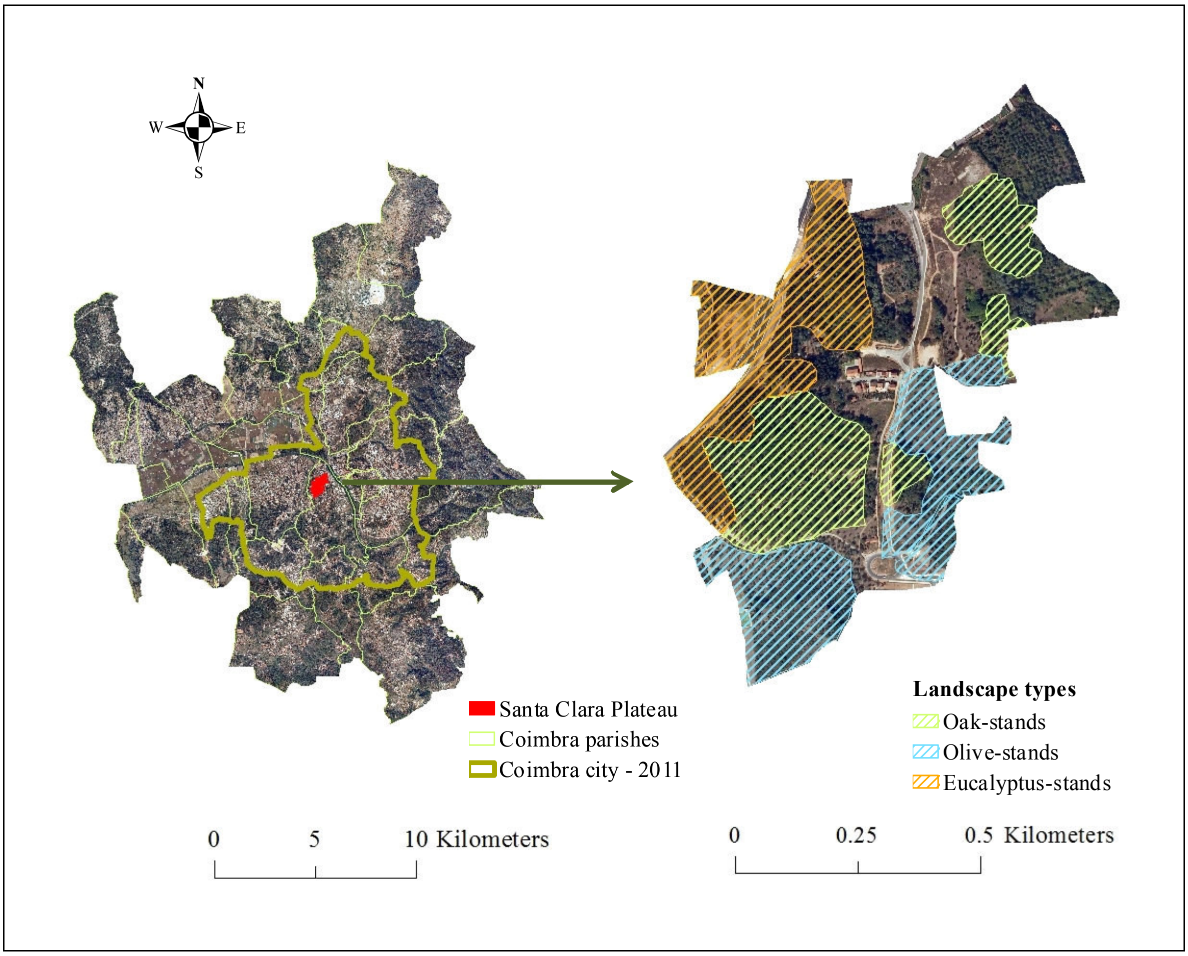


Figure 4.1 - Location of the study area and the three landscape types.

Since the 1950s this area has been occupied by some scattered urban buildings for forestry and agricultural use, similar to the situation described by Pato *et al.* (2008) regarding a small-scale hydrological basin in an area adjacent to the Santa Clara Plateau (on the western side). However, given its role as a green support area for the city of Coimbra, the pattern of land use development in the Santa Clara Plateau was different from the scenario described by Pato *et al.* (2008), as urban settlements did not emerge. However, the trend towards replacing agricultural areas with forest and/or abandoned areas is similar to what took place in the hydrological basin. Consequently, land use fragmented the Santa Clara Plateau into three major landscape types, designated in this study as Oak-stands, Olive-stands, and Eucalyptus-stands (Figure 4.2).

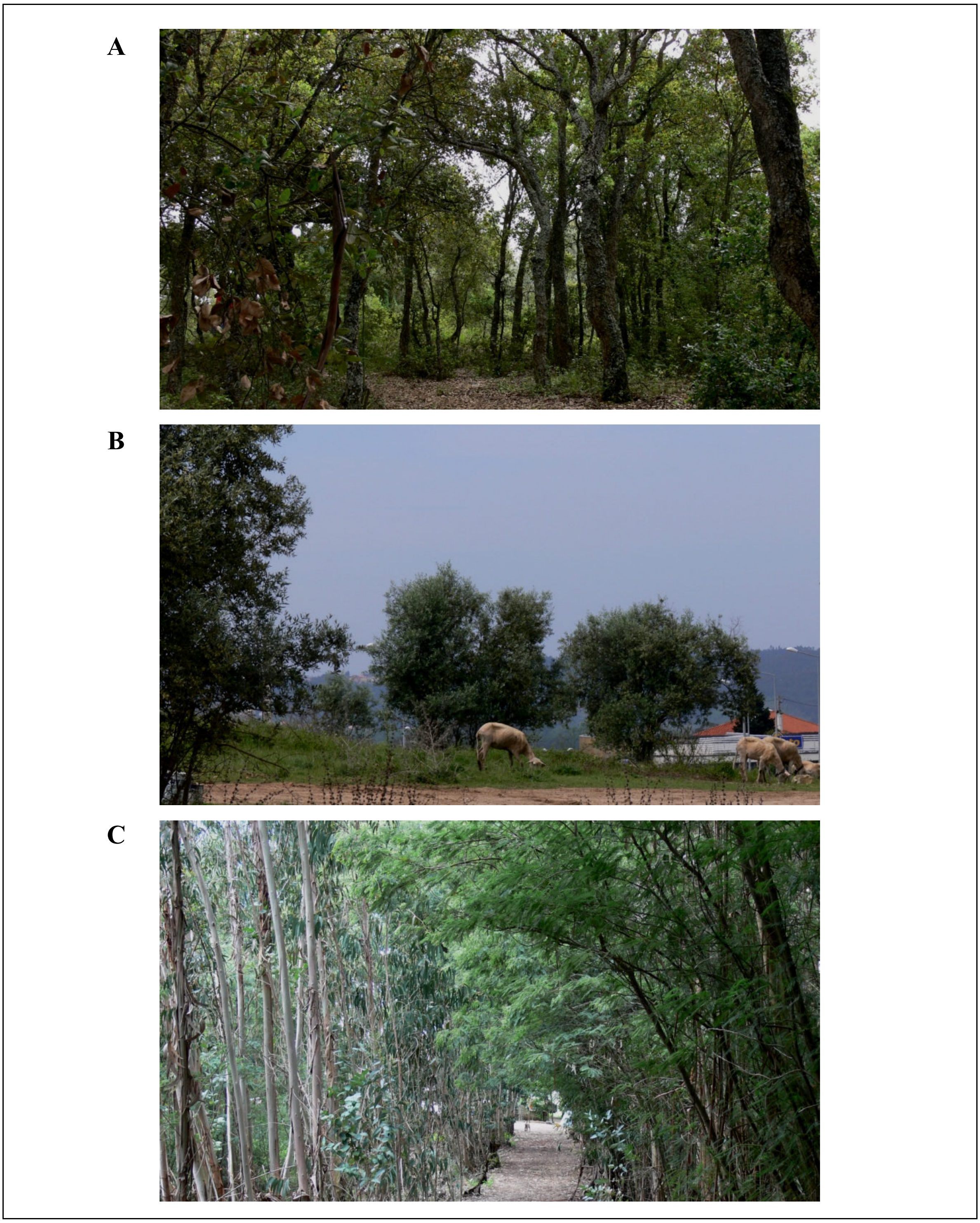


Figure 4.2 - The three major landscape types found in the Santa Clara Plateau. Oak-stands (A), Olive-stands (B), and Eucalyptus-stands (C).

The Oak-stands (11.7 ha) are dominated by the evergreen cork oak (*Quercus suber*), with many Mediterranean native taxa present (Figure 4.2-A). The Olive-stands (11.3 ha) consist of old olive plantations (*Olea europaea*) in which extensive agro-pastoral activities take place, with natural pastures used for grazing sheep alternating with crop production (Figure 4.2-B). The Eucalyptus-stands (10.6 ha) correspond to 40-year plantations of *Eucalyptus globulus* commercially developed until the late 1990s, in which the establishment and expansion of invasive plant taxa is more noticeable (Figure 4.2-C). The cork oak is a native species from the Mediterranean Basin and is predominantly an ectomycorrhizal tree (Smith and Read, 2008). The eucalyptus is an exotic species (introduced in Portugal in the 19^{th} century) and forms both arbuscular mycorrhizas and ectomycorrhizas (Chilvers, 1968; Smith and Read, 2008). The olive tree, native from the Mediterranean Basin (long-ago introduced in Portugal) establishes arbuscular mycorrhizas (Calvente *et al.*, 2004; Meddad-Hamza *et al.*, 2010).

4.3.2. Floristic survey

The floristic survey was conducted in the spring of 2008 and 2009 and comprised three different steps. The first step was carried out in the spring of 2008 and involved a preliminary floristic inventory. The taxa composition was sampled randomly by walking along the network of paths within the study area and also along their edges, following the methodology used by Santos *et al.* (2009). The area was thoroughly searched (about 80% of the total area) until no new taxa were discovered. In step two, the three major landscape types were defined, and their spatial distribution and extent mapped and projected to the national coordinate system (PT-TM06/ETRS89) using ArcGIS® version 10.2 (ESRI, Redlands, CA, USA). Finally, in step three, carried out in the spring of 2009, a quantitative vegetation analysis was performed, based on determining the presence and abundance of individual taxa in the three major landscape types. Within each landscape type, 12 plots of 5 m x 5 m with nested plots of 3 m x 3 m and 2 m x 2 m used for sampling trees, shrubs and herbaceous taxa, respectively, were selected using the methodology adapted from Mueller-Dombois and Ellenberg (1974) and Lindgren and Sullivan (2001). In each plot, the abundance of each taxon was determined by a visual estimate of percentage cover. For this study, the tree growth-form included taxa that were either adult trees or seedlings. The shrub growth-form included all taxa designated as shrub or woody climbing taxa and the herbaceous growth-form comprised all taxa designated as herbaceous or non-woody climbing taxa.

Plant taxa were identified according to Franco and Afonso (1971-2003) and Castroviejo *et al.* (1986-2010) and plant specimens from the Herbarium of University of Coimbra (COI). English common names and potential uses were described according to Huxley *et al.* (1992), Garrido-Lestache (2001), Cunha *et al.* (2003), Mabberley (2008), and Wink and van Wyk (2008). The invasive plant taxa were classified in accordance with Portuguese law (Ministério do Ambiente, 1999).

4.3.3. Macromycete survey

This study focused exclusively on the macromycete community - saprobic and ectomycorrhizal fungi - based on fruiting bodies. Although fruit bodies's production is unlikely to reflect the belowground fungal community (Lilleskov and Bruns, 2001), surveys can be particularly valuable as indicators for assessing the impacts of different land use types on macromycete populations, as observed by Azul *et al.* (2009).

In 2008 and 2009, four plots of 20 x 20 m were randomly selected in each landscape type. A minimum distance of 100 m per plot was considered to guarantee the fruiting incidence to be independent among the neighbouring plots. Field surveys included the species richness and abundance of macromycetes, following the methodology used by Azul *et al.* (2009), and were carried out every two weeks during the main fruiting period (October-December). The clumped distribution was determined by counting the fruit bodies. The observations did not include species forming hypogeous or resupinate fruit bodies.

Macromycetes were identified according to Bon (1988), Gerhardt *et al.* (2000), and Courtecuisse and Duhem (2005). Author citations for each taxon are abbreviated according to the Index Fungorum (see at www.speciesfungorum.org). The quantification of the fruit bodies was used instead of biomass analysis to evaluate the macromycete community, as different taxa produce different sizes of fruit bodies and biomass measurements would have obscured abundant fruiting of smaller macromycetes.

4.3.4. Data analysis

The plant and macromycete diversity in each plot was estimated using the following descriptors: 1) species richness (S) the total number of taxa sampled within a plot; 2) the

Shannon's diversity index (H’) and 3) Simpson’s diversity index (1/D) which combine species richness and abundance; 4) Pielou’s evenness (J’) and 5) Simpson’s evenness ($E_{1/D}$) which quantify how similar taxa are in their abundance (Magurran, 2004).

Shannon's diversity index (H') was calculated as:

$$H' = - \Sigma p_i \ln p_i$$

Simpson’s diversity index (D) was calculated as:

$$D = \Sigma p_i^2$$

► $p_i = n_i/N$;
► n_i is the abundance of the taxon i;
► N is the total abundance.

Simpson’s diversity index varies inversely with heterogeneity *i.e.*, as the index (D) increases, diversity decreases. Therefore this index is usually expressed as 1/D or 1-D. In this study, the first expression 1/D was used. Simpson's diversity index is less sensitive to species richness and heavily weighted towards the most abundant taxa in the sample (Magurran, 2004).

Pielou’s evenness (J’) was calculated as:

$$J' = H'/\ln S$$

Simpson’s evenness ($E_{1/D}$) was calculated as:

$$E_{1/D} = (1/D)/S$$

► S is the total number of taxa.

The importance value (IV) which gives an overall estimate of the dominance of a taxon within the community (Curtis and McIntosh, 1951) was calculated for all plant taxa in each landscape type using the following formula (Karavas *et al.*, 2005):

$$IV_i = RC_i + RF_i$$

► RC_i is the relative cover rate of taxon i;
► RF_i is the relative frequency of taxon i.

Macromycete data analysis also included: 1) taxon abundance, estimated as the cumulative number of fruit bodies produced by a given taxon during the two consecutive fruiting seasons; 2) species frequency, calculated as the percentage within the landscape type in which a given taxon fruited at least once during the entire sampling period, 3) fruit body fructification, defined as the total number of fruit bodies counted over the study period, and 4) relative abundance, determined as the total number of fruit bodies of a given taxon per total fruit bodies. Data on macromycetes was pooled within each plot and the differences between the two years of the main fruiting period (2008 and 2009) were analysed.

One-way analysis of variance (ANOVA) and the Tukey test ($p \leq 0.05$) for overall comparisons were used to test for significant differences in the species cover and indices calculated for the different landscape types. All the data were checked for normality and homogeneity of variance, and transformed if necessary to meet ANOVA assumptions (Zar, 1996). Statistical analyses were performed using SPSS 21 software for Windows (SPSS Inc., IL, USA).

4.4. Results

4.4.1. Floristic inventory

A total of 287 taxa of vascular plants belonging to 66 families and 200 genera were found in the study area (Appendix 4.A). These included 25 trees, 39 shrubs and 223 herbaceous plants. The three dominant families, Fabaceae (38 taxa), Asteraceae and Poaceae (34 taxa each), comprised 36% of the total genera and 37% of the total taxa. In terms of significant biological and conservation value, the presence of *Quercus suber,* a species protected under Portuguese law (Ministério da Agricultura, do Desenvolvimento Rural e das Pescas, 2001), *Quercus faginea* subsp. *broteroi*, an endemic taxa in Portugal, and *Ruscus aculeatus*, included in Annex V (animal and plant species of community interest whose taking in the wild and exploitation may be subject to management measures) of the Habitats Directive (Directive 92/43/EEC, 1992), should be highlighted. The presence of nine invasive species recognized by Portuguese law (Ministério do

Ambiente, 1999) should also be emphasized, of which *Acacia dealbata*, *Acacia melanoxylon* and *Ailanthus altissima* are the most common.

4.4.2. Richness and diversity of floristic species

The mean species richness ranged from 10.08 (Eucalyptus-stands) to 13.33 (Olive-stands) (Figure 4.3-A). Significant differences (p = 0.041) were found between landscape types, with more plant taxa found in the Olive-stands. When compared by growth-forms, there were significant differences in species richness for trees and herbaceous (p < 0.001) and shrubs (p = 0.018) between the different landscape types. The highest values for trees were found in Eucalyptus- and Oak-stands, while the highest values for shrubs and herbaceous plants were found in Oak- and Olive-stands, respectively (Figure 4.3-A).

The total species cover ranged from 111% (Oak-stands) to 148% (Eucalyptus-stands) (Figure 4.3-B), and did not show any significant differences (p = 0.142) in terms of landscapes. The mean species cover for growth-forms was significantly different in the landscape types for trees and herbaceous (p < 0.001) and shrubs (p = 0.002). The highest values corresponded to trees in Eucalyptus- and Oak-stands, shrubs in Eucalyptus-stands, and herbaceous plants in Olive-stands (Figure 4.3-B).

Although the Shannon and Simpson diversity indices did not reveal any significant differences between landscape types, Olive-stands had the highest values, mainly as a result of the many herbaceous taxa present, whereas tree and shrub taxa dominated in the other two landscapes (Table 4.1). With regard to growth-forms, the two diversity indices showed similar tendencies among growth-forms with the highest value found in Eucalyptus-stands for trees, Olive-stands for herbaceous plants and Oak-stands for shrubs. Nevertheless, the Shannon diversity index was significantly different in terms of vegetation types for trees and herbaceous plants and the Simpson diversity index was significantly different only for shrubs (Table 4.1).

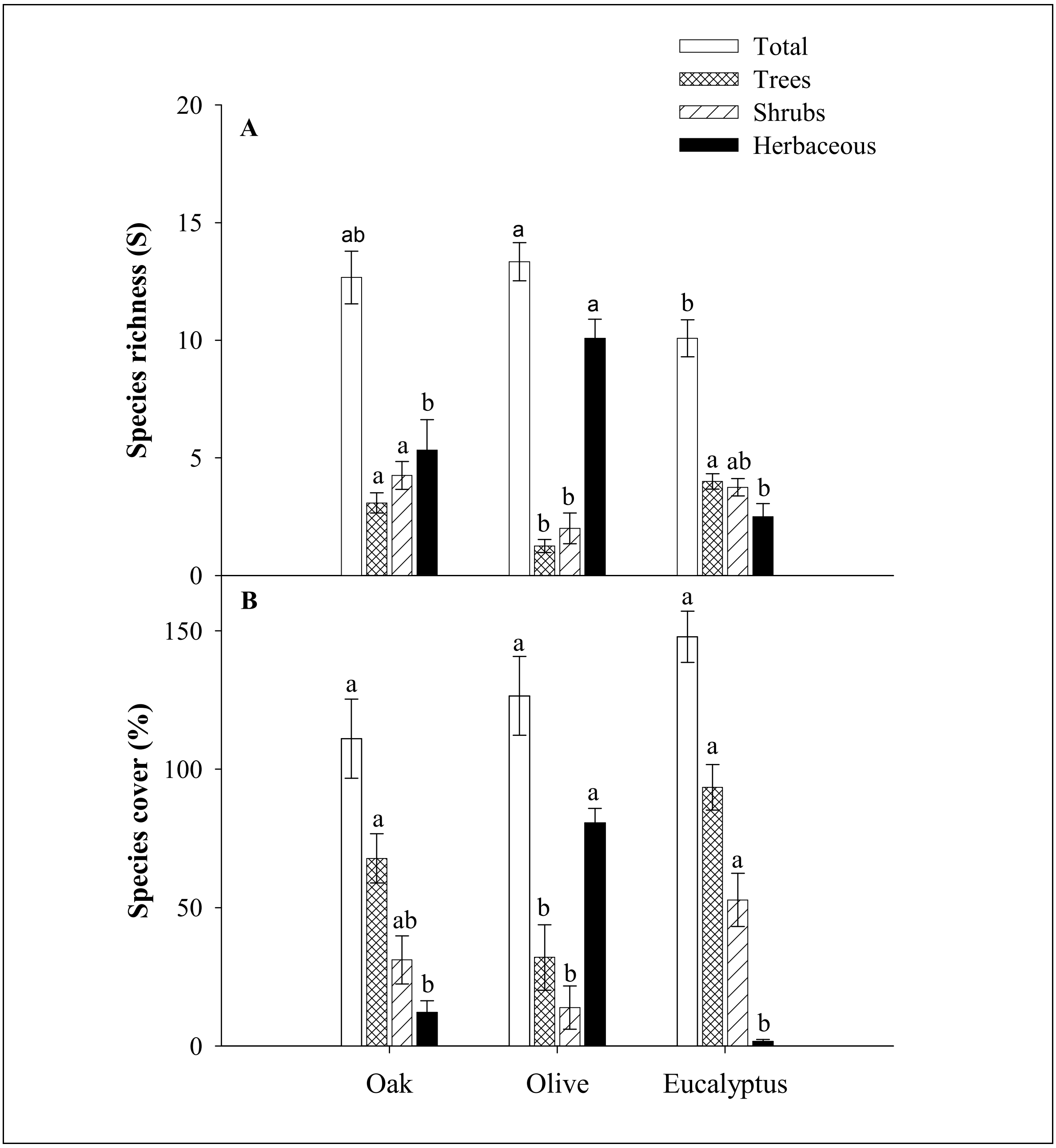


Figure 4.3 - Plant species richness (A) and plant species cover (B) for the three landscape types. Values are means ± SE. The different letters above the bars indicate significant differences ($p \leq 0.05$) between landscape types.

Despite the fact that the Pielou and Simpson evenness indices did not differ significantly between landscape types, both presented the lowest values in Oak-stands (Table 4.1). When analysed by growth-forms, only herbaceous equitability was significantly lower in the Olive-stands according to the Simpson evenness index (Table 4.1).

Table 4.1 - Descriptive statistics of different diversity indices for vascular plants present in the three landscape types. Values are means ± SE.

	Oak-stands	**Olive-stands**	**Eucalyptus-stands**	***p***
Shannon's diversity index (H')				
Total diversity	1.42 ± 0.12	1.63 ± 0.12	1.32 ± 0.08	0.137
Growth-form				
Trees	0.52 ± 0.12 ab	0.26 ± 0.10 b	0.68 ± 0.11 a	0.010**
Shrubs	0.89 ± 0.16	0.42 ± 0.16	0.72 ± 0.07	0.057
Herbaceous	0.89 ± 0.19 ab	1.32 ± 0.13 a	0.61 ± 0.16 b	0.015*
Simpson's diversity index (1/D)				
Total diversity	3.26 ± 0.39	4.30 ± 0.64	3.12 ± 0.25	0.175
Growth-form				
Trees	1.67 ± 0.21	1.07 ± 0.22	1.77 ± 1.17	0.053
Shrubs	2.50 ± 0.39 a	1.32 ± 0.44 b	1.86 ± 0.14 ab	0.013*
Herbaceous	2.32 ± 0.40	3.39 ± 0.57	2.14 ± 0.56	0.200
Pielou's evenness index (J')				
Total evenness	0.57 ± 0.04	0.63 ± 0.04	0.58 ± 0.03	0.489
Growth-form				
Trees	0.42 ± 0.10	0.33 ± 0.12	0.49 ± 0.06	0.518
Shrubs	0.57 ± 0.09	0.37 ± 0.11	0.63 ± 0.08	0.143
Herbaceous	0.53 ± 0.09	0.57 ± 0.04	0.55 ± 0.12	0.944
Simpson's evenness index ($E_{1/D}$)				
Total evenness	0.27 ± 0.04	0.32 ± 0.04	0.33 ± 0.03	0.404
Growth-form				
Trees	0.62 ± 0.08	0.67 ± 0.12	0.46 ± 0.04	0.200
Shrubs	0.65 ± 0.07	0.46 ± 0.11	0.59 ± 0.08	0.336
Herbaceous	0.50 ± 0.08 ab	0.34 ± 0.05 b	0.69 ± 0.11 a	0.018*

* Significant differences at $p \leq 0.05$.
** Significant differences at $p \leq 0.01$.

The highest importance value corresponded to the *Quercus* taxa in Oak-stands (about 33%), despite these taxa also presented a considerable value in Eucalyptus-stands (about 12%) (Table 4.2). Trees and shrubs jointly represented 87% of the total importance value in Eucalyptus-stands, while herbaceous plants (about 70%) were clearly dominant in Olive-stands (Table 4.2). It is worth noting that *Ruscus aculeatus* (Annex V of the Habitats Directive) was found in both Oak- and Eucalyptus-stands, but with a higher importance value in the former. Table 4.2 also illustrates the importance of the two invasive *Acacia* species (*Acacia melanoxylon* and *Acacia dealbata*) in the Eucalyptus-stands, which together represented almost 9% of the total importance value.

Table 4.2 - Importance value (IV) of the vascular plant taxa found in the three landscape types (only the 15 taxa with highest values are recorded).

Oak-stands		Olive-stands		Eucalyptus-stands	
Taxa	**IV (%)**	**Taxa**	**IV (%)**	**Taxa**	**IV (%)**
Quercus suber	24.58	*Olea europaea* subsp. *europaea*	11.64	*Eucalyptus globulus*	26.09
Quercus faginea subsp. *broteroi*	8.19	*Brachypodium distachyon*	7.97	*Rubus ulmifolius*	10.06
Rubus ulmifolius	7.10	*Dactylis glomerata*	7.57	*Acacia melanoxylon*	7.43
Hedera maderensis subsp. *iberica*	6.45	*Hyparrhenia hirta*	5.43	*Ulex europaeus* subsp. *latebracteatus*	7.15
Laurus nobilis	4.36	*Crataegus monogyna*	4.59	*Lonicera periclymenum*	6.86
Lonicera periclymenum	3.98	*Poa pratensis*	3.09	*Quercus suber*	6.28
Rosa canina	2.87	*Rhamnus alaternus*	3.05	*Quercus faginea* subsp. *broteroi*	5.66
Rubia peregrina	2.81	*Asparagus aphyllus*	2.74	*Hedera maderensis* subsp. *iberica*	3.71
Dactylis glomerata	2.38	*Avena alba*	2.59	*Rubia peregrina*	2.54
Osyris alba	2.26	*Dittrichia viscosa*	2.50	*Rosa canina*	2.00
Geranium purpureum	2.09	*Rubia peregrina*	2.46	*Tamus communis*	1.77
Briza maxima	2.08	*Origanum virens*	2.41	*Oxalis corniculata*	1.66
Daphne gnidium	1.99	*Rosa canina*	1.99	*Acacia dealbata*	1.39
Ruscus aculeatus	1.81	*Vicia sativa*	1.92	*Pinus pinaster*	1.33
Crataegus monogyna	1.78	*Rubus ulmifolius*	1.83	*Crataegus monogyna*	1.30

4.4.3. Macromycete inventory

Overall, 6 109 fruit bodies were recorded in the three landscape types during the two consecutive fruiting seasons (Table 4.3). We registered 96 taxa consisting of 36 ectomycorrhizal fungi and 60 saprobic fungi (Appendix 4.B); the genera *Russula* (9 taxa), *Amanita* (6 taxa), *Mycena* (5 taxa), and *Scleroderma* (5 taxa) were the best represented. Macromycetes of economic interest were represented by several edible species (Appendix 4.B) and three medicinal species: *Fomes fomentarius, Schizophyllum commune*, and *Trametes versicolor*.

Table 4.3 - Total macromycete taxa and fruit bodies, over the two years of fruiting seasons, for the three landscape types.

Community	Oak-stands		Olive-stands		Eucalyptus-stands	
	Taxa	Fruit bodies	Taxa	Fruit bodies	Taxa	Fruit bodies
Ectomycorrhizal	29	697	1	22	13	1 883
Saprobic	43	879	30	1 149	40	1 479
Total	72	1 576	31	1 171	53	3 362
% ectomycorrhizal fungi in macromycetes community	40	44	3	2	25	56

4.4.4. Macromycete richness and diversity

Macromycetes diversity and abundance were distinct in the three landscape types. The species richness of the macromycete community was statistically different, with higher values found in Oak-stands, in particular, for the ectomycorrhizal fungi community (Table 4.4). The saprobic community dominated in all landscape types in which, about 85% consisted of basidiomycetes. As a macromycete group, ectomycorrhizal fungi include a wide range of ascomycetes and basidiomycetes with different host specificity (Molina *et al.*, 1992), but in this study only basidiomycetes were recorded.

Table 4.4 - Descriptive statistics of different diversity indices for macromycete communities present in the three landscape types. Values are means ± SE.

	Oak-stands	Olive-stands	Eucalyptus-stands	*p*
Mean species richness (S)				
Total species	59 ± 3 a	22 ± 9 b	48 ± 4 ab	0.037*
Community				
Ectomycorrhizal	24 ± 2 a	1 ± 0 c	11 ± 3 b	0.007**
Saprobic	35 ± 1	21 ± 9	36 ± 1	0.195
Mean abundance (A)				
Total abundance	788 ± 70	586 ± 138	1682 ± 489	0.147
Community				
Ectomycorrhizal	349 ± 96	11 ± 10	942 ± 266	0.059
Saprobic	439 ± 25	575 ± 128	719 ± 205	0.467
Shannon's diversity index (H')				
Total diversity	4.70 ± 0.09	3.25 ± 0.46	3.62 ± 0.08	0.068
Community				
Ectomycorrhizal	3.22 ± 0.12 a	0.00 ± 0.00 c	1.36 ± 0.02 b	0.000**
Saprobic	4.11 ± 0.01	3.20 ± 0.42	4.19 ± 0.11	0.114
Simpson's diversity index (1/D)				
Total diversity	16.26 ± 2.76 a	6.86 ± 1.56 ab	5.40 ± 0.08 b	0.045*
Community				
Ectomycorrhizal	6.40 ± 1.24 a	1.00 ± 0.00 b	1.85 ± 0.08 b	0.024*
Saprobic	11.01 ± 0.53	6.63 ± 1.36	12.99 ± 1.33	0.062
Pielou's evenness index (J')				
Total evenness	0.80 ± 0.02 a	0.76 ± 0.00 a	0.65 ± 0.00 b	0.011*
Community				
Ectomycorrhizal	0.70 ± 0.04	- - -	0.40 ± 0.04	0.043*
Saprobic	0.81 ± 0.01	0.76 ± 0.02	0.81 ± 0.02	0.131
Simpson's evenness index ($E_{1/D}$)				
Total evenness	0.06 ± 0.01	0.15 ± 0.04	0.19 ± 0.00	0.055
Community				
Ectomycorrhizal	0.16 ± 0.03	- - -	0.54 ± 0.02	0.011*
Saprobic	0.09 ± 0.00	0.16 ± 0.03	0.08 ± 0.01	0.116

* Significant differences at $p \leq 0.05$
** Significant differences at $p \leq 0.01$.

Clumped distribution of fruit bodies in the Oak-stands was particularly noticeable for the ectomycorrhizal species *Astraeus hygrometricus* and *Laccaria laccata*, with 212 and 101 fruit bodies, respectively, and the saprobic species *Marasmius oreades*, with 206 fruit bodies. These three species together accounted for 33% of the total fruit bodies observed.

Although not significant, the Eucalyptus-stands showed higher fructification values (Table 4.4), particularly due to the abundance of *Laccaria laccata*, with 1 345 fruit bodies evenly distributed in the plots. Clumped distribution of fruit bodies in the Eucalyptus-stands was particularly evident for the saprobic species *Coprinellus micaceus* and *Cyathus striatus,* with 209 and 174 fruit bodies, respectively. These two species together accounted for 11% of the total community.

Patchiness in the ectomycorrhizal and saprobic fungal community was consistently observed during the two years study in the Oak- and Eucalyptus-stands. Olive-stands registered the lowest fructification with about 32% of the total macromycetes taxa (across all sites) (Table 4.3). The saprobic community was represented by 30 taxa. The clumped distribution of fruit bodies was observed for *Marasmius oreades*, with 347 fruit bodies, that accounted for 30% of the total fruit bodies. The species *Scleroderma polyrhizum* was the only ectomycorrhizal fungi present in these stands.

Significant differences were noticed in the Shannon diversity index for the ectomycorrhizal community, with the highest values obtained in the Oak-stands (Table 4.4). The Simpson diversity index exposed significant differences between the three landscape types for the total macromycetes diversity and the ectomycorrhizal community, also with highest values registered in Oak-stands (Table 4.4). The Pielou and Simpson evenness indices showed different distribution patterns between the three landscape types and communities (Table 4.4).

4.5. Discussion

Although the total area allocated to periurban land in the Santa Clara Plateau has remained substantially the same in recent decades, the patterns of agriculture and forest uses have led to important changes in the establishment and spatial dominance of plant communities.

The overall results obtained from this study revealed the presence of a considerable diversity of plants and macromycetes in the Santa Clara Plateau, an urban green space. In total, 287 taxa of vascular plants (Appendix 4.A) and 96 taxa of macromycetes (Appendix 4.B) were recorded, 37.5 % of them ectomycorrhizal. The diversity of vascular plants found in the Santa Clara Plateau represents 8.7% of the total taxa found in Portugal (Sequeira *et al.*, 2011). With regard to macromycete's communities, the diversity corresponds to 41% of the total taxa observed in old-growth Mediterranean forest dominated by *Quercus ilex* (Richard *et al.*, 2004) and 56% of the total taxa observed in managed woodlands dominated by *Quercus suber* (Azul *et al.*, 2009).

Moreover, 21% of the vascular plants and several macromycetes taxa observed in the Santa Clara Plateau may be of multiple potential interest (*e.g.*, food, aromatics, medicinal, wood, plant fitness, soil protection) (Appendix 4.A and Appendix 4.B), demonstrating that we should take into account not only the biological and ecological perspectives of the landscapes but also their potential products and environmental services with regard to future land use and urban life.

The plant diversity and richness indices showed similar trends among the landscape types, with variations in the overall stands depending on the dominant canopy. Although not significantly different, the highest values were found in the Olive-stands, declining as the tree canopy increased (Table 4.1 and Figure 4.3). When analysed by growth-forms, the Olive-stands showed the lowest and highest Shannon diversity index for trees and herbaceous plants, respectively (Table 4.1). Consistent with this result, previous studies have demonstrated that greater biodiversity may exist in open woodlands than in forests with closed canopies (Pérez-Ramos *et al.*, 2008; Peterson and Reich, 2008; Rad *et al.*, 2009), and that the ground flora in Olive-stands is dominated by herbaceous plants (Allen *et al.*, 2006). In contrast, the Eucalyptus-stands showed the lowest and highest Shannon diversity index for herbaceous species and trees, respectively (Table 4.1). The small number of herbaceous taxa in Eucalyptus-stands was also evident in their importance values (Table 4.2). Fabião *et al.* (2002) also found that a small number of species prevailed in the understory cover in habitats dominated by *Eucalyptus* sp. In fact, our results suggest that the closed canopy observed in the stands may reduce the possibility of regeneration of the undergrowth due to the high growth rate and competitive advantage of *Eucalyptus* in terms of light, water, and nutrients (Carneiro *et al.*, 2008). The presence of some invasive taxa such as *Acacia* in these stands (Table 4.2) may also influence the growing conditions for herbaceous species (Marchante *et al.*, 2008). Cork oak showed a high capacity for regeneration (field observations) in this landscape, which is likely due to increased seed sources, probably because of the progressive abandonment of the commercial exploitation of *Eucalyptus* which may have allowed the habitat to follow the natural succession process.

Oak-stands showed the highest Simpson diversity index for shrubs (Table 4.1), including some native species such as *Asparagus aphyllus*, *Myrtus communis*, *Ruscus* *aculeatus*, *Smilax aspera,* and *Viburnum tinus*, which are species characteristic of *Quercus suber* forests (ALFA, 2004). In these stands, *Quercus suber* and *Quercus faginea* subsp. *broteroi* showed the highest importance values (Table 4.2), jointly representing 32%. The flora present in Oak-stands considerably increases the biological and conservation values of this type of habitat, which should be taken into consideration in any urban strategic planning. The biological and ecological importance associated to *Quercus suber* ecosystems is widely acknowledged (Pereira and Fonseca, 2003; Azul *et al.*, 2009; Azul, 2011), in addition to their socio-economic role and value to agroforestry and potential as sustainable management ecosystems (INE, 2009; Pereira *et al.*, 2009).

Regarding macromycetes, the diversity and richness indices also revealed clear differences depending on the landscape type, especially in the ectomycorrhizal macromycetes community (Table 4.4). The dominance of vegetation cover and the presence of a broad host range species may influence soil fungi fruiting patterns (Richard *et al.*, 2004; Azul *et al.*, 2009). In the Santa Clara Plateau, Oak-stands exhibited the highest ectomycorrhizal macromycetes's diversity values, and the species richness was 1.2 and 2.7 times higher than that of Eucalyptus- and Olive-stands, respectively. The ecological value provided by the ectomycorrhizal fungi in this type of landscape is broadly recognized in the literature (Azul *et al.*, 2009; Azul *et al.*, 2010). The significance of ectomycorrhizal fungi in balancing ecosystems can be highly relevant, since they can be used to increase plant resistance/tolerance to abiotic stresses (Ahonen-Jonnarth *et al.*, 2003; Finlay, 2008; Colpaert *et al.*, 2011), interact with soil bacteria (Frey-Klett *et al.* 2007), and protect against pathogenic fungi, bacteria and nematodes (Duchesne, 1994; Compant *et al.*, 2005; Wehner *et al.*, 2010), with the added advantage of improving the vegetative growth and nutrient status of the plant with which they established the symbiosis (Smith and Read, 2008). In addition, the extraradical mycelium of ectomycorrhizal fungi provides a direct pathway for translocation of photosynthetically derived carbon to microsites in the soil and a large surface area for interaction with other microorganisms (Finlay, 2008).

The ectomycorrhizal fungi fructification was higher in the Eucalyptus-stands (Table 4.3), mostly due to the species *Laccaria laccata*. However, we believe that the regeneration capacity of the cork oak found in these stands may also have contributed to increase macromycete's abundance. Some ectomycorrhizal species, such as *Laccaria laccata* and *Pisolithus tinctorius,* recorded in both Oak- and Eucalyptus-stands, form associations with a broader range of host plants (Parladé *et al.*, 1996). Other ectomycorrhizal fungi exhibit a much narrower host specificity, including host specificity of genus-species and species-species specificity, such as *Cortinarius trivialis* and *Russula amoenolens* with angiosperms, *Lactarius chrysorrheus* with *Quercus* sp., and *Scleroderma polyrhizum* with Mediterranean shrubs and trees in thermophilic areas. The Eucalyptus-stands shared seven ectomycorrhizal fungi with Oak-stands. The lower presence of ectomycorrhizal fungi in the Olive-stands is due to the fact that, contrary to what is observed for oaks or eucalyptus species, olive trees do not form ectomycorrhizal associations.

The processes influencing ectomycorrhizal fungi ecology and succession remain unclear, but the key role of host plants and land use is becoming increasingly recognized (Azul *et al.*, 2009; Diédhiou *et al.*, 2009 Bueé *et al.*, 2010). Saprobic fungi richness and abundance seemed to be less affected by vegetation composition. The greater abundance of saprobic fungi in the Eucalyptus-stands may be related to the accumulation of dead woody debris and the role they play in decomposition and nutrient-release processes suggested by Azul *et al.* (2009) and Azul *et al.* (2010).

The preservation of natural processes helps support a functioning city, prevent or mitigate environmental risks and improve well-being. Thus, biodiversity values and habitat conservation are important issues that should be considered for the planning of balanced ecosystems in this city.

4.6. Conclusions

In conclusion, our analysis provides new insights into wildlife and biological paramenters in three distinct landscapes types in a Mediterranean urban context, underlining four important findings regarding land use and the specific attributes of each habitat. Firstly, plant and macromycetes composition and diversity were clearly different and dependent on human intervention in recent decades. Secondly, the Oak-stands exhibited a large number of plant and macromycetes native taxa with high environmental and conservation value, particularly ectomycorrhizal fungi. Thirdly, our data demonstrated that in this climate, and when subjected to some level of abandonment, these areas revealed a high potential for regeneration, allowing for the establishment of a natural succession process towards a typical *Quercus suber* forest. Fourtly, the plant and macromycete communities revealed to be sensitive indicators of habitat quality in urban ecosystems. This is of high relevance, particularly for ectomycorrhizal fungi which are recognized as a pivotal component of soil in terrestrial ecosystems.

The area of the municipality of Coimbra presents physical contrasts that are crucial and conditional in the natural hazard and in the risks involved, such as flooding, landmass movements or wildfires (Tavares *et al.*, 2010).

Urban Oak-stands are nowadays represented only by very small, disperse fragments, highlighting the necessity to protect and manage them. Besides connecting humans to nature, these habitats provide additional benefits including cleaner air, resistance to fire and recreational areas.

Appendix 4.A - Vascular plant taxa recorded in the study area.

Taxa	English common names	Family	Potential uses/impacts
Allium roseum L. var. r*oseum*	Rosy garlic	Alliaceae	Ornamental
Pistacia lentiscus L.	Mastic, Lentisco	Anacardiaceae	Woodwork
Daucus carota L. subsp. *carota* L.	Wild carrot	Apiaceae	Edible (root)
Eryngium campestre L.	Sea holly, Field eryngo	Apiaceae	
Foeniculum vulgare Mill.	Fennel	Apiaceae	Edible, aromatic
Smyrnium olusatrum L.	Alexanders, Horse parsley	Apiaceae	Edible (leaves)
Thapsia villosa L.		Apiaceae	Ornamental
Torilis arvensis (Huds.) Link	Hedge parsley, Field hedge parsley, Spreading hedge parsley	Apiaceae	
Vinca difformis Pourret	Periwinkle	Apocynaceae	Medicinal, poisonous (monoterpene indole alcaloids)
Arisarum simorrhinum Durieu	Friar's cowl	Araceae	
Arisarum vulgare Targ.-Tozz.	Friar's cowl	Araceae	
Arum italicum Mill.	Lords-and-ladies, Cuckoo-pint	Araceae	Poisonous (aroin, calcium oxalate, cyanogenic glucosides, saponins), irritant for the mucous membranes
Hedera maderensis K. Koch ex A. Rutherf. subsp. *iberica* Mc Allister	Ivy, Common-ivy	Araliaceae	Ornamental, poisonous (triterpene saponins, sesquiterpenes, falcarinol). Causes contact dermatitis
Aristolochia sempervirens L.	Birthwort, Dutchman's pipe	Aristolochiaceae	Medicinal, poisonous (aristolochic acid and related alkaloids)
Asparagus aphyllus L.	Prickly asparagus	Asparagaceae	
Asparagus officinalis L.	Asparagus	Asparagaceae	Edible (young shoots)
Drimia maritima (L.) Stearn	Sea onion, Squill	Asparagaceae	Medicinal, poisonous (bufadienolides), raticide
Ruscus aculeatus L.	Butcher's broom, Box holly, Jew's myrtle	Asparagaceae	Ornamental, poisonous (steroidal saponins)
Asplenium adiantum-nigrum L.	Black sleepenwort	Aspleniaceae	Ornamental
Achillea ageratum L.	Sweet nancy	Asteraceae	Medicinal. Causes contact allergies
Andryala integrifolia L.	Rabbit's bread	Asteraceae	

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Anthemis arvensis L.	Corn chamomile, Mayweed, Scentless chamomile	Asteraceae	Weed
Arctotheca calendula (L.) Levyns.	Cape weed	Asteraceae	Ornamental, invasive
Bellis perennis L.	Daisy	Asteraceae	Ornamental
Carduncellus caeruleus (L.) C. Presl		Asteraceae	
Carduus tenuiflorus Curtis	Thistle	Asteraceae	
Carlina racemosa L.	Carlina thistle	Asteraceae	
Chamaemelum nobile (L.) All.	Chamomile	Asteraceae	
Cichorium intybus L.	Chicory, succory, witloof	Asteraceae	Medicinal, edible
Coleostephus myconis (L.) Reichenb. fil.	Chrysanthemum goblin, Chrysanthemum gold plate, Yellow daisy	Asteraceae	Weed
Conyza canadensis (L.) Cronq.	Horseweed, Mule-tail	Asteraceae	
Cotula australis (Spreng.) Hook.f.	Brass buttons	Asteraceae	
Crepis vesicaria L.	Beaked hawksbeard	Asteraceae	
Cynara humilis L.	Artichoke, Cardoon	Asteraceae	
Dittrichia viscosa (L.) W. Greuter	False yellowhead, Strong-smelling Inula	Asteraceae	
Erigeron karvinskianus DC.	Daisy, Daisy fleabane, Mexican daisy fleabane	Asteraceae	Ornamental, invasive
Galactites tomentosa Moench		Asteraceae	
Hypochaeris radicata L.	Spotted cat's ear, Hairy's cat's ear, Frogbit	Asteraceae	
Lactuca serriola L.	Prickly lettuce	Asteraceae	Poisonous (sesquiterpene lactones)
Leontodon taraxacoides (Vill.) Mérat	Lesser hawkbit	Asteraceae	
Leontodon taraxacoides subsp. *longirostris* Finch and P. D. Sell		Asteraceae	

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Pallenis spinosa (L.) Cass.	Spiny starwort	Asteraceae	
Phagnalon saxatile (L.) Cass.		Asteraceae	
Picris echioides L.	Bristly ox-tongue	Asteraceae	
Pseudognaphalium luteo-album (L.) Hilliard and B. L. Burtt	Jersey cudweed, Kettlehole cudweed	Asteraceae	
Pulicaria odora (L.) Reichenb.	Fleabane	Asteraceae	
Scolymus hispanicus L.	Golden thistle, Spanish oyster thistle	Asteraceae	
Senecio jacobaea L.	Common ragwort	Asteraceae	Medicinal, poisonous (pyrrolizidine alkaloids)
Senecio sylvaticus L.	Woodland ragwort, Heath groundsel	Asteraceae	Medicinal, poisonous (pyrrolizidine alkaloids)
Senecio vulgaris L.	Common groundsel, Old man in the Spring	Asteraceae	Medicinal, poisonous (pyrrolizidine alkaloids)
Sonchus asper (L.) Hill	Milk thistle	Asteraceae	
Sonchus oleraceus L.	Milk thistle	Asteraceae	Edible, foraging
Tolpis barbata (L.) Gaertner	European umbrella milkwort, Yellow hawkweed	Asteraceae	
Cynoglossum creticum Miller	Hond's tong	Boraginaceae	
Echium plantagineum L.	Paterson's curse, Salvation Jane, Lady Campbell weed	Boraginaceae	Melliferous, poisonous (pyrrolizidine alkaloids)
Echium tuberculatum Hoffmanns. and Link		Boraginaceae	Melliferous, poisonous (pyrrolizidine alkaloids)
Myosotis ramosissima Rochel	Common forget-me-not, Scorpion grass	Boraginaceae	
Cardamine hirsuta L.	Bittercress	Brassicaceae	
Hirschfeldia incana (L.) Lagr.-Foss.	Buchanweed, Mediterranean mustard, Shortpod mustard	Brassicaceae	Weed
Raphanus raphanistrum L.	Wild radish, Mediterranean radish	Brassicaceae	Edible
Rapistrum rugosum (L.) All.	Bastard Cabbage,Turnip weed, Wild turnip	Brassicaceae	Weed

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Sinapis alba L.	White mustard, Salad mustard	Brassicaceae	
Campanula rapunculus L.	Rampion	Campanulaceae	Ornamental
Jasione montana L.	Sheep's bit	Campanulaceae	Ornamental
Lonicera periclymenum L.	Honeysuckle, Woodbine	Caprifoliaceae	Ornamental, poisonous (berries - cyanogenic glucosides, saponins)
Viburnum tinus L.	Laurustinus	Caprifoliaceae	Ornamental
Cerastium glomeratum Thuill.	Mouse-ear chickweed	Caryophyllaceae	
Cerastium pumilum Curtis	Dwarf mouse-ear, European chickweed	Caryophyllaceae	
Polycarpon tetraphyllum (L.) L.	Four-leaved allseed, Fourleaf manyseed	Caryophyllaceae	
Silene gallica L.	Campion, Catchfly	Caryophyllaceae	
Silene vulgaris (Moench) Garcke	Campion, Catchfly	Caryophyllaceae	
Stellaria media (L.) Vill.	Chickweed	Caryophyllaceae	Edible
Beta vulgaris L.	Beetroot	Chenopodiaceae	Edible
Cistus crispus L.	Rock rose	Cistaceae	Ornamental, melliferous
Cistus monspeliensis L.	Rock rose	Cistaceae	Ornamental, melliferous
Cistus salviifolius L.	Sageleaf rockrose	Cistaceae	Ornamental, melliferous
Xolantha guttata (L.) Raf.	European frostweed, tuberaria, Spotted rockrose	Cistaceae	Ornamental, melliferous
Hypericum humifusum L.	Trailing St John's Wort	Clusiaceae	Ornamental, poisonous (dianthrones, hyperforin), skin-irritant
Hypericum perforatum L.	St Jonh's wort	Clusiaceae	Ornamental, poisonous (dianthrones, hyperforin), skin-irritant
Tradescantia fluminensis Vell.	Spider-lily, Spider-wort	Commelinaceae	Invasive
Convolvulus althaeoides L.	Hollyhock bindweed, Mallow bindweed	Convolvulaceae	Poisonous
Convolvulus arvensis L.	Field bindweed	Convolvulaceae	Poisonous

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Umbilicus rupestris (Salisb.) Dandy	Navel wort, Penny wort	Crassulaceae	
Cupressus lusitanica Mill.	Portuguese cypress, Mexican cypress, Cedar of Goa	Cupressaceae	Ornamental, allergenic, poisonous (monoterpenes, sesquiterpenes)
Carex peregrina Link	Sedge	Cyperaceae	
Carex depressa Link	Sedge	Cyperaceae	
Carex distachya Desf.	Sedge	Cyperaceae	
Carex divulsa Stokes	Sedge, Berkeley sedge, European grey sedge	Cyperaceae	
Carex flacca Schreb.	Sedge, Blue sedge	Cyperaceae	
Cyperus longus L.	Common galingale, Sweet galingale	Cyperaceae	Weed
Tamus communis L.	Black briony, murraim berries	Dioscoreaceae	Poisonous (steroid sponins, calcium oxalate raphides). Causes dermatitis
Dipsacus fullonum L.	Common teasel, Wild teasel, Fuller's teasel, Venuscup teasel	Dipsacaceae	
Scabiosa atropurpurea L.	Mournfull widow, Sweet scabious	Dipsacaceae	Ornamental
Arbutus unedo L.	Strawberry tree	Ericaceae	Edible (berries)
Calluna vulgaris (L.) Hull	Scotts heather	Ericaceae	Ornamental, melliferous
Erica arborea L.	Tree heath	Ericaceae	Ornamental, melliferous
Erica umbellata Loefl. ex L.	Dwarf spanish heath	Ericaceae	Ornamental, melliferous
Euphorbia characias L.	Spurge, Mediterranean spurge	Euphorbiaceae	Ornamental, poisonous
Acacia dealbata Link	Silver wattle, Mimosa	Fabaceae	Melliferous, invasive, allergenic (pollen)
Acacia longifolia (Andrews) Willd.	Sydney golden wattle, Sallow wattle	Fabaceae	Melliferous, invasive, allergenic (pollen)
Acacia melanoxylon R. Br.	Blackwood	Fabaceae	Melliferous, invasive, allergenic (pollen)
Anthyllis vulneraria L. subsp. *maura* (Beck) Maire	Kidney vetch	Fabaceae	
Cercis siliquastrum L.	Judas tree	Fabaceae	Ornamental

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Coronilla scorpioides (L.) W.D.J. Koch	Crown vetch	Fabaceae	Ornamental, poisonous (glycosides with cardiac activity,)
Cytisus striatus (Hill) Rothm.	Broom	Fabaceae	Ornamental, medicinal, melliferous, poisonous (quinolizidine alkaloids)
Genista triacanthos Brot.	Broom, Woodwaxen	Fabaceae	Melliferous, poisonous (quinolizidine alkaloids)
Lathyrus annuus L.	Vetchling	Fabaceae	Poisonous (non-protein amino acids)
Lathyrus aphaca L.	Yellow vetchling	Fabaceae	Poisonous (non-protein amino acids)
Lathyrus hirsutus L.	Singletary pea, Caley pea, Rough pea	Fabaceae	Poisonous (non-protein amino acids)
Lathyrus sphaericus Retz.	Grass pea	Fabaceae	Poisonous (non-protein amino acids)
Lathyrus sylvestris L.	Flat pea, Narrow-leaved everlasting pea	Fabaceae	Poisonous (non-protein amino acids)
Lathyrus tingitanus L.	Tangier pea	Fabaceae	Ornamental, poisonous (non-protein amino acids)
Lotus angustissimus L.	Slender bird's foot trefoil	Fabaceae	Poisonous (cyanogenic glycosides)
Medicago doliata Carmign.	Medic, Medick	Fabaceae	
Medicago lupulina L.	Black medick, Hop clover, Nonsuch	Fabaceae	
Medicago minima (L.) L.	Medic, Medick	Fabaceae	
Medicago orbicularis (L.) Bartal.	Medic, Medick	Fabaceae	
Melilotus indicus (L.) All.	Indian sweet clover, Sour clover, Small-flowered melilot	Fabaceae	Poisonous (coumarins)
Ononis reclinata L.	Rest-harrow	Fabaceae	
Ononis viscosa L.	Rest-harrow	Fabaceae	
Ornithopus compressus L.	Yellow serradella	Fabaceae	
Scorpiurus muricatus L.	Prickly scorpion's-tail, Many-flowered Scorpiurus	Fabaceae	
Scorpiurus vermiculatus L.	Single-flowered Scorpiurus	Fabaceae	
Spartium junceum L.	Spanish broom, Weaver's broom	Fabaceae	Ornamental, poisonous (quinolizidine alkaloids)

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Trifolium angustifolium L.	Narrow-leaved clover, Narrowleaf crimson clover	Fabaceae	Foraging, melliferous
Trifolium arvense L.	Haresfoot clover, Rabbitfoot clover, Stone clover	Fabaceae	Foraging, melliferous
Trifolium campestre Schreb.	Low Hop Clover, Field Clover, Large Hop Clover	Fabaceae	Foraging, melliferous
Trifolium dubium Sibth.	Suckling clover, Lesser yellow trefoil	Fabaceae	Foraging, valuable as nitrogen-fixing, melliferous
Trifolium repens L.	White clover, Dutch clover, Shamrock	Fabaceae	Foraging, poisonous (benzofuranocoumarins, isoflavones)
Trifolium tomentosum L.	Wooly clover	Fabaceae	Foraging, melliferous
Ulex europaeus L. subsp. *latebracteatus* (Mariz) Rothm.	Gorse, Common gorse	Fabaceae	Melliferous, poisonous (quinolizidine alkaloids)
Ulex minor Roth	Dwarf furze, Dwarf gorse	Fabaceae	Melliferous, poisonous (quinolizidine alkaloids)
Vicia angustifolia L.	Vetch, Tare	Fabaceae	
Vicia benghalensis L.	Vetch, Tare	Fabaceae	
Vicia disperma DC.	Vetch, Tare	Fabaceae	
Vicia sativa L.	Spring vetch, Tare	Fabaceae	Foraging, poisonous (glycosides of pyrimidines, non-protein amino acids)
Castanea sativa Mill.	Sweet chestnut, Spanish chestnut	Fagaceae	Edible (nuts), medicinal, ornamental, woodwork
Quercus coccifera L.	Kermes oak, Grain oak	Fagaceae	Poisonous (tanins and other polyphenols)
Quercus faginea Lam. subsp. *broteroi* (Cout.) A. Camus	Portuguese oak	Fagaceae	Woodwork, tanning, allergenic, poisonous (tanins and other polyphenols)
Quercus pyrenaica Willd.	Pyrenean oak, Spanish oak	Fagaceae	Woodwork, tanning, allergenic (pollen), poisonous (tanins and other polyphenols)
Quercus robur L.	English oak, Common oak, Pedunculate oak	Fagaceae	Medicinal, woodwork, allergenic (pollen), tanning, poisonous (tanins and other polyphenols)
Quercus suber L.	Cork oak	Fagaceae	Cork production, edible (acorns), allergenic (pollen), tanning, poisonous (tanins and other polyphenols)

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Blackstonia perfoliata (L.) Hudson	Yellow wort	Gentianaceae	
Centaurium erythraea Rafn	Common centaury, European centaury	Gentianaceae	Poisonous (secoiridoids)
Centaurium maritimum (L.) Fritsch	Yellow centaury	Gentianaceae	Rare, poisonous (secoiridoids)
Centaurium tenuiflorum (Hoffmanns. and Link) Fritsch	Yellow star thistle, Geeldissel, Golden star thistle	Gentianaceae	Poisonous (secoiridoids)
Erodium cicutarium (L.) L'Herit.	Storksbill, Heron's bill	Geraniaceae	
Geranium columbinum L.	Long stalked cranes bill	Geraniaceae	
Geranium dissectum L.	Cranesbill, Wild geranium, Cut leaved geranium	Geraniaceae	
Geranium lucidum L.	Shining crane's bill, Shining geranium	Geraniaceae	
Geranium purpureum Vill.	Herb Robert, Robert geranium	Geraniaceae	
Geranium rotundifolium L.	Round-leaved geranium, Round-leaved crane's bill	Geraniaceae	
Pteridium aquilinum (L.) Kuhn	Bracken, Brake	Hypolepidaceae	Poisonous (ptaquiloside, thiaminase)
Gladiolus illyricus W. D. J. Kock	Wild gladiolus	Iridaceae	Ornamental
Iris foetidissima L.	Roast beef plant, Stinking gladwyn	Iridaceae	Ornamental, poisonous (safranal)
Juncus bufonius L.	Toad rush	Juncaceae	
Luzula campestris (L.) DC.	Field wood-rush	Juncaceae	
Calamintha sylvatica Bromf.	Common calamint	Lamiaceae	Aromatic, spice
Clinopodium vulgare L.	Wild basil, cushion calamint	Lamiaceae	Ornamental
Lavandula pedunculata (Miller) Cav.	French lavender	Lamiaceae	Ornamental, aromatic, melliferous
Melissa officinalis L.	Bee balm, Lemon balm	Lamiaceae	Medicinal, aromatic
Mentha pulegium L.	Pennyroyal	Lamiaceae	Medicinal, aromatic
Mentha rotundifolia (L.) Huds.	False apple mint, Round leaved mint	Lamiaceae	Aromatic
Micromeria graeca (L.) Reichenb.		Lamiaceae	Aromatic, spice

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Origanum virens Hoffmanns. & Link		Lamiaceae	Spice
Origanum vulgare L.	Wild marjoram, Oregano	Lamiaceae	Aromatic, spice
Prunella vulgaris L.	Common selfheal	Lamiaceae	
Salvia verbenaca L.	Vervain, Wild clary	Lamiaceae	Ornamental, melliferous
Stachys arvensis (L.) L.	Betony, Hedge nettle	Lamiaceae	Melliferous
Stachys germanica L.	Downy woundwort	Lamiaceae	Ornamental, melliferous
Thymus vulgaris L.	Common thyme, Garden thyme	Lamiaceae	Aromatic, spice, melliferous
Laurus nobilis L.	True laurel, Bay laurel, Sweet bay	Lauraceae	Spice
Linum bienne Miller	Pale flax	Linaceae	Poisonous (cyanogenic glucisides, podophyllotoxin, saponins)
Linum setaceum Brot.	Flax	Linaceae	Poisonous (cyanogenic glucisides, podophyllotoxin, saponins)
Linum strictum L.	Flax	Linaceae	Poisonous (cyanogenic glucisides, podophyllotoxin, saponins)
Lavatera arborea L.	Tree mallow	Malvaceae	Ornamental
Lavatera trimestris L.	Annual mallow, English rose mallow, Royal mallow	Malvaceae	Ornamental
Malva sylvestris L.	Tall mallow, High mallow, Cheeses	Malvaceae	Ornamental
Eucalyptus globulus Labill.	Tasmanian blue gum, Blue gum	Myrtaceae	Medicinal, pulp production
Myrtus communis L.	Myrtle	Myrtaceae	Ornamental
Fraxinus angustifolia Vahl	Ash, Narrow leaved ash	Oleaceae	Ornamental, medicinal
Fraxinus excelsior L.	Common European ash	Oleaceae	Ornamental
Olea europaea L. subsp. europaea L.	Common olive, Edible olive	Oleaceae	Edible (olives, olive oil), allergenic (pollen)
Olea europea L. var. *sylvestris* (Miller) Lehr.	Common olive, Edible olive	Oleaceae	Allergenic (pollen)
Anacamptis pyramidalis (L.) Rich.	Pyramid orchid	Orchidaceae	Ornamental

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Serapias lingua L.	Tongue orchid	Orchidaceae	
Oxalis corniculata L.	Procumbent yellow sorrel, Creeping oxalis	Oxalidaceae	Poisonous
Oxalis pes-caprae L.	Bermuda buttercup, English-weed	Oxalidaceae	Invasive, poisonous (calcium oxalate)
Fumaria capreolata L.	Climbing Fumitory, Fumitory, White ramping fumitory	Papaveraceae	
Fumaria muralis Sond. ex W.D.J. Koch	Fumaria, Wall fumitory	Papaveraceae	
Papaver dubium L.	Poppy	Papaveraceae	
Papaver rhoeas L.	Corn poppy, Field poppy, Flanders poppy	Papaveraceae	
Phytolacca americana L.	Pokeweed, Skoke, Garget	Phytolaccaceae	Poisonous (lectins, triterpene saponins)
Pinus pinaster Aiton	Maritime pine	Pinaceae	Woodwork, edible (seeds)
Pinus pinea L.	Stone pine	Pinaceae	Woodwork, edible (seeds)
Pittosporum undulatum Vent.	Victorian box, Cheesewood	Pittosporaceae	Ornamental, invasive
Plantago afra L.	Flea wort	Plantaginaceae	Allergenic (pollen)
Plantago lanceolata L.	English plantain, Ribwort, Buckhorn	Plantaginaceae	Allergenic (pollen)
Plantago serraria L.	Plantain	Plantaginaceae	Allergenic (pollen)
Agrostis curtisii Kerguélen	Bristle bent	Poaceae	Allergenic (pollen)
Aira praecox L.	Early hair grass	Poaceae	
Arrhenatherum elatius (L.) P. Beauv.	False oat-grass, Tall oat-grass, Tall meadow oat	Poaceae	
Arundo donax L.	Giant reed	Poaceae	Ornamental
Avena alba L.	Oat	Poaceae	
Brachypodium distachyon (L.) P. Beauv.	False brome, Purple false brome, Stiff brome	Poaceae	

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Brachypodium phoenicoides (L.) Roemer and Schultes	Thinleaf false brome	Poaceae	
Briza maxima L.	Great quaking grass	Poaceae	Ornamental
Briza media L.	Common quaking grass, didder	Poaceae	Ornamental
Briza minor L.	Lesser quaking grass	Poaceae	Ornamental
Bromus diandrus Roth	Brome, Chess	Poaceae	
Bromus hordeaceus L.	Brome, Chess	Poaceae	
Bromus rigidus Roth	Brome, Chess	Poaceae	
Cynodon dactylon (L.) Pers.	Bermuda grass, Bahama grass, kweek	Poaceae	
Cynosurus echinatus L.	Rough dog's tail grass	Poaceae	
Dactylis glomerata L.	Cocksfoot, Orchard grass	Poaceae	Allergenic (pollen)
Dactylis glomerata L. subsp. *hispanica* (Roth) Nyman	Cocksfoot, Orchard grass	Poaceae	Allergenic (pollen)
Gastridium ventricosum (Gouan) Schintz and Tell.	Nit grass	Poaceae	
Hordeum murinum L.	Barley	Poaceae	
Hordeum secalinum Schreber	Barley	Poaceae	
Hyparrhenia hirta (L.) Stapf	Thatching grass, Coolatai grass	Poaceae	
Lolium rigidum Gaudin	Ryegrass, Darnel	Poaceae	Allergenic (pollen)
Melica uniflora Retz.	Wood melic	Poaceae	
Periballia involucrata (Cav.) Janka		Poaceae	
Phalaris aquatica L.	Toowomba canary grass, Harding grass	Poaceae	
Phalaris arundinacea L.	Reed canary grass, Gardener's garter	Poaceae	
Phleum pratense L.	Timothy grass	Poaceae	Allergenic (pollen)

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Piptatherum miliaceum (L.) Cosson	Smilo grass	Poaceae	
Poa annua L.	Annual bluegrass, Annual meadow grass	Poaceae	Allergenic (pollen)
Poa pratensis L.	Kentucky blue grass, June grass	Poaceae	Allergenic (pollen)
Poa trivialis L.	Meadowgrass, blue grass	Poaceae	Allergenic (pollen)
Polypogon viridis (Gouan) Breistr.	Beardless rabbitsfoot grass	Poaceae	
Pseudarrhenatherum longifolium (Thore) Rouy		Poaceae	
Vulpia muralis (Kunth) Nees		Poaceae	
Polygonum aviculare L.	Knotweed, Smartweed	Polygonaceae	Allergenic (pollen)
Rumex acetosa L.	Garden sorrel, Sour dock	Polygonaceae	Poisonous (anthraquinones, tanins, oxalates), allergenic (pollen)
Rumex bucephalophorus L.	Dock, Sorrel	Polygonaceae	Poisonous (anthraquinones, tanins, oxalates), allergenic (pollen)
Rumex conglomeratus Murray	Dock, Sorrel	Polygonaceae	Poisonous (anthraquinones, tanins, oxalates), allergenic (pollen)
Rumex crispus L.	Curled dock	Polygonaceae	Poisonous (anthraquinones, tanins, oxalates), allergenic (pollen)
Polypodium vulgare L.	Common polypody, Adder's fern, Wall fern	Polypodiaceae	Ornamental
Anagallis arvensis L.	Scarlet pimpernel, Shepperd's clock	Primulaceae	Ornamental, poisonous (cucurbitacins, oxalates, triterpene saponins)
Anagallis monelli L.	Blue pimpernel	Primulaceae	Ornamental
Clematis campaniflora Brot.	Virgin's bower, Leather flower	Ranunculaceae	Ornamental
Ranunculus bulbosus L. subsp. *aleae* (Willk.) Rouy and Foucaud	Buttercup, Crowfoot	Ranunculaceae	Poisonous (protoanemonin)
Ranunculus muricatus L.	Buttercup, Crowfoot	Ranunculaceae	Poisonous (protoanemonin)

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Ranunculus parviflorus L.	Buttercup, Crowfoot	Ranunculaceae	Poisonous (protoanemonin)
Reseda luteola L.	Mignonette	Resedaceae	
Reseda media Lag.	Mignonette	Resedaceae	
Frangula alnus Mill.	Alder buckthorn	Rhamnaceae	Medicinal, poisonous (anthracene glycosides, anthranol derivatives, dianthrones)
Rhamnus alaternus L.	Buckthorn	Rhamnaceae	Medicinal, woodwork, tanning
Agrimonia eupatoria L.	Agrimony	Rosaceae	Medicinal
Aphanes arvensis L.	Parsley piert, Parsley breakstone	Rosaceae	
Crataegus monogyna Jacq.	English hawthorn	Rosaceae	Ornamental, medicinal
Cydonia oblonga Mill.	Quince, Portuguese quince	Rosaceae	Edible, medicinal
Eriobotrya japonica (Thunb.) Lindl.	Loquat, Japanese plum	Rosaceae	Edible (berries)
Geum urbanum L.	Avens, Chocolate root, Benedicte	Rosaceae	
Potentilla reptans L.	Cinquefoil, Five fingers	Rosaceae	
Prunus avium L.	Bird cherry, Sweet cherry, Gean	Rosaceae	Edible (drupes), ornamental
Prunus cerasifera cv. *atropurpurea* H. Jaeger	Cherry plum	Rosaceae	Edible (drupes), ornamental
Prunus cerasifera Ehrh.	Cherry plum, Myrobalan	Rosaceae	Edible (drupes), ornamental
Prunus spinosa L.	Sloe, Blackthorne	Rosaceae	Edible (drupes)
Pyrus communis L.	Common pear	Rosaceae	Edible (pomes)
Rosa canina L.	Dog rose, Dog brier	Rosaceae	
Rubus ulmifolius Schott.	Brumble	Rosaceae	Edible (aggregate fruit)
Sanguisorba minor Scop.	Burnet, Garden burnet	Rosaceae	Medicinal
Galium murale (L.) All.	Tiny bedstraw, Small goosegrass, Yellow wall bedstraw	Rubiaceae	
Rubia peregrina L.	Wild Madder, Levant Madder	Rubiaceae	
Sherardia arvensis L.	Field Madder, Spurwort	Rubiaceae	

Appendix 4.A - Continued.

Taxa	English common names	Family	Potential uses/impacts
Citrus reticulata Blanco	Mandarine orange, tangerine, lementine, satsuma	Rutaceae	Edible (hesperidium)
Citrus sinensis (L.) Osbeck	Orange, sweet orange	Rutaceae	Edible (hesperidium)
Osyris alba L.	Osyris	Santalaceae	Tanning
Digitalis purpurea L.	Purple foxglove	Scrophulariaceae	Medicinal, poisonous (cardenolides)
Kickxia spuria (L.) Dumort.	Roundleaf cancerwort, Roundleaf fluellen	Scrophulariaceae	
Misopates orontium (L.) Raf.	Weasel's Snout	Scrophulariaceae	
Scrophularia grandiflora DC.	Figwort	Scrophulariaceae	Poisonous (active principle unknown)
Verbascum sinuatum L.	Wavyleaf mullein, Scalop-leaved mullein	Scrophulariaceae	
Verbascum virgatum Stokes	Twiggy Mullein	Scrophulariaceae	Ornamental
Veronica arvensis L.	Speedwell, Bird's Eye	Scrophulariaceae	
Ailanthus altissima (Miller) Swingle	Tree of heaven	Simaroubaceae	Invasive
Smilax aspera L.	Common Smilax, Prickly ivy, Rough Smilax, Salsaparilla	Smilacaceae	Medicinal
Solanum sublobatum Willd. ex Roem. and Schult.	Black nightshade, Poisonberry	Solanaceae	Poisonous (steroidal glyco-alkaloids)
Daphne gnidium L.	Flax-leaved Daphne, Spurge-flax	Thymelaeaceae	Poisonous (phorbol esters, coumarin glycosides), skin irritant
Ulmus minor Mill.	Eurpean fiel elm, Smooth-leaved elm	Ulmaceae	Woodwork, medicinal, allergenic (pollen)
Parietaria judaica L.	Pellitory of the wall	Urticaceae	Allergenic
Urtica dioica L.	Stinging nettle	Urticaceae	Edible, medicinal, skin irritant
Centranthus calcitrapae (L.) Dufr.	Annual valerian, Pink valerian, Cut-leaved valerian	Urticaceae	
Verbena officinalis L.	Common verbena	Valerianaceae	Medicinal
Vitis vinifera L.	Common grape vine	Verbenaceae	Edible (grapes, wine)

Appendix 4.B - Macromycete taxa recorded in the study area.

Taxa	**Family**	**Host Range**	**Edibility**
Agaricus arvensis Schaeff.	Agaricaceae	Saprobic	Edible
Agaricus campestris L.	Agaricaceae	Saprobic	Edible
Agaricus xanthodermus Genev.	Agaricaceae	Saprobic	Not edible, poisonous
Bovista plumbea Pers.	Agaricaceae	Saprobic	Edible at young stage
Coprinus comatus (O.F. Müll.) Pers.	Agaricaceae	Saprobic	Edible
Coprinus plicatilis (Curtis) Fr.	Agaricaceae	Saprobic	Not edible
Cyathus striatus (Huds.) Willg.	Agaricaceae	Saprobic	Not edible
Lepiota clypeolaria (Bull.) P. Kumm.	Agaricaceae	Saprobic	Not edible, poisonous
Lycoperdon perlatum Pers.	Agaricaceae	Saprobic	Edible at young stage
Macrolepiota procera (Scop.) Singer	Agaricaceae	Saprobic	Edible, excellent
Rickenella fibula (Bull.) Raithelh	Agaricomycetes	Saprobic	Not edible
Amanita citrina (Schaeff.) Pers.	Amanitaceae	ECM/Broad HR	Not edible
Amanita muscaria (L.) Lam.	Amanitaceae	ECM/Broad HR	Not edible, poisonous
Amanita pantherina (DC.) Krombh.	Amanitaceae	ECM/Broad HR	Not edible, poisonous
Amanita phalloides (Vaill. ex Fr.) Link	Amanitaceae	ECM/Broad HR	Not edible, mortal
Amanita rubescens Pers.	Amanitaceae	ECM/Broad HR	Edible
Amanita vaginata (Bull.) Lam.	Amanitaceae	ECM/Broad HR	Edible
Boletus chrysenteron Bull.	Boletaceae	ECM/Broad HR	Edible
Boletus subtomentosus L.	Boletaceae	ECM/Broad HR	Edible
Cantharellus lutescens Fr.	Cantharellaceae	ECM/Broad HR	Edible, excellent
Cortinarius trivialis J.E. Lange	Cortinariaceae	ECM/Angiosperms	Not edible
Calocera cornea (Batsch) Fr.	Dacrymycetaceae	Saprobic	Not edible
Astraeus hygrometricus (Pers.) Morgan	Diplocystidiaceae	ECM/Broad HR	Not edible
Bisporella citrina (Batsch) Korf and S.E. Carp.	Diplocystidiaceae	Saprobic	Not edible
Ramaria formosa (Pers.) Quél.	Gomphaceae	Saprobic	Not edible, purgative
Ramaria stricta (Pers.) Quél.	Gomphaceae	ECM/Broad HR	Edible, low value
Chroogomphus rutilus (Schaeff.) O. K. Mill.	Gomphidiaceae	ECM/Broad HR	Edible
Hydnum repandum L.	Hydnaceae	ECM/Broad HR	Edible
Laccaria laccata (Scop.) Cooke	Hydnangiaceae	ECM/Broad HR	Edible
Hygrocybe conica (Scop.) P. Kum.	Hygrophoraceae	Saprobic	Not edible
Inonotus radiatus (Sowerby) P. Karst.	Hymenochaetaceae	Saprobic	Not edible
Crepidotus variabilis (Pers.) P. Kumm.	Inocybaceae	Saprobic	
Inocybe sp1	Inocybaceae	ECM/Broad HR	
Marasmius oreades (Bolton) Fr.	Marasmiaceae	Saprobic	Edible
Micromphale foetidum (Snowerby) Singer	Marasmiaceae	Saprobic	Not edible

Appendix 4.B - Continued.

Taxa	Family	Host Range	Edibility
Omphalotus illudens (Schwein.) Bresinsky and Besl	Marasmiaceae	Saprobic	Not edible, poisonous
Rhodocollybia butyracea (Bull.) Lennox	Marasmiaceae	Saprobic	Edible, low value
Abortiporus biennis (Bull.) Singer	Meruliaceae	Saprobic	
Mycena epipterygia (Pers.) P. Kumm.	Mycenaceae	Saprobic	Not edible
Mycena galopus (Pers.) P. Kumm.	Mycenaceae	Saprobic	
Mycena pura (Pers.) P. Kumm.	Mycenaceae	Saprobic	Not recommended, hallucinogenic properties
Mycena rorida (Fr.) Quél.	Mycenaceae	Saprobic	Not edible
Mycena seynesii Quél.	Mycenaceae	Saprobic	
Nectria cinnabarina (Tode) Fr.	Nectriaceae	Saprobic	Not edible
Pulcherricium caeruleum (Lam.) Parmasto	Phanerochaetaceae	Saprobic	Not edible
Armillaria mellea (Vahl) P. Kumm.	Physalacriaceae	Saprobic	Edible at young stage
Fomes fomentarius (L.) J.J. Kickx	Polyporaceae	Saprobic	Not edible, medicinal
Trametes hirsuta (Wulfen) Pilát	Polyporaceae	Saprobic	Not edible
Trametes versicolor (L.) Lloyd	Polyporaceae	Saprobic	Not edible, medicinal
Trichaptum abietinum (Dicks.) Ryvarden	Polyporaceae	Saprobic	Not edible
Coprinellus micaceus (Bull.) Vilgalys, Hopple and Jacq. Johnson	Psathyrellaceae	Saprobic	
Coprinopsis atramentaria (Bull.) Redhead, Vilgalys and Moncalvo	Psathyrellaceae	Saprobic	Not edible, poisonous when consumed with alcohol
Coprinopsis picacea (Bull.) Redhead, Vilgalys and Moncalvo	Psathyrellaceae	Saprobic	
Psathyrella velutina (Pers.) Singer	Psathyrellaceae	Saprobic	Not edible
Aleuria aurantia (Pers.) Fuckel	Pyronemataceae	Saprobic	Edible
Humaria hemisphaerica (F.H. Wigg.) Fuckel	Pyronemataceae	Saprobic	
Otidea cochleata (Huds.) Fuckel	Pyronemataceae	Saprobic	
Scutellinia scutellata (L.) Lambotte	Pyronemataceae	Saprobic	
Lactarius chrysorrheus Fr.	Russulaceae	ECM/Quercus sp	Edible
Lactarius deliciosus (L.) Gray	Russulaceae	ECM/Broad HR	Edible, excellent
Russula amoenolens Romagn.	Russulaceae	ECM/Angiosperms	
Russula cyanoxantha (Schaeff.) Fr.	Russulaceae	ECM/Broad HR	Edible
Russula delica Fr.	Russulaceae	ECM/Broad HR	Edible, low value
Russula nigricans (Bull.) Fr.	Russulaceae	ECM/Broad HR	Edible at young stage
Russula sp1	Russulaceae	ECM	
Russula sp2	Russulaceae	ECM	

Appendix 4.B - Continued.

Taxa	Family	Host Range	Edibility
Russula sp3	Russulaceae	ECM	
Russula virescens (Schaeff.) Fr.	Russulaceae	ECM/Broad HR	Edible
Russula xerampelina (Schaeff.) Fr.	Russulaceae	ECM/Broad HR	
Sarcoscypha coccinea (Jacq.) Sacc.	Sarcoscyphaceae	Saprobic	
Schizophyllum commune Fr.	Schizophyllaceae	Saprobic	Not edible, medicinal
Pisolithus tinctorius (Mont.) E. Fisch.	Sclerodermataceae	ECM/Broad HR	Edible at young stage
Scleroderma areolatum Ehrenb.	Sclerodermataceae	ECM/Broad HR	
Scleroderma bovista Fr.	Sclerodermataceae	ECM/Broad HR	
Scleroderma citrinum Pers.	Sclerodermataceae	ECM/Broad HR	
Scleroderma polyrhizum (J.F. Gmel.) Pers.	Sclerodermataceae	ECM/Thermophilic	
Scleroderma verrucosum (Bull.) Pers.	Sclerodermataceae	ECM/Broad HR	
Stereum hirsutum (Wild.) Pers.	Stereaceae	Saprobic	Not edible
Stereum reflexulum D.A. Reid	Stereaceae	Saprobic	Not edible
Gymnopilus junonius (Fr.) P.D. Orton	Strophariaceae	Saprobic	Not edible
Gymnopilus penetrans (Fr.) Murrill	Strophariaceae	Saprobic	Not edible
Hypholoma fasciculare (Huds.) P. Kumm.	Strophariaceae	Saprobic	Not edible, poisonous
Stropharia aurantiaca (Cooke) M. Imai	Strophariaceae	Saprobic	Not edible
Tremella foliacea Pers.	Tremellaceae	Saprobic	
Tremella mesenterica Retz.	Tremellaceae	Saprobic	
Clitocybe costata Kühner and Romagn.	Tricholomataceae	Saprobic	Edible
Clitocybe gibba (Pers.) P. Kumm.	Tricholomataceae	Saprobic	Edible
Clitocybe odora (Bull.) P. Kumm.	Tricholomataceae	Saprobic	Edible
Lepista nuda (Bull.) Cooke	Tricholomataceae	Saprobic	Edible
Lepista sordida (Fr.) Singer	Tricholomataceae	Saprobic	
Melanoleuca melaleuca (Pers.) Murrill	Tricholomataceae	Saprobic	Edible
Tricholoma fracticum (Britzelm.) Kreisel	Tricholomataceae	ECM/Broad HR	Edible only after cooked, low value
Tricholoma sulphureum (Bull.) P. Kumm.	Tricholomataceae	ECM/Broad HR	Not edible, poisonous
Tricholoma portentosum (Fr.) Quél.	Tricholomataceae	ECM/Broad HR	Edible
Lycogala epidendrum (J.C. Buxb. ex L.) Fr.	Tubiferaceae	Saprobic	Not edible
Xylaria hypoxylon (L.) Grev.	Xylariaceae	Saprobic	Not edible

ECM - Ectomycorrhizal; HR - Host Range.

Chapter 5

Biodiversity in urban forests and gardens and its contribution to improve the environmental quality of the city of Coimbra

5.1. Abstract

The preservation of urban green spaces has become important in the political agenda in many regions. Urban green spaces can play important roles on the protection of environmental quality improving air quality or reducing the energy costs of cooling buildings. They also provide services in which the leisure and sport facilities are available to urban dwellers, ultimately improving the quality of life. The purpose of this study was to evaluate plant and soil microorganisms diversity in two different types of green spaces (public gardens and urban forests) in the city of Coimbra. A total of 252 taxa of vascular plants were recorded within the two types of green spaces, belonging to 201 genera and 89 families dominated by Poaceae, Asteraceae and Fabaceae. The Shannon and Simpson diversity indices showed similar tendencies among growth-forms, and were significantly different for shrubs, with the forests presenting the highest values. The forests also showed a clear importance since they harbour taxa with high conservation and ecological value. Although the cluster analysis of the DGGE banding patterns did not showed significant differences among the soil bacterial and fungal communities from gardens and forests, the soil bacterial community richness was higher in forests. Therefore, an integrated approach regarding the planning, monitoring, designing, and maintenance of different types of urban green spaces is required to improve the environmental quality of the city of Coimbra.

Keywords

urban green spaces; gardens; forests; vascular plants; soil microorganisms; DGGE

5.2. Introduction

The urban green spaces and the ways in which these spaces can benefit cities and their residents has an increasingly relevant interest (Sandström, 2002; Tzoulas *et al.*, 2007). As defined in the Chapter 1, urban green spaces are "green spaces in urban areas, covered by vegetation and contribute as recreational and leisure areas, and for the environment quality" (CMC, 1993). As reported in the Municipal Master Plan of Coimbra (1993), two typologies of green spaces can be distinguished: green spaces for public use and green spaces for the protection of environmental quality. The first typology is dedicated to recreation and leisure and to be enjoyed by the entire population, such as the gardens and parks. Belonging to the second typology, the forests are used to protect the biophysical stability of the steep slopes, cropland areas and waterlines as well as road infrastructures.

Urban green spaces provide a wide range of services and are likely to become more important for achieving sustainable development and maintaining and enhancing the quality of life for citizens and environmental quality (Thwaites *et al.*, 2005; Wolch *et al.*, 2014). There is a broad agreement about the value of green spaces in cities, as presently constructed, as well as on its importance in planning ecological and sustainable cities (Heidt and Neef, 2008). Cities will have to cope with climate change, and the green spaces can greatly improve the urban microclimate, as they will reduce the harmful effects of air warming by mitigating the heat island effect (Dimoudi and Nikolopoulou, 2003; Boukhabla and Alkama, 2012). Green spaces provide other benefits as reducing air pollution and improving air quality by filtering some dust, decrease the effect of runoff by intercepting rainfall, and protect against erosion (Heidt and Neef, 2008; Boukhabla and Alkama, 2012). They also provide opportunities for a wide range of leisure and sport activities (del Saz Salazar and Menéndez, 2007). It is known that regular contact with nature and green spaces enhance the mental health and influence the psychological well-being (Pretty *et al.*, 2007).

The human population has huge impacts on the local, regional, and global environments, particularly in urban areas where the concentration of people fragments and transforms the natural resources, often resulting in drastic environmental consequences (Nowak *et al.*, 2001; Dislich and Pivello, 2002). This has negative impacts on the health and well-being of urban residents who live, work, and spend most of their leisure time in urban areas (Nowak *et al*., 2001). The access to green spaces is under threat within urban areas mainly due to the reclamation of land for construction, such as housing, office buildings, roadways, and other artificial structures. As the population grows and the urban area expands rapidly, the remaining green spaces are being shared among an increasing number of people (Kline, 2006). Green spaces need to be uniformly distributed throughout the city area and the total area occupied by these spaces should be large enough to accommodate the city population' needs (Haq, 2011).

Cities need to become more energy efficient and strike a balance between three fundamental goals: quality of life, economic competitiveness, and environmental protection (UN-Habitat, 2013). To achieve these goals, it is essential to follow the principles presented in Florence in October 2000 at the European Landscape Convention, where the Council of Europe quoted that to achieve sustainability, the development should be “based on a balanced and harmonious relationship between social needs, economic activity, and the environment” (Council of Europe, 2000). In order to achieve these goals, the World Urban Campaign, coordinated by UN-Habitat, launched the slogan “I’m a City Changer” with the aim of promoting sustainable urban development and creating awareness among citizens for a better urban future (see at unhabitat.org/urban-initiatives/world-urban-campaign). The "Urban Planning for City Leaders", is also an UN-Habitat initiative, and aims to provide local leaders and decision makers with the tools to support urban planning good practice. It also proposes to inform leaders about the value that urban planning could bring to their cities and to facilitate a collaborative dialogue between leaders, policy makers and planners on urban development (UN-Habitat, 2013).

The Horizon 2020 is the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness (see at ec.europa.eu/programmes/horizon2020). The Europe 2020 strategy sets out a vision of Europe's social market economy for the 21st century, putting forward three mutually reinforcing priorities: smart, sustainable, and inclusive growth (European Commission, 2010a). The smart growth aims to develop an economy based on knowledge and innovation. It propose improving the Europe's performance in: (1) education by encouraging people to learn, study, and update their skills; (2) research/innovation by creating new products/services that generate growth and jobs, and help address social challenges; and (3) digital society by using information and communication technologies.

Promoting a more resource efficient, greener, and more competitive economy are objectives of the sustainable growth. The sustainable growth means: (1) building a more competitive low-carbon economy that makes efficient, sustainable use of resources; (2) protecting the environment, reducing emissions and preventing biodiversity loss; (3) capitalizing on Europe's leadership in developing new green technologies and production methods; (4) introducing efficient smart electricity grids; (5) harnessing European-scale networks to give our businesses (especially small manufacturing firms) an additional competitive advantage; (6) improving the business environment, in particular for small and medium enterprises; and (7) helping consumers make well-informed choices. The inclusive growth aims to foster a high-employment economy delivering social and territorial cohesion. It signifies: (1) raising Europe's employment rate - more and better jobs, especially for women, young people, and older workers; (2) helping people of all ages anticipate and manage change through investment in skills and training; (3) modernizing labour markets and welfare systems; and (4) ensuring that benefits of growth reach all parts of the Europe.

The urban public green spaces began to emerge as part of the urban setting in the industrial revolution era (19th century) (Stormann, 1991). The urban park movement was created with the objective of improving the quality of urban life in the over-crowded conditions of the rapidly growing industrial cities (Jordan, 1994). This movement started in England, with the Victoria Park in 1841 (Newton, 1971) which is considered the first urban park in history (see at www.towerhamlets.gov.uk). Other emblematic project of such movement was the Central Park of New York City, built in 1858 (see at www.centralparknyc.org).

Studies about the planning of urban green spaces have also been made, as the project "Development of Urban Green Spaces to Improve the Quality of Life in Cities and Urban Regions" (URGE) that was accomplished from 2001 to 2004. This project was supported by the European Commission under the fifth framework programme with the key action "The city of tomorrow and cultural heritage" (CORDIS, 1998). The aim of the URGE project (see at www.urge-project.ufz.de) was to develop interdisciplinary tools for scientists as well as for planners all over Europe for the planning and management of urban green spaces. Therefore, it was designed to improve the provision of cities with green spaces, both qualitatively and quantitatively, thus enhancing the quality of life of the urban population and contributing to the sustainable development of European cities.

Different types of green spaces may lead to significant changes in the nature and dynamics of soil organic matter and associated nutrients (Turrión *et al*., 2001; Omidi *et al*., 2008), and consequently to significant changes in the composition and distribution of soil microorganisms communities (Donnison *et al*., 2000; Miller and Lodge, 2007; Miki *et al*., 2010). In natural ecosystems, soil nutrient cycling, soil structure, and other properties are substantially regulated by the activity of a highly diverse soil microorganisms community (Giller, 1996). On the other hand, plant cover and diversity are important components of urban ecosystems influencing the composition and abundance of associated biota (Matson *et al*., 1997; Antipina, 2003). Factors such as soil fertility, geographic position, climate, herbivory, and disturbance are known to influence plant species richness as well as the soil microorganisms, especially those that live in symbiosis with plants, contributing to plant diversity (van der Heijden *et al*., 2008).

Biodiversity is crucial for the functioning of ecosystems that support the provisioning of ecosystem services that ultimately affect human well-being. Conservation of biodiversity is essential as a source of particular biological resources to sustain different ecosystem services, to maintain the resilience of ecosystems in the face of a changing environment, and to provide options for the future (MEA, 2005b).

The tenth Conference of the Parties to the Convention on Biological Diversity (CBD), held in Nagoya in 2010, led to the adoption of a global Strategic Plan for biodiversity 2011-2020. This Strategic Plan includes, besides strategic goals, also 20 targets, known as the Aichi Biodiversity Targets (CBD, 2013). The Europe 2020 biodiversity target is underpinned by the recognition that, in addition to its intrinsic value, biodiversity and the services it provides have significant economic value that is seldom captured in markets (European Commission, 2011a). Take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet’s variety of life, and contributing to human well-being and poverty eradication. To ensure this, pressures on biodiversity are reduced, ecosystems are restored, biological resources are sustainably used, and benefits arising out of utilization of genetic resources are shared in a fair and equitable manner. Moreover, adequate financial resources are provided, capacities are enhanced, biodiversity issues and values mainstreamed, appropriate policies are effectively implemented, and decision-making is based on sound science and the precautionary approach (CBD, 2013).

In the municipality of Coimbra, the urban green spaces began to be considered as areas of ecological interest, being considered fundamental to the environmental balance itself, with the publication of the Municipal Master Plan in 1993. It defined as objectives the conservation of the environment and ecological balance, the preservation of the structure of agricultural production and plant cover, the preservation of water courses and natural drainage lines, the defense and protection of cultural and environmental heritage, the operation and expansion of infrastructure and equipment, and the implementation of the planned infrastructure or project (CMC, 1993).

The 1st Revision of the Municipal Master Plan came into force on 2 July 2014 with the broad guiding principles to stress the need for affirmation of Coimbra as a territory of high urban-environmental quality (National Official Journal, 2014). This revision aimed to reinforce the measures for the safeguard and valorization of the natural and landscape resources, with a strategic relevance for Coimbra sustainability, identity, and attractiveness. It also aimed to focus the urban policies in questions related to territory sustainability and humanization, making a strategic commitment in the revitalizing of environmental quality, in an integrated perspective of valorization of the biophysical components of green spaces.

Coimbra constitutes an highlighted municipality by its extent of green spaces where the leisure areas (gardens, parks, and sport and leisure facilities) and forests cover more than 40% of the total area (see Chapters 2 and 3). However, almost 90% of leisure areas and almost 20% of forests are located in the city area. The city of Coimbra is highly urbanized (327.4 buildings/km^2) and densely populated (1 343.9 habitants/km^2) where the leisure areas occupy only 2.1%, while forests cover 25.5% (see Chapter 3). Therefore, forests are important green spaces that can play an important role in improving the quality of urban environments as well as in maintaining the stability of the urban ecosystem in Coimbra.

The present work was conducted to evaluate the plants and soil microorganisms diversity in two typologies of urban green spaces. Therefore, a floristic survey and soil sampling were performed in public gardens and forests, located in the city of Coimbra.

This study also aimed to provide relevant information to help the planners on preserving and promoting the urban sustainability and making this city a more attractive place.

5.3. Material and Methods

5.3.1. Study area

The study was conducted in the right bank of the Mondego river in the city of Coimbra, between latitudes 40º9' N and 40º16' N, and longitudes 8º22' W and 8º30' W (Figure 5.1). The urban green spaces occupy almost 30% of the city area (see Chapter 3). Field sampling was conducted in two typologies of green spaces: public gardens (Figure 5.2) and urban forests dominated by oak trees (Figure 5.3). Public gardens are, in this context, managed green spaces with a mixture of grasses, larger trees and shrubs, mainly comprising ornamental plants. The selected Oak-stands are less managed areas dominated by *Quercus* taxa with many Mediterranean native taxa present. They are typically remnants of natural ecosystems where natural succession processes are unimpeded by human activities. In each typology of green space three sampling sites were selected (Figure 5.2 and Figure 5.3).

Penedo da Saudade has a geological formation composed of sands and gravels and a soil type consisting of Chromic Cambisols. The geological formation of the Quinta da Maia has composed of red stoneware, calcareous generally dolomitic and a soil type consisting of Lithosols Eutric associated with Luvisols. The other four green spaces have a geological formation composed of red stoneware, calcareous generally dolomitic and a soil type consisting of Chromic Cambisols (APA, 1971).

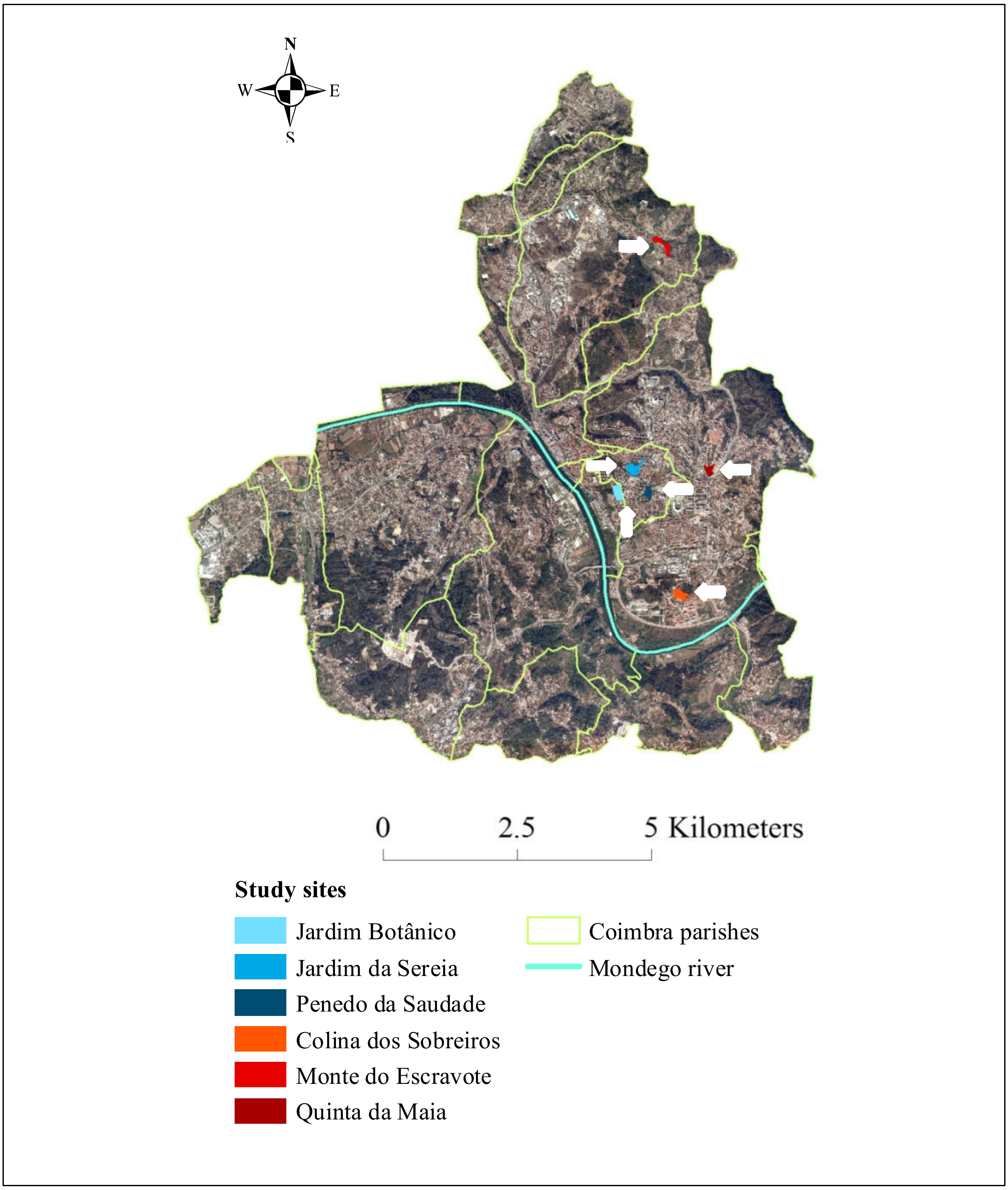


Figure 5.1 - Location of the study sites (white arrows) in the city of Coimbra (city area in 2011 - see Chapter 3).

Figure 5.2 - The three public gardens sampled in this study. Jardim Botânico (A), Jardim da Sereia (B), and Penedo da Saudade (C).

A

B

C

Figure 5.3 - The three urban forests sampled in this study. Colina dos Sobreiros (A), Monte do Escravote (B), and Quinta da Maia (C).

5.3.2. Floristic survey

The floristic survey was conducted in the spring of 2012. During this period, a quantitative floristic analysis was performed based on determining the presence and abundance of individual plant taxa in each sampling site. According to the methodology described by Mueller-Dombois and Ellenberg (1974) and Lindgren and Sullivan (2001), within each sampling site, 6 or 8 plots (Table 5.1) of 10 m x 10 m with nested plots of 4 m x 4 m and 2 m x 2 m were used for sampling trees, shrubs, and herbaceous taxa, respectively. In each plot, abundance (percentage cover) of each taxon was determined. For this study the tree growth-form included taxa that were either adult trees or seedlings. The shrub growth-form included all taxa designated as shrub or woody climbing taxa and the herbaceous growth-form comprised all taxa designated as herbaceous or non-woody climbing taxa.

Table 5.1 - Characteristics of the sampling sites.

Urban green spaces	Area (ha)	Number of plots
Gardens		
Jardim Botânico (JB)	4.3	8
Jardim da Sereia (JS)	4.4	8
Penedo da Saudade (PS)	3.1	6
Forests		
Colina dos Sobreiros (CS)	3.9	8
Monte do Escravote (ME)	3.1	6
Quinta da Maia (QM)	2.7	6

Plant taxa were identified according to Franco and Afonso (1971-2003) and Castroviejo *et al.* (1986-2010), and by consulting plant specimens from the Herbarium of University of Coimbra (COI). English common names and potential uses were described according to Huxley *et al*. (1992), Garrido-Lestache (2001), Cunha *et al*. (2003), Mabberley (2008), and Wink and van Wyk (2008). The invasive plant taxa were classified in accordance with the Portuguese law (Ministério do Ambiente, 1999).

5.3.3. Soil sampling

Soil samples (soil and the leaf litter layer) were collected from all sampling sites using a soil core sampler (diameter, 7.5 cm; length, 10 cm) in spring 2012. In each plot of

10 m x 10 m, used in the floristic survey, four soil cores were sampled. Then, soil samples were pooled (each layer separately), mixed, and placed in a plastic bag to be transported to the laboratory. Subsequently, samples were divided and used for soil chemical analyses and DNA extraction.

Samples for soil and leaf litter analysis were air-dried and stored at room temperature, while samples for DNA extraction were frozen at -20 ºC until analysis. To detect differences between bacteria and fungi communities per study site, samples were analysed by DGGE (Denaturing Gradient Gel Electrophoresis). This allowed us to evaluate the diversity behind bands with identical electrophoretic mobility in the bacteria and fungi communities' profiles.

5.3.4. Soil analysis

Soil available phosphorus (P) was extracted with sodium bicarbonate and determined by colorimetric analysis using the molybdenum blue method and ascorbic acid as the reducing agent (Olsen and Sommers, 1982). The procedure to determine the percentage of organic matter in soil samples was adapted from Midgley *et al*. (2007). Organic matter was determined by weighing 5 g of soil, and mass loss was measured after 3 h at 105 ºC followed by 3 h at 360 ºC in a muffle furnace. The amount of leaf litter was determined by weighing the samples after 24 h at 60 ºC.

Exchangeable calcium (Ca), potassium (K), sodium (Na), and magnesium (Mg) were extracted using ammonium acetate and measured using an atomic absorption spectrophotometer (Knudsen *et al*., 1982; Lanyon and Heald, 1982). The pH value of the soil samples was determined according to the procedure described by White (1997) where pH was measured in 0.01 M $CaCl_2.2H_2O$ solution using 1:5 soil weight/liquid volume ratio (g ml^{-1}) in a Crison digital pH meter. Carbon (C) and nitrogen (N) content were determined using the Kjeldahl method.

5.3.5. DNA extraction and amplification

Total DNA was extracted from 0.3 g of the soil samples using the "PowerSoil^{TM} DNA Isolation Kit" (MO BIO, Laboratories, Inc.) according to the manufacturer protocol. DNA was amplified by polymerase chain reaction (PCR) using eubacteria-specific-primers for the 16S rRNA gene (Muyzer *et al.*, 1993) and fungal specific-primers (ITS1 and ITS4B-GC) targeted at the fungal 18S rRNA gene (White *et al.*, 1990; Gardes and Bruns, 1993). All PCRs were performed in a final volume of 25 μl, containing 1 μl of template DNA, 2.5 μl 10 x NH_4 reaction buffer (160 mM $(NH_4)_2SO_4$, 670 mM Tris–HCl pH 8.8, 0.1% 100 mM KCl, 50 mM $MgCl_2$), 25 μM of each primer, 10 mM dNTPs, and 1 U of the Biotaq DNA polymerase (Bioline, Germany).

The PCR conditions for bacteria were: an initial denaturing step at 94 ºC for 5 min followed by 30 cycles of 30 s at 94 ºC, 30 s of annealing at 55 ºC, and 30 s at 72 ºC followed by a final extension step at 72 ºC for 30 min. The PCR conditions for fungi were: an initial denaturing step at 94 ºC for 3 min followed by 35 cycles of 1 min at 94 ºC, 1 min of annealing at 50 ºC, and 1 min at 72 ºC followed by a final extension step at 72 ºC for 30 min. All PCRs analyses were performed in a GeneAmp PCR 2400 (Perkin Elmer). All PCRs included a negative control reaction without DNA to test the reproducibility of the results. Aliquots (5 μl) of each PCR reaction were examined by electrophoresis in an agarose gel (1%, w/v) stained with GelRed™ to check fragment size and integrity. Successful PCR amplification was confirmed for all soil DNA samples, producing one band of 300 bp for bacteria and 700 bp for fungi. All PCRs were performed using a GeneAmp 9700 (Applied Biosys-tems, PerkinElmer, CA, USA).

5.3.6. Denaturing gradient gel electrophoresis (DGGE) analysis

Each PCR product (20 ml) was analysed on a denaturing gradient gel containing 8% (w/v) acrylamide. The linear gradient ranged from 40% to 75% denaturant for bacteria and from 33% to 40% for fungi, while 100% denaturing acrylamide was defined as containing 7 M urea and 40% (v/v) formamide. Gels (22 cm x 17 cm) were run in 21 litres of 1 x TAE buffer at 20 V for 15 min, followed by 16 h at 65 V, and maintained at a constant temperature of 60 ºC in a DGGE-2401 system from CBS Scientific (CA, USA). Afterwards, gels were stained for 20 min in 1.0 x GelStar® and destained for 30 min in distilled water prior to visualization.

5.3.7. Data analysis

Plant diversity in each plot was estimated using the following descriptors: 1) species richness (S); 2) the Shannon's diversity index (H'); 3) Simpson's diversity index (1/D); 4) Pielou's evenness (J'), and 5) Simpson's evenness ($E_{1/D}$) (Magurran, 2004), as described in Chapter 4.

GelCompar II® (Applied Maths, Belgium) was used for the cluster analysis of soil bacteria and fungi based on the DGGE results. Cluster analysis based on the unweighted pair group method with arithmetic mean (UPGMA) and Pearson correlation coefficient were used to construct a dendrogram to calculate the similarities between samples. Bacterial and fungal richness was calculated as the total number of bands per sample.

The t-test ($p \leq 0.05$) for overall comparisons was used to test for significant differences between public gardens and urban forests. All the data were checked for normality and homogeneity of variance, and transformed if necessary to parametric requirements (Zar, 1996). Statistical analyses were performed using SPSS 21® software for Windows (SPSS Inc., IL, USA).

5.4. Results

5.4.1. Richness and plant diversity

A total of 252 taxa of vascular plants belonging to 201 genera and 89 families were found in the two typologies of green spaces (Appendix 5.A). These included 69 trees, 70 shrubs, and 113 herbaceous plants. The three dominant families, Poaceae (19 taxa), Asteraceae (18 taxa), and Fabaceae (12 taxa), comprised 21.4% of the total genera. Public gardens and urban forests presented 161 and 119 taxa, respectively. The presence of 6 and 5 invasive species recognized by the Portuguese law (Ministério do Ambiente, 1999) in gardens and forests, respectively, should also be emphasized.

The mean cover of the 30 most abundant taxa in the studied green spaces is provided in Figure 5.4. These 30 taxa represent 70.7% and 84.7% of the total plant cover in the gardens and forests, respectively.

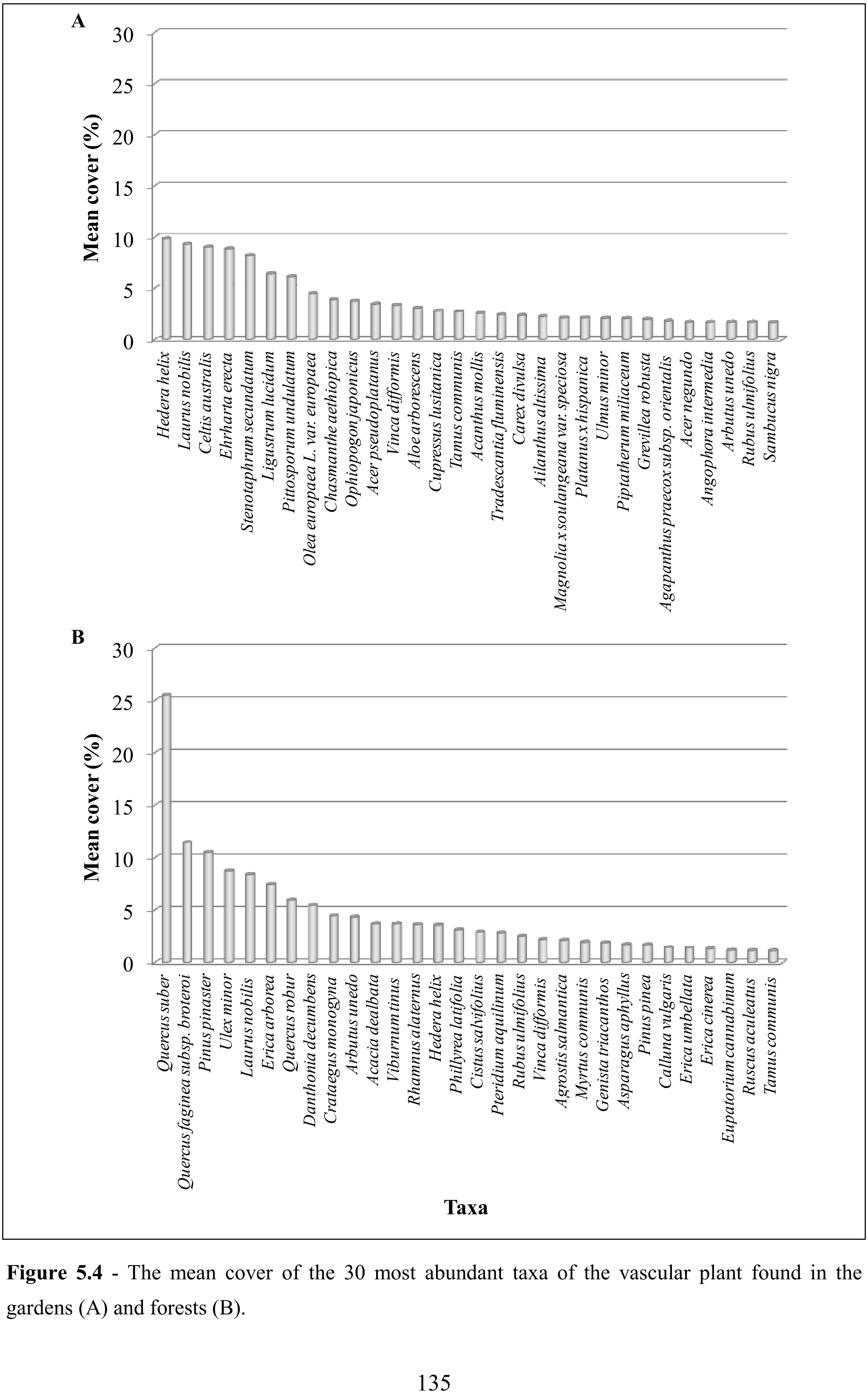


Figure 5.4 - The mean cover of the 30 most abundant taxa of the vascular plant found in the gardens (A) and forests (B).

The most abundant taxa in gardens were *Hedera helix* (9.8%) followed by *Laurus nobilis* (9.3%) and *Celtis australis* (9.0%). The presence of *Pittosporum undulatum* (6.1%), *Tradescantia fluminensis* (2.4%), and *Ailanthus altissima* (2.2%), three invasive species recognized by the Portuguese law (Ministério do Ambiente, 1999), should also be highlighted (Figure 5.4-A).

The highest mean cover in forest areas corresponded to the taxa *Quercus suber* with almost 26% followed by *Quercus faginea* subsp. *broteroi* (11.4%) and *Pinus pinaster* (10.5%). These *Quercus* taxa are plants with significant biological and conservation value. *Quercus suber* is a species protected under the Portuguese law (Ministério da Agricultura, do Desenvolvimento Rural e das Pescas, 2001) and *Quercus faginea* subsp. *broteroi* is an endemic taxon in Portugal. The presence of *Ruscus aculeatus* in forest areas, with a mean cover of 1.1%, should also be highlighted since it is included in the Annex V of the Habitats Directive (animal and plant species of community interest whose taking in the wild and exploitation may be subject to management measures) (Directive 92/43/EEC). The mean cover of *Acacia dealbata* (3.6%), an invasive species, should also be emphasized (Figure 5.4-B). Of the 30 most abundant taxa, six were found in both typologies of green spaces, namely, *Arbutus unedo*, *Hedera helix*, *Laurus nobilis*, *Rubus ulmifolius*, *Tamus communis*, and *Vinca difformis* (Figure 5.4).

Species richness was not significantly different (p = 0.325) when comparing both typologies of green spaces (Figure 5.5-A), where mean values of 16.9 in gardens and 18.2 in forests were observed. When compared by growth-forms, there were only significant differences in species richness for shrubs (p = 0.001), with the highest value found in the urban forests.

Total species cover reached 160.5% in forests and 162.6% in gardens (Figure 5.5-B) and was significantly different for herbaceous (p = 0.008), with the highest values found in the city gardens.

The Shannon and Simpson diversity indices did not reveal any significant differences between the two typologies of green spaces (Table 5.2). The two diversity indices showed similar tendencies among growth-forms and were significantly different only for shrubs. The highest values of both diversity indices for shrubs were found in forests.

Despite the fact that the Pielou and Simpson evenness indices did not differ significantly between the two typologies of green spaces, both presented the highest values in gardens. When analysed by growth-forms, only shrubs equitability was significantly higher in gardens according to the Simpson evenness index (Table 5.2).

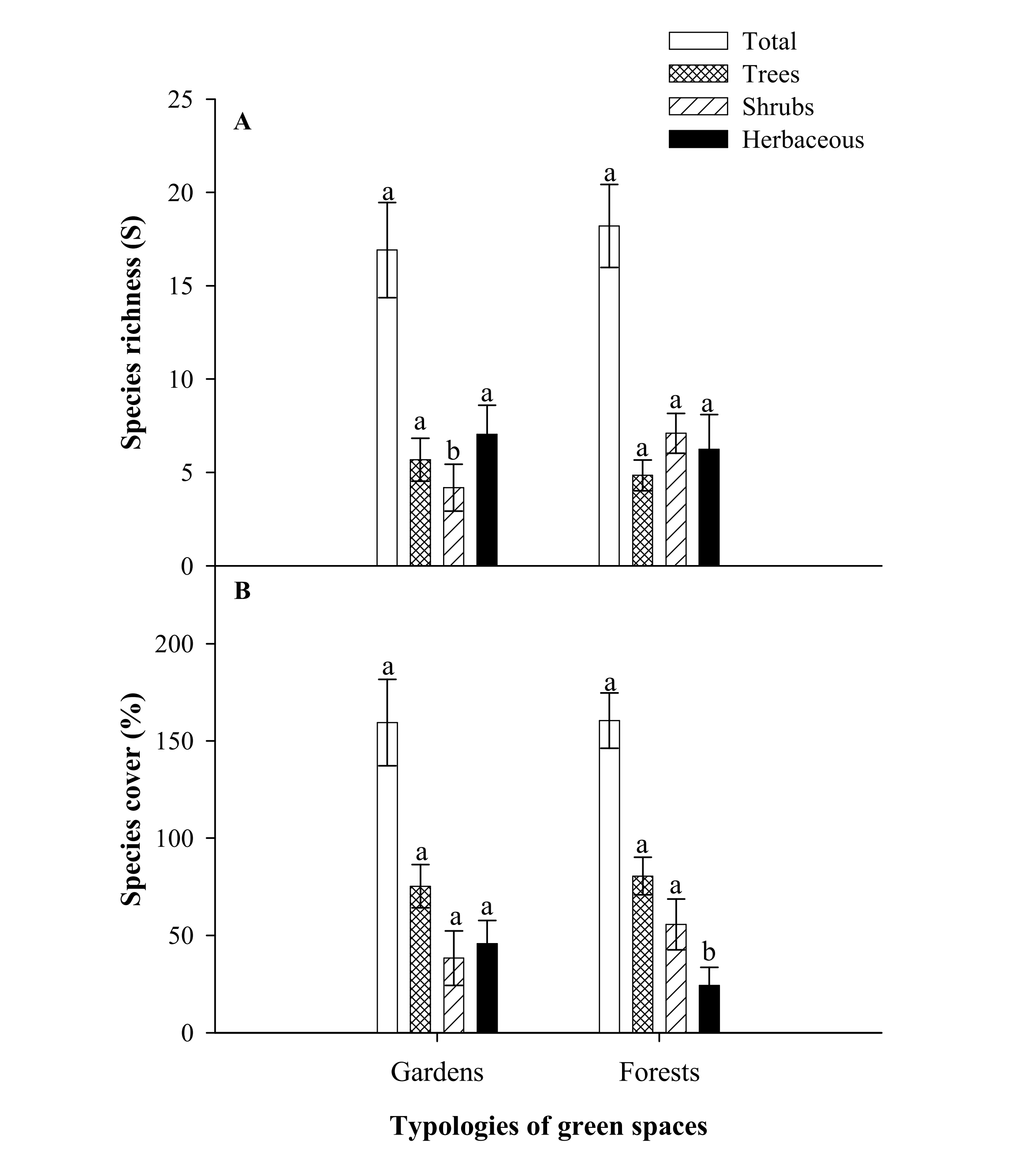


Figure 5.5 - Plant species richness (A) and plant species cover (B) for the two typologies of green spaces. Values are means ± SE. The different letters above the bars indicate significant differences ($p \leq 0.05$) between gardens and forests.

Table 5.2 - Descriptive statistics of different diversity indices for vascular plants present in the two typologies of green spaces. Values are means ± SE.

	Gardens	**Forests**	***p***
Shannon's diversity index (H')			
Total diversity	2.23 ± 0.07	2.25 ± 0.07	0.882
Growth-form			
Trees	1.32 ± 0.10	1.24 ± 0.08	0.559
Shrubs	0.91 ± 0.14	1.51 ± 0.09	0.003**
Herbaceous	1.36 ± 0.12	1.30 ± 0.14	0.731
Simpson's diversity index (1/D)			
Total diversity	7.68 ± 0.90	7.07 ± 0.56	0.682
Growth-form			
Trees	3.58 ± 0.34	3.18 ± 0.30	0.465
Shrubs	2.68 ± 0.41	4.03 ± 0.33	0.015*
Herbaceous	3.70 ± 0.51	3.68 ± 0.48	0.996
Pielou's evenness index (J')			
Total evenness	0.80 ± 0.02	0.78 ± 0.01	0.361
Growth-form			
Trees	0.79 ± 0.04	0.81 ± 0.03	0.850
Shrubs	0.63 ± 0.08	0.80 ± 0.03	0.060
Herbaceous	0.73 ± 0.04	0.79 ± 0.05	0.241
Simpson's evenness index ($E_{1/D}$)			
Total evenness	0.45 ± 0.03	0.39 ± 0.02	0.078
Growth-form			
Trees	0.67 ± 0.04	0.67 ± 0.04	0.887
Shrubs	0.73 ± 0.05	0.59 ± 0.04	0.029*
Herbaceous	0.54 ± 0.04	0.66 ± 0.05	0.115

* Significant differences at $p < 0.05$.
** Significant differences at $p \leq 0.01$.

5.4.2. Soil properties and microbial communities

Forests showed a higher percentage of soil organic matter and amount of leaf litter than gardens (Table 5.3). Soil total C and N, and the C/N ratio also were significantly higher in forests as compared to gardens. Soil available phosphorus, Ca^{2+} and Mg^{2+} contents, and soil pH were significantly higher in gardens than in forests (Table 5.3).

Table 5.3 - Chemical characteristics of soils in the two typologies of green spaces. Values are means ± SE.

Soil properties	Gardens	Forests	*p*
Organic matter (%)	5.82 ± 0.43	10.06 ± 0.69	0.001**
Leaf litter (g)	9.99 ± 1.31	15.73 ± 1.52	0.006**
pH	5.53 ± 0.15	4.67 ± 0.17	0.001**
Phosphorus available (μg g^{-1})	18.43 ± 1.55	9.09 ± 1.24	0.001**
Ca^{2+} exchangeable (mg g^{-1})	2.67 ± 0.24	2.05 ± 0.28	0.039*
K^{+} exchangeable (mg g^{-1})	0.15 ± 0.02	0.12 ± 0.01	0.177
Mg^{2+} exchangeable (mg g^{-1})	0.43 ± 0.05	0.28 ± 0.04	0.024*
Na^{+} exchangeable (mg g^{-1})	0.02 ± 0.00	0.02 ± 0.00	0.346
C total (g kg^{-1})	38.70 ± 3.10	63.44 ± 5.62	0.001**
N total (g kg^{-1})	3.05 ± 0.21	4.60 ± 0.29	0.001**
C/N	12.48 ± 0.20	13.49 ± 0.33	0.011*

* Significant differences at $p < 0.05$.
** Significant differences at $p \leq 0.01$.

UPGMA cluster analysis of the DGGE banding patterns did not show significant differences among the soil bacterial communities between gardens and forests (Figure 5.6) as a result of a very heterogeneous community structure of soil bacteria, independent of the typology of green space. The cluster analysis established two main groups with 63% of similarity, where the samples from Colina dos Sobreiros and Penedo da Saudade were clustered together and apart from the other four sampling sites. In the first group, a subgroup was obtained that separated Colina dos Sobreiros and Penedo da Saudade sites. The similarity between both clusters was 81%. Within the second group a subgroup was obtained where the samples from Monte do Escravote, Quinta da Maia, and Jardim da Sereia were clustered together and apart from the Jardim Botânico. The similarity between clusters was 69%. The homogeneity between the samples of the same sampling site was indicated by the high similarities.

Significant difference for species richness was observed ($p \leq 0.001$) between the two typologies of green spaces, where the number of bacterial species in forests was higher than in gardens (Figure 5.7).

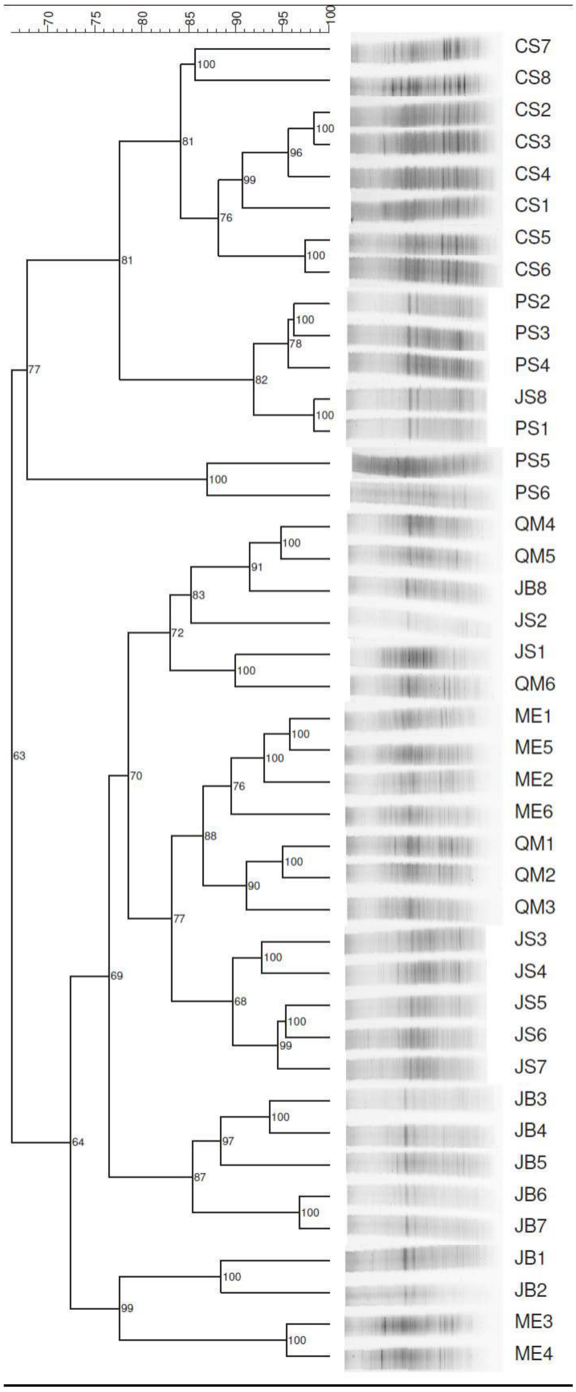


Figure 5.6 - Community structure of soil bacteria. Dendrogram of soil bacteria based on PCR-DGGE bands, using the unweighted pair-group method with arithmetic mean algorithm (UPGMA) and the Pearson product–moment correlation coefficient. JB - Jardim Botânico; JS - Jardim da Sereia; PS - Penedo da Saudade; CS - Colina dos Sobreiros; ME - Monte do Escravote; QM - Quinta da Maia.

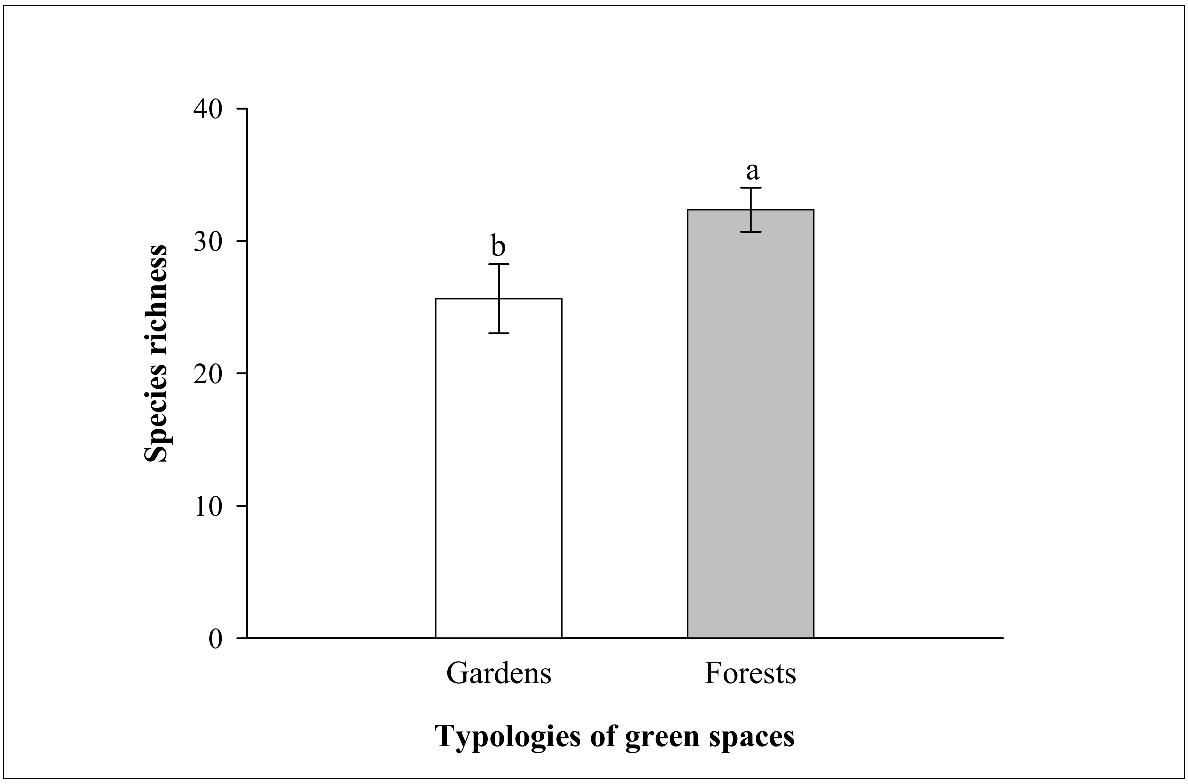


Figure 5.7 - Species richness of soil bacteria for the two typologies of green spaces. Values are means ± SE. The different letters above the bars indicate significant differences ($p \leq 0.05$) between gardens and forests.

The cluster analysis of the DGGE banding patterns did not show significant differences among the soil fungal communities when comparing gardens and forests (Figure 5.8). However, some differences could be distinguished between sampling sites within each studied typology, which reflected a very heterogeneous soil fungi community structure, independent of the typology of green space, as occurred for the bacterial community. The cluster analysis clearly showed two main groups with 67% of similarity, where the samples from Colina dos Sobreiros, Jardim da Sereia, and Penedo da Saudade were clustered together and apart from the Jardim Botânico. The samples from Monte do Escravote and Quinta da Maia were scattered between both groups. The homogeneity among the samples of the same sampling site was indicated by the high similarity values.

No significant statistical differences ($p = 0.258$) were found in fungal species richness between the two typologies of green spaces (Figure 5.9).

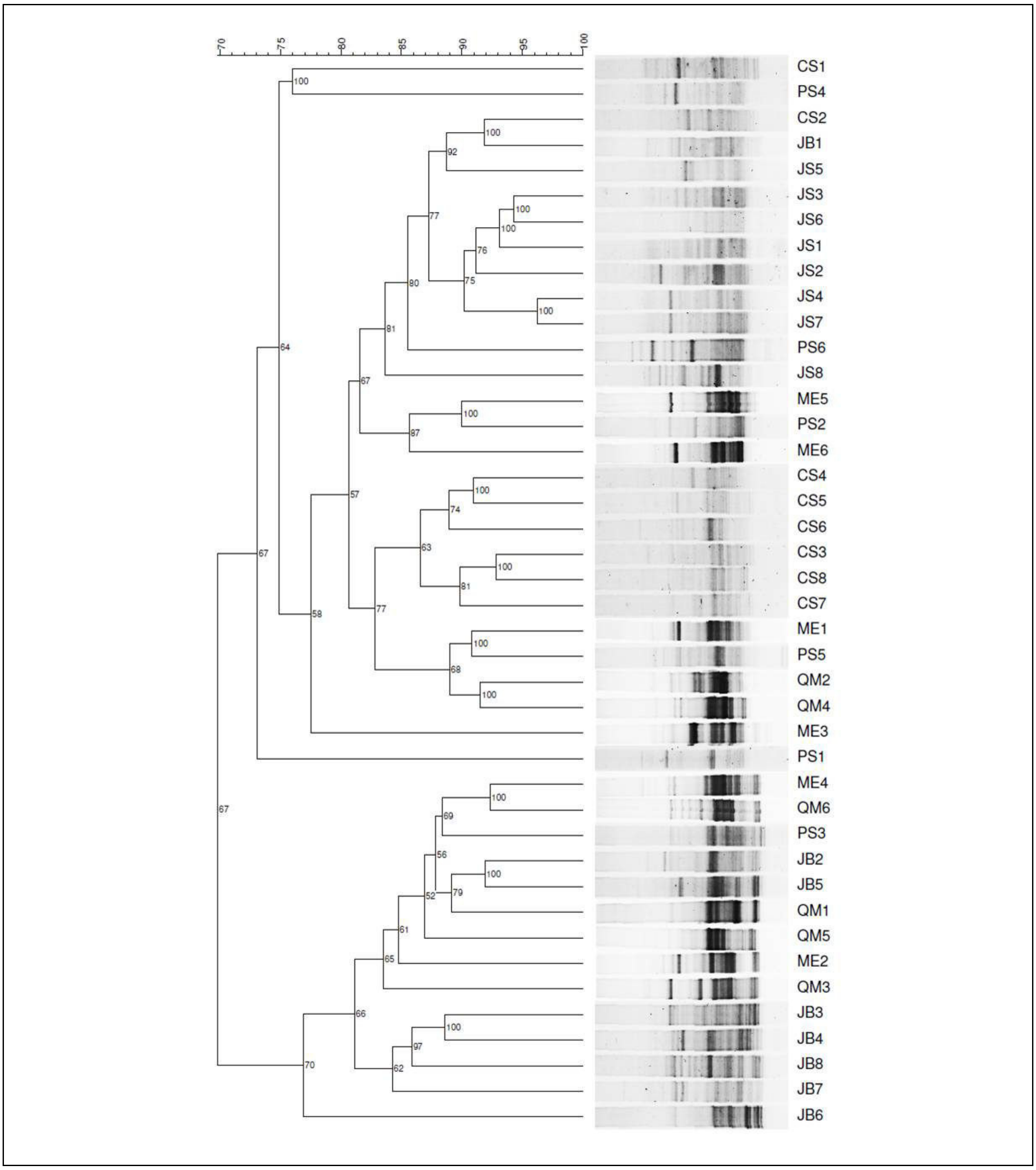


Figure 5.8 - Community structure of soil fungi. Dendrogram of soil fungi based on PCR-DGGE bands, using the unweighted pair-group method with arithmetic mean algorithm (UPGMA) and the Pearson product–moment correlation coefficient. JB - Jardim Botânico; JS - Jardim da Sereia; PS - Penedo da Saudade; CS - Colina dos Sobreiros; ME - Monte do Escravote; QM - Quinta da Maia.

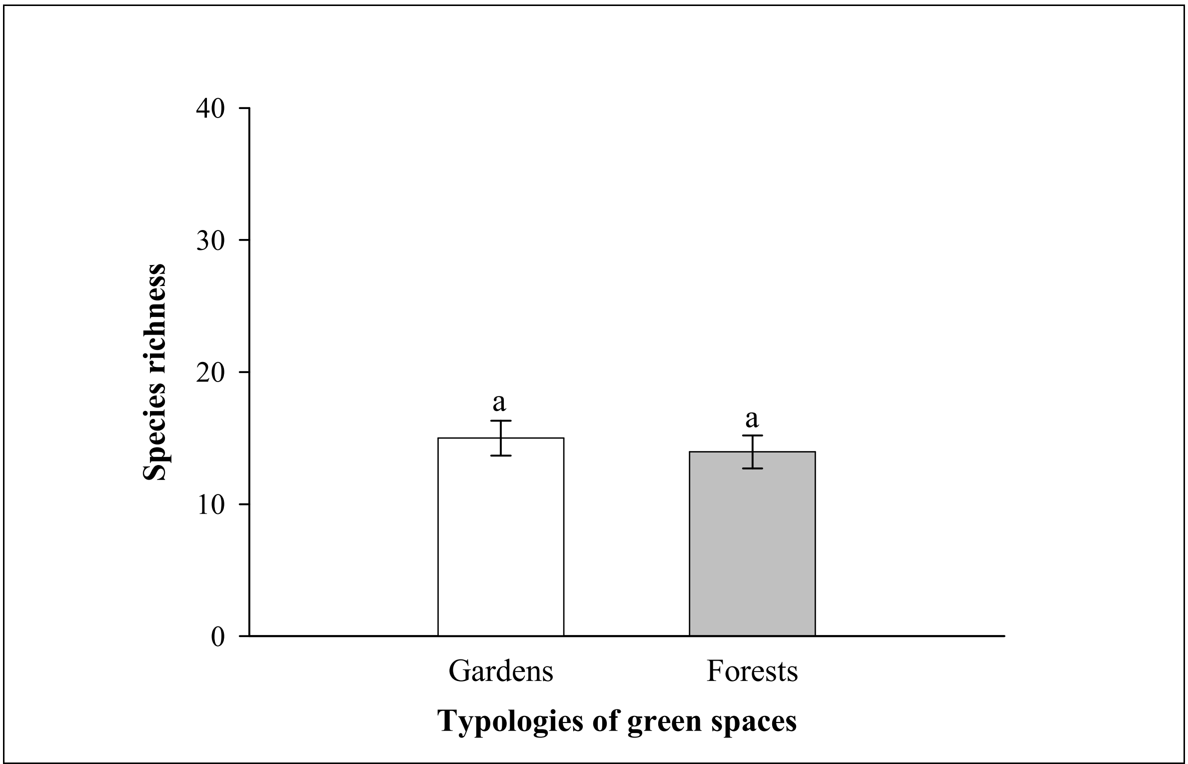


Figure 5.9 - Species richness of soil fungi for the two typologies of green spaces. Values are means ± SE. The different letters above the bars indicate significant differences ($p \leq 0.05$) between gardens and forests.

5.5. Discussion

Urban areas are often biologically diverse since the human actions directly and indirectly increase the total number of species, for example, through introduced species and increased landscape heterogeneity (Araújo, 2003; LaPaix and Freedman, 2010). This finding was supported by this research where a high floristic diversity was observed in the studied green spaces within the city of Coimbra (Appendix 5.A), representing 7.6% of the total taxa found in Portugal (Sequeira *et al.*, 2011). The management of city gardens is mainly designed to ornament the environment by constructing new landscape sites or introduce ornamental and exotic plants in order to attract more visitors (Weifeng *et al.*, 2006), and therefore flora become more diverse.

The percentage cover of invasive species found for the studied areas is an indicator of the level of disturbance caused by human activities (Sukopp, 2004). Three invasive species (*Pittosporum undulatum*, *Tradescantia fluminensis*, and *Ailanthus altissima*) found in the public gardens contributed for 10.8% of the total cover (Figure 5.4-A). The presence of *Acacia dealbata* in the urban forests, contributing for 3.6% of the total cover (Figure 5.4-B), may result from the fact that they are spaces artificially influenced by the proximity to housing areas which may foster the invasiveness process. The species pool available to gardens provides a wide choice, and the gardeners, usually, choose the hardier exotic plants for cultivation purposes (Lubbe *et al.*, 2010), with a problematic outcome for the gardens, since these urban adaptable species tend to become more widespread and abundant due to human activities (McKinney, 2006). The herbaceous species *Stenotaphrum secundatum* presented the fifth greater coverage in the public gardens (Figure 5.4-A), contributing to the highest value of species cover for herbaceous plants found in this typology of green space (Figure 5.5-B). This plant species is used in lawns, playing an important role in the areas with the function of leisure spaces, as the public gardens.

Despite the similar plant species richness and diversity indices found in both typologies of green spaces, taxa with higher ecological and conservation value mostly occurred in the urban forest areas. Particularly important, the percentage cover of the species *Quercus suber*, *Quercus faginea* subsp. *broteroi*, and *Ruscus aculeatus*, where jointly represented 38% of the total cover (Figure 5.4-B). The presence of some native shrub species such as *Viburnum tinus*, *Myrtus communis, Ruscus aculeatus*, and *Asparagus aphyllus*, which are species characteristic of *Quercus suber* forests (ALFA, 2004), contributed to the highest value of species richness for shrub plants found in the urban forests (Figure 5.5-A). Oak-stands are associated with a remarkable biodiversity and constitute an ecosystem recognized for their ecological value (Pereira and Fonseca, 2003). This ecological importance was taken into account in the classification of Oak-stands as protected habitats in the framework of the Natura 2000 Network, established by the European Union (Directive 92/43/CEE). The significant resistance of cork oak to fire present a considerable advantage compared to other forest systems, since much less effort is normally needed to rehabilitate the burned area (Silva and Catry, 2006). This should be taken into consideration due to the existence of a high incidence of forest fires in the municipality of Coimbra in recent years, in particular, the fire in 2005 (ICNF, 2013b; see Chapter 2).

Urban plant communities vary greatly in their species composition and ecological integrity, from remnants of original habitats surviving in natural areas to the widespread anthropogenic ecosystems occurring in most gardens (Turner *et al*., 2005). Urban forests are an integral part of community ecosystems, whose numerous elements (such as people, animals, buildings, infrastructure, water, and air) interact to significantly affect the quality of urban life (Nowak *et al*., 2010). The importance of urban forests and their benefits is increasing because of the expansion of urban land (Nowak and Dwyer, 2007). Urbanization threatens forest sustainability through an increased risk from fire at the wild land-urban interface, exotic pest infestations, unmanaged outdoor recreation, and forest fragmentation (Nowak and Walton, 2005). Thus, sustaining the urban forests become increasingly important in terms of their extent and the critical ecosystem services they provide to sustain human health and environmental quality in/and around urban areas (Nowak and Walton, 2005; Nowak *et al*., 2010). Urban forests provide a diverse wildlife habitat and have also been shown to harbour endangered species and species of high conservation value (Alvey, 2006; Nowak *et al*., 2010). Urban forests in Sweden are home to endangered species as identified on the Red List of Swedish species. It is estimated that densely populated Stockholm County contains two-thirds of red-listed species (Gustafsson, 2002; Colding *et al*., 2003).

The soil chemical and biological properties were significantly different between the two typologies of green spaces (Table 5.3). The highest percentage of soil organic matter, amount of leaf litter, and soil total C and N were verified in forests, where a richer soil bacterial community also occurred (Figure 5.7). Soils under Oak-stands have well-developed soil horizons with high organic matter and nutrient content because of high litter inputs (Downie and Taskey, 1997; Vacca, 2000). Soil organic matter is the organic fraction of the soil that is made up of decomposed plant and animal materials as well as microbial organisms (Chan, 2008). The amount of leaf litter that falls on the soil plays a vital role to enrich the soil organic matter content as it is naturally decomposed and any excess nutrients is released into the soil in forms that plants can use (Melillo *et al*., 1989; Chowdhury *et al*., 2008). As a food source for soil fauna and flora, soil organic matter plays an important role in the soil food web by controlling the number and types of soil inhabitants which serve important functions, such as nutrient cycling and availability, assisting root growth and plant nutrient uptake, creating burrows, and even, suppressing plant diseases (Chan, 2008).

The leaf litter in the soil surface contributes to the biological activity and carbon cycling process in the soil. Carbon cycling is the continuous transformation of organic and inorganic carbon compounds by plants and soil organisms between the soil, plants, and the atmosphere (FAO, 2005). If more carbon is stored in the soil, it will reduce the amount present in the atmosphere, and therefore help to alleviate the problem of global warming and climate change (Chan, 2008). Since the highest soil carbon was encountered in urban forest, they will play an important function in the soil carbon sequestration. Litter decomposition is also among the most important factors that control the nitrogen cycle in ecosystems (Saj *et al*., 2009). During the decomposition process the soil organic matter is cleaved from large polymers to largely bio-available monomers which are accessible to both plants and microorganisms. Soil microorganisms can further degrade these organic monomers to form ammonium (ammonification or nitrogen mineralization). Ammonium as well as organic nitrogen can also be oxidized to nitrate (nitrification). Therefore, both ammonium and nitrate can either be taken up by plants or immobilized by microorganisms (Butterbach-Bahl *et al*., 2011). The soil organic matter can ensure the sustained supply of nitrogen and other nutrients to plants, and therefore maintain appropriate soil quality such as aeration, permeability, water-holding capacity, and nutrient preserving capacity (Smith *et al*., 2012).

The public gardens showed the highest soil available phosphorus, and Ca^{2+} and Mg^{2+} contents (Table 5.3), probably due to the addition of fertilizer which is a common management practice in this typology of green space. However, they showed a lowest percentage of soil organic matter, amount of leaf litter, and N (Table 5.3). The study accomplished by Chowdhury *et al*. (2008) indicated that leaf litter was superior to chemical fertilizer for increasing the organic matter and N in soil. On the other hand, the lowest percentage of soil organic matter and amount of leaf litter found in the public gardens were also probably caused by less input of litter and higher mineralization of soil organic matter due to the management practices, as the clearing of the litter layer and vegetation (Xu *et al*., 2008), usually used in these human-managed green spaces because of their use as recreational areas. These management practices destroy the litter layer and so diminish the amount of organic matter returned to the soil and eliminate the organisms that inhabit the surface soil and litter layer (FAO, 2005).

Although higher soil pH values were found in the public gardens, both typologies of green spaces showed acidic pH values (Table 5.3). Higher soil pH in gardens can be explained by addition of fertilizer (Thimonier *et al*., 1992; Honnay *et al*., 2002a), possibly due to the increase of mineralization rate (Honnay *et al*., 2002b). The soil acidity can also be decreased through reactions with alkaline dust particles containing metal oxides and carbonates (Lovett *et al*., 2000; Devlaeminck *et al*., 2005). Depositions of Ca^{2+} and Mg^{2+} ions have been positively correlated with urbanization, particularly the deposition of Ca^{2+} because it is a constituent of cements and mortars (Lovett *et al*., 2000).

The public gardens also showed the lowest levels of soil bacterial community richness (Figure 5.7). The study carry out by Wallis *et al*. (2010) showed that fertilizer additions significantly reduced the soil bacterial community richness as a result of a less diverse more specialized soil microbial community (Tiquia *et al*., 2002). On the other hand, no significant statistical differences were found in fungal richness between gardens and forests (Figure 5.9). In this study, the primer pair used for PCR has a higher specificity for basidiomicete and ascomycete than other fungal groups (Wang *et al*., 2009). The basidiomicete are among the most important and widespread soil fungal groups (Caesar-TonThat and Cochran, 2000; Lynch and Thorn, 2006) with a high heterogeneity and clumped-distribution of mycelium in the soils (Brundrett and Abbott, 1995; Thiet and Boerner, 2007), which may average results. Moreover, urban vegetation is likely to be highly fragmented, with fungal populations possibly isolated due to restricted spore dispersal (Newbound *et al*., 2010).

Both bacterial and fungal communities were very heterogeneous and independent of the typology of green space (Figure 5.6 and Figure 5.8). The soil proprieties and microbial communities that reside within them are the result of complex interactions between biotic and abiotic factors (Swallow *et al*., 2009) which certainly contributed to the heterogeneity observed in this study. The soil type consists of Chromic Cambisols in all studied green spaces, except in Quinta da Maia where Lithosols Eutric associated with Luvisols are present (see Study area in Material and Methods section). Additionally, both studied typologies of green spaces presented acidic soils (Table 5.3). Microbial community composition in the rhizosphere is affected by a complex interaction between soil type, plant species, and root zone location (Marschner *et al*., 2001; Berg and Smalla, 2009). Different soil types are assumed to harbor specific microbial communities, as shown by

Fierer and Jackson (2006). Soil pH was also shown to be an important factor determining soil-borne microbial community composition (Kuramae *et al*., 2010).

Plants also exert a strong influence on the composition of microbial communities in the soil through rhizodeposition and the decay of litter and roots (Nannipieri *et al*., 2003). The supply of photosynthates and decaying plant material to the root-associated microorganisms, together with microbial-induced changes in rooting patterns, and the supply of available nutrients to plants, as derived from microbial activities, are key issues in rhizosphere formation and functioning (Barea *et al*., 2002). The stronger effects of plant community composition than species richness on the microbial communities are indicative of the importance of plant species traits for soil and ecosystem properties (Tilman *et al*., 1997; Hector *et al*., 1999). There are microbial species that are typically associated with only a few or a single plant species as in the beneficial interactions Rhizobium-legumes (Berg and Smalla, 2009). Moreover, the spatial arrangement of the plant community, particularly the dominant species, have strong effects on the soil microbial community as showed by Massaccesi *et al*. (2015). These researchers found that the *Lotus* dominance shifted the microbial community towards a more bacterial dominated system with faster rates of nitrogen cycling. This is probably in response to the higher nitrogen content of litter associated with legumes compared to the other species (Saj *et al*., 2009). However, the plant species community composition did not appear to have a significant effect on the soil microbial communities in the studied typologies of green spaces. Similar result has also been reported by Kuramae *et al*. (2011). It must be stressed that were examined soil samples, where plant effects might be expected to be less pronounced, a focus on the rhizosphere may yield a greater impact of vegetation (Kowalchuk *et al*., 2002).

Plant species can differ in their effects on almost every aspect of ecosystem structure and function (Eviner and Chapin, 2003). Because plant species differ in their biochemical composition, changes in plant composition could alter the production as well as the range of organic compounds in detritus that limit, and thus, control the composition and function of microbial communities (Zak *et al*., 2003; de Deyn *et al*., 2008). Many plant attributes that influence ecosystems are largely independent of one another (Eviner, 2004). For example, species differ in how their exudation patterns vary in response to environmental changes (Biondini *et al*., 1988). Since a heterogenic vegetation composition would be ideal to promote biodiversity in urban green spaces (Beninde *et al*., 2015), is crucial to maintain different typologies of green spaces, with different habitats, for the development of environment conservation strategies.

Natural forest remains within urban areas provide important refuges for endangered species and species of high conservation value, and are less frequently inhabited by exotic species than other urban habitats (LaPaix and Freedman, 2010; Uno *et al*., 2010). Given its ecological value, the conservation of forests in urban areas should be considered in urban planning. On the other hand, given that green spaces can help to produce cool air, absorb noise, dust and pollutants, is necessary a compensation in highly built-up areas and provide suitable consideration to both ecological and social requirements (Sukopp, 2004). The forest areas, representative of natural ecosystems within urban areas, can be a help to provide benefits both for people, by enhancing public use opportunities, and for the environment by improving urban ecosystem health. Therefore, the vegetation and ecosystems in a city should not be seen as simply passive decorations, but as opportunities for active involvement by residents, and as a part of the life of a dynamic city (Botkin and Beveridge, 1997). As cities are expected to grow at a rapid rate in the coming decades, it is important that ecosystem services in urban areas are understood and valued by city planners and political decision-makers (Bolund and Hunhammar, 1999).

Additionally, the potential of the urban green spaces to harbour considerable amounts of biodiversity needs to be recognized by city planners so that management practices that preserve and promote the diversity can be pursued (Alvey, 2006). In the city of Coimbra, the green spaces are essentially occupied by forests, thus its conservation should therefore be central in urban management decisions. On the other hand, the occurrence of different habitats in urban areas favours the biodiversity. Although the urban green spaces are increasingly valued due to its leisure benefits, the city planners should also consider their cultural services that support aesthetic and leisure values but without compromising the ecological services of the green spaces.

5.6. Conclusions

The purpose of this paper was to study the vascular plants and soil microorganisms diversity in two typologies of green spaces in the city of Coimbra. The results revealed a high floristic diversity in the studied green spaces. Although our results showed similar floristic species diversity and richness, except for the shrubs, the soil bacterial community richness was higher in forests than in gardens. The bacterial and fungal communities were very heterogeneous and independent of the typology of green space. On the other hand, the forests showed a clear importance since they harbour taxa with high conservation and ecological value. Thus, to best conserve the biodiversity and sustainable development in urban areas, maintaining different habitats may be most beneficial. Therefore, the city planners should promote the urban development by incorporating a more ecological perspective into their management plans to enhance human health and global environmental quality.

Appendix 5.A - Vascular plant taxa recorded in the study area.

Taxa	English common names	Family	Potential uses/impacts	Typology of green space
Acanthus mollis L.	Bear's breeches	Acanthaceae	Ornamental	Forest, Garden
Thunbergia mysorensis (Wight) T. Anderson	Clock vine, Lady sleeper creeper, Doll's shoes	Acanthaceae	Ornamental	Garden
Yucca sp.		Agavaceae	Ornamental	Garden
Liquidambar styraciflua L.	Sweet gum	Altingiaceae	Ornamental	Garden
Chenopodium album L.		Amaranthaceae	Allergenic (pollen), poisonous	Garden
Chenopodium murale L.		Amaranthaceae	Allergenic (pollen), poisonous	Forest
Agapanthus praecox Willd. subsp. *orientalis*	Blue lily, African lily, Lily of the Nile, Common Agapanthus	Amaryllidaceae	Ornamental, poisonous (the rhizome contains saponins)	Garden
Thapsia villosa L.		Apiaceae	Ornamental	Forest
Torilis arvensis (Huds.) Link	Hedge parsley, Field hedge parsley, Spreading hedge parsley	Apiaceae		Forest, Garden
Physospermum cornubiense (L.) DC.	Tulip-wood tree, Brazilian pink wood	Apiaceae	Poisonous (lectins, triterpene saponins)	Forest
Pimpinella villosa Schousb.		Apiaceae		Forest
Vinca difformis Pourret	Periwinkle	Apocynaceae	Medicinal, poisonous (monoterpene indole alcaloids)	Forest, Garden
Nerium oleander L.	Oleander, Rose bay	Apocynaceae	Ornamental, very poisonous (oleandrine and other cardenolides)	Garden
Arum italicum Mill.	Lords-and-ladies, Cuckoo-pint	Araceae	Poisonous (aroin, calcium oxalate, cyanogenic glucosides, saponins), irritant for the mucous membranes	Forest
Arum maculatum L.	Lords-and-ladies, Cuckoo-pint	Araceae	Poisonous (aroin, calcium oxalate, cyanogenic glucosides, saponins), irritant for the mucous membranes	Garden
Zantedeschia aethiopica (L.) Spreng.	Arum lily, Calla lily	Araceae	Ornamental, poisonous (raphides of calcium oxalate)	Garden
Hedera maderensis K. Koch ex A. Rutherf. subsp. *iberica* Mc Allister	Ivy, Common-ivy	Araliaceae	Ornamental, poisonous (triterpene saponins, sesquiterpenes, falcarinol). Causes contact dermatitis	Forest, Garden
Araucaria angustifolia (Bertol.) Kuntze	Parana pine, Brazilian pine, Candelabra tree	Araucariaceae	Ornamental	Garden
Araucaria bidwillii Hook.	Bunya bunya	Araucariaceae	Ornamental, the seeds are edible	Garden
Araucaria heterophylla (Salisb.) Franco	Norfolk island pine, House pine	Araucariaceae	Ornamental	Garden
Arconthophoenix cunninghamiana H. Wendl. & Drude	Piccabben palm	Arecaceae	Ornamental	Garden
Butia capitata Mart. Becc. var. *capitata*	Jelly palm, Wine palm, Pindo palm	Arecaceae	Ornamental, the fruits are edible	Garden

Appendix 5.A - Continued.

Taxa	**English common names**	**Family**	**Potential uses/impacts**	**Typology of green space**
Livistona australis (R. Br.) Mart.	Gippsland palm, Cabbage palm, Australian fan palm, Australian palm	Arecaceae	Ornamental	Garden
Livistona chinensis (Jacq.) R.Br. ex Mart.	Chinese fan palm	Arecaceae	Ornamental	Garden
Phoenix canariensis Chabaud	Canary Island date palm	Arecaceae	Ornamental	Garden
Trachycarpus fortunei (Hook.) H.Wendl.	Chusan palm, Chinese windmill palm, Windmill palm	Arecaceae	Ornamental	Garden
Chamaerops humilis L.	Dwarf fan palm, Mediterranean fan palm, African hair palm	Arecaceae	Ornamental	Garden
Aristolochia sempervirens L.	Birthwort, Dutchman's pipe	Aristolochiaceae	Medicinal, poisonous (aristolochic acid and related alkaloids)	Garden
Asparagus aphyllus L.	Prickly asparagus	Asparagaceae	Ornamental	Forest, Garden
Asparagus falcatus L.	Large forest asparagus, Sicklethorn, Yellowwood asparagus	Asparagaceae	Ornamental	Garden
Asparagus setaceus (Kunth.) Jessop		Asparagaceae		Garden
Cordyline australis (J. R. Forst.) Endl.	Cabbage tree	Asparagaceae	Ornamental, edible (the rhizomes accumulate natural sugars)	Garden
Ophiopogon japonicus (Thunb.) Ker Gawl.	Mondo grass, dwarf lilyturf	Asparagaceae	Ornamental	Garden
Ruscus aculeatus L.	Butcher's broom, Box holly, Jew's myrtle	Asparagaceae	Ornamental, poisonous (steroidal saponins)	Forest, Garden
Asplenium adiantum-nigrum L.	Black sleepenwort	Aspleniaceae	Ornamental	Forest
Asplenium onopteris L.	Irish spleenwort	Aspleniaceae	Ornamental	Forest
Andryala integrifolia L.	Rabbit's bread	Asteraceae		Forest
Carlina corymbosa L.	Clustered carline thistle	Asteraceae		Forest
Conyza canadensis (L.) Cronq.	Horseweed, Mule-tail	Asteraceae	Medicinal (disentery, rheumatism)	Forest, Garden
Crepis capillaris (L.) Wallr.	Smooth hawksbeard, Green crepis	Asteraceae	Melliferous	Forest
Crepis lampsanoides (Gouan) Taush		Asteraceae	Melliferous	Garden
Crepis taraxacifolia Thuill.	Beaked hawksbeard	Asteraceae	Melliferous	Garden
Dittrichia viscosa (L.) W. Greuter	False yellowhead, Strong-smelling Inula	Asteraceae	Melliferous	Forest
Erigeron karvinskianus DC.	Daisy, Daisy fleabane, Mexican daisy fleabane	Asteraceae	Ornamental, invasive	Forest, Garden
Eupatorium cannabinum L.	Common Dutch agrimony, Boneset, Eupatorio, Holy rope	Asteraceae	Ornamental	Forest
Eupatorium viburnoides DC.	Boneset, Snakeroot, Thouroughwort	Asteraceae	Ornamental	Garden
Hieracium dumosum Jord.		Asteraceae		Garden
Hypochaeris radicata L.	Spotted cat's ear, Hairy's cat's ear, Frogbit	Asteraceae		Forest
Lapsana communis L.	Nipplewort, Common niplewort	Asteraceae		Forest, Garden

Appendix 5.A - Continued.

Taxa	English common names	Family	Potential uses/impacts	Typology of green space
Phagnalon saxatile (L.) Cass.		Asteraceae		Garden
Pulicaria odora (L.) Reichenb.	Fleabane	Asteraceae	Melliferous	Forest
Senecio jacobaea L.	Common ragwort	Asteraceae	Medicinal, poisonous (pyrrolizidine alkaloids)	Garden
Sonchus oleraceus L.	Milk thistle	Asteraceae	Edible, foraging (rabbits, guinea-pigs, etc.)	Forest, Garden
Urospermum picroides (L.) Scop. ex F. W. Schmidt	Nettle, Stinging nettle	Asteraceae		Forest
Campsis radicans (L.) Bureau	Trumpet creeper	Bignoniaceae	Ornamental	Garden
Lithospermum diffusum Lag		Boraginaceae		Forest
Buxus sempervirens L.	Common box, European box, Boxwood	Buxaceae	Ornamental, poisonous (steroidal alkaloids)	Garden
Campanula rapunculus L.	Rampion	Campanulaceae	Ornamental	Forest
Jasione montana L.	Sheep's bit	Campanulaceae	Ornamental	Forest
Trachelium caeruleum L.	Blue throatwort, Blue lace flower	Campanulaceae	Ornamental	Garden
Celtis australis L.	European nettle tree, Nettle tree, Mediterranean hackberry	Cannabaceae	Woodwork	Garden
Humulus lupulus L.	Common hop, European hop, Bine	Cannabaceae	Edible (brewing)	Forest
Abelia x grandiflora (Rovelli ex André) Rehder	Glossy abelia	Caprifoliaceae	Ornamental	Garden
Diervilla sessilifolia Buckley	Southern bush honeysuckle, Bush honeysuckle	Caprifoliaceae	Ornamental	Garden
Lonicera japonica Thunb. var. *aureo reticulata* (T. Moore) Nicholles	Japanese honeysuckle, Gold and silver flower	Caprifoliaceae	Ornamental	Garden
Lonicera periclymenum L.	Honeysuckle, Woodbine	Caprifoliaceae	Ornamental, moderately poisonous (berries - cyanogenic glucosides, saponins)	Forest
Viburnum tinus L.	Laurustinus	Caprifoliaceae	Ornamental	Forest
Sambucus nigra L.	Elder, Common elder, Judas tree, Pipe tree, Bourtree	Caprifoliaceae	Medicinal (flowers - infusions against flu), ornamental, poisonous	Garden
Cerastium glomeratum Thuill.	Mouse-ear chickweed	Caryophyllaceae		Garden
Polycarpon tetraphyllum (L.) L.	Four-leaved allseed, Fourleaf manyseed	Caryophyllaceae		Garden
Stellaria media (L.) Vill.	Chickweed	Caryophyllaceae	Edible	Garden
Euonymus japonicus L.	Japanese euonymus, Japanese spindle tree	Celastraceae	Ornamental, poisonous (cardenolides, alkaloids)	Garden
Cistus albidus L.	Rock rose, Sun rose,	Cistaceae	Ornamental, melliferous	Forest
Cistus crispus L.	Rock rose	Cistaceae	Ornamental, melliferous	Forest
Cistus monspeliensis L.	Rock rose	Cistaceae	Ornamental, melliferous	Forest
Cistus psilosepalus Sweet	Rock rose	Cistaceae	Ornamental, melliferous	Forest
Cistus salviifolius L.	Sageleaf rockrose	Cistaceae	Ornamental, melliferous	Forest

Appendix 5.A - Continued.

Taxa	English common names	Family	Potential uses/impacts	Typology of green space
Xolantha guttata (L.) Raf.	European frostweed, tuberaria, Spotted rockrose	Cistaceae	Ornamental, melliferous	Forest
Hypericum perforatum L.	St Jonh's wort	Clusiaceae	Ornamental, poisonous (dianthrones, hyperforin), skin-irritant	Garden
Hypericum pulchrum L.	Slender St John's wort	Clusiaceae		Forest
Tradescantia fluminensis Vell.	Spider-lily, Spider-wort	Commelinaceae	Invasive	Garden
Calystegia sepium (L.) R. Br.	Hedge bindweed, Larger bindweed, Rutland beauty, Bugle vine	Convolvulaceae	Ornamental, poisonous	Garden
Convolvulus arvensis L.	Field bindweed	Convolvulaceae	Poisonous (tropane and possibly ergot alkaloids)	Garden
Ipomoea indica (Burm.) Merr.	Blue dawn flower	Convolvulaceae	Ornamental, invasive	Forest, Garden
Umbilicus rupestris (Salisb.) Dandy	Navel wort, Penny wort	Crassulaceae		Garden
Bryonia dioica Jacq.	Red bryony, White bryony, British mandrake, Grapewort	Cucurbitaceae	Ornamental, poisonous (lectins, unsaturated poly-hidroxy acids and the protein brydiofin)	Garden
Chamaecyparis lawsoniana (A. Murray) Parl.	Lawson's cypress, Oregon cedar, Port Orford cedar	Cupressaceae	Ornamental	Garden
Chamaecyparis pisifera (Siebold & Zucc.) Endl.	Sawara cypress	Cupressaceae	Ornamental	Garden
Cupressus lusitanica Mill.	Portuguese cypress, Mexican cypress, Cedar of Goa	Cupressaceae	Ornamental, allergenic, poisonous (monoterpenes, sesquiterpenes)	Garden
Platycladus orientalis (L.) Franco	Arborvitae, Chinese arborvitae, Oriental arborvitae	Cupressaceae	Ornamental, poisonous (essential oil with thujone)	Garden
Sequoia sempervirens (Lamb.) Endl.	Coast redwood, Redwood, Sequoia	Cupressaceae	Ornamental	Garden
Sequoiadendron giganteum (Lindl.) J.Buchholz	Giant sequoia, Giant redwood, Sierra redwood, Wellingtonia	Cupressaceae	Ornamental	Garden
Cycas revoluta Thunb.	Sago palm, Japanese sago palm, King sago	Cycadaceae	Ornamental, poisonous [alkaloids, β-Methylamino-L-alanine (BMAA)]	Garden
Carex depressa Link	Sedge	Cyperaceae		Forest
Carex divulsa Stokes	Sedge, Berkeley sedge, European grey sedge	Cyperaceae		Garden
Carex pendula Huds.	Pendulous sedge, Drooping sedge, Hanging sedge	Cyperaceae	Ornamental	Garden
Cyperus longus L. subsp. *badius*	Common galingale, Sweet galingale	Cyperaceae	Weed	Garden
Nephrolepis exaltata (L.) Schott	Boston fern	Davalliaceae	Ornamental	Garden
Tamus communis L.	Black briony, murraim berries	Dioscoreaceae	Poisonous (steroid sponins, calcium oxalate raphides). Causes dermatitis	Forest, Garden
Equisetum telmateia Ehrh.	Giant horsetail	Equisetaceae	Poisonous (thiaminase, saponins, alkaloids)	Forest

Appendix 5.A - Continued.

Taxa	English common names	Family	Potential uses/impacts	Typology of green space
Arbutus unedo L.	Strawberry tree	Ericaceae	Edible (berries)	Forest, Garden
Calluna vulgaris (L.) Hull	Scotts heather	Ericaceae	Ornamental, melliferous	Forest
Erica arborea L.	Tree heath	Ericaceae	Ornamental, melliferous	Forest
Erica cinerea L.	Scotch heath, Bell heather	Ericaceae	Ornamental, melliferous	Forest
Erica umbellata Loefl. ex L.	Dwarf spanish heath	Ericaceae	Ornamental, melliferous	Forest
Escallonia rubra (Ruiz & Pav.) Pers.	Escallonia, Redclaws	Escalloniaceae	Ornamental	Garden
Euphorbia peplus L.	Petty spurge, Milkweed, Cancer weed	Euphorbiaceae	Poisonous (phorbol esters, triterpenoids)	Garden
Acacia dealbata Link	Silver wattle, Mimosa	Fabaceae	Melliferous, allergenic (pollen), invasive	Forest
Acacia melanoxylon R. Br.	Blackwood	Fabaceae	Melliferous, allergenic (pollen), invasive	Forest
Cercis siliquastrum L.	Judas tree	Fabaceae	Ornamental	Garden
Coronilla glauca L.	Mediterranean crownvetch, Glaucous scorpion-vetch	Fabaceae	Ornamental, melliferous	Forest
Genista triacanthos Brot.	Broom, Woodwaxen	Fabaceae	Melliferous, poisonous (quinolizidine alkaloids)	Forest
Gleditsia triacanthos L.	Honey locust	Fabaceae	Ornamental	Forest
Medicago lupulina L.	Black medick, Hop clover, Nonsuch	Fabaceae		Garden
Robinia pseudoacacia L.	Black locust, False acacia	Fabaceae	Invasive	Garden
Trifolium pratense L.	Bee bread, Cow clover, Cow grass, Meadow, Purple clover, Wild clover	Fabaceae	Ornamental (lawns), poisonous (pods - polycyclic aromatic compounds)	Forest
Ulex minor Roth	Dwarf furze, Dwarf gorse	Fabaceae	Melliferous, poisonous (quinolizidine alkaloids)	Forest
Vicia hirsuta (L.) Gray	Tiny vetch, Hairy vetch, Hairy tare	Fabaceae		Garden
Wisteria sinensis (Sims) Sweet	Chinese wisteria, Chinese kidney bean	Fabaceae	Ornamental, toxic (the seeds and pods contain lectins)	Garden
Castanea sativa Mill.	Sweet chestnut, Spanish chestnut	Fagaceae	Edible (nuts), medicinal, ornamental, woodwork	Forest
Quercus coccifera L.	Kermes oak, Grain oak	Fagaceae	Poisonous (tanins and other polyphenols)	Forest
Quercus faginea Lam. subsp. *broteroi* (Cout.) A. Camus	Portuguese oak	Fagaceae	Woodwork, tanning, allergenic (pollen), poisonous (tanins and other polyphenols)	Forest
Quercus ilex L. subsp. *ballota* (Desf.) Samp.	Holm oak, Evergreen oak, Holly-leaved oak	Fagaceae	Edible (acorns), tanning, allergenic (pollen), firewood	Forest
Quercus robur L.	English oak, Common oak, Pedunculate oak	Fagaceae	Medicinal, woodwork, allergenic (pollen), tanning, poisonous (tanins and other polyphenols)	Forest
Quercus suber L.	Cork oak	Fagaceae	Cork production, edible (acorns), allergenic (pollen), tanning, poisonous (tanins and other polyphenols)	Forest, Garden
Geranium dissectum L.	Cranesbill, Wild geranium, Cut leaved geranium	Geraniaceae		Forest

Appendix 5.A - Continued.

Taxa	English common names	Family	Potential uses/impacts	Typology of green space
Geranium molle L.		Geraniaceae		Forest
Geranium purpureum Vill.	Herb Robert, Robert geranium	Geraniaceae		Forest, Garden
Geranium rotundifolium L.	Round-leaved geranium, Round-leaved crane's bill	Geraniaceae		Garden
Ginkgo biloba L.	Maidenhair tree	Ginkgoaceae	Ornamental	Garden
Philadelphus floridus Beadle	Florida mock orange	Hydrangeaceae	Ornamental	Garden
Deutzia scabra Thunb.	Fuzzy pride of Rochester, Fuzzy deutzia	Hydrangeaceae	Ornamental	Garden
Pteridium aquilinum (L.) Kuhn	Bracken, Brake	Hypolepidaceae	Poisonous (ptaquiloside, thiaminase)	Forest, Garden
Chasmanthe aethiopica (L.) N. E. Br.	Cobra lily, Adam's rib, African corn flag	Iridaceae	Ornamental	Garden
Gladiolus illyricus W. D. J. Kock	Wild gladiolus	Iridaceae	Ornamental	Forest
Luzula multiflora (Retz.) Lej.	Many-flowered wood-rush	Juncaceae		Forest
Calamintha sylvatica Bromf.	Common calamint	Lamiaceae	Can be used to flavour olives	Forest
Lavandula stoechas L. subsp. *luisieri* (Rozeira) Rozeira	French lavender	Lamiaceae	Ornamental, aromatic	Forest
Lavandula pedunculata (Miller) Cav.	French lavender	Lamiaceae	Ornamental, aromatic, melliferous	Forest
Mentha rotundifolia (L.) Huds.	False apple mint, Round leaved mint	Lamiaceae	Aromatic	Forest
Origanum virens Hoffmanns. & Link		Lamiaceae	Edible (spice)	Forest
Teucrium salviastrum Schreb.		Lamiaceae		Forest
Urginea maritima (L.) Baker	White squill, Red squill	Lamiaceae	Poisonous (cardiac glycosides)	Forest
Akebia quinata (Houtt.) Decne.	Chocolate vine	Lardizabalaceae	Ornamental	Garden
Apollonias barbujana (Cav.) A. Br. subsp. *barbujana*	Canary laurel	Lauraceae	Ornamental, woodwork	Garden
Laurus nobilis L.	True laurel, Bay laurel, Sweet bay	Lauraceae	Ornamental, spice	Forest, Garden
Liriodendron tulipifera L.	Tulip tree, Yellow poplar, Tulip poplar, Canary whitewood	Magnoliaceae	Ornamental	Garden
Magnolia x *soulangeana* Soul.-Bod. var. *speciosa* Van Geel	Saucer magnolia, Chinese magnolia	Magnoliaceae	Ornamental	Garden
Ficus repens Roxb. ex Sm.		Moraceae	Ornamental	Garden
Morus alba L.	White mulberry	Moraceae	Ornamental, edible (multiple fruits)	Garden
Morus nigra L.	Black mulberry	Moraceae	Ornamental, edible (multiple fruits)	Forest
Angophora floribunda (Sm.) Sweet		Myrtaceae		Garden
Eucalyptus globulus Labill.	Tasmanian blue gum, Blue gum	Myrtaceae	Medicinal, pulp production	Garden
Eugenia uniflora L.	Brazilian cherry, Barbados cherry, Cayenne cherry, Surinam cherry	Myrtaceae	Ornamental, edible (berries)	Garden
Myrtus communis L.	Myrtle	Myrtaceae	Ornamental	Forest

Appendix 5.A - Continued.

Taxa	English common names	Family	Potential uses/impacts	T Typology ype of green space
Ochna multiflora DC.	Mickey-mouse plant, Bird's eye bush	Ochnaceae		Garden
Fraxinus angustifolia Vahl	Ash, Narrow leaved ash	Oleaceae	Ornamental, medicinal	Forest, Garden
Fraxinus ornus L.	Flowering ash, Manna ash	Oleaceae	Ornamental, woodwork, medicinal (laxative)	Forest
Jasminum mesnyi Hance		Oleaceae		Garden
Olea europaea L. subsp. *europaea* L.	Common olive, Edible olive	Oleaceae	Edible (olives, olive oil), allergenic (pollen)	Forest, Garden
Osmanthus fragans Lour.	Fragant olive, Sweet tea	Oleaceae	Ornamental	Garden
Ligustrum lucidum W. T. Aiton	Chinese privet, White wax tree	Oleaceae	Ornamental, poisonous (syringin, an irritant glucoside)	Garden
Ligustrum vulgare L.	Common privet	Oleaceae	Ornamental, poisonous (syringin, an irritant glucoside)	Garden
Phillyrea latifolia L.	Green olive tree	Oleaceae	Ornamental	Forest, Garden
Oenothera rosea L'Hérit. ex Aiton	Rose evening primrose, Pink evening-primrose	Onagraceae	Ornamental	Garden
Epipactis lusitanica D.Tyteca		Orchidaceae	Ornamental	Forest
Orobanche hederae Vaucher ex Duby	Ivy broomrape	Orobanchaceae		Garden
Oxalis articulata Savigny	Common wood-sorrel, Bent wood-sorrel	Oxalidaceae	Poisonous (oxalic acid)	Garden
Oxalis corniculata L.	Procumbent yellow sorrel, Creeping oxalis	Oxalidaceae	Poisonous (oxalic acid)	Garden
Oxalis debilis Kunth subsp. *corymbosa* (DC) O. Bolòs & Vigo	Pink woodsorrel	Oxalidaceae	Poisonous (oxalic acid)	Garden
Oxalis pes-caprae L.	Bermuda buttercup, English-weed	Oxalidaceae	Poisonous (calcium oxalate), invasive	Forest
Fumaria capreolata L.	Climbing Fumitory, Fumitory, White ramping fumitory	Papaveraceae		Garden
Passiflora sp.	Passion flowers, Passion vines	Passifloraceae	Ornamental Ornamental	Garden
Phytolacca americana L.	Pokeweed, Skoke, Garget	Phytolaccaceae	Poisonous (lectins, triterpene saponins)	Forest, Garden
Picea asperata Mast.	Dragon spruce	Pinaceae	Ornamental	Garden
Pinus halepensis Mill.	Aleppo pine	Pinaceae	Ornamental, woodwork	Garden
Pinus pinaster Aiton	Maritime pine	Pinaceae	Woodwork, edible (seeds)	Forest
Pinus pinea L.	Stone pine	Pinaceae	Woodwork, edible (seeds)	Forest
Pseudotsuga menziezii (Mirb.) Franco var. *glauca*	Douglas fir, Green Douglas fir	Pinaceae	Ornamental	Garden
Pittosporum tobira (Thunb.) W.T. Aiton	Tobira, Mock orange	Pittosporaceae	Ornamental	Garden
Pittosporum undulatum Vent.	Victorian box, Cheesewood	Pittosporaceae	Ornamental, invasive	Garden
Antirrhinum majus L.	Snapdragon	Plantaginaceae	Ornamental	Garden
Hebe speciosa (R. Cunn. ex A. Cunn.) Andersen		Plantaginaceae	Ornamental	Garden

Appendix 5.A - Continued.

Taxa	English common names	Family	Potential uses/impacts	Typology of green space
Plantago major L.	Broadleaf plantain, Greater plantain	Plantaginaceae	Allergenic (pollen)	Forest
Platanus x *hispanica* Mill. ex Münchh.	London plane	Platanaceae	Ornamental	Garden
Agrostis pourretii Willd.		Poaceae	Allergenic (pollen)	Forest
Avena barbata Pott. ex Link	Slender wild oat	Poaceae	Allergenic (pollen)	Forest, Garden
Brachypodium distachyon (L.) P. Beauv.	False brome, Purple false brome, Stiff brome	Poaceae	Allergenic (pollen)	Forest
Brachypodium sylvaticum (Huds.) P. Beauv.	False brome	Poaceae	Allergenic (pollen)	Forest
Briza maxima L.	Great quaking grass	Poaceae	Allergenic (pollen)	Forest
Cynosurus echinatus L.	Rough dog's tail grass	Poaceae	Ornamental (dried flowers arrangements)	Forest
Dactylis glomerata L.	Cocksfoot, Orchard grass	Poaceae	Allergenic (pollen)	Forest
Danthonia decumbens (L.) DC.	Common heath grass, Heath grass	Poaceae	Allergenic (pollen)	Forest
Desmazeria rigida (L.) Tutin	Ferngrass, Stiffgrass	Poaceae	Allergenic (pollen)	Garden
Ehrharta erecta Lam.		Poaceae		Garden
Holcus lanatus L.	Common velvetgrass	Poaceae	Allergenic (pollen), ornamental (dry flowers, for decorative uses)	Forest
Melica minuta L.	Black medic, Hop clover, Nonsuch, Yellow trifoil	Poaceae		Forest
Molinia caerulea (L.) Moench	Purple moor-grass	Poaceae	Allergenic (pollen)	Forest
Piptatherum miliaceum (L.) Cosson	Smilo grass	Poaceae	Allergenic (pollen)	Forest, Garden
Poa annua L.	Annual bluegrass, Annual meadow grass	Poaceae	Allergenic (pollen)	Forest, Garden
Poa pratensis L.	Kentucky blue grass, June grass	Poaceae	Allergenic (pollen)	Garden
Setaria viridis (L.) P. Beauv.	Green foxtail, Green bristlegrass	Poaceae	Allergenic (pollen)	Garden
Sporobolus indicus (L.) R. Br.	Smut grass	Poaceae		Garden
Stenotaphrum secundatum (Walter) Kuntze	St Augustine grass, Buffalo grass	Poaceae		Garden
Rumex acetosa L.	Garden sorrel, Sour dock	Polygonaceae	Poisonous (anthraquinones, tanins, oxalates), allergenic (pollen)	Forest
Rumex conglomeratus Murray	Dock, Sorrel	Polygonaceae	Poisonous (anthraquinones, tanins, oxalates), allergenic (pollen)	Garden
Anagallis arvensis L.	Scarlet pimpernel, Shepperd's clock	Primulaceae	Ornamental, poisonous (cucurbitacins, oxalates, triterpene saponins)	Garden
Asterolinon linum-stellatum (L.) Duby		Primulaceae		Forest
Primula acaulis (L.) L.		Primulaceae		Forest
Grevillea robusta A. Cunn. ex R. Br.	Silky oak	Proteaceae	Ornamental	Garden
Ranunculus muricatus L.	Buttercup, Crowfoot	Ranunculaceae	Poisonous (protoanemonin)	Forest

Appendix 5.A - Continued.

Taxa	English common names	Family	Potential uses/impacts	Typology of green space
Rhamnus alaternus L.	Buckthorn	Rhamnaceae	Medicinal, woodwork, tanning	Forest
Crataegus monogyna Jacq.	English hawthorn	Rosaceae	Ornamental, medicinal	Forest
Duchesnea indica (Andrews) Focke	Indian mock strawberry, Knotweed	Rosaceae	Ornamental, edible (berries)	Garden
Fragaria vesca L.	Wild strawberry, Woods strawberry, Woodland strawberry	Rosaceae	Ornamental, edible (berries)	Garden
Geum urbanum L.	Avens, Chocolate root, Benedicte	Rosaceae		Garden
Rubus ulmifolius Schott.	Brumble	Rosaceae	Edible (aggregate fruit)	Forest, Garden
Prunus laurocerasus L.	Cherry laurel, Laurel cherry, Laurel	Rosaceae	Ornamental, poisonous (cyanogenic glucosides)	Garden
Pyracantha crenulata (Roxb.) Roem	Nepalese white thorn	Rosaceae	Ornamental	Forest
Pyrus communis L.	Common pear	Rosaceae	Edible (pomes)	Forest
Rosa sp.1		Rosaceae	Ornamental	Garden
Rosa sp.2		Rosaceae	Ornamental	Garden
Galium sp.		Rubiaceae		Garden
Rubia peregrina L.	Wild Madder, Levant Madder	Rubiaceae	Ornamental	Forest, Garden
Salix atrocinerea Brot.	Grey willow, Rusty sallow	Salicaceae	Ornamental, medicinal (salicylic acid from the bark)	Forest
Salix sp.	Willow	Salicaceae	Ornamental, medicinal (salicylic acid from the bark)	Garden
Populus alba L.	White poplar, Silver-leaved poplar, Abele	Salicaceae	Ornamental, woodwork, medicinal (superficial wounds, burnings)	Garden
Acer negundo L.	Box elder	Sapindaceae	Ornamental	Garden
Acer pseudoplatanus L.	Sycamore, Great maple, Scottish maple	Sapindaceae	Ornamental	Garden
Veronica persica Poir.	Bird's eye spidwell, Persian speedwell	Scrophulariaceae		Forest, Garden
Selaginella denticulata (L.) Spring	Mediterranean clubmoss	Selaginellaceae	Ornamental	Forest
Ailanthus altissima (Miller) Swingle	Tree of heaven	Simaroubaceae	Poisonous and skin irritant (ailanthin, indole alkaloids), invasive	Garden
Smilax aspera L.	Common Smilax, Prickly ivy, Rough Smilax, Salsaparilla	Smilacaceae	Medicinal	Forest
Solanum chenopodioides Lam.	Forked nightshade, Velvety nightshade, Black nightshade	Solanaceae	Poisonous (tropane alkaloids)	Garden
Solanum nigrum L.	Black nightshade, Common nightshade, Deadly nightshade, Hound's berry	Solanaceae	Poisonous (tropane alkaloids)	Garden
Camellia japonica L.	Camellia	Theaceae	Ornamental	Garden
Daphne gnidium L.	Flax-leaved Daphne, Spurge-flax	Thymelaeaceae	Poisonous (phorbol esters, coumarin glycosides), skin irritant	Forest

Appendix 5.A - Continued.

Taxa	English common names	Family	Potential uses/impacts	Typology of green space
Tropaeolum majus L.	Nasturtium, Garden nasturtium, Indian cress	Tropaeolaceae	Ornamental, mildly toxic	Garden
Ulmus minor Mill.	European field elm, Smooth-leaved elm	Ulmaceae	Woodwork, medicinal, allergenic (pollen)	Forest, Garden
Ulmus pumila L.	Siberian elm	Ulmaceae	Ornamental, woodwork, medicinal (anti-diarrhoea, anti-infectious)	Garden
Parietaria judaica L.	Pellitory of the wall	Urticaceae	Allergenic	Garden
Urtica dioica L.	Stinging nettle	Urticaceae	Edible, medicinal, skin irritant, edible after boiling	Forest
Urtica membranacea Poir.	Large-leaved nettle	Urticaceae	Skin irritant, edible (after boiling)	Forest
Lantana camara L.	Shrub verbena, lantana	Verbenaceae	Poisonous (lantadenes)	Garden
Viola odorata L.	Sweet violet, Wood violet, English violet	Violaceae	Ornamental	Garden
Viola riviniana Rchb.	Common dog violet, Wood violet	Violaceae	Ornamental, toxic	Forest
Aloe arborescens Miller	Candelabra aloe, Octopus plant, Torch plant	Xanthorrhoeaceae	Ornamental	Garden
Simethis mattiazzi (Vand.) Sacc.	Kerry lily	Xanthorrhoeaceae	Ornamental	Forest
Ceratozamia mexicana Brongn.	Mexican horncone	Zamiaceae	Ornamental	Garden
Dioon edule Lindl.	Virgin palm, Mexican cycad, Chesnut dioon	Zamiaceae	Ornamental, poisonous (azoxyclucosides, *e.g.*, Cycasin)	Garden
Encephalartos horridus (Jacq.) Lehm.	Eastern Cape blue cycad	Zamiaceae	Ornamental, poisonous (cycasin, macrozamin)	Garden
Encephalartos villosus Lem.	Poor man's cycad	Zamiaceae	Ornamental, poisonous (cycasin, macrozamin)	Garden

Chapter 6

Assessing the quality of life and urban development in the municipality of Coimbra based on a perception survey of its residents

6.1. Abstract

Local authorities play a crucial role in providing public goods and services to the municipalities, and the citizen satisfaction surveys are essential to understand the individuals' evaluation regarding the urban development. This study analysed the citizens' perception about the development of the municipality of Coimbra, particularly, to evaluate the services provided by the local authorities, contributing to the overall quality of life perceived by each one. A total of 382 questionnaires were validated. Most of the respondents reported that they were satisfied with the quality of life in their municipality and agreed that Coimbra is a good place to live. Overall, the respondents expressed a high level of satisfaction with the economic and socio-cultural conditions. Nevertheless, they viewed several areas to be particularly important to the municipality whose authorities should prioritize, such as "support for industry, trade and establishment of companies", "accessibility for people with disabilities", and "support for the elderly". The more influential factor was the age of the respondents. Those who were between 18 and 25 years old expressed significantly higher levels of satisfaction with the majority of the issues examined in this survey. The respondent's opinion can be very useful in order to achieve a deeper understanding of the local conditions. This type of assessment is fundamental in defining urban policies and should be considered by municipal authorities when drawing up strategies for the improvement of plans and quality of life.

Keywords: perception survey; questionnaire; level of satisfaction; municipal services; Coimbra's residents

6.2. Introduction

The priority of local governments should consist in improving the quality of life and well-being of society through their capacity to attract active and participatory citizenships as well as stimulating and supporting economic agents (Duque *et al*., 2013). Taking this into account, improving the relationship with its citizens has been a goal of local governments (Schellong, 2005).

The attention given to assessments of citizens' satisfaction has been increasing since the 1970s, especially with regard to local services (Stipak, 1979). They received a substantial boost in popularity and importance in the early 1990s with the developments in the measurement instruments and research at economic and marketing departments (Bouckaert and van de Walle, 2003). The 21st century has witnessed an increase in surveys conducted in cities to obtain the peoples' opinions on their quality of life (Lever, 2000; Michalski, 2001: Roch and Poister, 2006; James, 2009; Mizrahi *et al*., 2009; Morais *et al*., 2013). These surveys allow to capture the perception of the citizens about the various components of the quality of life, and thus obtain an additional element to support decision-making relating to public action fields, strategies, and priorities (Johansson, 2002; Møller and Dickow, 2002; Veenhoven, 2002; Senlier *et al*., 2009). Hence it is not surprising that these types of surveys have been embraced worldwide (Howard, 2010).

Europe is characterized by a high degree of urbanization. Today, about 73% of the European population lives in cities (United Nations, 2014). Therefore, is very important at European, national, regional or local level, to understand what is happening economically and socially in Europe's cities (Feldmann, 2008). The quality of life is increasingly considered as an essential element for the development of cities, since a good quality of life is crucial for attracting and retaining a skilled labour force, businesses, students, tourists and, most of all, residents (Feldmann, 2008; Morais *et al*., 2013). For this reason, urban quality of life and well-being are realities that have also been demanding increased attention from the authorities of European institutions, namely through the Urban Audit project from the European Commission (see at stat.gov.pl/en/regional-statistics/regional-surveys/urban-audit). The Urban Audit, which started in 1999, is a Europe-wide collection of quantitative information on the quality of life in cities and is the result of a joint effort by the participating cities, the Statistical Offices belonging to the European Statistical System, Eurostat, and the Directorate-General for Regional Policy (European Commission, 2007a). It provides an in-depth analysis of demography, social conditions, economic aspects, education, civic involvement, environment, transport, and culture, as well as investigates how the competences of city authorities and local governments vary across Europe (European Commission, 2007a; Feldmann, 2008).

Since, much of the effective practice of a democracy depends on the existence of a link between the citizens and local governments, the citizen participation is usually considered a valuable element of democratic citizenship and democratic decision-making (Michels, 2011). Therefore, the citizen survey has become the most common method adopted to understand citizens' satisfaction levels, needs, concerns, and priorities (Kelly, 2003). The European Commission has been using such surveys for several years to get a snapshot of people's opinions on a range of urban issues. The first survey was conducted in 2004 and measured the local perceptions of quality of life in 31 European cities (European Commission, 2004). The perception survey on quality of life in European cities was also conducted in 2007 and 2010, and measured local perceptions in 75 cities (European Commission, 2007b, 2010b). The last survey was carried out in 2013 and measured local perceptions of quality of life in 79 European cities (European Commission, 2013b). In all these surveys two Portuguese cities, Lisbon and Braga, were included.

The municipality of Coimbra, centre of Portuguese culture through the centuries, owns a unique monumental, artistic and literary heritage, which demonstrates its importance. This municipality has a set of collective facilities of excellence, placing it in a privileged position in the network of urban centres in the country (CMC, 2012). The school network is secured by 110 schools, providing primary and secondary schools and 82 kindergartens (pre-school). In higher education, Coimbra stands out at the regional and national context, highlighting the University of Coimbra and Superior Schools. Health facilities are centered in 4 hospitals with supra-regional or national influence, which include all the basic and highly differentiated specialties. In the area of sports equipment, there are 372 facilities, some of them due to their size and large capacity audience, enable the realization of very important competitions both nationally and internationally (CMC, 2008).

In terms of population evolution, the municipality of Coimbra recorded in the decade of 2001-2011, a slight decrease of inhabitants (-5 047) (see Chapter 3), following the evolutionary trend in most Portuguese cities (INE, 2011). There is also a decrease in the number of residents in the urban centre, accompanied by its aging and by a loss of economic dynamism, stemmed mainly from the closing of some traditional trade as well as the relocation of community facilities and services attractiveness to out of centre (INE, 2011; CMC, 2012).

In 2013, the historic zone of the city of Coimbra, including the University of Coimbra, was classified as World Heritage by UNESCO. This classification relates to historical buildings, but also includes an immaterial dimension justified by the role of the University as a contractor and diffuser for centuries of the Portuguese language and culture (to know more on the UNESCO World Heritage, consult whc.unesco.org and www.cm-coimbra.pt). An approach to the heritage aspects of Coimbra, in its global significance and dimension, individualize up three strands, which stand out in the context of its enormous historical and cultural richness: the built, urban and landscape heritages (CMC, 2008, 2012).

The financial crisis has forced governments to reduce spending on public services in order to curb public debt and benefits (van de Walle and Jilke, 2014). Municipal authorities deal with limited resources which need to be targeted to activities that most benefit their citizens. To allocate resources towards goods and services that are most valued by citizens is an important criterion for decision-making (Chapel Hill Survey, 2014). Therefore, understanding citizens' levels of satisfaction on the quality of services provided and urban development are important assessments mechanisms for understanding the level of performance of governmental agencies (Roch and Poister, 2006), particularly at local level.

The main goal of this work was to assess Coimbra citizens' perception about the environmental, economic, and socio-cultural conditions provided by the municipality as well as to evaluate the performance of local authorities. Ultimatly this assessment reflected their evaluation on the status of their quality of live in the urban environment. Differences in satisfaction among individuals may exist because differences in socio-demographic characteristics, such as gender, age, and education are linked to varying attitudes that are closely related to satisfaction (Roch and Poister, 2006). A further aim of the investigation was to relate the levels of satisfaction/importance with the socio-demographic profile of respondents. In sum, this research attempted to contribute towards the understanding how citizens form judgments and opinions about the quality of municipal services. The purpose of this study also was to provide the competent authorities with results and suggestions which can be helpful for the development of future management plans and programmes in this municipality.

6.3. Material and Methods

6.3.1. Methodological approach and questionnaire design

Through the individual analysis, the purpose of this study was to measure the citizens' satisfaction level regarding their life framework and perception based on their personal experience. With respect to the methodological approach, this assessment was based on a questionnaire sent by e-mail and answered by citizens exclusively residing in the municipality.

Likert-type scale is a widely used psychometric scale in survey research (Sum *et al*., 2010; Tavares *et al*., 2010; Li, 2013). A 4-point Likert-type scale was used as a data collection instrument in order to obtain respondents perception on the several parameters evaluated, except in one question (question 2.1) where responses were measured on a 3-point Likert-type scale. In both scales the highest values indicated greater levels of satisfaction/importance. In all questions, the respondents were asked to select only a single answer (simple choice answers), except in question 4.4.1 where they could select one or more alternatives (multiple choice answers).

The questionnaire (Appendix 6.A) was divided into 4 main sections. The first section integrated the socio-demographic profile of respondents. In this section a set of personal characteristics as gender, age, education degree, working status, and length of residency in the municipality of Coimbra were exploited. The second section included the respondents' perception in relation to some economic and socio-cultural conditions of the municipality. Here, the respondents were asked to rate their level of satisfaction about the quality of life in the municipality on 24 listed issues. The third section adressed the performance of municipal authorities. This section was designed to evaluate the level of satisfaction of the respondents with the services of the municipal authorities as well as to rate the level of importance of the investment that should be given by the authorities on 19 issues listed. The last section integrated the respondents' perception relative to the requalification and urban planning of the municipality. Thus, the respondents were asked to provide their level of satisfaction about the requalification and urban planning as well as about the quality of the public spaces in the municipality of Coimbra. In this assessment seven green spaces were listed.

The questionnaire was conducted on-line from September 2013 to June 2014. It included exclusively closed-ended questions, which are easy to understand and reduce propability of error when responding. Providing response choices in the survey reduces ambiguity, and respondents are more likely to answer the question that the researcher really wants them to answer (Check and Schutt, 2012). The variables' measurement comprised only three or four mutually exclusive categories (*e.g.*, "improved, remained or worsened" and "very good, good, reasonable or bad"), ensuring a merely categorical level of measurement.

6.3.2. Methodological limitations

Limitations always exist in any study. In particular, there are issues of questionnaire validation regarding the survey's on-line format. First, the studied population transcends the on-line community, which raises problems of representativeness and precision. Second, the link for the survey was only published on the Facebook page of a research unit of the University of Coimbra (Centre for Functional Ecology) and the e-mails with this link were only sent to the University community and Polytechnic Institutes of Coimbra (although it was also requested to forward it to their family and friends). Given these constraints, not all the residents in the municipality of Coimbra had access to the questionnaire, therefore this survey is not statistically representative of the entire population, which inevitably weakens the survey's external validation.

6.3.3. Statistical analysis

A quantitative assessment has been used to analyse and interpret the data collected. For the interpretation of the results, descriptive statistics were used, namely, frequency distributions, and percentages to describe what the respondents thought about the foremost features of the municipality.

Since the respondents were asked to rate their answers on a scale (Likert-type scale), the responses were analysed using a score as used by other authors (Chiesura, 2004; Christensen and Laegreid, 2005; Pan, 2012). For example, one of the formats of the 4-point Likert-type scale ranged from "very good" (score = 4), "good" (score = 3), "reasonable" (score = 2) to "bad" (score = 1). The format of the 3-point Likert-type scale ranged from "improved" (score = 3), "remained" (score = 2) to "worsened" (score = 1). Higher numbers indicate higher levels of satisfaction/importance and the mean point on the scales mark a neutral position. Thus, calculating the mean value of all the questions was possible to know whether respondents were generally satisfied or not, by how high or low the mean value was. The response options “don’t know” weren’t considered into the calculation of the mean scores values.

In order to determine whether socio-demographic characteristics of respondents could influence their answers, analysis of variance and factor analysis were performed. One-way analysis of variance (ANOVA) and the Tukey test ($p \leq 0.05$) for overall comparisons were used to test for significant differences in the respondents' opinion with regard to their socio-demographic characteristics. All the data were checked for normality and homogeneity of variance (Zar, 1996). Statistical analyses were performed using SPSS 17.0 software for Windows (SPSS Inc., IL, USA).

6.4. Results

6.4.1. Socio-demographic profile of the respondents

The total number of valid responses to the survey was 382 (Table 6.1). It was quite clear that out of the total respondents investigated for this study, overwhelming majority (65%) of them were females. Age of the respondents was one of the most important characteristics in understanding their views and awareness about quality of the resources and services of their municipality. Over half of respondents (55%) were between 26 to 45 years old (Table 6.1).

Regarding the education degree, 87% of all respondents had a university degree (Table 6.1). This result revealed a substantial divergence between the survey sample and the general population, as the percentage of people with an university degree in Coimbra is just about 29%, although this percentage is approximately the double when compared to the population nationwide (INE, 2011). Moreover, 32% of all respondents were students or research fellows. Thus, it must be taken into account that the survey respondents were considerably more educated than the general population, which is not unusual on when using online questionnaires, and in addition, the e-mails with the link for the survey were sent solely to the University community and Polytechnic Institutes of Coimbra. It was also evident that more than half of the total respondents (57%) were employed and 26% were students (Table 6.1).

Over fifty percent of the survey sample (53%) has lived in the municipality of Coimbra for more than twenty years. An additional 28% of respondents reported less than ten years of residence in this municipality (Table 6.1).

Table 6.1 - Socio-demographic profile of the respondents.

	Frequency	Percentage
Gender		
Female	249	65
Male	133	35
Age (years)		
18 to 25	74	19
26 to 35	122	32
36 to 45	89	23
46 to 55	60	16
> 55	37	10
Education degree		
Secondary education or lower	47	12
Bachelor degree	119	31
Master degree	118	31
Doctorate degree	94	25
Other educational qualification	4	1
Working status		
Employed	217	57
Unemployed	29	7
Student	99	26
Research fellow	23	6
Retired	10	3
Other professional activity	4	1
Length of residency in Coimbra (years)		
< 10	105	28
10-15	36	9
16-20	38	10
> 20	203	53

6.4.2. Perception in relation to the municipality conditions

In order to evaluate the residents' opinion about the quality of life in the municipality of Coimbra, the respondents were asked to answer two questions rated along a measurement scale. The first question was: "You consider that the quality of life in the municipality of Coimbra has improved, remained the same or worsened in the last five years?" The second question was: "In general, you think that living in this municipality is very good, good, reasonable or bad"?

As shown in Figure 6.1-A, when asked to characterize how the quality of life in the municipality of Coimbra had changed in the last five years, respondents most frequently (47%) chose the second alternative, that there has been no change. Moreover, it must be taken into account that many respondents (30%) reported that over the five past years, their municipality has become a better place to live, whereas 18% indicated that Coimbra is worse today than it was five years ago.

Relativelly to the second question, they were quite positive on this matter, as a majority of respondents (63%) said that Coimbra is a good place to live (Figure 6.1-B) and only 1% assumed that this municipality is a bad place to live.

The mean scores were 2.13 (SE = 0.037) out of a total of 3, for the first question and 2.94 (SE = 0.033) out of a total of 4, for the second question. In both cases, the values were placed well above the central point in the scale, revealing a high level of satisfaction recognized by the respondents.

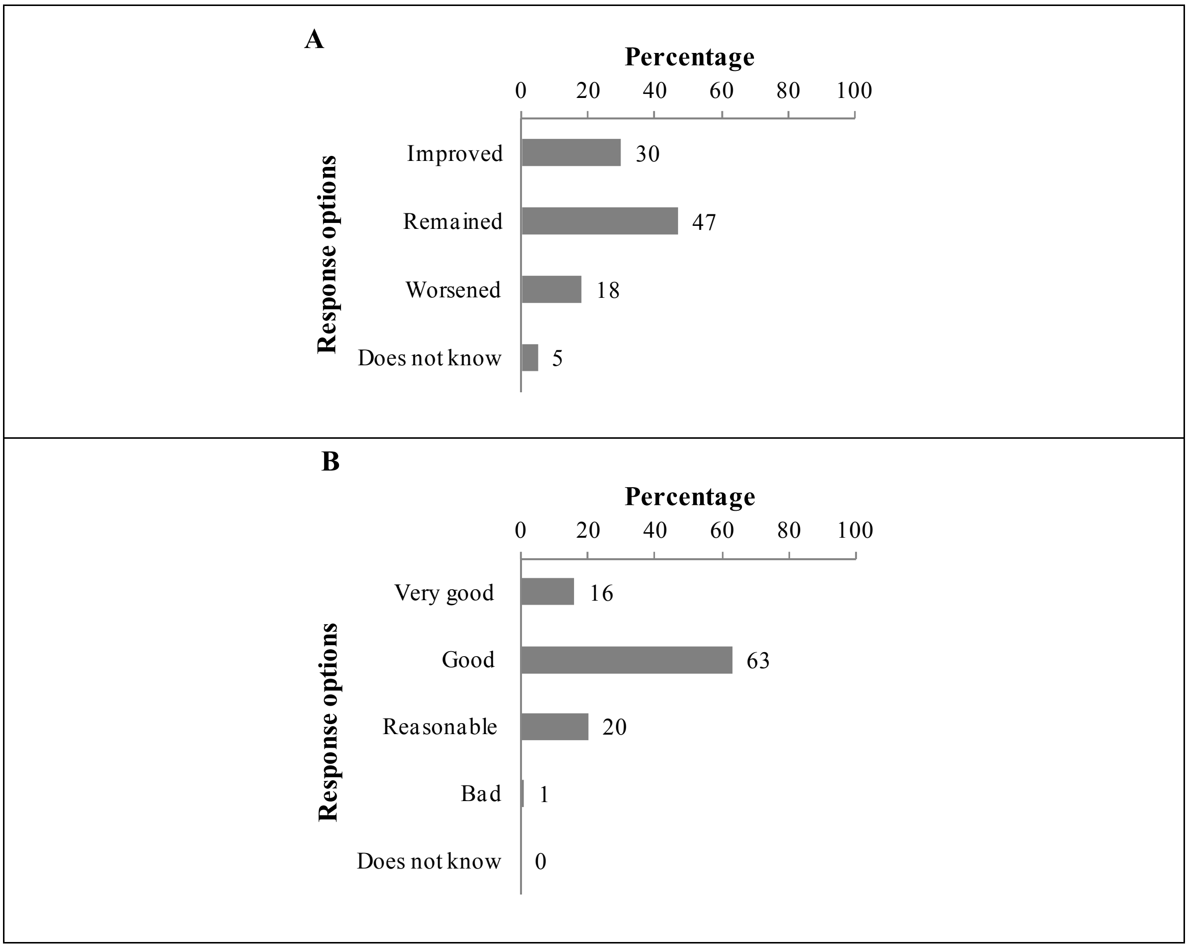


Figure 6.1 - Percentage of responses relative to the respondents' opinion about the progress of the quality of life in Coimbra in the last five years (A) and satisfaction with the quality of the municipality as a place to live (B).

Socio-demographic characteristics of the respondents had a statistical influence on the responses to both questions. The age group showed significant differences in the respondents' level of satisfaction with regard to the quality of life in the municipality

($p = 0.030$). Younger age group proved to be more satisfied with the quality of life than the older age group (> 55 years old) (Figure 6.2).

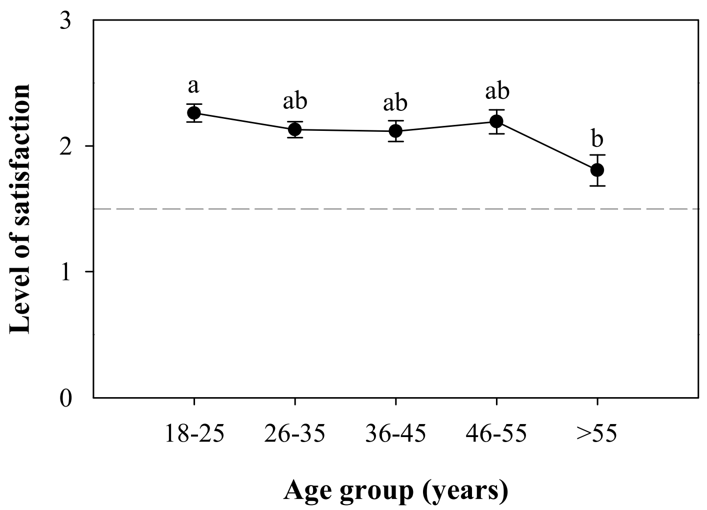


Figure 6.2 - Respondents' level of satisfaction with the progress of the quality of life in the municipality of Coimbra by different age groups. Values are means ± SE. The dashed line indicates the central point on the 3-point scale signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between age groups.

Significant differences were also found between the age groups ($p = 0.024$) and working status ($p = 0.047$) regarding the level of satisfaction with Coimbra as a good place to live (Figure 6.3). The younger respondents (18-25 years old) stand out from the rest showing to be more satisfied living in Coimbra, except when comparing to the 46-55 age group's responses (Figure 6.3-A). In the case of working satus, the students revealed a higher level of satisfaction with Coimbra as a place to live than the employed and unemployed respondents (Figure 6.3-B).

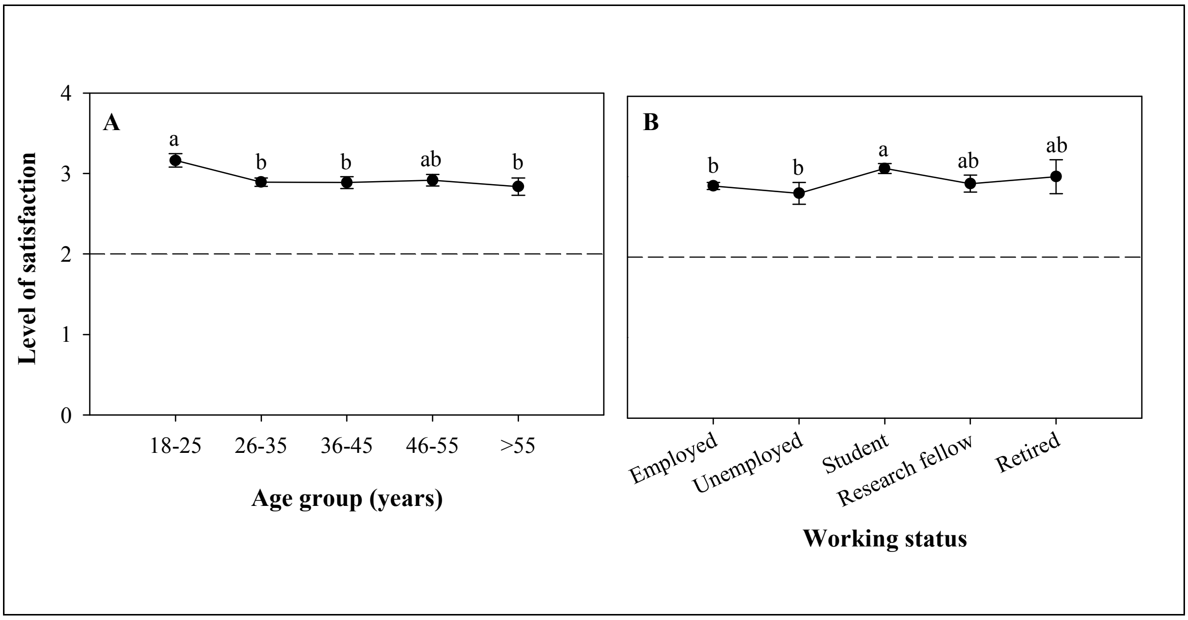


Figure 6.3 - Respondents' level of satisfaction with Coimbra as a place to live by different age groups (A) and working status (B). Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between age groups (A) and working status (B).

To give their opinion about some economic and socio-cultural conditions of the municipality, the respondents were asked to classify the quality of 24 conditions provided by the municipality according to Table 6.2. The responses "reasonable" and "good" were the most frequently referred, despite seven conditions were classified below the mean value (= 2.0). Residents seemed to particularly give value to the four last listed services of the table (21 to 24). Classification as "very good" was selected more times by respondents to express their views on health services accounting 46% of the total answers. In the three issues "accessibility for people with disabilities", "housing price", and "bike paths" the response "bad" was the most frequently mentioned by respondents, accounting 47%, 57%, and 74% of the options, respectively (Table 6.2).

Respondents' levels of satisfaction ranged from 1.30 to 3.31 (Table 6.2). The results showed that only 7 out of 24 issues presented values below the central point (= 2.0) in the scale of 1 to 4, revealing a level of dissatisfaction between respondents. The four issues that won the highest levels of satisfaction were "health services", "education", "water supply", and "basic sanitation". On the contrary, the respondents were least satisfied with "bike paths", "housing price", "accessibility for people with disabilities", and "parking" (Table 6.2).

Table 6.2 - Percentage of responses and ranking of respondent's opinion by the mean scores (± SE) about the level of satisfaction with regard to the quality of 24 listed conditions provided by the municipality.

Issues	Responses (%)				Mean scores
	Very good	Good	Reasonable	Bad	
1. Bike paths	0	3	23	74	1.30 (± 0.028)
2. Housing price	0	9	34	57	1.53 (± 0.034)
3. Accessibility for people with disabilities	0	8	45	47	1.62 (± 0.033)
4. Parking	1	13	44	42	1.73 (± 0.037)
5. Employment	0	12	50	38	1.74 (± 0.034)
6. Conditions of the buildings	1	13	55	31	1.83 (± 0.034)
7. Spatial planning	2	16	48	34	1.86 (± 0.039)
8. Combating poverty and social exclusion	2	26	59	13	2.16 (± 0.035)
9. Pedestrian areas	3	31	45	21	2.17 (± 0.041)
10. Support for the elderly	4	27	57	12	2.23 (± 0.036)
11. Accessibility	6	31	45	18	2.23 (± 0.042)
12. Transit	4	32	50	14	2.26 (± 0.038)
13. Public transport	7	41	39	13	2.42 (± 0.042)
14. Leisure and recreation areas	6	43	43	8	2.46 (± 0.038)
15. Cultural and sport areas	6	42	45	7	2.48 (± 0.037)
16. Air quality	7	53	37	3	2.64 (± 0.034)
17. Public safety	10	53	33	4	2.68 (± 0.036)
18. Waste collection and selection	14	54	27	5	2.76 (± 0.039)
19. Public lighting	14	55	27	4	2.80 (± 0.037)
20. Cultural heritage	25	47	24	4	2.93 (± 0.041)
21. Basic sanitation	26	58	14	2	3.08 (± 0.035)
22. Water supply	30	54	15	1	3.12 (± 0.036)
23. Education	42	46	11	1	3.29 (± 0.036)
24. Health services	46	40	12	2	3.31 (± 0.038)

Note: Ranking was made on a 4-point Likert-type scale, with higher values indicating higher levels of satisfaction.

The statistical results for the four worst- and best-ranked issues with regard to the socio-demographic profile of respondents are presented in Table 6.3. The length of residency in Coimbra was the characteristic that influenced the most people's opinion where five out of eight issues revealed significant differences. It is worth noting that all socio-demographic classes showed significant differences with regard to the issue "accessibility for people with disabilities". By contrast, the issue "bike paths" had no significant differences in any of the socio-demographic characteristics of the respondents (Table 6.3).

Table 6.3 - The statistical results relative to the four worst-ranked issues (1-4) and the four best-ranked issues (5-8) with regard to socio-demographic profile of the respondents.

Issues	**Gender**	**Age**	**Education degree**	**Working status**	**Length of residency in Coimbra**
1. Bike paths	$p = 0.553$	$p = 0.095$	$p = 0.817$	$p = 0.118$	$p = 0.204$
2. Housing price	$p = 0.104$	$p < 0.001$**	$p = 0.145$	$p < 0.001$**	$p = 0.020$*
3. Accessibility for people with disabilities	$p = 0.027$*	$p < 0.001$**	$p = 0.006$**	$p < 0.001$**	$p = 0.014$*
4. Parking	$p = 0.090$	$p = 0.163$	$p = 0.014$*	$p = 0.228$	$p = 0.163$
5. Basic sanitation	$p = 0.025$*	$p = 0.023$*	$p = 0.064$	$p = 0.082$	$p = 0.026$*
6. Water supply	$p = 0.032$*	$p = 0.337$	$p = 0.368$	$p = 0.578$	$p = 0.001$**
7. Education	$p = 0.466$	$p = 0.078$	$p < 0.001$**	$p = 0.535$	$p = 0.072$
8. Health services	$p = 0.083$	$p = 0.029$*	$p < 0.001$**	$p = 0.265$	$p < 0.001$**

* Significant differences at $p < 0.05$.
** Significant differences at $p \leq 0.01$.

Significant gender-related differences were found with regard to the "accessibility for people with disabilities", "basic sanitation", and "water supply" (Table 6.3). Generally, males respondents showed a higher level of satisfaction than females (Figure 6.4).

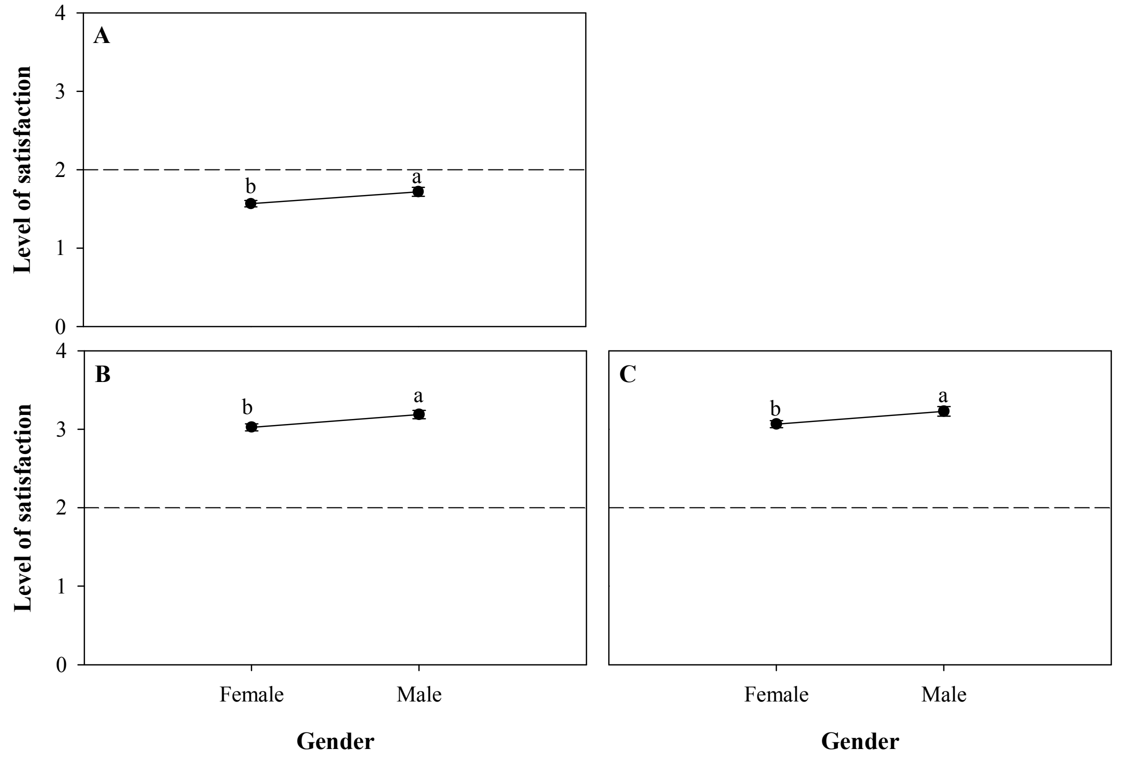


Figure 6.4 - Respondents' level of satisfaction by gender categories relatively to the conditions of accessibility for people with disabilities (A), basic sanitation (B), and water supply (C). Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between genders.

The age of the respondents revealed significant differences in their level of satisfaction in relation to "housing price", "accessibility for people with disabilities", "basic sanitation", and "health services" (Table 6.3). The younger age group proved to be more satisfied with the current situation in the municipality relatively to "housing price" and "accessibility for people with disabilities" than the other age groups (Figure 6.5-A, B). The younger age group also proved to be more satisfied with the "basic sanitation" than the older age group (> 55 years old) (Figure 6.5-C). Regarding the "health services" in the municipality, the group 36-45 years old showed a higher level of satisfaction than the younger age group (Figure 6.5-D).

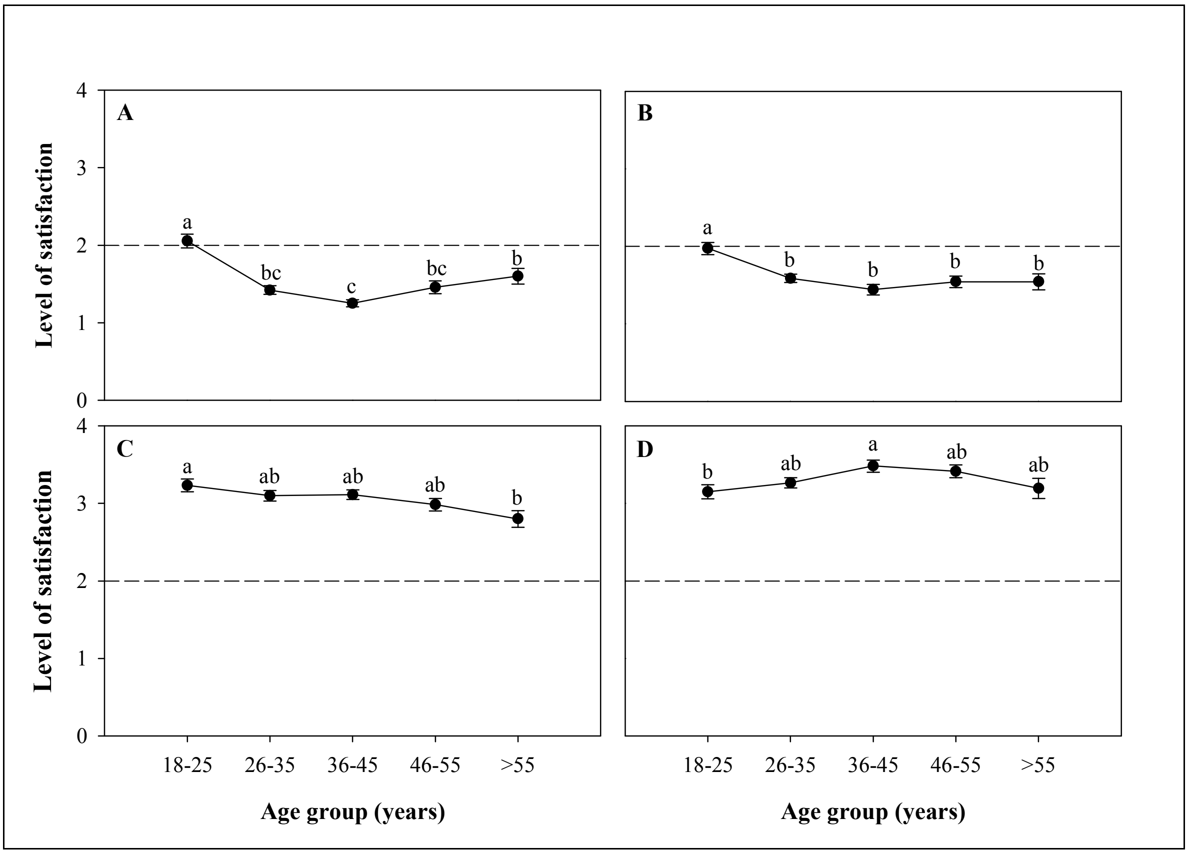


Figure 6.5 - Respondents' level of satisfaction by different age groups relatively to housing price (A), accessibility for people with disabilities (B), basic sanitation (C), and health services (D) in the municipality. Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between age groups.

The results also showed that the respondent's satisfaction in relation to the "accessibility for people with disabilities", "parking", "education", and "health services" in the municipality were significantly different among education degrees (Table 6.3). Relative to the "accessibility for people with disabilities", the group composed by respondents with lower education degree revealed more pleased with the access conditions for this peoples than the group composed by respondents with bachelor's and doctorate degrees (Figure 6.6-A). The respondents with lower education degree also showed a higher level of satisfaction with the conditions of the "parking" in the municipality than the groups composed by respondents with master's and doctorate degrees (Figure 6.6-B). In contrast, the respondents with lower education degree revealed less satisfaction with the situation of the municipality in relation to the "education" (Figure 6.6-C) and "health services" (Figure 6.6-D) than the respondents with master's and doctorate degrees.

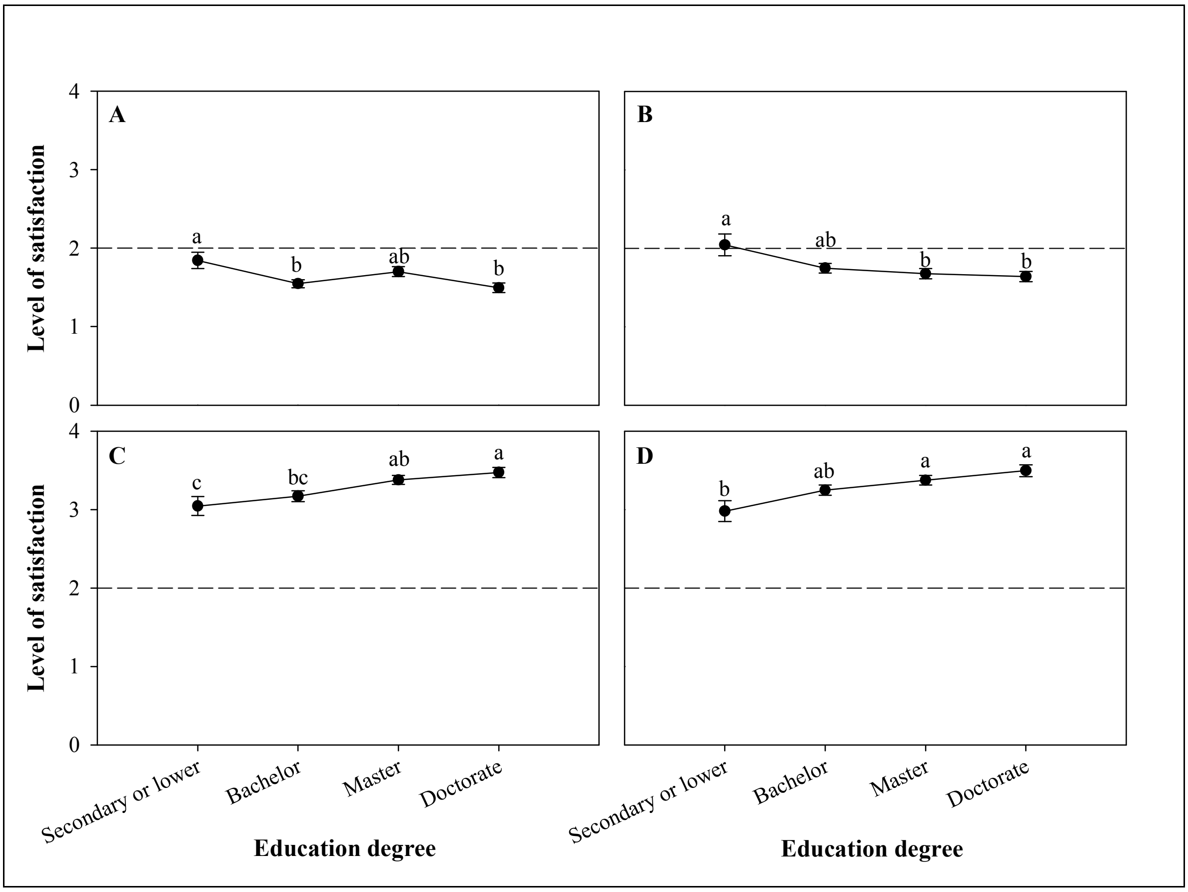


Figure 6.6 - Respondents' level of satisfaction by different education degrees relatively to accessibility for people with disabilities (A), parking (B), education (C), and health services (D) in the municipality. Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between education degrees.

There were also significant differences between working status with regard to the "housing price" and "accessibility for people with disabilities" in the municipality (Table 6.3). Students proved to be more satisfied with the situation in the municipality relatively to the "housing price" (Figure 6.7-A) and "accessibility for people with disabilities" (Figure 6.7-B) than the employed respondents.

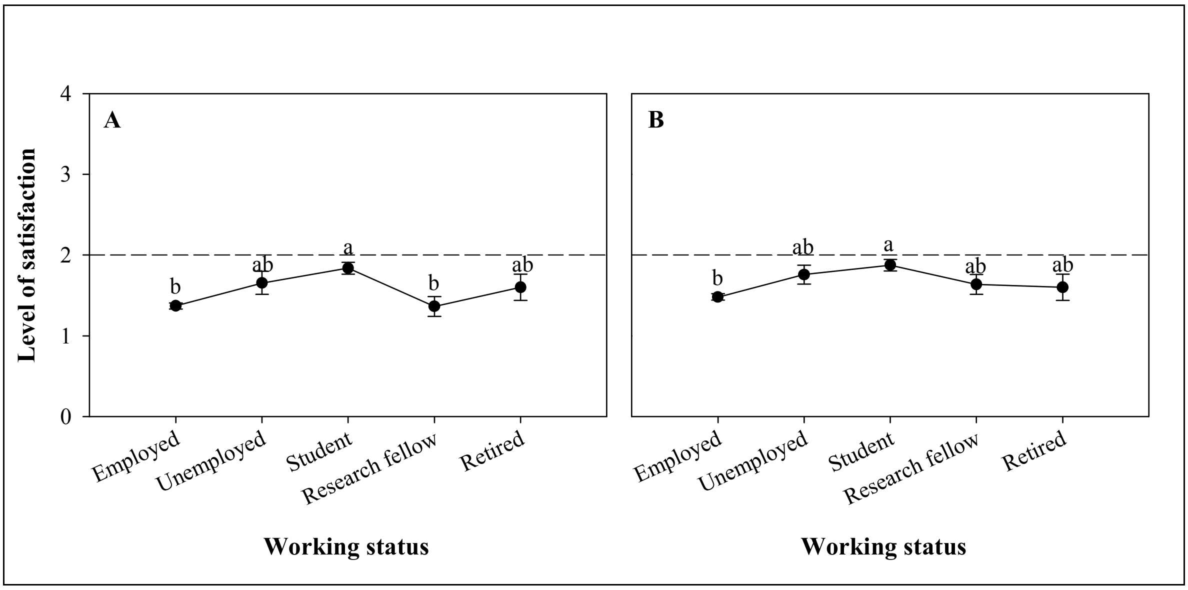


Figure 6.7 - Respondents' level of satisfaction by different working status relatively to housing price (A) and accessibility for people with disabilities (B) in the municipality. Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between working status.

The length of residency in Coimbra seemed to influence the level of satisfaction in relation to five issues: "housing price", "accessibility for people with disabilities", "basic sanitation", "water supply", and "health services" (Table 6.3). The residents who have lived for less than 10 years in Coimbra showed a higher level of satisfaction with the "housing price" than those who live in Coimbra between 10-15 years (Figure 6.8-A). The residents who have lived between 16-20 years in Coimbra rated higher the other four issues. They proved to be more satisfied with the "accessibility for people with disabilities" than the ones who have lived between 10-15 years or for more than 20 years in this municipality (Figure 6.8-B). They also evidenced a higher level of satisfaction with the conditions of the "basic sanitation" (Figure 6.8-C), "water supply" (Figure 6.8-D) and "health services" (Figure 6.8-E) than those who have lived for less than 10 years in the municipality.

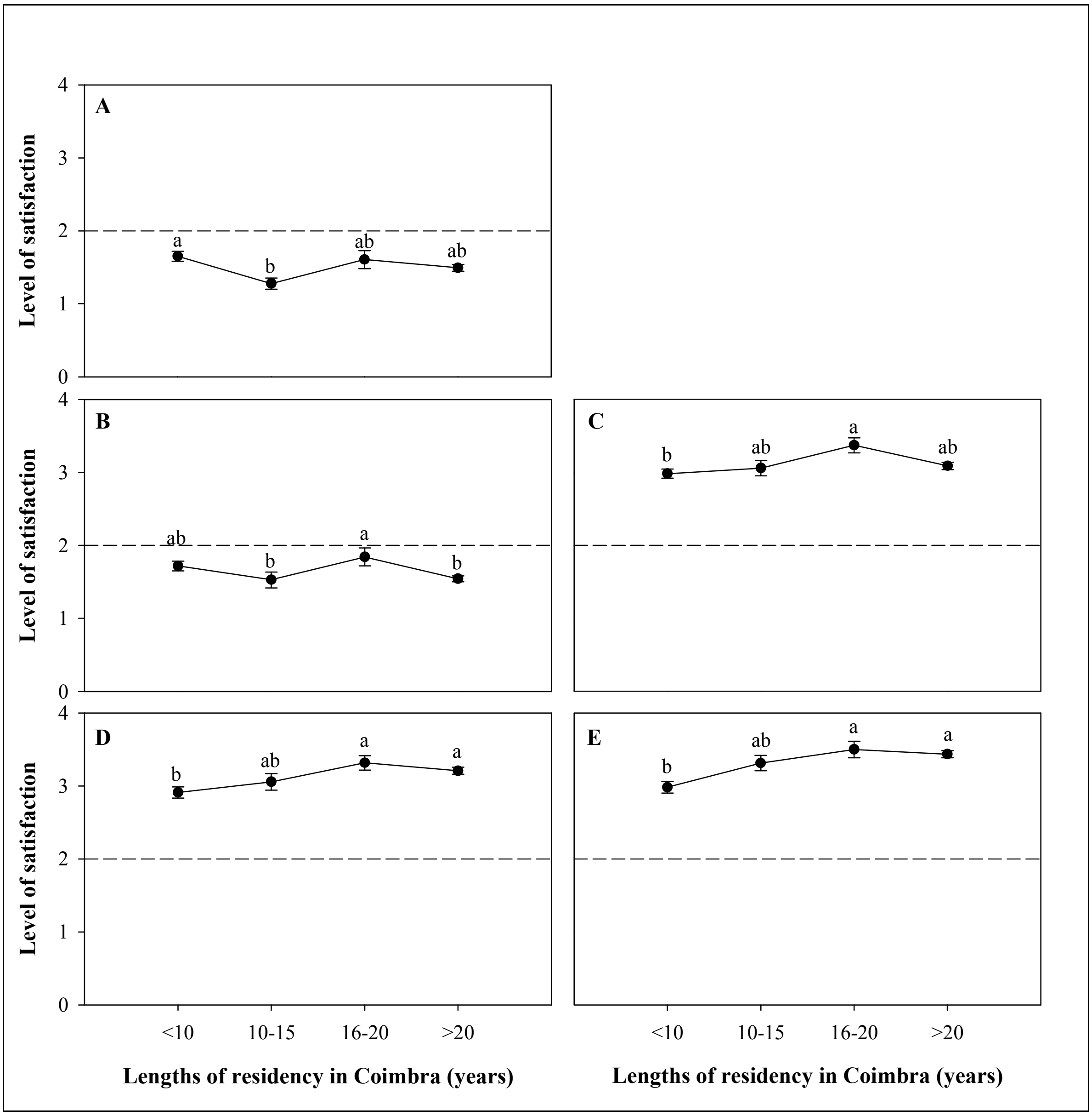


Figure 6.8 - Respondents' level of satisfaction by different lengths of residency in Coimbra relatively to housing price (A), accessibility for people with disabilities (B), basic sanitation (C), water supply (D), and health services (E) in the municipality. Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between lengths of residency.

6.4.3. Performance of municipal authorities

In order to evaluate the residents' opinion about the services of municipal authorities, they were enquired to answer the following two questions: "Overall, how satisfied are you with the services of your City Council and Parish Council?" The responses were rated along a measurement scale (very satisfied, satisfied, somewhat satisfied and not at all satisfied). More than half of the respondents said that they were satisfied with the services provided by the City Council (53%) and Parish Council (65%) with mean scores of 2.58 (SE = 0.032) and 2.74 (SE = 0.030) for first and second municipal authorities, respectively (Figure 6.9). In both cases, the level of satisfaction was placed above the central point (= 2.0) in the scale of 1 to 4, which showed that respondents were satisfied with both types of local authorities but seemed to prefer those provided by the Parish Council.

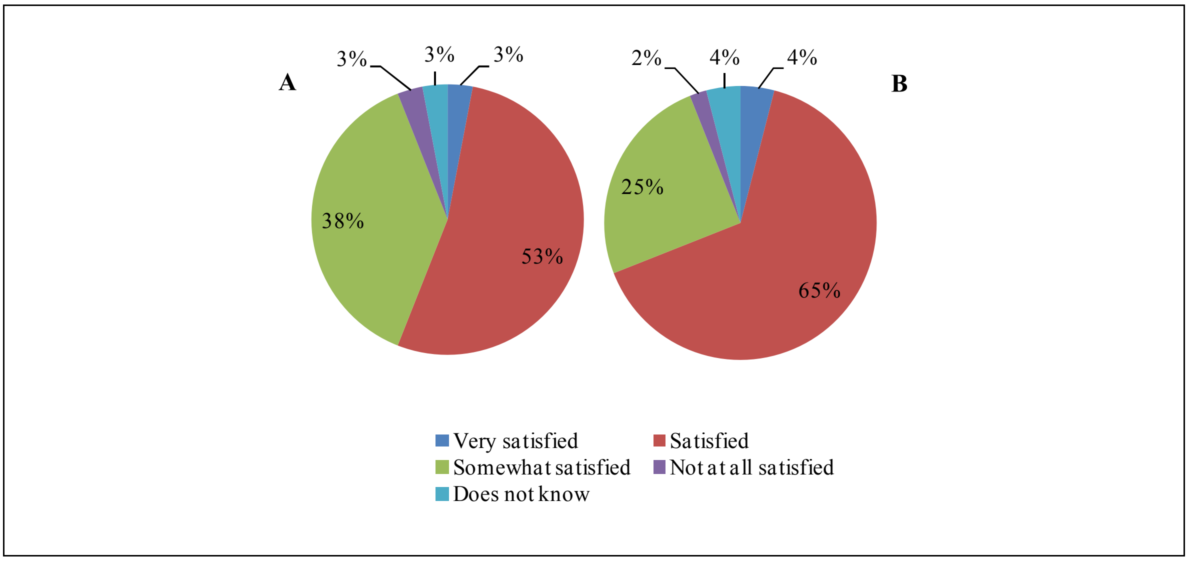


Figure 6.9 - Percentage of responses relative to the respondents' opinion about the services provided by the City Council (A) and Parish Council (B).

The results showed that the level of satisfaction with the services of City Council and Parish Council were related to some socio-demographic characteristics of the residents namely, the age group ($p < 0.001$), working status ($p < 0.001$), and residence time in Coimbra ($p < 0.001$) (Figure 6.10). Relative to age group, younger people proved to be more satisfied with the City Council's services than the respondentes with more than 36 years old (Figure 6.10-A). As shown in Figure 6.10-B, the students group were more satisfied with the City Council services than the retired respondents. Respondents who live for more than 20 years in the municipality of Coimbra provided evidence that they were less pleased with the City Council services than the other residents (Figure 6.10-C).

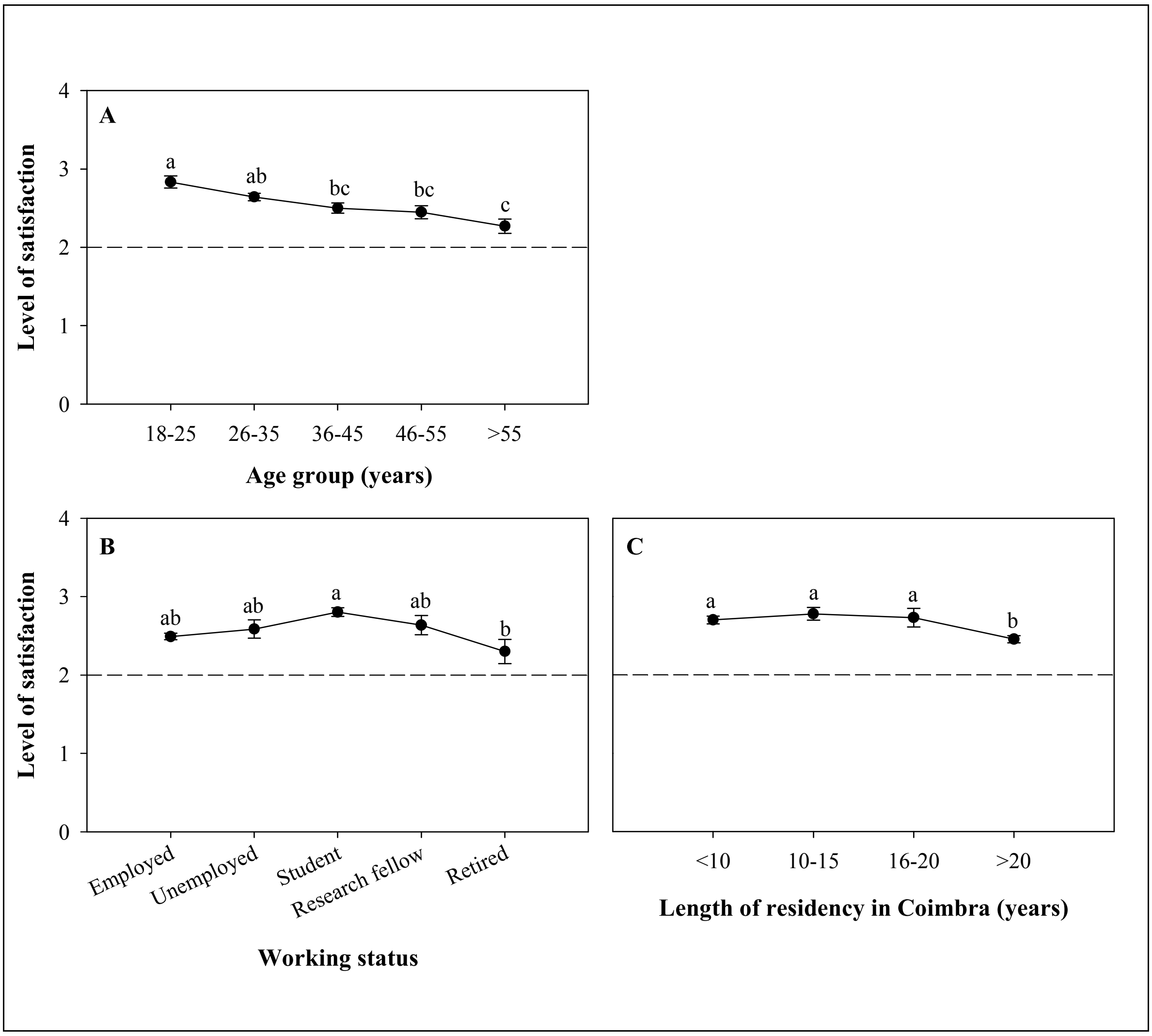


Figure 6.10 - Respondents' level of satisfaction with the City Council services by different age groups (A), working status (B), and length of residency in Coimbra (C). Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between age groups (A), working status (B), and lengths of residency (C).

The age group (p = 0.014) also showed significant differences with regard to the level of satisfaction with the Parish Council services (Figure 6.11). The younger age group showed to be more satisfied with the Parish Council services than the respondents with 46-55 years old.

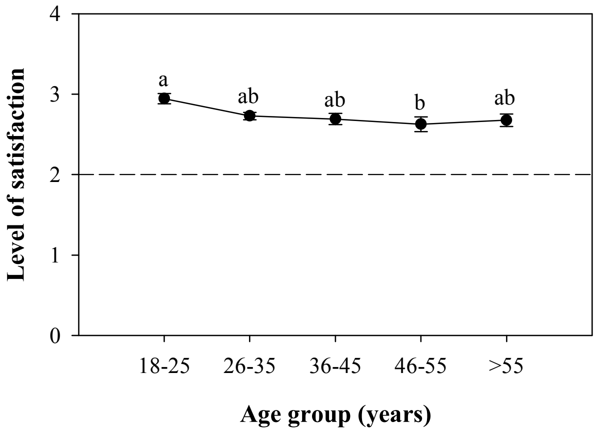


Figure 6.11 - Respondents' level of satisfaction with the Parish Council services by different age groups. Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between age groups.

In order to assess the respondent's opinion about the investments that the municipal authorities should give more emphasis, the respondents were asked to indicate the level of importance for each service listed in the Table 6.4. The responses were rated along a measurement scale (very important, important, somewhat important, and not at all important). In general, respondents agreed that the local authorities should place great emphasis on the investment and development of all issues. The overall level of importance was very high, ranging from 3.08 to 3.67, comparatively higher than the central point (= 2.0) in the scale of 1 to 4 (Table 6.4). Of the 19 issues, the respondents would like that the municipal authorities give more emphasis to "support for industry, trade and establishment of companies", "accessibility for people with disabilities", "support for the elderly", and "social action" which showed the highest levels of importance among the respondents. In contrast, "housing sector", "water supply", "public lighting", and "municipal roads and paths" showed the lowest levels of importance among the respondents (Table 6.4).

Table 6.4 - Percentage of responses and ranking of respondent's opinion by the mean scores (± SE) about the level of importance that should be given by the municipal authorities with regard to the 19 services listed.

Issues	Responses (%)				Mean scores
	Very important	Important	Somewhat important	Not at all important	
1. Housing sector	28	54	15	3	3.08 (± 0.038)
2. Water supply	32	47	19	2	3.08 (± 0.040)
3. Public lighting	32	50	17	1	3.12 (± 0.037)
4. Municipal roads and paths	28	56	16	0	3.12 (± 0.034)
5. Parking	38	45	15	2	3.20 (± 0.038)
6. Systems of waste collection	38	48	13	1	3.23 (± 0.037)
7. Leisure areas	38	49	12	1	3.25 (± 0.035)
8. Basic sanitation	43	42	14	1	3.27 (± 0.038)
9. Public safety	48	44	8	0	3.39 (± 0.033)
10. Culture and sports	49	43	8	0	3.40 (± 0.033)
11. Public cleanliness	49	43	7	1	3.41 (± 0.034)
12. Spatial planning	50	41	8	1	3.42 (± 0.034)
13. Education	56	35	9	0	3.47 (± 0.034)
14. Parks and gardens	54	41	5	0	3.48 (± 0.031)
15. Public transport	61	32	7	0	3.53 (± 0.033)
16. Social action	61	36	3	0	3.58 (± 0.028)
17. Support for the elderly	63	34	2	1	3.60 (± 0.029)
18. Accessibility for people with disabilities	66	31	3	0	3.62 (± 0.029)
19. Support for industry, trade and establishment of companies	71	26	3	0	3.67 (± 0.028)

Note: Ranking was made on a 4-point Likert-type scale, with higher values indicating higher levels of importance.

The statistical results for the four worst- and best-ranked issues with regard to the socio-demographic profile of respondents are presented in Table 6.5. The age group of the respondents was the characteristic that most influenced the answers. In this case, four of the eight issues revealed significant differences. It is worth noting that all socio-demographic characteristics of the participants in this study showed significant differences with regard to the issue "support for the elderly". In contrast, the services "housing sector", "water supply", "municipal roads and paths", and "support for industry, trade and establishment of companies" weren´t affected by the socio-demographic characteristics of respondents (Table 6.5).

Table 6.5 - The statistical results relative to the four worst-ranked issues (1-4) and four best-ranked issues (5-8) with regard to socio-demographic profile of the respondents.

Issues	Gender	Age	Education degree	Work ing status	Length of residency in Coimbra
1. Housing sector	$p = 0.209$	$p = 0.074$	$p = 0.397$	$p = 0.205$	$p = 0.141$
2. Water supply	$p = 0.329$	$p = 0.589$	$p = 0.635$	$p = 0.390$	$p = 0.765$
3. Public lighting	$p = 0.001$**	$p = 0.020$*	$p = 0.826$	$p = 0.005$**	$p = 0.601$
4. Municipal roads and paths	$p = 0.189$	$p > 0.05$	$p = 0.441$	$p = 0.146$	$p = 0.762$
5. Social action	$p = 0.226$	$p < 0.001$**	$p = 0.019$*	$p > 0.05$	$p = 0.220$
6. Support for the elderly	$p = 0.013$*	$p < 0.001$**	$p = 0.001$**	$p = 0.003$**	$p = 0.017$*
7. Accessibility for people with disabilities	$p = 0.051$	$p = 0.050$*	$p = 0.012$*	$p = 0.093$	$p = 0.290$
8. Support for industry, trade and establishment of companies	$p = 0.645$	$p = 0.351$	$p = 0.871$	$p = 0.858$	$p = 0.394$

* Significant differences at $p < 0.05$.
** Significant differences at $p \leq 0.01$.

Significant gender-related differences were found with regard to the level of importance of investment that should be given by the municipal authorities to "public lighting" and "support for the elderly" in the municipality (Table 6.5) where females respondents recognized that the municipal authorities should invest more in these two topics (Figure 6.12).

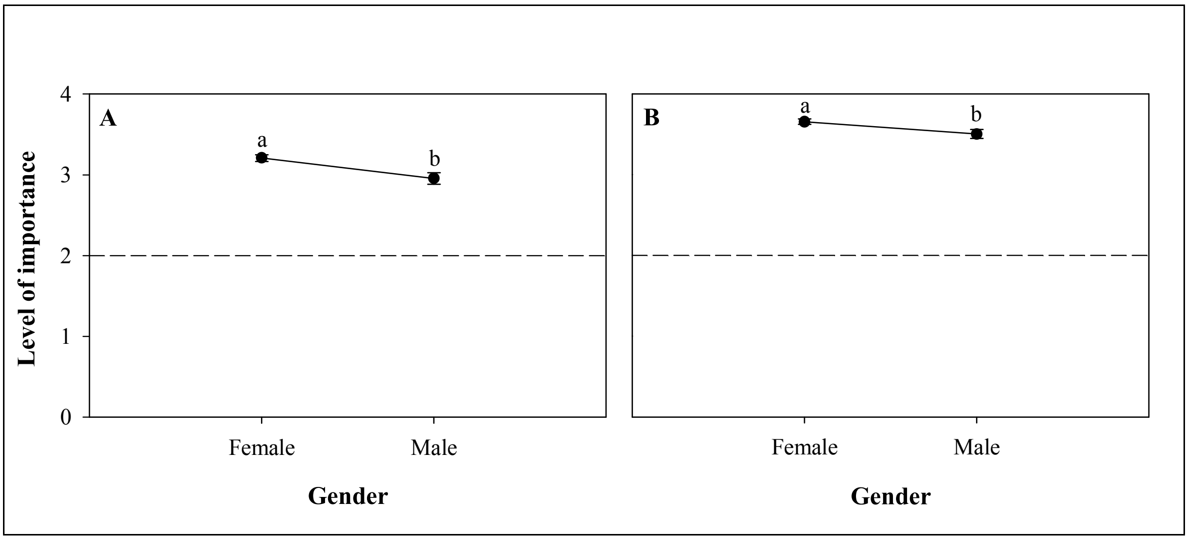


Figure 6.12 - The level of importance that should be given by the municipal authorities to the public lighting (A) and support for the elderly (B), by gender categories. Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between genders.

A general trend was found when relating the age groups and the importance that should be given to the listed services "public lighting", "social action", "support for the elderly", and "accessibility for people with disabilities" where older respondants seemed to value more the necessity of investment (Figure 6.13). The younger respondents showed the lowest levels of importance relative to these 4 issues. They known that the municipal authorities should invest less in the "public lighting" than the older age group (older than 55 years) (Figure 6.13-A), as well as invest less in the "social action" (Figure 6.13-B) and "support for the elderly" (Figure 6.13-C) than the respondents older than 36 years. The younger age group also recognized that the municipal authorities should invest less in the "accessibility for people with disabilities" than the 36-45 age group (Figure 6.13-D).

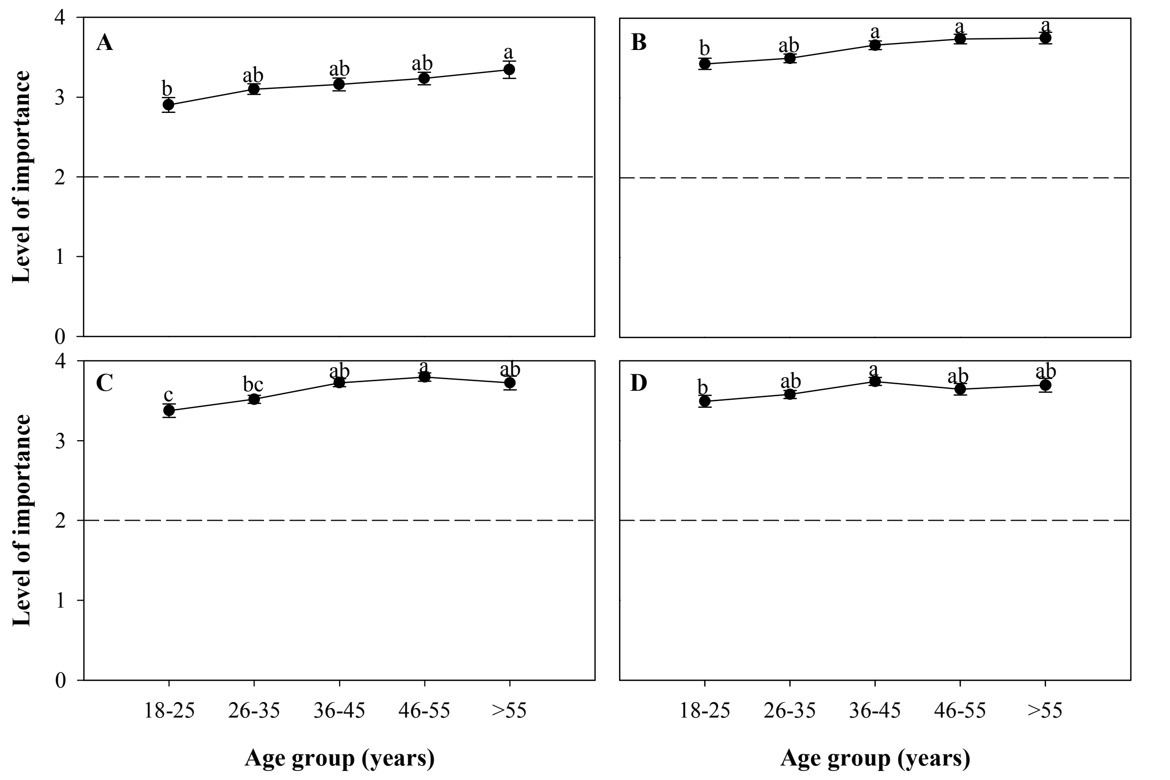


Figure 6.13 - The level of importance that should be given by the municipal authorities to the public lighting (A), social action (B), support for the elderly (C), and accessibility for people with disabilities (D), by different age groups. Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between age groups.

The lowest levels of importance were showed by respondents with master´s degree concerning “social action", "support for the elderly”, and "accessibility for people with disabilities" (Figure 6.14). While acknowledging the importance of these investments, they agreed that the municipal authorities should invest less in the "social action" (Figure 6.14-A) than the respondents with doctorate degree, and also invest less in the services of "support for the elderly" (Figure 6.14-B) and "accessibility for people with disabilities" (Figure 6.14-C) when compared with the respondents with bachelor's and doctorate degrees.

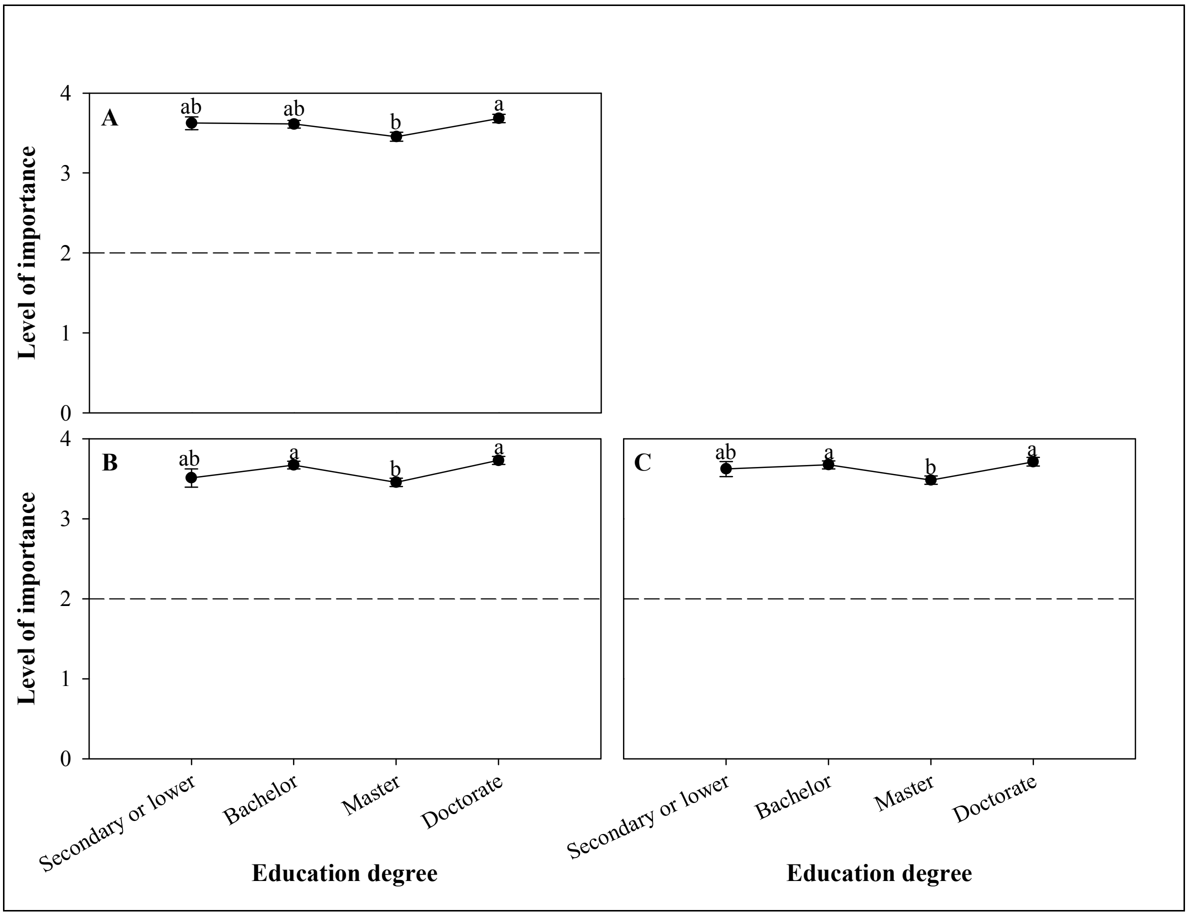


Figure 6.14 - The level of importance that should be given by the municipal authorities to the social action (A), support for the elderly (B), and accessibility for people with disabilities (C), by different education degrees. Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between education degrees.

There are also significant differences between working status with regard to "public lighting" and "support for the elderly" in the municipality (Table 6.5). The students group acknowledged that the municipal authorities should invest less in these two issues than the employed and retired respondents (Figure 6.15).

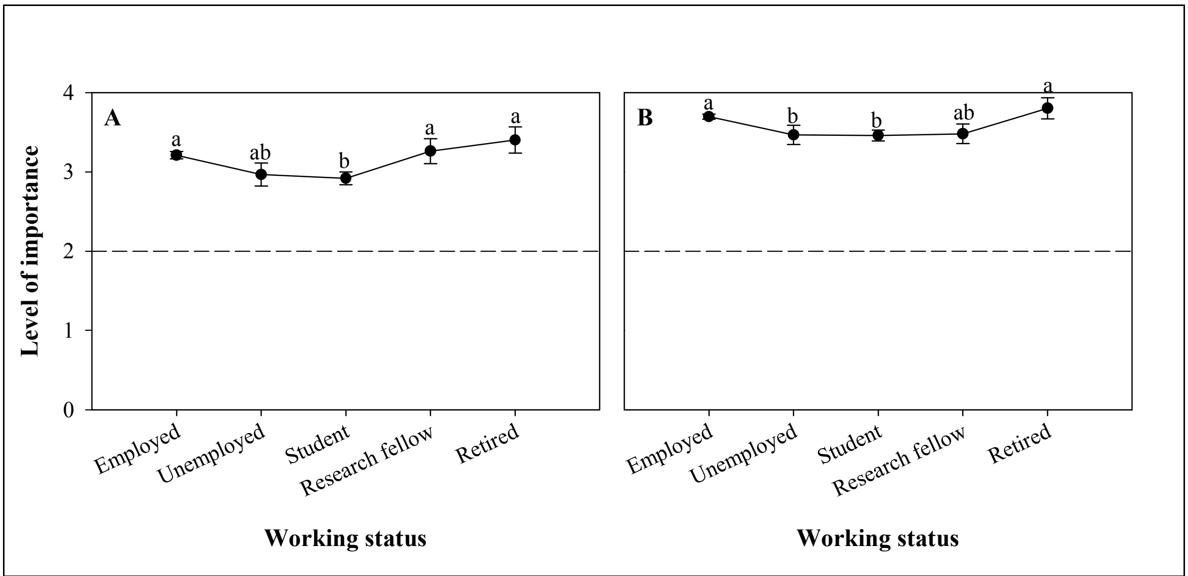


Figure 6.15 - The level of importance that should be given by the municipal authorities to the public lighting (A) and support for the elderly (B), by different working status. Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between working status.

The length of residency was only significantly related with "support for the elderly" (Table 6.5). The residents who have lived for less than 10 years or over 20 years in Coimbra recognized that the municipal authorities should invest more in this issue than those belonging to the group 16-20 years old (Figure 6.16).

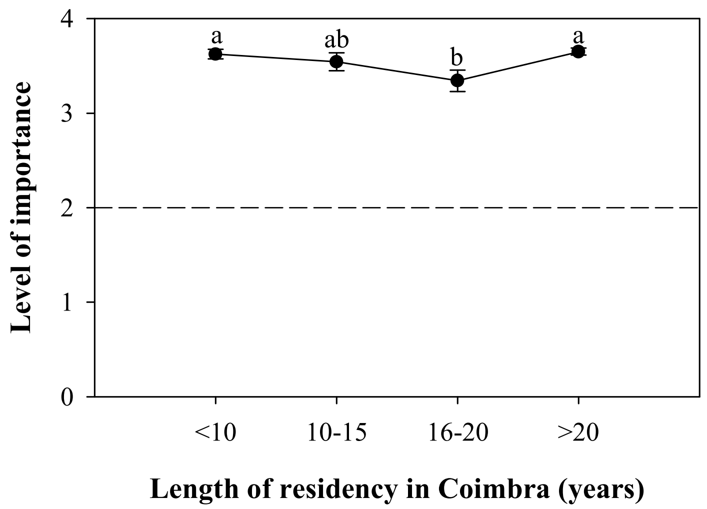


Figure 6.16 - The level of importance that should be given by the municipal authorities to the support for the elderly, by different lengths of residency of respondents in Coimbra. Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between lengths of residency.

6.4.4. Requalification and urban planning

In order to evaluate the residents' opinion about the requalification and urban planning of their municipality, the respondents were asked to answer two questions rated along a measurement scale. The first question was: "As regards the requalification of urban space, do you consider your municipality very requalified, moderately requalified, slightly requalified or degraded?" The second question was: "Concerning the spatial planning, do you consider the urban space of your municipality very orderly, moderately orderly, slightly orderly or disorderly"?

The results indicated that “moderately requalified” and "moderately orderly" were the responses most mentioned by the respondents in the first and second questions, respectively, accounting 56% in the first (Figure 6.17-A) and 59% in the second question (Figure 6.17-B). The mean scores were 2.54 (SE = 0.039) and 2.56 (SE = 0.037), respectively, in a total of 4, for the first and second questions, respectively. This indicates that the respondents revealed similar averaged levels of satisfaction in both questions with a mean score value slightly above the central point in the scale (= 2.0).

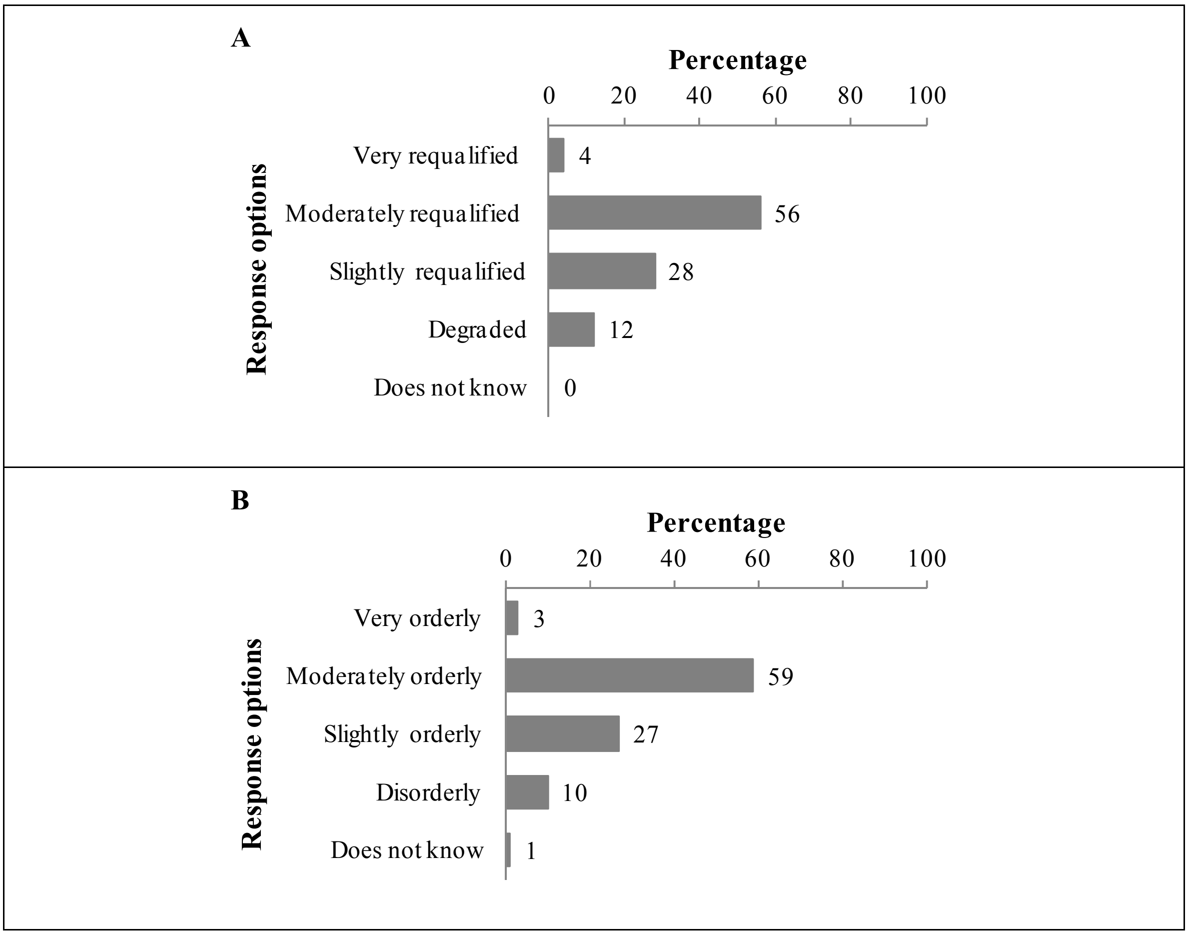


Figure 6.17 - Percentage of responses relative to the respondents' opinion about the urban requalification (A) and urban planning (B) in the municipality of Coimbra.

When analysed according to the socio-demographic profile of the respondents, significant differences were observed for the age group (p = 0.001) and working status (p < 0.001) (Figure 6.18). Younger and students people proved to be more satisfied with the urban requalification and spatial planning.

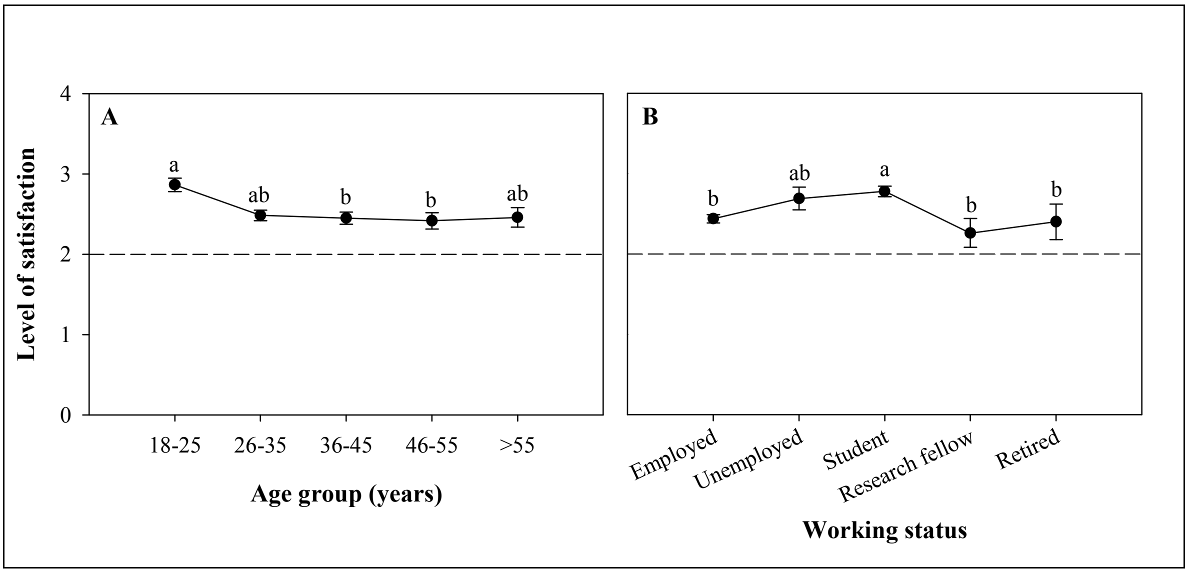


Figure 6.18 - Respondents' level of satisfaction with the urban requalification in the municipality of Coimbra, by different age groups (A) and working status (B). Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between age groups (A) and working status (B).

Significant differences were also found between age groups ($p = 0.004$) and working status ($p = 0.002$) with regard to the degree of satisfaction expressed by respondents concerning the urban planning in the municipality of Coimbra (Figure 6.19). The younger age group also recognized that urban planning was more well-ordered than the respondents with 36-45 years old (Figure 6.19-A). Relative to the working status of respondents, the students group proved to be more satisfied with the urban planning than the employed and research fellows (Figure 6.19-B).

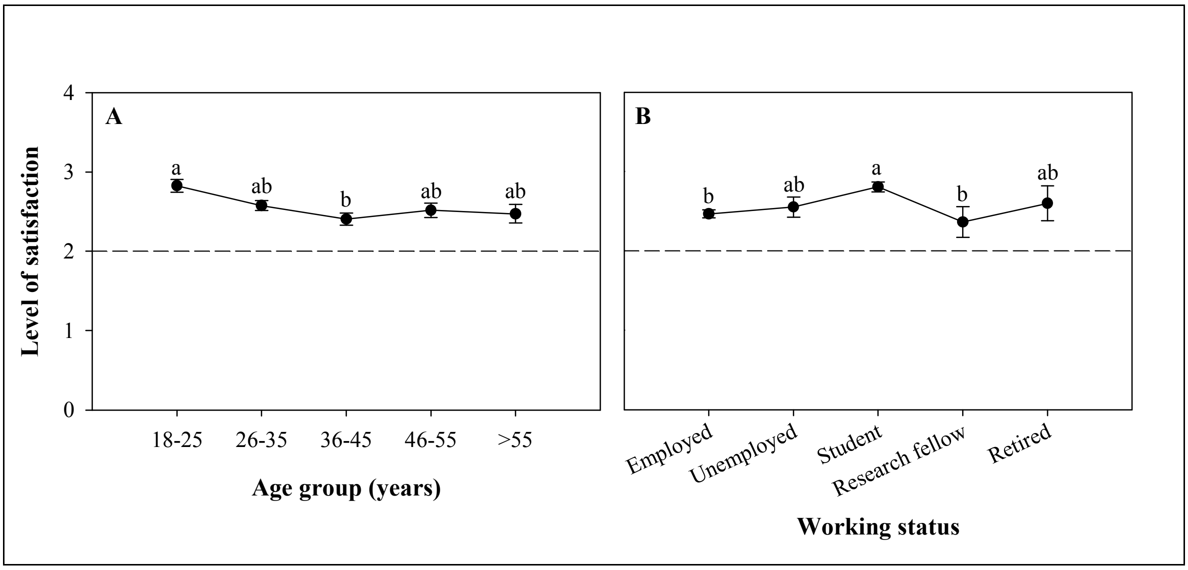


Figure 6.19 - Respondents' level of satisfaction with the urban planning in the municipality of Coimbra, by different age groups (A) and working status (B). Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between age groups (A) and working status (B).

From a list of 14 public spaces, respondents were requested to select those they visited most often. The largest proportion of respondents chose the "Parque Verde do Mondego", "Praça da República", and "Centro Histórico" (Figure 6.20). Overall, the respondents regularly attend the public spaces, since they selected more than one option.

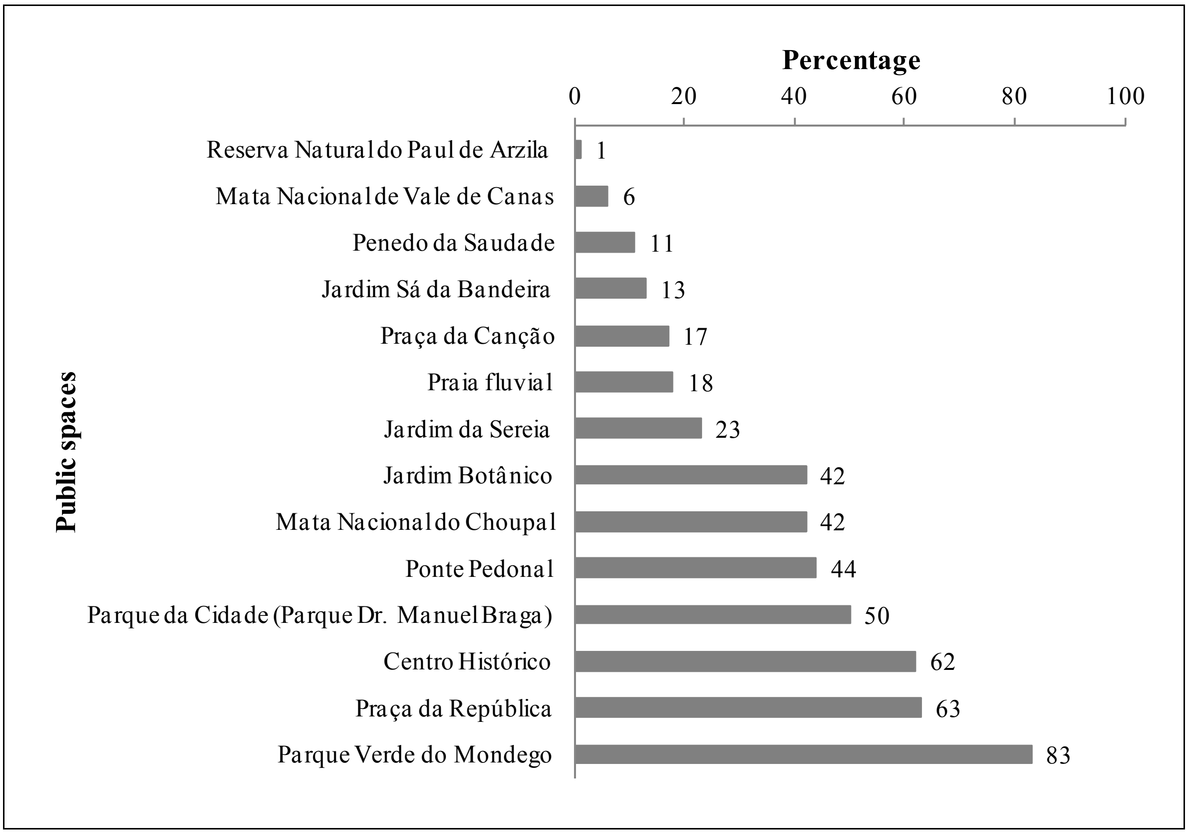


Figure 6.20 - Ranked by percentage of respondents who chosen each public space (multiple choices could be made).

Finally, the respondents were inquired to give their opinion about the quality of public spaces in the municipality of Coimbra. The response was rated along a measurement scale (very good, good, reasonable, and bad). The overwhelming majority of survey respondents who use the public spaces believed that they have a good or reasonable quality (Figure 6.21). The mean score was 2.61 (SE = 0.032) in of a total of 4, indicating a mean value above the central point in the scale (= 2.0) and thus a fair level of satisfaction with the quality of public spaces in this municipality.

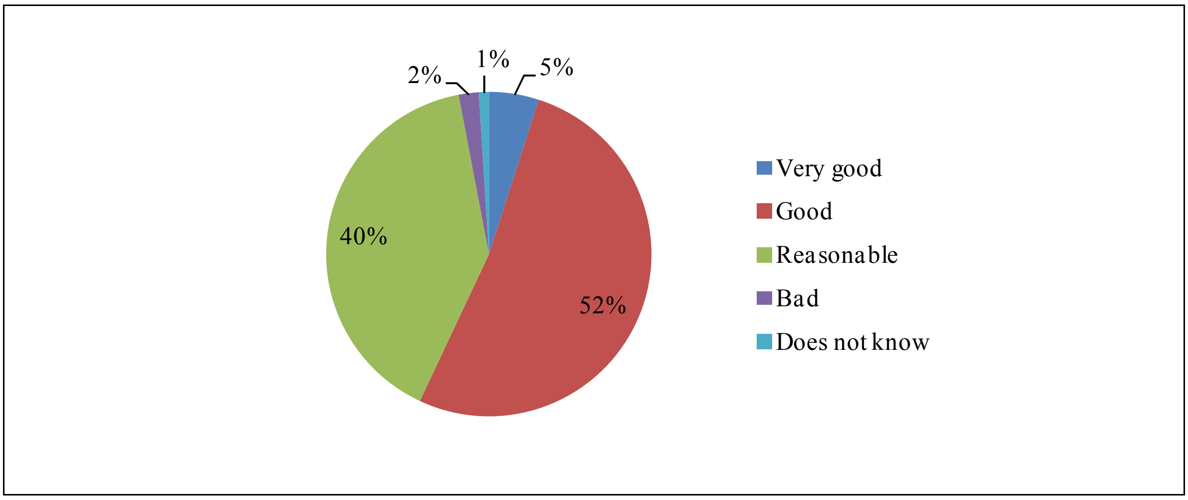


Figure 6.21 - Percentage of responses relative to the respondents' opinion about the quality of public spaces in the municipality of Coimbra.

The results showed that the level of satisfaction about the quality of public spaces was related to the socio-demographic profile of the respondents. Their age group (p = 0.006) and working status (p = 0.002) revealed significant differences with regard to the level of satisfaction with this matter (Figure 6.22). The younger age group revealed a higher level of satisfaction than those over 36 years old (Figure 6.22-A). The students proved to be more satisfied with the quality of public spaces than the employed and research fellows (Figure 6.22-B).

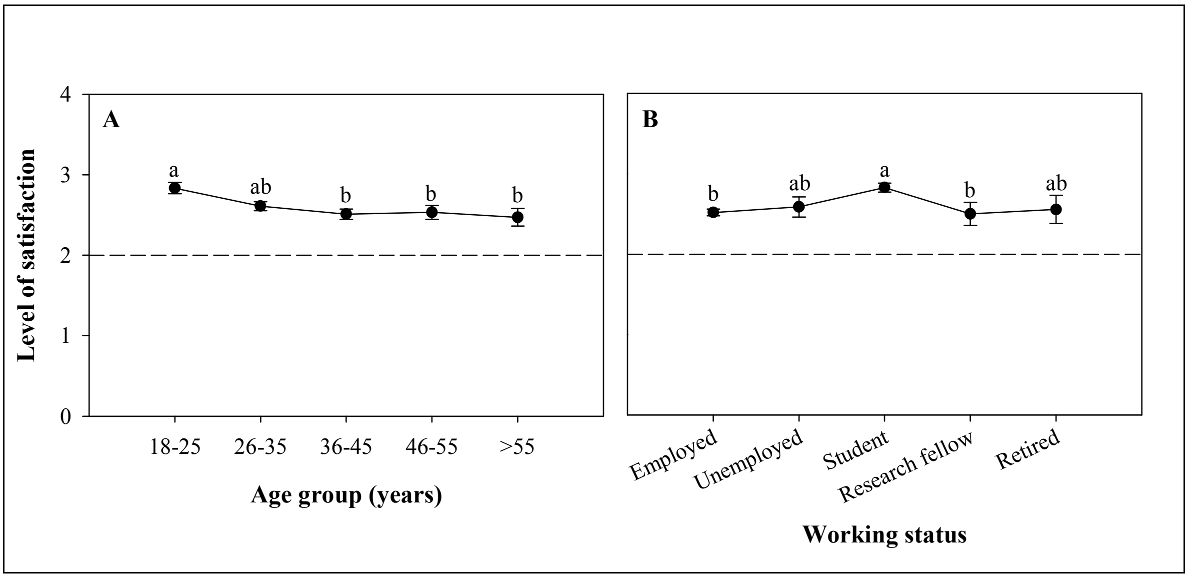


Figure 6.22 - Respondents' level of satisfaction with the quality of public spaces in the municipality of Coimbra, by different age groups (A) and working status (B). Values are means ± SE. The dashed line indicates the central point on the 4-point scale, signifying a neutral position. The different letters above the values indicate significant differences ($p \leq 0.05$) between age groups (A) and working status (B).

6.5. Discussion

This study presented the findings related to a perception survey on how citizens residing in Coimbra evaluated the public spaces, municipal resources and services as well as the performance of the municipal authorities.

A majority of respondents showed to be satisfied with the services provided by the municipal authorities, revealing however, a highest level of satisfaction with the Parish Council than with the City Council (Figure 6.9). The younger respondents (18-25 years old) showed the highest levels of satisfaction with both municipal authorities (Figure 6.10-A and Figure 6.11). When asked to characterize how the quality of life in the municipality of Coimbra has changed in the last five years, respondents most frequently answered that either there was no change or their municipality has became a better place to live (Figure 6.1-A). Furthermore, overall there was a high level of satisfaction with regard to the municipality in which respondents live (Figure 6.1-B), with the highest levels of satisfaction found in younger age group and students (Figure 6.3-A, B). These finding were generally in accordance with the survey carried out by the European Commission (2013b) which revealed that most European citizens were satisfied in living in their cities. This study included respondents of two Portuguese cities, Lisbon and Braga, and in both, more than 90% of them were pleased to live there. Moreover, the survey carried out by the Eurofound (2013a) showed an average life satisfaction across Europe, which ranged from 8.4 to 5.5 (on a scale of 1 to 10), where Portugal presented a mean score value of 6.8. Portugal is a country where life satisfaction has risen consistently during the years covered by the Eurofound surveys (2003, 2007, and 2011) (Eurofound, 2013b). In new economies, attracting human capital means attracting firms and investment and thus economic development for cities (Morais *et al*., 2013). For this reason, the key priority for the local authorities is ensuring that a good basic standard of services is available locally (Ipsos MORI, 2010). Therefore, quality of life is increasingly considered as an essential element for the development of cities. The identification of the cities with better conditions to attract this human capital, and thus investments, is a useful tool to politicians, and in an European perspective, an important asset to justify the allocation of funds in order to assist economic development (Morais *et al*., 2013).

Relative to the economic and socio-cultural conditions of the municipality, all the respondents generally agreed that they were good. Health services and education were selected by respondents as the two issues with better conditions (Table 6.2). Moreover, according to the analysis, the highest degrees of education seemed to be value more education and health services (Figure 6.6-C, D). In other words, an increase in the education degree caused an increase in the level of satisfaction of respondents. Similar results were found for 79 European (European Commission, 2013b), where more than half of the respondents from Lisbon and Braga recorded a high level of satisfaction with health services and educational facilities. In particular, respondents in Braga recorded the highest level of satisfaction with educational facilities among the 79 cities surveyed. The survey carried out by the Eurofound (2013b) showed similar results for the health services and quality of educational system during the three years analysed, where both remained stable between 2003 and 2007 and rose between 2007 and 2011. Education and health services satisfaction are the most important determinants of life satisfaction (Eurofound, 2013a). Education not only improves the qualifications and competences of a person but also their subjective well-being. They also increase access to paid work and economic resources that increase the sense of control over life (Eurofound, 2013b). Therefore, to avoid lock-in effects and social immobility it is crucial to ensure that everyone, especially those in young ages, have access to an education with good quality (European Union, 2011). Health services are fundamental to well-being and form the largest sector of employment and expenditure among the services of general interest. The European Union seeks to ensure universal access to quality health services for all by increasing the effectiveness, sustainability, and responsiveness of health care and long-term care (Eurofound, 2013b).

By contrast, seven out of the 24 conditions provided by the municipality were ranked below the central point in the 4-point scale (from 1.30 to 1.86) (Table 6.2). The lowest levels of satisfaction were expressed for "bike paths" and "housing price", as the two issues with worse conditions. Regardless of socio-demographic profile of respondents, they agreed that the municipality of Coimbra needs to become more pedestrian and bike-friendly. The respondents also judged that it is important to ensure that pedestrian and bike infrastructures are safe, accessible, and comfortable for all users. The use of bike paths and pedestrian activities can help to create healthier and more livable communities (EEA, 2009; European Union, 2011).

Although a majority of respondents disagreed with the idea that it was easy to find good housing at a reasonable price (Table 6.2), the younger age group (Figure 6.5-A), students (Figure 6.7-A), and residents who have lived for less than 10 years in Coimbra (Figure 6.8-A) proved to be more satisfied with housing price in the municipality. Given the steep increase of housing prices in many countries in the Europe, and especially in cities, it comes as no surprise that only in 18 out of the 79 cities included in the scope of the survey carried out by European Commission (2013b), the majority of respondents agreed with this statement.

On the other hand, the "housing sector" was considered the service with the lowest level of importance of investment that should be given by the municipal authorities (mean score = 3.08) than the other issues (Table 6.4). Additionally, the respondents proved to be dissatisfied with the "conditions of the buildings", showing a level of satisfaction below the central point in the 4-point scale (mean score = 1.83) (Table 6.2). This may be indicative of buildings' deterioration and a cause for decrease in the number of residents in the municipality between 2001 and 2011 (see Chapter 3). In fact, Coimbra has a significant amount of the buildings considered to have bad conditions (30%), principally in their urban area (Coimbra, 2012). Given the general trend of ageing in the Coimbra population (see Chapter 2) as well as in the general of the European population, cities need to adapt their economic strategies and social services to an ageing population (Bernd *et al.*, 2009;

Beard *et al*., 2011; European Union, 2011; Misir, 2012). An age-friendly city encourages active ageing by optimizing opportunities for health, participation, and security in order to enhance quality of life, as people age, adapting its structures and services so as to be accessible to and inclusive of older people with varying needs and capacities (World Health Organization, 2007). Moreover, the ageing of the population and buildings deterioration verified in the municipality of Coimbra will be responsible for the urban degradation, principally of their urban centre (see Chapter 2). According to the European Union (2011), to achieve a fine balance between eradicating poverty and deprivation, the municipalities have to provide affordable and attractive housing with suitable conditions.

The respondents, on average, revealed a slight level of satisfaction with the requalification and planning of the urban space in their city (Figure 6.17), with the younger and students respondents showing to be more satisfied (Figure 6.18). The urban requalification and the improvement of the urban environment generally contribute to an increase of the attractiveness of cities and its competitiveness (Partidário and Correia, 2004), which seemed to be the case here. Despite the amount of buildings in bad conditions (Coimbra, 2012), local authorities have embraced some requalification programmes. The PROHABITA (*Programa de Financiamento para Acesso à Habitação* - Funding Programme for Access to Housing) regulated by Decreto-Lei n.º 135/2004 of 3 June, revised by Decreto-Lei n.° 54/2007 of 12 March, was a programme aimed at solving situations of serious housing shortage of households resident in the Portuguese territory. This programme encourages the rehabilitation of old or degraded houses as an alternative solution for the accommodation of families with lower incomes, thus allowing municipalities to combine the resolution of situations of housing shortage with the rehabilitation of buildings and the use of vacant dwellings. Beeing a city with high demand on housing for higher education students, usually under 25 years old, this type of urban solutions ultimately end up favoring these groups. In most Member States, municipalities are responsible for implementing social housing programmes to ensure access to adequate housing for all (United Nations, 2009; European Union, 2011). In some countries, such as Sweden and Austria, the size of the municipal housing stock is 21% and 14%, respectively. In France, the law obliges municipalities with more than 3 500 inhabitants to provide at least 20% of social housing (European Union, 2011).

The participants in this survey agreed that municipal authorities should invest in all services that were listed, since all issues were ranked well above the central point in the 4-point scale (above 3.08) (Table 6.4). Preferences were directed to the economic and social strategies. Regardless of their socio-demographic profile, the respondents agreed that the municipal authorities should give priority to "support for industry, trade and establishment of companies". Younger people and well educated (master degrees) groups did not favor the funding for "accessibility for people with disabilities", "support for the elderly", and "social action" (Figure 6.13 and Figure 6.14). Moreover, the "employment" situation and the conditions of the "accessibility for people with disabilities" revealed a level of dissatisfaction between respondents, showing mean central values below 2.0 (Table 6.2). Some respondents suggested since conditions at the basic level were assured (*e.g.*, "basic sanitation", "water supply", "education", and "health services"), it was justified the investment in cultural actions as well as in services that could attract investment and create work, boosting the city development. These findings seemed to be in accordance with other European cities (European Commission, 2013b), where respondents disagreed with the idea that it is easy to find a job in their city. As reported by the European Union (2011), European cities of tomorrow should encourage job creation and be places of advanced social progress. They should also foster high quality of life and well-being through the existence of strong social services, where the elderly can live their lifes with dignity and autonomy and where people with disabilities can be more independent. Most cities will face the challenge of adapting to the needs, demands, and requirements of an ageing population, since a large share of the elderly population will need some form of daily care (World Health Organization, 2007; European Union, 2011).

Overall, the respondents said that they usually visit the public spaces of their municipality. The level of satisfaction with the public spaces quality was generally high (Figure 6.21), with the younger age group and students showing the higher levels of satisfaction (Figure 6.22). Nevertheless, the respondents agreed that the municipality of Coimbra needs more public spaces and some of them need to be valued and rehabilitated. A consensus was also observed to improve cultural dynamism, principally on the implementation and dissemination of events. Satisfaction with regard to public spaces quality was also generally quite high in European cities analysed by European Commission (2013b), including the Portuguese cities, Lisbon (69%) and Braga (76%). It is recognized that the quality and the aesthetic environment of the public spaces are important factors for a city's attractiveness, and can act as symbols of a city (European Union, 2011). The creation of more safe, and aesthetically attractive, urban spaces became increasingly a prerequisite for the design and development of urban regeneration programmes (Raco, 2003). Ideally, public spaces should be multi-functional and multi-generational, elderly-friendly, accommodate children, be meeting places as well as to offer specific functions like libraries, playgrounds or education (European Union, 2011).

The future success of the European urban development model is of extreme importance for the economic, social, and territorial cohesion of the European Union. It is, therefore, of the utmost importance that cities are allowed to develop in a balanced and socially inclusive way, strengthening their competitiveness and attractiveness (European Union, 2011). The 2012/2013 State of the World's Cities Report, "Prosperity of Cities", introduces a notion of prosperity. It examines how cities can generate and equitably distribute the benefits and opportunities associated with prosperity, ensuring economic well-being, social cohesion, environmental sustainability, and a better quality of life in general (UN-HABITAT, 2013). Despite the methodological limitations previously recognized, this survey was the first effort to access information on the perception of Coimbra residents have about quality of the resources and the services provided by the municipal authorities. This can be an important encouragement for local authorities to develop and implement assertive and reliable urban indicators on the quality of life and well-being of its citizens. The findings can also contribute with valuable information that may help policy-makers and urban planners to tackle problems in urban development, making this municipality a better place to live and work.

6.6. Conclusions

This study measured the level of satisfaction/importance of the residents in the municipality of Coimbra regarding its available resources and provided services using an on-line questionnaire. Among the full sample, about one-third of respondents believed that the quality of life in Coimbra had improved in the last five years, while about half suggested that things had not really changed. They also were satisfied with the majority of the economic and socio-cultural conditions that the municipality offers today, expressing the highest levels of satisfaction with the health services and education. Residents would like to see better conditions for bike paths and were displeased with the prices of houses. The respondents agreed that the municipality of Coimbra needs to become more pedestrian- and bike-friendly. They were even much pessimistic about buildings' conditions and agreed that they need to be rehabilitated and become more affordable, attractive, and suitable for households needs.

Although the respondents had expressed a high level of satisfaction with the services of the City and Parish Councils, they agree that municipal authorities should place huge emphasis on the investment and development on all the 19 services examined. This means that there is space for urban development and improvement so to meet the expectations of citizens, creating more positive impacts on the quality of life and well-being. The respondents regularly attend the public spaces of the municipality and proved to be satisfied with their quality. Nevertheless, they still seem to think that the municipality of Coimbra needs more public spaces and some of them need to be rehabilitated. The socio-demographic profile of respondents showed to influence their opinion, being the age group that influenced the most. The younger age group expressed significantly higher levels of satisfaction with the majority of the issues examined in this survey.

Improving the quality of life is one of the priority of local governments and the challenges of adopting policies that promote a better quality of life seem to be decisive given the intensity of some of the problems being faced locally (Santos and Martins, 2007). The results of this citizen satisfaction survey may be useful to managers, decision-makers as an integrative part of a multiple approach to evaluate municipal service's quality.

Appendix 6.A - Questionnaire elaborated to assess Coimbra citizens' perception about the environmental, economic, and socio-cultural conditions provided by the municipality, as well as to evaluate the performance of local authorities.

1. Perfil Sócio-Demográfico

1.1. Sexo

- ○ Masculino
- ○ Feminino

1.2. Idade

- ○ 18-25
- ○ 26-35
- ○ 36-45
- ○ 46-55
- ○ Mais de 55

1.3. Habilitações

- ○ Ensino Secundário ou menos
- ○ Ensino Superior (Bacharelato/Licenciatura)
- ○ Mestrado
- ○ Doutoramento
- ○ Outra

1.4. Condição profissional

- ○ Empregado
- ○ Desempregado
- ○ Estudante
- ○ Bolseiro de investigação
- ○ Reformado
- ○ Outra

1.5. Há quanto tempo reside no concelho de Coimbra?

- ○ Menos de 10 anos
- ○ 10-15 anos
- ○ 16-20 anos
- ○ Mais de 20 anos

2. Percepção em relação ao concelho

2.1. Acha que, nos últimos 5 anos, a qualidade de vida no concelho:

○ Melhorou
○ Manteve-se
○ Piorou
○ Não sabe

2.2. De uma maneira geral, acha que viver no concelho é:

○ Muito bom
○ Bom
○ Razoável
○ Mau

2.3. Na sua opinião, qual é a situação do concelho em relação aos seguintes aspetos:

Itens	Muito boa	Boa	Razoável	Má
Emprego	○	○	○	○
Serviços de saúde	○	○	○	○
Combate à pobreza e à exclusão social	○	○	○	○
Apoio aos idosos	○	○	○	○
Educação	○	○	○	○
Preço da habitação	○	○	○	○
Estado dos edifícios	○	○	○	○
Trânsito	○	○	○	○
Estacionamento	○	○	○	○
Acessibilidades	○	○	○	○
Ordenamento do território	○	○	○	○
Património cultural	○	○	○	○
Segurança pública	○	○	○	○
Acessos para cidadãos com deficiência	○	○	○	○
Qualidade do ar	○	○	○	○
Áreas de lazer e recreio	○	○	○	○
Espaços culturais e desportivos	○	○	○	○
Zonas de circulação pedonal	○	○	○	○
Ciclovias	○	○	○	○
Abastecimento de água	○	○	○	○
Saneamento básico	○	○	○	○
Iluminação pública	○	○	○	○
Recolha e seleção de lixo	○	○	○	○
Rede de transportes públicos	○	○	○	○

3. Desempenho da autarquia

3.1. Está satisfeito com o funcionamento dos serviços da sua Câmara Municipal?

○ Muito satisfeito
○ Satisfeito
○ Pouco satisfeito
○ Nada satisfeito

3.2. Está satisfeito com o funcionamento dos serviços da sua Junta de Freguesia?

○ Muito satisfeito
○ Satisfeito
○ Pouco satisfeito
○ Nada satisfeito

3.3. Qual o grau de importância que atribui aos investimentos que a sua autarquia deverá fazer nas seguintes áreas:

Itens	Muito importante	Importante	Pouco importante	Nada importante
Habitação	○	○	○	○
Parques e jardins	○	○	○	○
Estacionamento	○	○	○	○
Abastecimento de água	○	○	○	○
Sistemas de recolha de lixo	○	○	○	○
Limpeza pública	○	○	○	○
Iluminação pública	○	○	○	○
Transportes públicos	○	○	○	○
Estradas e caminhos municipais	○	○	○	○
Educação	○	○	○	○
Cultura e desporto	○	○	○	○
Ação social	○	○	○	○
Apoio aos idosos	○	○	○	○
Segurança pública	○	○	○	○
Acessos para cidadãos com deficiência	○	○	○	○
Áreas de lazer	○	○	○	○
Saneamento básico	○	○	○	○
Apoio à indústria, comércio e fixação de empresas	○	○	○	○
Ordenamento do território	○	○	○	○

4. Requalificação urbana e ambiental

4.1. Quanto à requalificação do espaço urbano do seu concelho, considera que está:

- ○ Muito requalificado
- ○ Pouco requalificado
- ○ Medianamente requalificado
- ○ Degradado

4.2. Quanto ao ordenamento territorial, considera que o espaço urbano do seu concelho está:

- ○ Muito ordenado
- ○ Pouco ordenado
- ○ Medianamente ordenado
- ○ Desordenado

4.3. Dos seguintes espaços públicos do seu concelho, indique quais usufrui com maior frequência.

- ○ Jardim da Sereia
- ○ Jardim Botânico
- ○ Jardim Sá da Bandeira
- ○ Penedo da Saudade
- ○ Parque da Cidade (Parque Dr. Manuel Braga)
- ○ Parque Verde do Mondego
- ○ Mata Nacional de Vale de Canas
- ○ Mata Nacional do Choupal
- ○ Reserva Natural do Paul de Arzila
- ○ Praça da Canção
- ○ Praça da República
- ○ Ponte Pedonal
- ○ Praia fluvial
- ○ Centro Histórico
- ○ Nenhum
- ○ Outro

4.4. Como avalia a qualidade dos espaços públicos do seu concelho?

- ○ Muito boa
- ○ Boa
- ○ Razoável
- ○ Má

5. Comentários gerais

Chapter 7

General conclusions

The integrated approach carried out in this work based on the examination of the model of urban expansion and transformations on land use between 1990 and 2010, together with the assessment of biodiversity parameters in green spaces aimed at assessing ecological implications at local level that have resulted from these changes. The municipality of Coimbra proved to be a very dynamic territory, and the perception of its residents regarding the observed urban developments and the quality of resources and services provided was also considered.

The spatial and temporal patterns of land use in the municipality of Coimbra indicated that this municipality was mainly dominated by cropland and forest areas, but an evident expansion of built-up land was observed.

The spread of this type of artificialize soil occurred mainly into the surrounding agricultural areas.

This urbanization process helped creating more sealed and impervious surfaces which in turn contribute to increase hazardous events and its effects particularly derived from floods and heat waves, commonly observed in the region.

Urban sprawl was the model of urban development undertaken at local level where the sprawl of the physical pattern of the city was based in a low density expansion configuration.

Coimbra has become a less compact city due to the faster growth of the urban area and a parallel decrease in the population density.

The physical, disturbance, demographic, and socio-economic variables analysed in this study showed interesting correlations with spatial land use distribution over the selected years.

Although the built-up land mainly occupied lower altitude and flatter areas it was still encountered on the slopes above 15°. It also occurred closer to the water bodies. This may increase the risk levels of landslides and environmental impacts' consequences of flooding events.

Fires events occurred principally in steeper slopes where the forest areas were the dominant land use category.

The older population and those with higher school degree lived in the most densely populated urban area.

Despite the low density urbanization process and consequent fragmentation of habitats and the subdivision of the land, green spaces in the urban environment evidenced supporting important biological and ecological features.

A total of 443 taxa of vascular plants were found in the city of Coimbra, representing 13.4% of the total taxa found in Portugal, more than half on the Santa Clara Plateau, where well preserved Oak-stands may be found.

With regard to growth-forms, the plant diversity and richness indices show significant differences among the landscape types and typologies of green spaces, although with more evidence among the landscape types.

More natural habitats (Oak-stands), despite fragmented and distributed as patchy elements, showed to comprise more important biological values, such as protected and natives plant species, or other organisms that play important ecological roles, like ectomycorrhizal fungi.

The cluster analysis of the DGGE banding patterns did not showed significant differences among the soil bacterial and fungal communities from gardens and urban forests (Oak-stands) but the soil bacterial community richness was higher in urban forests.

Urban gardens are green spaces created mainly to provide recreational and aesthetic services contributing to improve the citizens' quality of life and the city attractiveness. However, these spaces also contained significant richness and diversity values.

Additionally, soil properties and microorganisms also contribute to the sustainability of the urban ecosystem since they provide habitat for important species, allow aquifer recharge and regulate air and surface temperatures.

The highest percentage of soil organic matter, amount of leaf litter, soil carbon, and nitrogen were verified in urban forests. The leaf litter plays a vital role to enrich the soil organic matter content which serves important functions, such as food source for soil fauna and flora. Leaf litter also contributes to the biological activity and carbon cycling processes in the soil as well as improve the carbon sequestration.

The survey performed to the population of Coimbra demonstrated that overall, residents expressed a high level of satisfaction regarding the urban development and generally ranked well the quality of life and the economic and socio-cultural conditions of the municipality, principally those residents with younger age and with high levels of education. The services that they valued the most were the health services and education.

Despite this, residents still find important that local authorities continue to invest and create better conditions for living in the city. Several subjects were important but those related with social-economic areas were preferred.

A better understanding of the spatial and temporal dynamics of the city's growth and an integrated approach regarding the planning, monitoring, designing, and maintaining of urban green spaces for enhancing citizens' quality of life are essential for the future urban development.

References

Aalborg Charter (1994). Charter of European cities and towns towards sustainability. Accessed in June 2014 from: http://www.sustainablecities.eu/fileadmin/content/JOIN/Aalborg_Charter_english_1_.pdf.

Ahonen-Jonnarth U., Göransson A. and Finlay R.D. (2003). Growth and nutrient uptake of ectomycorrhizal *Pinus sylvestris* seedlings in a natural substrate treated with elevated Al concentrations. Tree Physiology, 23(3): 157-167.

Alberti M. (2010). Maintaining ecological integrity and sustaining ecosystem function in urban areas. Current Opinion in Environmental Sustainability, 2(3): 178-184.

Alberti M. (2008a). Modeling the urban ecosystem: a conceptual framework. In Marzluff J., Shulenberger E., Endlicher W., Alberti M., Bradley G., Ryan C., ZumBrunnen C. and Simon U. (Eds.), Urban ecology: an international perspective on the interaction between humans and nature. Springer, New York, pp. 623-646.

Alberti M. (2008b). Advances in urban ecology: integrating humans and ecological processes in urban ecosystems. Springer, New York, 384 pp.

Alberti M. (2005). The effects of urban patterns on ecosystem function. International Regional Science Review, 28(2): 168-192.

Alberti M. and Marzluff J.M. (2004). Ecological resilience in urban ecosystems: linking urban patterns to human and ecological functions. Urban Ecosystems, 7(3): 241-265.

Alberti M., Marzluff J.M., Shulenberger E., Bradley G., Ryan C. and Zumbrunnen C. (2003). Integrating humans into ecology: opportunities and challenges for studying urban ecosystems. BioScience, 53(12): 1169-1179.

ALFA (Associação Lusitana de Fitossociologia - Lusitana Association Phytosociology) (2004). Tipos de habitat naturais e semi-naturais do Anexo I da Directiva 92/43/CEE (Portugal Continental): fichas de caracterização ecológica e de gestão para o plano sectorial da Rede Natura 2000 (Types of natural and semi-natural habitat in the Annex I of Directive 92/43 / EEC (Portugal Continental): chips of ecological characterization and management for the sector plan Natura 2000). Relatório, Lisboa. Accessed in January 2011 from: http://www.icnf.pt/portal/naturaclas/rn2000/p-set/hab-1a9. [**in Portuguese**].

Alig R.J., Kline J.D. and Lichtenstein M. (2004). Urbanization on the US landscape: looking ahead in the 21^{st} century. Landscape and Urban Planning, 69(2-3): 219-234.

Allen H.D., Randall R.E., Amable G.S. and Devereux B.J. (2006). The impact of changing olive cultivation practices on the ground flora of olive groves in the Messara and Psiloritis regions, Crete, Greece. Land Degradation and Development, 17(3): 249-273.

Altieri L., Cocchi D., Pezzi G., Scott E.M. and Ventrucci M. (2014). Urban sprawl scatterplots for urban morphological zones data. Ecological Indicators, 36: 315-323.

Alvey A.A. (2006). Promoting and preserving biodiversity in the urban forest. Urban Forestry and Urban Greening, 5(4): 195-201.

Antipina G.S. (2003). Urban flora as a component of the urban ecosystems in the taiga zone: an example of Karelian cities. Russian Journal of Ecology, 34(4): 215-218.

Antrop M. (2008). Landscapes at risk: about change in the European landscapes. In: Dostal P. (Ed.), Evolution of geographical systems and risk processes in the global context. Charles University in Prague. Faculty of Science, Department of Geography, Prague, pp. 57-79.

Antrop M. (2005). Why landscapes of the past are important for the future. Landscape and Urban Planning, 70(1-2): 21-34.

Antrop M. (2004). Landscape change and the urbanization process in Europe. Landscape and Urban Planning, 67(1-4): 9-26.

Antrop M. (2000). Changing patterns in the urbanized countryside of Western Europe. Landscape Ecology, 15(3): 257-270.

APA (Agência Portuguesa do Ambiente - Portuguese Environment Agency) (1971). Carta dos Solos - Atlas do Ambiente Digital (Soil Map - Atlas of the Digital Environment). Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional. Accessed in February 2011 from: http://www.apambiente.pt/index.php?ref=19&subref=174. [**in Portuguese**].

Araújo M.B. (2003). The coincidence of people and biodiversity in Europe. Global Ecology and Biogeography, 12(1): 5-12.

Arnfield A.J. (2003). Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. International Journal of Climatology, 23(1): 1-26.

Arribas-Bel D., Nijkamp P. and Scholten H. (2011). Multidimensional urban sprawl in Europe: a self-organizing map approach. Computers, Environment and Urban Systems, 35(4): 263-275.

Arrow K., Bolin B., Costanza R., Dasgupta P., Folke C., Holling C S, Jansson B.-O., Levin S, Mäler K.-G., Perrings C. and Pimentel D. (1995). Economic growth, carrying capacity, and the environment. Ecological Economics, 15(2): 91-95.

Ascione M., Campanella L., Cherubini F. and Ulgiati S. (2009). Environmental driving forces of urban growth and development: an emergy-based assessment of the city of Rome, Italy. Landscape and Urban Planning, 93(3-4): 238-249.

Azul A.M. (2011). Diálogos e modos de actuação colectiva com vista à sustentabilidade do sobreiro em Portugal (Dialogues and modes of collective action for sustainability of the cork oak in Portugal). e-cadernos CES. 10: 70-90. [**in Portuguese**].

Azul A.M., Sousa J.P., Agerer R., Martín M.P. and Freitas H. (2010). Land use practices and ectomycorrhizal fungal communities from oak woodlands dominated by *Quercus suber* L. considering drought scenarios. Mycorrhiza, 20(2): 73-88.

Azul A.M., Castro P., Sousa J.P. and Freitas H. (2009). Diversity and fruiting patterns of ectomycorrhizal and saprobic fungi as indicators of land-use severity in managed woodlands dominated by *Quercus suber* - a case study from southern Portugal. Canadian Journal of Forest Research, 39(12): 2404-2417.

Barea J.-M., Azcón R. and Azcón-Aguilar C. (2002). Mycorrhizosphere interactions to improve plant fitness and soil quality. Antonie van Leeuwenhoek, 81(1-4): 343-351.

Baus P., Kováč U., Pauditšová E., Kohutková I. and Komorník J. (2014). Identification of interconnections between landscape pattern and urban dynamics - case study Bratislava, Slovakia. Ecological Indicators, 42: 104-111.

Baycan-Leven T., van Leeuwen E., Rodenburg C. and Nijkamp P. (2002). Development and management of green spaces in European cities: a comparative analysis. 38º International Planning Congress on "The Pulsar Effect" Planning with Peaks, Athens, Greece, 21-26 of September, 12 pp.

Beard J.R., Biggs S., Bloom D.E., Fried L.P., Hogan P., Kalache A. and Olshansky S.J. (Eds.) (2011). Global population ageing: peril or promise? World Economic Forum, Geneva, 144 pp.

Beardsley K., Thorne J.H., Roth N.E., Gao S. and McCoy M.C. (2009). Assessing the influence of rapid urban growth and regional policies on biological resources. Landscape and Urban Planning, 93(3-4): 172-183.

Beninde J., Veith M. and Hochkirch A. (2015). Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation. Ecology Letters, [online]: DOI: 10.1111/ele.12427.

Berg G. and Smalla K. (2009). Plant species and soil type cooperatively shape the structure and function of microbial communities in the rhizosphere. FEMS Microbiology Ecology, 68(1): 1-13.

Berkes F. and Folke C. (Eds.) (1998). Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press, Cambridge, 476 pp.

Bernd R., Doyle Y., Grundy E. and McKee M. (2009). How can health systems respond to population ageing? World Health Organization, Copenhagen, 34 pp.

Bezák P. and Lyytimäki J. (2011). Complexity of urban ecosystem services in the context of global change. Ekológia (Bratislava), 30(1): 22-35.

Biondini M., Klein D.A. and Redente E.F. (1988). Carbon and nitrogen losses through root exudation by *Agropyron cristatum*, *A. smithii* and *Bouteloua gracilis*. Soil Biology and Biochemistry, 20(4): 477-482.

Bolund P. and Hunhammar S. (1999). Ecosystem services in urban areas. Ecological Economics, 29(2): 293-301.

Bon M. (1988). Guía de campo de los hongos de Europa (Field guide to fungi of Europe). Omega, Barcelona, 352 pp. [**in Spanish**].

Botkin D.B. and Beveridge C.E. (1997). Cities as environments. Urban Ecosystems, 1(1): 3-19.

Bouckaert G. and van de Walle S. (2003). Comparing measures of citizen trust and user satisfaction as indicators of "good governance": difficulties in linking trust and satisfaction indicators. International Review of Administrative Sciences, 69(3): 329-344.

Boukhabla M. and Alkama D. (2012). Impact of vegetation on thermal conditions outside, thermal modeling of urban microclimate, case study: the street of the republic, Biskra. Energy Procedia, 18: 73-84.

Braimoh A.K. and Onishi T. (2007). Spatial determinants of urban land use change in Lagos, Nigeria. Land Use Policy, 24(2): 502-515.

Brown L. R. (2001). Eco-economy: building an economy for the Earth. W. W. Norton & Co, New York, 322 pp.

Brundrett M.C. and Abbott L.K. (1995). Mycorrhizal fungus propagules in the jarrah forest. II: spatial variability in inoculum levels. New Phytologist, 131(4): 461-469.

Buée M., Maurice J.-P., Zeller B., Andrianariso S., Ranger J., Courtecuisse R., Marçais B. and Le Tacon F. (2010). Influence of tree species on richness and diversity of epigeous fungal communities in a French temperate forest stand. Fungal Ecology, 4(1): 22-31.

Bugliarello G. (2006). Urban sustainability: dilemmas, challenges and paradigms. Technology in Society, 28(1-2): 19-26.

Bürgi M., Hersperger A.M. and Schneeberger N. (2004). Driving forces of landscape change - current and new directions. Landscape Ecology, 19(8): 857-868.

Butterbach-Bahl K., Gundersen P., Ambus P., Augustin J., Beier C., Boeckx P., Dannenmann M., Gimeno B.S., Ibrom A., Kiese R., Kitzler B., Rees R.M., Smith K.A., Stevens C., Vesala T. and Zechmeister-Boltenstern S. (2011). Nitrogen processes in terrestrial ecosystems. In: Sutton M.A., Howard C.M., Erisman J.W., Billen G., Bleeker A., Grennfelt P., van Grinsven H. and Gizzetti B. (Eds.), The European nitrogen assessment: sources, effects and policy perspectives. Cambridge University Press, Cambridge, pp. 99-125.

Cadenasso M.L. and Pickett S.T.A. (2008). Urban principles for ecological landscape design and management: scientific fundamentals. Cities and the Environment, 1(2): article 4, 16 pp.

Caesar-TonThat T.-C. and Cochran V.L. (2000). Soil aggregate stabilization by a saprophytic lignin-decomposing basidiomycete fungus. I. Microbiological aspects. Biology and Fertility of Soils, 32(5): 374-380.

Caetano M., Nunes V. and Nunes A. (2009). CORINE Land Cover 2006 for Continental Portugal. Technical Report, Portuguese Geographic Institute, 81 pp.

Calvente R., Cano C., Ferrol N., Azcón-Aguilar C. and Barea J.M. (2004). Analysing natural diversity of arbuscular mycorrhizal fungi in olive tree (*Olea europaea* L.) plantations and assessment of the effectiveness of native fungal isolates as inoculants for commercial cultivars of olive plantlets. Applied Soil Ecology, 26(1): 11-19.

Camagni R., Gibelli M.C. and Rigamonti P. (2002). Urban mobility and urban form: the social and environmental costs of different patterns of urban expansion. Ecological Economics, 40(2): 199-216.

CAOP (Carta Administrativa Oficial de Portugal - Portuguese Official Administrative Cartography) (2010). Accessed in July 2011 from: http://www.dgterritorio.pt/cartografia_e_geodesia/cartografia/carta_administrativa_oficial_de_portugal__caop_/caop__download_/. [**in Portuguese**].

Cariñanos P. and Casares-Porcel M. (2011). Urban green zones and related pollen allergy: a review. Some guidelines for designing spaces with low allergy impact. Landscape and Urban Planning, 101(3): 205-214.

Carmo M., Moreira F., Casimiro P. and Vaz P. (2011). Land use and topography influences on wildfire occurrence in northern Portugal. Landscape and Urban Planning, 100(1-2): 169-176.

Carneiro M., Fabião A., Martins M.C., Fabião A., da Silva M.A., Hilário L., Lousã M. and Madeira M. (2008). Effects of harrowing and fertilisation on understory vegetation and timber production of a *Eucalyptus globulus* Labill. plantation in Central Portugal. Forest Ecology and Management, 255(3-4): 591-597.

Carpenter S.R. and Folke C. (2006). Ecology for transformation. Trends in Ecology and Evolution, 21(6): 309-315.

Castroviejo S. *et al.* (Eds.) (1986-2010). Flora Iberica. Plantas Vasculares de la Península Ibérica e Islas Baleares (Iberian Flora. Vascular Plants of the Iberian Peninsula and Balearic Islands). Real Jardín Botánico, Madrid. [**in Spanish**].

Catalán B., Saurí D. and Serra P. (2008). Urban sprawl in the Mediterranean? Patterns of growth and change in the Barcelona Metropolitan Region 1993-2000. Landscape and Urban Planning, 85(3-4): 174-184.

CBD (Convention on Biological Diversity) (2013). Quick guides to the Aichi Biodiversity Targets. Accessed in March 2015 from: http://www.cbd.int/doc/strategic-plan/targets/compilation-quick-guide-en.pdf.

CBD (Convention on Biological Diversity) (1992). United Nations Convention on Biological Diversity. Accessed in September 2013 from: https://www.cbd.int/doc/legal/cbd-en.pdf.

Chan Y (2008) Increasing soil organic carbon of agricultural land. PrimeFacts, NSW 735: 1-5.

Chapel Hill Survey (2014). DirectionFinder® community survey: final results. ETC Institute, Olathe, Kansas, 61 pp.

Chapin III F.S., Zavaleta E.S., Eviner V.T., Naylor R.L., Vitousek P.M., Reynolds H.L., Hooper D.U., Lavorel S., Sala O.E., Hobbie S.E., Mack M.C. and Diaz S. (2000). Consequences of changing biodiversity. Nature, 405(6783): 234-242.

Check J. and Schutt R.K. (2012). Research design and data collection. In: Research methods in education, University of Massachusetts Boston, pp. 159-185.

Chiesura A. (2004). The role of urban parks for the sustainable city. Landscape and Urban Planning, 68(1): 129-138.

Childers D.L., Pickett S.T.A., Grove J.M., Ogden L. and Whitmer A. (2014). Advancing urban sustainability theory and action: challenges and opportunities. Landscape and Urban Planning, 125: 320-328.

Chilvers G.A. (1968). Some distinctive types of eucalypt mycorrhiza. Australian Journal of Botany, 16(1): 49-70.

Chowdhury A.H.M.R.H., Rahman G.M.M., Saha B.K. and Chowdhury M.A.H. (2008). Addition of some tree leaf litters in forest soil and their effect on the growth, yield and nutrient uptake by red amaranth. Journal of Agroforestry and Environment, 2(1): 1-6.

Christensen T. and Laegreid P. (2005). Trust in government: the relative importance of service satisfaction, political factors and demography. Public Performance and Management Review, 28(4): 487-511.

CIESIN (Center for International Earth Science Information Network), IFPRI (International Food Policy Research Institute), CIAT (Centro Internacional de Agricultura Tropical) (2011). Global rural-urban mapping project, Version 1 (GRUMPv1): Urban Extents Grid. NASA Socioeconomic Data and Applications Center (SEDAC). Accessed in October 2014 from: http://dx.doi.org/10.7927/H4GH9FVG.

CMC (Câmara Municipal de Coimbra - City Council of Coimbra) (2012). Coimbra rio - área de reabilitação urbana: estudos de caracterização. (Coimbra river - area of urban rehabilitation: characterization studies). Coimbra, Parquexpo, 134 pp. [**in Portuguese**].

CMC (Câmara Municipal de Coimbra - City Council of Coimbra) (2008). Plano Diretor Municipal de Coimbra - revisão: estudos de caracterização. (Municipal master plan of Coimbra - review: characterization studies). Direção Municipal de Administração do Território, Departamento de Planeamento, Divisão de Ordenamento e Estratégia, Coimbra, 95 pp. [**in Portuguese**].

CMC (Câmara Municipal de Coimbra - City Council of Coimbra) (1993). Plano Director Municipal de Coimbra (Municipal master plan of Coimbra). Resolução do Conselho de Ministros Nº 24/94, 44 pp. [**in Portuguese**].

Coisnon T., Oueslati W. and Salanié J. (2014). Urban sprawl occurrence under spatially varying agricultural amenities. Regional Science and Urban Economics, 44: 38-49.

Colding J., Elmqvist T., Lundberg J., Ahrné K., Andersson E., Barthel S., Borgström S., Duit A., Ernstsson H. and Tengö M. (2003). The Stockholm urban assessment (SUA - Sweden). Millennium Ecosystem Assessment Sub-Global Summary Report, Stockholm, 28 pp.

Colpaert J.V., Wevers J.H.L., Krznaric E. and Adriaensen K. (2011). How metal-tolerant ecotypes of ectomycorrhizal fungi protect plants from heavy metal pollution. Annals of Forest Science, 68(1): 17-24.

Compant S., Duffy B., Nowak J., Clément C. and Barka E.A. (2005). Use of plant growth-promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action, and future prospects. Applied and Environmental Microbiology, 71(9): 4951-4959.

CORDIS (Community Research and Development Information Service) (1998). Fifth Framework Programme (1998-2002). Accessed in March 2014 from: http://cordis.europa.eu/fp5/about.htm.

Council of Europe (2000). The European Landscape Convention. European Treaty Series - No. 176, Florence. Accessed in March 2014 from: https://rm.coe.int/CoERMPublicCommonSearchServices/DisplayDCTMContent?documentId=09000016800805ce.

Courtecuisse R. and Duhem B. (2005). Guía de los hongos de la Península Ibérica, Europa y Norte de África (Guide to fungi of the Iberian Peninsula, Europe and North Africa). Omega, Barcelona, 488 pp. [**in Spanish**].

Cox N. (1981). Geomorphological Techniques. Edited for the British Geomorphological Research group by Goudie A., Burt M., Lewin J., Richards K., Whalley B. and Worsley P. (Eds.), George Allen and Unwin, London, 395 pp.

Cunha A.P., Silva A.P. and Roque O.R. (2003). Plantas e produtos vegetais em fitoterapia (Plants and plant products in phytotherapy). Fundação Calouste Gulbenkian, Lisboa. [**in Portuguese**].

Curtis J.T. and McIntosh R.P. (1951). An upland forest continuum in the prairie-forest border region of Wisconsin. Ecology, 32(3): 476-496.

Daily G.C., Alexander S., Ehrlich P.R., Goulder L., Lubchenco J., Matson P.A., Mooney H.A., Postel S., Schneider S.H., Tilman D. and Woodwell G.M. (1997). Ecosystem services: benefits supplied to human societies by natural ecosystems. Issues in Ecology, 2: 1-16.

Dana E.D., Vivas S. and Mota J.F. (2002). Urban vegetation of Almería City - a contribution to urban ecology in Spain. Landscape and Urban Planning, 59(4): 203-216.

Davies Z.G., Edmondson J.L., Heinemeyer A., Leake J.R. and Gaston K.J. (2011). Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. Journal of Applied Ecology, 48(5): 1125-1134.

Decreto Lei n.º 54/2007, de 12 de Março (2007) - (Decree-Law n.º 54/2007 of 12 March 2007). In: Diário da República - 1.ª Série, 50: 1530-1551. [**in Portuguese**].

Decreto Lei n.º 135/2004, de 3 de Junho (2004) - (Decree-Law n.º 135/2004 of 3 June 2004). In: Diário da República - 1.ª Série - A, 130: 3490-3498. [**in Portuguese**].

de Deyn G.B., Cornelissen J.H.C. and Bardgett R.D. (2008). Plant functional traits and soil carbon sequestration in contrasting biomes. Ecology Letters, 11(5): 516-31.

de Groot R.S., Alkemade R., Braat L., Hein L. and Willemen L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity, 7(3): 260-272.

de Groot R.S., Wilson M.A. and Boumans R.M.J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics, 41(3): 393-408.

de Groot R.S. (1992). Functions of nature: evaluation of nature in environmental planning, management and decision making. Wolters-Noordhoff, Groningen, 315 pp.

DeFries R.S., Foley J.A. and Asner G.P. (2004). Land-use choices: balancing human needs and ecosystem function. Frontiers in Ecology and the Environment, 2(5): 249-257.

del Saz Salazar S. and Menéndez L.G. (2007). Estimating the non-market benefits of an urban park: does proximity matter? Land Use Policy, 24(1): 296-305.

Depietri Y., Renaud F.G. and Kallis G. (2012). Heat waves and floods in urban areas: a policy-oriented review of ecosystem services. Sustainability Science, 7(1): 95-107.

Devlaeminck R., Schrijver A.D. and Hermy M. (2005). Variation in throughfall deposition across a deciduous beech (*Fagus sylvatica* L.) forest edge in Flanders. Science of the Total Environment, 337(1-3): 241-252.

Diédhiou A.G., Dupouey J.L., Buée M., Dambrine E., Laüt L. and Garbaye J. (2009). Response of ectomycorrhizal communities to past Roman occupation in an oak forest. Soil Biology and Biochemistry, 41(10): 2206-2213.

Dimoudi A. and Nikolopoulou M. (2003). Vegetation in the urban environment: microclimatic analysis and benefits. Energy and Buildings, 35(1): 69-76.

Diogo V. and Koomen E. (2010). Explaining land-use change in Portugal 1990-2000. 13th AGILE International Conference on Geographic Information Science, 11-14 of May, Guimarães, Portugal, 11 pp.

Directive 92/43/EEC (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Communities L 206, 22.7.1992:7, 50 pp.

Dislich R. and Pivello V.R. (2002). Tree structure and species composition changes in an urban tropical forest fragment (São Paulo, Brazil) during a five-year interval. Boletim de Botânica da Universidade de São Paulo, 20: 1-11.

Donnison L.M., Griffith G.S and Bardgett R.D. (2000). Determinants of fungal growth and activity in botanically diverse haymeadows: effects of litter type and fertilizer additions. Soil Biology and Biochemistry, 32(2): 289-294.

Downie D.E. and Taskey R.D. (1997). Soil characteristics of blue oak and coast live oak ecosystems. In: Pillsbury N.H., Verner J. and Tietje W.D, (Eds.), Proceedings of a symposium on oak woodlands: ecology, management, and urban interface issues, 19-22 March 1996, San Luis Obispo, CA. General Technical Report PSW-GTR-160. Albany, CA, USA: Pacific Southwest Research Station, Forest Service, USDA, pp. 65-74.

Du X., Jin X., Yang X., Yang X. and Zhou Y. (2014). Spatial pattern of land use change and its driving force in Jiangsu province. International Journal of Environmental Research and Public Health, 11(3): 3215-32.

Duchesne L.C. (1994). Role of ectomycorrhizal fungi in biocontrol. In: Pfleger F.L. and Linderman R.G. (Eds.), Mycorrhizae and plant health. American Phytopatholical Society, Press, St. Paul, USA, pp. 27-45.

Duque J., Varajão J., Vitor F. and Dominguez C. (2013). Implementation of CRM systems in Portuguese Municipalities. Local Government Studies, 39(6): 878-894.

EEA (European Environment Agency) (2010a). 10 messages for 2010: Urban ecosystems. EEA, Copenhagen, 11 pp.

EEA (European Environment Agency) (2010b). The European environment - state and outlook 2010: land use. EEA, Copenhagen, 48 pp.

EEA (European Environment Agency) (2009). Ensuring quality of life in Europe's cities and towns: tackling the environmental challenges driven by European and global change. EEA, Copenhagen, 108 pp.

EEA (European Environment Agency) (2006). Urban sprawl in Europe - the ignored challenge, EEA Report N. 10. Copenhagen, 56 pp.

EEA (European Environment Agency) (1995). Environment in the European Union 1995: Report for the review of the fifth environmental action programme. Copenhagen: European Environment Agency, 151 pp.

Eurofound (2013a). Third European quality of life survey - quality of life in Europe: subjective well-being. Publications Office of the European Union, Luxembourg, 124 pp.

Eurofound (2013b). Third European quality of life survey - quality of life in Europe: trends 2003-2012. Publications Office of the European Union, Luxembourg, 109 pp.

European Commission (2014). Factsheet on 2014-2020 Rural Development Programme for Portugal Continente. Accessed in April 2015 from: http://ec.europa.eu/agriculture/rural-development-2014-2020/country-files/pt/factsheet-continente_en.pdf.

European Commission (2013a). Communication from the Commission to the European Parliament, The Council, the European Economic and Social Committee and the Committee of the Regions. Green Infrastructure (GI) - Enhancing Europe's Natural Capital. COM(2013) 249 final, Brussels, 11 pp.

European Commission (2013b). Quality of life in cities: perception survey in 79 European cities. Flash Eurobarometer 366, Publications Office of the European Union, Brussels, 145 pp.

European Commission (2012). Science for environment policy in-depth report on soil sealing. Accessed in December 2014 from: http://ec.europa.eu/environment/archives/soil/pdf/sealing/Soil%20Sealing%20In-depth%20Report%20March%20version_final.pdf.

European Commission (2011a). Our life insurance, our natural capital: an EU biodiversity strategy to 2020. COM (2011) 244 final, Brussels, 16 pp.

European Commission (2011b). A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy. COM (2011) 21, Brussels, 16 pp.

European Commission (2011c). EU agricultural economic briefs. Rural areas and the Europe 2020 strategy: education. Agriculture and Rural Development, Brief N° 4, 9 pp.

European Commission (2010a). A strategy for smart, sustainable and inclusive growth. Brussels, COM(2010) 2020, Brussels, 32 pp.

European Commission (2010b). Survey on perception of quality of life in 75 European cities. Directorate-General Regional Policy, Brussels, 85 pp.

European Commission (2007a). State of European cities report - adding value to the European Urban Audit. European Union, Regional Policy, Brussels, 32 pp.

European Commission (2007b). Survey on perceptions of quality of life in 75 European cities. Directorate-General Regional Policy, Brussels, 16 pp.

European Commission (2004). Urban Audit perception survey: local perceptions of quality of life in 31 European cities. Flash Eurobarometer 156, Brussels, 21 pp.

European Union (2011). Cities of tomorrow: challenges, visions, ways forward. European Commission - Directorate General for Regional Policy, Publications Office of the European Union, Luxembourg, 100 pp.

Eviner V.T. (2004). Plant traits that influence ecosystem processes vary independently among species. Ecology, 85(8): 2215-2229.

Eviner V.T. and Chapin III F.S. (2003). Functional matrix: a conceptual framework for predicting multiple plant effects on ecosystem processes. Annual Review of Ecology, Evolution, and Systematics, 34: 455-485.

Fabião A., Martins M.C., Cerveira C., Santos C., Lousã M., Madeira M. and Correia A. (2002). Influence of soil and organic residue management on biomass and biodiversity of understory vegetation in a *Eucalyptus globulus* Labill. plantation. Forest Ecology and Management, 171(1-2): 87-100.

Fanan U., Dlama K.I. and Oluseyi I.O. (2011). Urban expansion and vegetal cover loss in and around Nigeria's Federal Capital City. Journal of Ecology and the Natural Environment, 3(1): 1-10.

FAO (Food and Agriculture Organization) (2007). The urban producer's resource book. A practical guide for working with low income urban and peri-urban producers organizations. FAO, Rome, 137 pp.

FAO (Food and Agriculture Organization) (2005). The importance of soil organic matter: key to drought-resistant soil and sustained food and production. FAO Soils Bulletin 80, Food and Agriculture Organization of the United Nations (FAO-UN), Rome, 78 pp.

FEDENATUR (European Federation of Metropolitan and Periurban Natural and Rural Areas) (2004). The place of periurban natural spaces for a sustainable city. European Commission, Direction General Environment, 39 pp.

Feldmann B. (2008). The Urban Audit - measuring the quality of life in European cities. Office for Official Publications of the European Communities, Luxembourg, 7 pp.

Feranec J., Jaffrain G., Soukup T. and Hazeu G. (2010). Determining changes and flows in European landscapes 1990-2000 using CORINE land cover data. Applied Geography, 30(1): 19-35.

Fierer N. and Jackson R.B. (2006). The diversity and biogeography of soil bacterial communities. Proceedings of the National Academy of Sciences of the United States of America (PNAS), 103(3): 626-631.

Finlay R.D. (2008). Ecological aspects of mycorrhizal symbiosis: with special emphasis on the functional diversity of interactions involving the extraradical mycelium. Journal of Experimental Botany, 59(5): 1115-1126.

Foley J.A., DeFries R., Asner G.P., Barford C., Bonan G., Carpenter S.R., Chapin F.S., Coe M.T., Daily G.C., Gibbs H.K., Helkowski J.H., Holloway T., Howard E.A., Kucharik C.J., Monfreda C., Patz J.A., Prentice I.C., Ramankutty N. and Snyder P.K. (2005). Global consequences of land use. Science, 309(5734): 570-574.

Franco J.A. and Afonso M.R. (1971-2003). Nova flora de Portugal (Continente e Açores) (New flora of Portugal (Continent and Azores). Sociedade Astória, Lisboa. [**in Portuguese**].

Frey-Klett P., Garbaye J. and Tarkka M. (2007). The mycorrhiza helper bacteria revisited. New Phytologist, 176(1): 22-36.

Frondoni R., Mollo B. and Capotorti G. (2011). A landscape analysis of land cover change in the Municipality of Rome (Italy): spatio-temporal characteristics and ecological implications of land cover transitions from 1954 to 2001. Landscape and Urban Planning, 100(1-2): 117-128.

Gardes M. and Bruns T.D. (1993). ITS primers with enhanced specificity for basidio-mycetes - application to the identification of mycorrhizae and rusts. Molecular Ecology, 2(2): 113-118.

Garrido-Lestache J.S. (2001). Polinosis en Madrid (Pollinosis in Madrid). In: Gutiérrez M., Sáenz C., Aránguez E. and Ordónez J. (Eds.), Polen atmosférico en la comunidad de Madrid (Atmospheric pollen in the Madrid community). Documentos Técnicos de Salud Pública nº 70: 27-35. Dirección General de Salud Pública. Consejería de Sanidad. Comunidad de Madrid. [**in Spanish**].

Gerhardt E., Vila J. and Llimona X. (2000). Hongos de España y de Europa (Mushrooms of Spain and Europe). Omega, Barcelona, 960 pp. [**in Spanish**].

Giannakourou G. (2005). Transforming spatial planning policy in Mediterranean countries: Europeanization and domestic change. European Planning Studies, 13(2): 319-331.

Giller P.S. (1996). The diversity of soil communities, the "poor man's tropical rainforest". Biodiversity and Conservation, 5(2): 135-168.

Gomes P.D.P.M. and Panagopoulos T. (2008). Opportunities for sustainable design in renovation of the Stanaway Park, Dublin, Ireland. 1st WSEAS International Conference on Landscape Architecture, Algarve, Portugal, pp. 81-85.

Grimm N.B., Faeth S.H., Golubiewski N.E., Redman C.L., Wu J., Bai X. and Briggs J.M. (2008). Global change and the ecology of cities. Science, 319(5864): 756-760.

Grimm N.B., Grove J.M., Pickett S.T.A. and Redman C.L. (2000). Integrated approaches to long-term studies of urban ecological systems. BioScience, 50(7): 571-584.

Grove J.M., Troy A.R., O'Neil-Dunne J.P.M., Burch W.R. Jr., Cadenasso M.L. and Pickett S.T.A. (2006). Characterization of households and its implications for the vegetation of urban ecosystems. Ecosystems, 9(4): 578-597.

Gustafsson L., Appelgren L. and Nordin A. (2005). Biodiversity value of potential forest fertilisation stands, as assessed by red-listed and ‘signal’ bryophytes and lichens. Silva Fennica, 39(2): 191-200.

Gustafsson L. (2002). Presence and abundance of red-listed plant species in Swedish forests. Conservation Biology, 16(2): 377-388.

Hadorn G.H., Bradley D., Pohl C., Rist S. and Wiesmann U. (2006). Implications of transdisciplinarity for sustainability research. Ecological Economics, 60(1): 119-128.

Haines-Young R. and Potschin M. (2010). The links between biodiversity, ecosystem services and human well-being. In: Raffaelli D.G. and Frid C.L.J. (Eds.), Ecosystem ecology. A new synthesis. BES Ecological Reviews Series, Cambridge University Press, Cambridge, pp. 110-139.

Hansen A.J., Knight R.L., Marzluff J.M., Powell S., Brown K., Gude P.H. and Jones K. (2005). Effects of exurban development on biodiversity: patterns, mechanisms, and research needs. Ecological Applications, 15(6): 1893-1905.

Haq S.Md.A. (2011). Urban green spaces and an integrative approach to sustainable environment. Journal of Environmental Protection, 2(5): 601-608.

Hector A., Schmid B., Beierkuhnlein C., Caldeira M.C., Diemer M., Dimitrakopoulos P.G., Finn J.A., Freitas H., Giller P.S., Good J., Harris R., Högberg P., Huss-Danell K., Joshi J., Jumpponen A., Körner C., Leadley P.W., Loreau M., Minns A., Mulder C.P.H., O'Donovan G., Otway S.J., Pereira J.S., Prinz A., Read D.J., Scherer-Lorenzen M., Schulze E.-D., Siamantziouras A.-S.D., Spehn E.M., Terry A.C., Troumbis A.Y., Woodward F.I., Yachi S. and Lawton J.H. (1999). Plant diversity and productivity experiments in European grasslands. Science, 286(5442): 1123-1127.

Heidt V. and Neef M. (2008). Benefits of urban green space for improving urban climate. In: Carreiro M.M., Song Y.-C. and Wu J. (Eds.), Ecology, planning, and management of urban forests: international perspectives. Springer Science+Business Media, LLC, New York, pp. 84-96.

Henderson F.M. and Xia Z.-G. (1997). SAR applications in human settlement detection, population estimation and urban land use pattern analysis: a status report. IEEE Transactions on Geoscience and Remote Sensing, 35(1): 79-85.

Heyerdahl E.K., Brubaker L.B. and Agee J.K. (2001). Spatial controls of historical fire regimes: a multiscale example from the interior west, USA. Ecology, 82(3): 660-678.

Hietel E., Waldhardt R. and Otte A. (2007). Statistical modeling of land-cover changes based on key socio-economic indicators. Ecological Economics, 62(3-4): 496-507.

Hietel E., Waldhardt R. and Otte A. (2004). Analysing land-cover changes in relation to environmental variables in Hesse, Germany. Landscape Ecology, 19(5): 473-489.

Honnay O., Verheyen K. and Hermy M. (2002a). Permeability of ancient forest edges for weedy plant species invasion. Forest Ecology and Management, 161(1-3): 109-122.

Honnay O., Bossuyt B., Verheyen K., Butaye J., Jacquemyn H. and Hermy M. (2002b). Ecological perspectives for the restoration of plant. Biodiversity and Conservation, 11(2): 213-242.

Hooke R.LeB., Martín-Duque J.F. and Pedraza J. (2012). Land transformation by humans: a review. GSA Today, 22(12): 4-10.

Howard C. (2010). Are we being served? A critical perspective on Canada's citizens first satisfaction surveys. International Review of Administrative Sciences, 76(1): 65-83.

Huong H.T.L. and Pathirana A. (2013). Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. Hydrology and Earth System Sciences, 17(1): 379-394.

Huxley A., Griffiths M. and Levy M. (1992). The new royal horticultural society dictionary of gardening. MacMillan Stockton Press, London and Basingstoke, 3200 pp.

ICNF (Instituto da Conservação da Natureza e das Florestas - Institute for Nature Conservation and Forestry) (2013a). Áreas dos usos do solo e das espécies florestais de Portugal Continental. Resultados preliminares. (Areas of land use and forest species of Continental Portugal. Preliminary results). 6º Inventário Florestal Nacional (IFN6). ICNF, Lisboa, 34 pp. [**in Portuguese**].

ICNF (Instituto da Conservação da Natureza e das Florestas - Institute for Nature Conservation and Forestry) (2013b). Cartografia nacional de áreas ardidas. (National Mapping of burnt areas). Accessed in September 2013 from: http://www.icnf.pt/portal/florestas/dfci/inc/info-geo. [**in Portuguese**].

IGeoE (Instituto Geográfico do Exército - Geographic Army Institute) (2002). Carta Militar de Portugal. (Portugal Military Chart). Folha 230 (Coimbra); Folha 241 (Coimbra-Sul), Escala 1:25 000, Série M 888. Edição 3; Edição 4, Lisboa, Portugal. [**in Portuguese**].

IGP (Instituto Geográfico Português - Portuguese Geographic Institute) (1990). Carta de Ocupação do Solo – COS 90. (Land use map – COS 90). Accessed in July 2011 from: http://www.igeo.pt. [**in Portuguese**].

INE (Instituto Nacional de Estatística - National Institute of Statistics) (2011). Censos 2011. (Census 2011). Accessed in September 2013 from: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_main. [**in Portuguese**].

INE (Instituto Nacional de Estatística - National Institute of Statistics) (2009). Estatísticas agrícolas - 2008 (Agricultural statistics - 2008). Lisboa, Instituto Nacional de Estatística. [**in Portuguese**].

Ipsos MORI (2010). What do people want, need and expect from public services? 2020 Public Services Trust, London, 48 pp.

Jaeger J.A.G., Bertiller R., Schwick C. and Kienast F. (2010). Suitability criteria for measures of urban sprawl. Ecological Indicators, 10(2): 397-406.

James O. (2009). Evaluating the expectations disconfirmation and expectations anchoring approaches to citizen satisfaction with local public services. Journal of Public Administration Research and Theory, 19(1): 107-123.

Johansson S. (2002). Conceptualizing and measuring quality of life for national policy. Social Indicators Research, 58(1-3): 13-32.

Jones N., de Graaff J., Rodrigo I. and Duarte F. (2011). Historical review of land use changes in Portugal (before and after EU integration in 1986) and their implications for land degradation and conservation, with a focus on Centro and Alentejo regions. Applied Geography, 31(3): 1036-1048.

Jooss R., Geissler-Strobel S., Trautner J., Hermann G. and Kaule G. (2009). "Conservation responsibilities" of municipalities for target species: prioritizing conservation by assigning responsibilities to municipalities in Baden-Wuerttemberg, Germany. Landscape and Urban Planning, 93(3-4): 218-228.

Jordan H. (1994). Public parks, 1885-1914. Garden History, 22(1): 85-113.

Karavas N., Georghiou K., Arianoutsou M. and Dimopoulos D. (2005). Vegetation and sand characteristics influencing nesting activity of *Caretta caretta* on Sekania beach. Biological Conservation, 121(2): 177-188.

Kasanko M., Barredo J.I., Lavalle C., McCormick N., Demicheli L., Sagris V. and Brezger A. (2006). Are European cities becoming dispersed? A comparative analysis of 15 European urban areas. Landscape and Urban Planning, 77(1-2): 111-130.

Kaye J.P., Groffman P.M., Grimm N.B., Baker L.A. and Pouyat R.V. (2006). A distinct urban biogeochemistry? TRENDS in Ecology and Evolution, 21(4): 192-199.

Keleş S., Sivrikaya F., Çakir G. and Köse S. (2008). Urbanization and forest cover change in regional directorate of Trabzon forestry from 1975 to 2000 using landsat data. Environmental Monitoring and Assessment, 140(1-3): 1-14.

Kelly J.M. (2003). Citizen satisfaction and administrative performance measures. Is there really a link? Urban Affairs Review, 38(6): 855-866.

Kline J.D. (2006). Public demand for preserving local open space. Society and Natural Resources, 19(7): 645-659.

Knudsen D., Peterson G.A. and Pratt P.F. (1982). Lithium, sodium, and potassium. In: Page A.L., Miller R.H. and Keeney D.R. (Eds.), Methods of soil analysis. Part 2 - Chemical and microbiological properties. Second edition, Soil Society of America, Inc., Madison, USA, pp. 225-246.

Kowalchuk G.A., Buma D.S., de Boer W., Klinkhamer P.G.L. and van Veen J.A. (2002). Effects of above-ground plant species composition and diversity on the diversity of soil-borne microorganisms. Antonie van Leeuwenhoek, 81(1-4): 509-520.

Kowarik I. (2011). Novel urban ecosystems, biodiversity, and conservation. Environmental Pollution, 159(8-9): 1974-1983.

Krausmann F., Haberl H., Schulz N.B., Erb K.-H., Darge E. and Gaube V. (2003). Land-use change and socio-economic metabolism in Austria, Part I: driving forces of land-use change: 1950-1995. Land Use Policy, 20(1): 1-20.

Kristensen S.P., Thenail C. and Kristensen L. (2001). Farmers' involvement in landscape activities: an analysis of the relationship between farm location, farm characteristics and landscape changes in two study areas in Jutland, Denmark. Journal of Environmental Management, 61(4): 301-318.

Kuramae E.E., Gamper H.A., van Veen J.A. and Kowalchuk G.A. (2011). Soil and plant factors driving the community of soil-borne microorganisms across chronosequences of secondary succession of chalk grasslands with a neutral pH. FEMS Microbiology Ecology, 77(2): 285-294.

Kuramae E.E., Gamper H.A., Yergeau E., Piceno Y.M., Brodie E.L., DeSantis T.Z., Andersen G.L., van Veen J.A. and Kowalchuk G.A. (2010). Microbial secondary succession in a chronosequence of chalk grasslands. The International Society for Microbial Ecology Journal, 4(5): 711-715.

Lambin E.F., Turner B.L., Geist H.J., Agbola S.B., Angelsen A., Bruce J.W., Coomes O.T., Dirzo R., Fischer G., Folke C., George P.S., Homewood K., Imbernon J., Leemans R., Li, X., Moran E.F., Mortimore M., Ramakrishnan P.S., Richards J.F., Skanes H., Steffen W., Stone G.D., Svedin U., Veldkamp T.A., Vogel C. and Xu J. (2001). The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change, 11(4): 261-269.

Lanyon L.E. and Heald W.R. (1982). Magnesium, calcium, strontium, and barium. In: Page A.L., Miller R.H. and Keeney D.R. (Eds.), Methods of soil analysis. Part 2 - Chemical and microbiological properties. Second edition, Soil Society of America, Inc., Madison, USA, pp. 247-262.

LaPaix R. and Freedman B. (2010). Vegetation structure and composition within urban parks of Halifax regional municipality, Nova Scotia, Canada. Landscape and Urban Planning, 98(2): 124-135.

Lever J.P. (2000). The development of an instrument to measure quality of life in Mexico city. Social Indicators Research, 50(2): 187-208.

Li F., Ye Y.P., Song B.W., Wang R.S. and Tao Y. (2014). Assessing the changes in land use and ecosystem services in Changzhou municipality, Peoples' Republic of China, 1991-2006. Ecological Indicators, 42: 95-103.

Li J.-J., Wang X.-R., Wang X.-J., Ma W.-C. and Zhang H. (2009). Remote sensing evaluation of urban heat island and its spatial pattern of the Shanghai metropolitan area, China. Ecological Complexity, 6(4): 413-420.

Li Q. (2013). A novel Likert scale based on fuzzy sets theory. Expert Systems With Applications, 40(5): 1609-1618.

Lilleskov E.A. and Bruns T.D. (2001). Nitrogen and ectomycorrhizal fungal communities: what we know, what we need to know. New Phytologist, 149(2): 154-158.

Lindgren P.M.F. and Sullivan T.P. (2001). Influence of alternative vegetation management treatments on conifer plantation attributes: abundance, species diversity, and structural diversity. Forest Ecology and Management, 142(1-3): 163-182.

Long H., Tang G., Li X. and Heilig G.K. (2007). Socio-economic driving forces of land-use change in Kunshan, the Yangtze River Delta economic area of China. Journal of Environmental Management, 83(3): 351-364.

López de Lucio R. (2003). Transformaciones territoriales recientes en la región urbana de Madrid. Urban, 8(11): 124-161. [**in Spanish**].

Loures L., Santos R. and Panagopoulos T. (2007). Urban parks and sustainable city planning - the case of Portimão, Portugal. WSEAS Transactions on Environment and Development, 3(10): 171-180.

Lovett G.M., Traynor M.M., Pouyat R.V., Carreiro M.M., Zhu W.-X. and Baxter J.W. (2000). Atmospheric deposition to oak forests along an urban-rural gradient. Environmental Science and Technology, 34(20): 4294-4300.

Lubbe C.S., Siebert S.J. and Cilliers S.S. (2010). Political legacy of South Africa affects the plant diversity patterns of urban domestic gardens along a socio-economic gradient. Scientific Research and Essays, 5(19): 2900-2910.

Lynch M.D.J. and Thorn R.G. (2006). Diversity of basidiomycetes in Michigan agricultural soils. Applied and Environmental Microbiology, 72(11): 7050-7056.

Mabberley D.J. (2008). Mabberley's plant - book: a portable dictionary of plants, their classification and uses. Third edition, Cambridge University Press, Cambridge, 1040 pp.

Magurran A.E. (2004). Measuring biological diversity. Blackwell Science Ltd, Malden, 256 pp.

MAMAOT (Ministério da Agricultura, do Mar, do Ambiente e do Ordenamento do Território - Ministry of Agriculture, Sea, Environment, and Spatial Planning) (2012). Rede rural Nacional (National rural network). pp. 120. [**in Portuguese**].

Marchante E., Kjøller A., Struwe S. and Freitas H. (2008). Short- and long-term impacts of *Acacia longifolia* invasion on the belowground processes of a Mediterranean coastal dune ecosystem. Applied Soil Ecology, 40(2): 210-217.

Marschner P., Yang C.-H., Lieberei R. and Crowley D.E. (2001). Soil and plant specific effects on bacterial community composition in the rhizosphere. Soil Biology and Biochemistry, 33(11): 1437-1445.

Marzluff J., Shulenberger E., Endlicher W., Alberti M., Bradley G., Ryan C., ZumBrunnen C. and Simon U. (Eds.) (2008). Urban ecology: an international perspective on the interaction between humans and nature. Springer, New York, 808 pp.

Massaccesi L., Bardgett R.D., Agnelli A., Ostle N., Wilby A. and Orwin K.H. (2015). Impact of plant species evenness, dominant species identity and spatial arrangement on the structure and functioning of soil microbial communities in a model grassland. Oecologia, 177(3): 747-759.

Mathieu R., Freeman C. and Aryal J. (2007). Mapping private gardens in urban areas using object-oriented techniques and very high-resolution satellite imagery. Landscape and Urban Planning, 81(3): 179-192.

Matson P.A., Parton W.J., Power A.G. and Swift M.J. (1997). Agricultural intensification and ecosystem properties. Science, 277(5325): 504-509.

Mazza L., Bennett G., de Nocker L., Gantioler S., Losarcos L., Margerison C., Kaphengst T., McConville A., Rayment M., ten Brink P., Tucker G. and van Diggelen R. (2011). Green Infrastructure implementation and efficiency. Final report for the European Commission, DG Environment on Contract ENV.B.2/SER/2010/0059. Institute for European Environmental Policy, Brussels and London, 266 pp.

McDonnell M.J. (2011). The history of urban ecology - an ecologist's perspective. In Niemalä J. (Ed.), Urban ecology: patterns, processes and applications. Oxford University Press, Oxford, pp. 5-13.

McDonnell M.J. and Pickett S.T.A. (1990). Ecosystem structure and function along urban-rural gradients: an unexploited opportunity for ecology. Ecology, 71(4): 1232-1237.

McGranahan D., Cromartie J. and Wojan T. (2010). Nonmetropolitan outmigration counties: some are poor, many are prosperous. United States Department of Agriculture (USDA), Economic Research Service, ERR - 107, 29 pp.

McKinney M.L. (2006). Urbanization as a major cause of biotic homogenization. Biological Conservation, 127(3): 247-260.

MEA (Millennium Ecosystem Assessment) (2005a). Ecosystems and human well-being: current state and trends. Island Press, Washington, 23 pp.

MEA (Millennium Ecosystem Assessment) (2005b). Ecosystems and human well-being: biodiversity synthesis. World Resources Institute, Washington, 86 pp.

MEA (Millennium Ecosystem Assessment) (2003). Ecosystems and human well-being: a framework for assessment. Island Press, Washington, 245 pp.

Meddad-Hamza A., Beddiar A., Gollotte A., Lemoine M.C., Kuszala C. and Gianinazzi S. (2010). Arbuscular mycorrhizal fungi improve the growth of olive trees and their resistance to transplantation stress. African Journal Journal of Biotechnology, 9(8): 1159-1167.

Melillo J.M., Aber J.D., Linkins A.E., Ricca A., Fry B. and Nadelhoffer K.J. (1989). Carbon and nitrogen dynamics along the decay continuum: plant litter to soil organic matter. Plant and Soil, 115(2): 189-198.

Mermoz M., Kitzberger T. and Veblen T.T. (2005). Landscape influences on occurrence and spread of wildfires in Patagonian forests and shrublands. Ecology, 86(10): 2705-2715.

Michalski J.H. (2001). Asking citizens what matters for quality of life in Canada. Results of CPRN's public dialogue process. Canadian Policy Research Networks (CPRN). Department of Sociology, Trent University, Ottawa, 60 pp.

Michels A. (2011). Innovations in democratic governance: how does citizen participation contribute to a better democracy? International Review of Administrative Sciences, 77(2): 275-293.

Midgley D.J., Saleeba J.A., Stewart M.I., Simpson A.E. and McGee P.A. (2007). Molecular diversity of soil basidiomycete communities in northern-central New South Wales, Australia. Mycological Research, 111(3): 370-378.

Miki T., Ushio M., Fukui S. and Kondoh M. (2010). Functional diversity of microbial decomposers facilitates plant coexistence in a plant - microbe - soil feedback model. Proceedings of the National Academy of Sciences of the United States of America (PNAS), 107(32): 14251-14256.

Miller R.M. and Lodge D.J. (2007). Fungal responses to disturbance: agriculture and forestry, in: Kubicek C.P. and Druzhinina I.S. (Eds.), The Mycota IV: environmental and microbial relationships. Second edition, Springer-Verlag BerlinHeidelberg, New York, pp. 47-68.

Ministério da Agricultura, do Desenvolvimento Rural e das Pescas - Ministry of Agriculture, Rural Development and Fisheries (2001). Decreto-Lei n.º 169/2001, de 25 de Maio de 2001 (Decree-Law n.º 169/2001 of 25 May 2001), in: Diário da República - I Série - A, 121:3053-3059. [**in Portuguese**].

Ministério do Ambiente - Ministry of the Environment (1999). Decreto-Lei n.º 565/99, de 21 de Dezembro de 1999 (Decree-Law n.º 565/99 of 21 December 1999). In: Diário da República - I Série - A, 295:9100-9114. [**in Portuguese**].

Misir T.L. (2012). Ageing modernity: growing old in the EU in the 21st century. European Union, Centre in Singapore, Background Brief No. 7, 13 pp.

Mizrahi S., Vigoda-Gadot E. and Cohen N. (2009). Trust, participation, and performance in public administration: an empirical examination of health services in Israel. Public Performance and Management Review, 33(1): 7-33.

Molina R., Massicotte H. and Trappe J. (1992). Specificity phenomena in mycorrhizal symbioses: community-ecological consequences and practical implications. In: Allen M.F. (Ed.), Mycorrhizal functioning: an integrated plant-fungal process. Chapman and Hall, New York, pp. 357-423.

Møller V. and Dickow H. (2002). The role of quality of life surveys in managing change in democratic transitions: the South African case. Social Indicators Research, 58(1-3): 267-292.

Morais P., Miguéis V.L. and Camanho A.S. (2013). Quality of life experienced by human capital: an assessment of European cities. Social Indicators Research, 110(1): 187-206.

Moreira F., Vaz P.J.G., Catry F.X. and Silva J.S. (2009). Regional variations in wildfire susceptibility of land cover types in Portugal: implications for landscape management to minimize fire hazard. International Journal of Wildland Fire, 18(5): 563-574.

Moreira F., Rego F. and Ferreira P. (2001). Temporal (1958-1995) pattern of change in a cultural landscape of northwestern Portugal: implications for fire occurrence. Landscape Ecology, 16(6): 557-567.

Mueller-Dombois D. and Ellenberg H. (1974). Aims and methods of vegetation ecology. John Wiley and Sons, New York, 547 pp.

Munafò M., Salvati L. and Zitti M. (2013). Estimating soil sealing rate at national level - Italy as a case study. Ecological Indicators, 26: 137-140.

Mundia C.N. and Aniya M. (2005). Analysis of land use/cover changes and urban expansion of Nairobi city using remote sensing and GIS. International Journal of Remote Sensing, 26(13): 2831-2849.

Muyzer G., de Waal E.C. and Uitierlinden A.G. (1993). Profiling of complex microbial populations by denaturing gradient gel electrophoresis analysis of polymerase chain reaction-amplified genes coding for 16S rRNA. Applied and Environmental Microbiology, 59(3): 695-700.

Mwavu E.N. and Witkowski E.T.F. (2008). Land-use and cover changes (1988-2002) around Budongo Forest Reserve, NW Uganda: implications for forest and woodland sustainability. Land Degradation and Development, 19(6): 606-622.

Naab F.Z., Dinye R.D. and Kasanga R.K. (2013). Urbanisation and its impact on agricultural lands in growing cities in developing countries: a case study of Tamale in Ghana. Modern Social Science Journal, 2(2): 256-287.

Næss P. (2001). Urban planning and sustainable development. European Planning Studies, 9(4): 503-524.

Nannipieri P., Ascher J., Ceccherini M.T., Landi L., Pietramellara G. and Renella G. (2003). Microbial diversity and soil functions. European Journal of Soil Science, 54(4): 655-670.

National Official Journal (2004). Notice No. 7635/2014. In: Diário da República - 2.ª Série, 124: 17016-17040. [**in Portuguese**].

Newbound M., McCarthy M.A. and Lebel T. (2010). Fungi and the urban environment: a review. Landscape and Urban Planning, 96(3): 138-145.

Newton N.T. (1971). Olmsted and Vaux: Central Park and prospect park. In: Design on the land. The development of landscape architectute. The Belknap Press of Harvard University Press, Cambridge, Chapter XIX, pp. 267-306.

Niemelä J. (2014). Ecology of urban green spaces: the way forward in answering major research questions. Landscape and Urban Planning, 125: 298-303.

Nijkamp P. and Vreeker R. (2000). Sustainability assessment of development scenarios: methodology and application to Thailand. Ecological Economics, 33(1): 7-27.

Nowak D.J., Stein S.M., Randler P.B., Greenfield E.J., Comas S.J., Carr M.A. and Alig R.J. (2010). Sustaining America’s urban trees and forests: a forests on the edge report. Gen. Tech. Rep. NRS-62, Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station, 27 pp.

Nowak D.J. and Dwyer J.F. (2007). Understanding the benefits and costs of urban forest ecosystems. In: Kuser J.E. (Ed.), Urban and Community Forestry in the Northeast. Springer Netherlands, pp. 25-46.

Nowak D.J. and Walton J.T. (2005). Projected urban growth (2000-2050) and its estimated impact on the US forest resource. Journal of Forestry, 103(8): 383-389.

Nowak D.J., Noble M.H., Sisinni S.M. and Dwyer J.F. (2001). People and trees: assessing the US urban forest resource. Journal of Forestry, 99(3): 37-42.

Nunes M.C., Vasconcelos M.J., Pereira J.M., Dasgupta N., Alldredge R.J. and Rego F.C. (2005). Land cover types and fire in Portugal: do fires burn land cover selectively? Landscape Ecology, 20(6): 661-673.

Olsen S.R. and Sommers L.E. (1982). Phosphorus. In: Page A.L., Miller R.H. and Keeney D.R. (Eds.), Methods of soil analysis, Part 2, Chemical and microbiological properties. Second edition, Soil Society of America, Inc., Madison, pp. 403-430.

Omidi H., Tahmasebi Z., Torabi H. and Miransari M. (2008). Soil enzymatic activities and available P and Zn as affected by tillage practices, canola (*Brassica napus* L.) cultivars and planting dates. European Journal of Soil Biology, 44(4): 443-450.

Pan A. (2012). A study on residents' risk perception in abrupt geological hazard. Journal of Risk Analysis and Crisis Response, 2(1): 44-55.

Park R. E., Burgess E. W. and McKenzie R. (1925). The city. Chicago, University of Chicago, Press, 250 pp.

Parladé J., Álvarez I.F. and Pera J. (1996). Ability of native ectomycorrhizal fungi from northern Spain to colonize Douglas-fir and other introduced conifers. Mycorrhiza, 6(1): 51-55.

Partidário M.R. and Correia F.N. (2004). Polis - the Portuguese programme on urban environment. A contribution to the discussion on European urban policy. European Planning Studies, 12(3): 409-424.

Pato R.L., Tavares A.O. and Magalhães M.C. (2008). Developments in land use in a periurban area of central Portugal: the importance of biophysical parameters. Geo-Environment and Landscape Evolution III. WIT Transactions on Built Environment, Vol 100. The New Forest, UK, pp. 109-117.

Pereira H.M., Domingos T., Vicente L. and Proença V. (Eds.) (2009). Ecossistemas e bem-estar humano: avaliação para Portugal do Millennium Ecosystem Assessment (Ecosystems and human well-being: assessment for Portugal Millennium Ecosystem Assessment). Escolar Editora, Lisboa, Portugal. [**in Portuguese**].

Pereira P.M. and Fonseca M.P. (2003). Nature vs. nurture: the making of the montado ecosystem. Conservation Ecology, **7**(3): 7. [online] URL: http://www.consecol.org/vol7/iss3/art7.

Pérez-Ramos I.M., Zavala M.A., Marañón T., Díaz-Villa M.D. and Valladares F. (2008). Dynamics of understorey herbaceous plant diversity following shrub clearing of cork oak forests: a five-year study. Forest Ecology and Management, 255(8-9): 3242-3253.

Peterson D.W. and Reich P.B. (2008). Fire frequency and tree canopy structure influence plant species diversity in a forest-grassland ecotone. Plant Ecology, 194(1): 5-16.

Peterson G., Allen C.R. and Holling C.S. (1998). Ecological resilience, biodiversity, and scale. Ecosystems, 1(1): 6-18.

Pickett S.T.A., Cadenasso M.L., Grove J.M., Boone C.G., Groffman P.M., Irwin E., Kaushal S.S., Marshall V., McGrath B.P., Nilon C.H., Pouyat R.V., Szlavecz K., Troy A. and Warren P. (2011). Urban ecological systems: scientific foundations and a decade of progress. Journal of Environmental Management, 92(3): 331-362.

Pickett S.T.A., Cadenasso M.L., Grove J.M., Nilon C.H., Pouyat R.V., Zipperer W.C. and Costanza R. (2001). Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annual Review of Ecology and Systematics, 32: 127-157.

Plieninger T., Höchtl F. and Spek T. (2006). Traditional land-use and nature conservation in European rural landscapes. Environmental Science and Policy, 9(4): 317-321.

Portuguese Commission for UNESCO (2014). UNESCO: Portugal and World Heritage. Ministry of Foreign Affairs, Lisbon, 55 pp. Accessed in October 2014 from: http://whc.unesco.org/en/list/1387.

Pretty J., Peacock J., Hine R., Sellens M., South N. and Griffin M. (2007). Green exercise in the UK countryside: effects on health and psychological well-being, and implications for policy and planning. Journal of Environmental Planning and Management, 50(2): 211-231.

Raco M. (2003). Remaking place and securitising space: urban regeneration and the strategies, tactics and practices of policing in the UK. Urban Studies, 40(9): 1869-1887.

Rad J.E., Manthey M. and Mataji A. (2009). Comparison of plant species diversity with different plant communities in deciduous forests. International Journal of Environmental Science and Technology, 6(3): 389-394.

Ramankutty N., Foley J.A. and Olejniczak N.J. (2002). People on the land: changes in global population and croplands during the 20^{th} century. Ambio, 31(3): 251-257.

Rao K.S. and Pant R. (2001). Land use dynamics and landscape change pattern in a typical micro watershed in the mid elevation zone of central Himalaya, India. Agriculture, Ecosystems and Environment, 86(2): 113-124.

Raudsepp-Hearne C., Peterson G.D., Tengö M., Bennett E.M., Holland T., Benessaiah K., MacDonald G.K. and Pfeifer L. (2010). Untangling the environmentalist's paradox: why is human well-being increasing as ecosystem services degrade? BioScience, 60(8): 576-589.

Richard F., Moreau P.-A., Selosse M.-A. and Gardes M. (2004). Diversity and fruiting patterns of ectomycorrhizal and saprobic fungi in an old-growth Mediterranean forest dominated by *Quercus ilex* L. Canadian Journal of Botany, 82(12): 1711-1729.

Roch C.H. and Poister T.H. (2006). Citizens, accountability, and service satisfaction: the influence of expectations. Urban Affairs Review, 41(3): 292-308.

Rockström J., Steffen W., Noone K., Persson Å., Chapin III F.S., Lambin E., Lenton T.M., Scheffer M., Folke C., Schellnhuber H.J., Nykvist B., de Wit C.A., Hughes T., van der Leeuw S., Rodhe H., Sörlin S., Snyder P.K., Costanza R., Svedin U., Falkenmark M., Karlberg L., Corell R.W., Fabry V.J., Hansen J., Walker B., Liverman D., Richardson K., Crutzen P. and Foley J. (2009). Planetary boundaries: exploring the safe operating space for Humanity. Ecology and Society 14(2): 32. [online] URL: http://www.ecologyandsociety.org/vol14/iss2/art32/.

Rodrigue J.-P., Comtois C. and Slack B. (2006). The geography of transport systems. Taylor and Francis Group, London, 284 pp.

Rosenthal J.K, Crauderueff R. and Carter M. (2008). Urban heat island mitigation can improve New York city's environment: research on the impacts of mitigation strategies on the urban environment. Sustainable South Bronx Working Paper, 47 pp.

Rothermel R. (1983). How to predict the spread and intensity of forest and range fires. USDA, Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT-143, 161 pp.

Saj S., Mikola J. and Ekelund F. (2009). Species-specific effects of live roots and shoot litter on soil decomposer abundances do not forecast plant litter-nitrogen uptake. Oecologia, 161(2): 331-341.

Salvati L., Bajocco S., Ceccarelli T., Zitti M. and Perini L. (2011). Towards a process-based evaluation of land vulnerability to soil degradation in Italy. Ecological Indicators, 11(5): 1216-1227.

Sandström U.G. (2002). Green infrastructure planning in urban Sweden. Planning Practice and Research, 17(4): 373-385.

Santos K., Kinoshita L.S. and Rezende A.A. (2009). Species composition of climbers in seasonal semideciduous forest fragments of Southeastern Brazil. Biota Neotropica, 9(4): 175-188.

Santos L. (1983). Planos de urbanização para a cidade de Coimbra (Urbanization plans for the city of Coimbra). Museu Nacional de Machado de Castro, Coimbra, 95 pp. [**in Portuguese**].

Santos L.D. and Martins I. (2007). Monitoring urban quality of life: the Porto experience. Social Indicators Research, 80(2): 411-425.

Scalenghe R. and Marsan F.A. (2009). The anthropogenic sealing of soils in urban areas. Landscape and Urban Planning, 90(1-2): 1-10.

Schellong A. (2005). CRM in the public sector: towards a conceptual research framework. Proceedings of the 2005 National Conference on Digital Government Research, Atlanta, Georgia, USA. May 15-18, pp. 326-332.

Schneider A. and Woodcock C.E. (2008). Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information. Urban Studies, 45(3): 659-692.

SCI (Sustainable Cities International) (2012). Indicators for sustainability: how cities are monitoring and evaluating their success. Vancouver, 84 pp.

Senlier N., Yildiz R. and Aktaş E.D. (2009). A perception survey for the evaluation of urban quality of life in Kocaeli and a comparison of the life satisfaction with the European cities. Social Indicators Research, 94(2): 213-226.

Sequeira M.M., Espírito-Santo D., Aguiar C., Capelo J. and Honrado J. (2011). Checklist da flora de Portugal (Continental, Açores e Madeira) (Checklist of the flora of Portugal (Continental, Azores and Madeira). Associação Lusitana de Fitossociologia (Alfa), Lisboa, 71 pp. [**in Portuguese**].

Silva J.S. and Catry F. (2006). Forest fires in cork oak (*Quercus suber* L.) stands in Portugal. International Journal of Environmental Studies, 63(3): 235-257.

Smith P., Davies C.A., Ogle S., Zanchi G., Bellarby J., Bird N., Boddey R.M., McNamara N.P., Powlson D., Cowie A., van Noordwijk M., Davis S.C., Richter D.B., Kryzanowski L., van Wijk M., Stuart J., Kirton A., Eggar D., Newton-Cross G., Adhya T. and Braimoh A.K. (2012). Towards an integrated global framework to assess the impacts of land use and management change on soil carbon: current capability and future vision. Global Change Biology, 18(7): 2089-2101.

Smith S.E. and Read D.J. (2008). Mycorrhizal symbiosis. Third edition, Academic Press, London, 787 pp.

Steffen W., Sanderson A., Tyson P.D., Jäger J., Matson P., Moore III B., Oldfield F., Richardson K., Schellnhuber J., Turner II B.L., and Wasson R. (2004). Global change and the Earth system: a planet under pressure. Springer-Verlag Berlin Heidelberg, New York, 40 pp.

Steiger J., Tabacchi E., Dufour S., Corenblit D. and Peiry J.-L. (2005). Hydrogeomorphic processes affecting riparian habitat within alluvial channel-floodplain river systems: a review for the temperate zone. River Research and Applications, 21(7): 719-737.

Stipak B. (1979). Citizen satisfaction with urban services: potential misuse as a performance indicator. Public Administration Review, 39(1): 46-52.

Stormann W.F. (1991). The ideology of the American urban parks and recreation movement: past and future. Leisure Sciences, 13(2): 137-151.

Sukopp H. (2004). Human-caused impact on preserved vegetation. Landscape and Urban Planning, 68(4): 347-355.

Sukopp H. (2002). On the early history of urban ecology in Europe. Preslia, 73: 373-393.

Sum V., McCaskey S.J. and Kyeyune C. (2010). A survey research of satisfaction levels of graduate students enrolled in a nationally ranked top-10 program at a mid-western university. Research in Higher Education Journal, 7(2): 1-17.

Sung C.Y., Yi Y.-j. and Li M.-H. (2013). Impervious surface regulation and urban sprawl as its unintended consequence. Land Use Policy, 32: 317-323.

Swallow M., Quideau S.A., MacKenzie M.D. and Kishchuk B.E. (2009). Microbial community structure and function: the effect of silvicultural burning and topographic variability in northern Alberta. Soil Biology and Biochemistry, 41(4): 770-777.

Tavares A.O., Pato R.L. and Magalhães M.C. (2012). Spatial and temporal land use change and occupation over the last half century in a peri-urban area. Applied Geography, 34: 432-444.

Tavares A.O., Mendes J.M., Basto E. and Cunha L. (2010). Risk perception, extreme events and institutional trust: a local survey in Portugal. Reliability. In: Briš R., Soares C.G. and Martorell S. (Eds.), Risk and Safety: Theory and Applications. Taylor and Francis Group, London, pp. 1245-1252.

Tavares A.O. (2004). Geotechnical and natural hazard mapping on urban and outer urban planning. In: Demers D., Leahy D., Lefebvre R. and Leroueil S. (Eds.), Paper presented at the GéoQuébec 2004 conference, Session 4C, pp. 27-33.

Tavares A.O. and Soares A.F. (2002). Instability relevance on land use planning in Coimbra municipality (Portugal). In McInnes R. and Jakeways J. (Eds.), Instability, planning and management, London, Thomas Telford, pp. 177-184.

Thiet R.K. and Boerner R.E.J. (2007). Spatial patterns of ectomycorrhizal fungal inoculum in arbuscular mycorrhizal barrens communities: implications for controlling invasion by *Pinus virginiana*. Mycorrhiza, 17(6): 507-17.

Thimonier A., Dupouey J.L. and Timbal J. (1992). Floristic changes in the herb-layer vegetation of a deciduous forest in the Lorraine Plain under the influence of atmospheric deposition. Forest Ecology and Management, 55(1-4): 149-167.

Thwaites K., Helleur E. and Simkins I.M. (2005). Restorative urban open space: exploring the spatial configuration of human emotional fulfilment in urban open space. Landscape Research, 30(4): 525-547.

Tilman D., Knops J., Wedin D., Reich P., Ritchie M. and Siemann E. (1997). The influence of functional diversity and composition on ecosystem processes. Science, 277(5330): 1300-1302.

Tiquia S.M., Lloyd J., Herms D.A., Hoitink H.A.J. and Michel Jr. F.C. (2002). Effects of mulching and fertilization on soil nutrients, microbial activity and rhizosphere bacterial community structure determined by analysis of TRFLPs of PCR amplified 16S rDNA genes. Applied Soil Ecology, 21(1): 31-48.

Tomaz C., Alegria C., Monteiro J.M. and Teixeira M.C. (2013). Land cover change and afforestation of marginal and abandoned agricultural land: a 10 year analysis in a Mediterranean region. Forest Ecology and Management, 308: 40-49.

Torres-Vera M.A., Prol-Ledesma R.M. and Garcia-Lopez D. (2009). Three decades of land use variations in Mexico City. International Journal of Remote Sensing, 30(1): 117-138.

Turner K., Lefler L. and Freedman B. (2005). Plant communities of selected urbanized areas of Halifax, Nova Scotia, Canada. Landscape and Urban Planning, 71(2-4): 191-206.

Turrión M.-B., Gallardo J.F., Haumaier L., González M.-I. and Zech W. (2001). ^{31}P-NMR characterization of phosphorus fractions in natural and fertilized forest soils. Annals of Forest Science, 58(1): 89-98.

Tzoulas K., Korpela K., Venn S., Yli-Pelkonen V., Kaźmierczak A., Niemelä J. and James P. (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: a literature review. Landscape and Urban Planning, 81(3): 167-178.

UNESCO (United Nations Educational, Scientific and Cultural Organization) (2000). World conference on science: science for the twenty-first century: a new commitment. UNESCO, Paris, 47 pp.

UN-Habitat (2013). Urban planning for city leaders. United Nations Human Settlements Programme, Nairobi, 176 pp.

United Nations (2014). Population division. World urbanization prospects: the 2014 Revision. Accessed in September 2014 from: http://esa.un.org/unpd/wup/.

United Nations (2009). The right to adequate housing. UN-HABITAT, Office of the United Nations High Commissioner for Human Rights, Geneva, 51 pp.

United Nations (1992). Agenda 21 - United Nations Conference on Environment & Development. Accessed in September 2014 from: https://sustainabledevelopment.un.org/index.php?page=view&nr=23&type=400.

Uno S., Cotton J. and Philpott S.M. (2010). Diversity, abundance, and species composition of ants in urban green spaces. Urban Ecosystems, 13(4): 425-441.

Vacca A. (2000). Effect of land use on forest floor and soil of a *Quercus suber* L. forest in Gallura (Sardinia, Italy). Land Degradation and Development, 11(2): 167-180.

Van T.T. (2008). Research on the effect of urban expansion on agricultural land in Ho Chi Minh City by using remote sensing method. VNU Journal of Science, Earth Sciences, 24: 104-111.

van de Walle S. and Jilke S. (2014). Savings in public services after the crisis: a multilevel analysis of public preferences in the EU-27. International Review of Administrative Sciences, 80(3): 597-618.

van der Heijden M.G.A., Bardgett R.D. and van Straalen N.M. (2008). The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecology letters, 11(3): 296-310.

van Herzele A. and Wiedemann T. (2003). A monitoring tool for the provision of accessible and attractive urban green spaces. Landscape and Urban Planning, 63(2): 109-126.

Veenhoven R. (2002). Why social policy needs subjective indicators. Social Indicators Research, 58(1-3): 33-45.

Veldkamp A and Fresco L.O. (1996). CLUE: a conceptual model to study the conversion of land use and its effects. Ecological Modelling, 85(2-3): 253-270.

Verburg P.H., Veldkamp T.(A.) and Bouma J. (1999). Land use change under conditions of high population pressure: the case of Java. Global Environmental Change, 9(4): 303-312.

Vitousek P.M., Mooney H.A., Lubchenco J. and Melillo J.M. (1997). Human domination of Earth's ecosystems. Science, 277(5325): 494-499.

Wallis P.D., Haynes R.J., Hunter C.H. and Morris C.D. (2010). Effect of land use and management on soil bacterial biodiversity as measured by PCR-DGGE. Applied Soil Ecology, 46(1): 147-150.

Wang G., Xu Y., Jin J., Liu J., Zhang Q. and Liu X. (2009). Effect of soil type and soybean genotype on fungal community in soybean rhizosphere during reproductive growth stages. Plant and Soil, 317(1-2): 135-144.

WCED (World Commission on Environment and Development) (1987). Our common future. Report of the World Commission on Environment and Development. Oxford University Press, New York, 242 pp. Accessed in June 2014 from: http://www.un-documents.net/our-common-future.

Wehner J., Antunes P.M., Powell J.R., Mazukatow J. and Rillig M.C. (2010). Plant pathogen protection by arbuscular mycorrhizas: a role for fungal diversity? Pedobiologia, 53(3): 197-201.

Weifeng L., Zhiyun O., Xuesong M. and Xiaoke W. (2006). Plant species composition in relation to green cover configuration and function of urban parks in Beijing, China. Ecological Research, 21(2): 221-237.

Weiland U. and Richter M. (2011). Urban ecology - brief history and present challenges. In Richter M. and Weiland U. (Eds.), Applied urban ecology: a global framework. Wiley-Blackwell, Chichester, England, pp. 1-11.

White R.E., 1997. Principles and practice of soil science - the soil as a natural resource. Third edition, Blackwell Science, Oxford, 348 pp.

White T.J., Buns T.D., Lee S. and Taylor J. (1990). Analysis of phylogenetic relationships by amplification and direct sequencing of ribosomal RNA genes. In: Innis M.A., Gefland D.H., Sninsky J.J. and White T.J. (Eds.), PCR protocols: a guide to methods and applications. Academic, New York, pp. 315–322.

Winguth A.M.E. and Kelp B. (2013). The urban heat island of the north-central Texas region and its relation to the 2011 severe Texas drought. Journal of Applied Meteorology and Climatology, 52(11): 2418-2433.

Wink M. and van Wyk B.-E. (2008). Mind-altering and poisonous plants of the World. Timber Press, Portland, London, 464 pp.

WMO (World Meteorological Organization) (2009). Integrated flood management: concept paper. WMO-No. 1047, Chairperson, Publications Board, Geneva, 27 pp.

Wolch J.R., Byrne J. and Newell J.P. (2014). Urban green space, public health, and environmental justice: the challenge of making cities "just green enough". Landscape and Urban Planning, 125: 234-244.

World Health Organization (2007). Global age-friendly cities: a guide. WHO Press, Geneva, 76 pp.

Wu J. (2014). Urban ecology and sustainability: the state-of-the-science and future directions. Landscape and Urban Planning, 125: 209-221.

Wu J., Xiang W.-N. and Zhao J. (2014). Urban ecology in China: historical developments and future directions. Landscape and Urban Planning, 125: 222-233.

Wu J., He C.Y., Huang G.L. and Yu D.Y. (2013a). Urban landscape ecology: past, present, and future. In Fu B.J. and Jones K.B. (Eds.), Landscape ecology for sustainable environment and culture. Springer Science+Business Media Dordrecht. pp. 37-53.

Wu K.-Y., Ye X.-Y., Qi Z.-F. and Zhang H. (2013b). Impacts of land use/land cover change and socioeconomic development on regional ecosystem services: the case of fast-growing Hangzhou metropolitan area, China. Cities, 31: 276-284.

Wu J. (2010). Urban sustainability: an inevitable goal of landscape research. Landscape Ecology, 25(1): 1-4.

Wu J. (2008a). Making the case for landscape ecology: an effective approach to urban sustainability. Landscape Journal, 27(1): 41-50.

Wu J. (2008b). Land use changes: economic, social, and environmental impacts. Agricultural and Applied Economics Association, 23(4): 6-10.

Wu J. (2006). Landscape ecology, cross-disciplinarity, and sustainability science. Landscape Ecology, 21(1): 1-4.

Wu X., Shen Z., Liu R. and Ding X. (2008). Land use/cover dynamics in response to changes in environmental and socio-political forces in the upper reaches of Yangtze River, China. Sensors, 8(12): 8104-8122.

Xie Y., Mei Y., Guangjin T. and Xuerong X. (2005). Socio-economic driving forces of arable land conversion: a case study of Wuxian City, China. Global Environmental Change, 15(3): 238-252.

Xu Q., Jiang P. and Xu Z. (2008). Soil microbial functional diversity under intensively managed bamboo plantations in southern China. Journal of Soils and Sediments, 8(3): 177-183.

Zak D.R., Holmes W.E., White D.C., Peacock A.D. and Tilman D. (2003). Plant diversity, soil microbial communities, and ecosystem function: are there any links? Ecology, 84(8): 2042-2050.

Zar J.H. (1996). Biostatistical analysis. Prentice Hall International, London, 662 pp.

Zhan J., Shi N., He S. and Lin Y. (2010). Factors and mechanism driving the land-use conversion in Jiangxi Province. Journal of Geographical Sciences, 20(4): 525-539.

Zhang T. (2001). Community features and urban sprawl: the case of the Chicago metropolitan region. Land Use Policy, 18(3): 221-232.

Accessed sites:

Agenda 21 - www.iisd.org/rio+5/agenda/default.htm.

Câmara Municipal de Coimbra (City Council of Coimbra) - www.cm-coimbra.pt.

Central Park - www.centralparknyc.org.

Horizon 2020 - ec.europa.eu/programmes/horizon2020.

Index Fungorum - www.speciesfungorum.org.

UNESCO World Heritage - whc.unesco.org.

UN-Habitat - unhabitat.org/urban-initiatives/world-urban-campaign.

Urban Audit - stat.gov.pl/en/regional-statistics/regional-surveys/urban-audit.

URGE project - www.urge-project.ufz.de.

Victoria Park - www.towerhamlets.gov.uk/default.aspx?page=12670.