UNIVERSITÀ DEGLI STUDI DI TORINO

SCUOLA DI DOTTORATO IN SCIENZE
DELLA NATURA E TECNOLOGIE INNOVATIVE

DOTTORATO IN
SCIENZE AGRARIE, FORESTALI ED AGROALIMENTARI

CICLO: XXXII

ECOSYSTEM SERVICES PROVIDED BY LANDSCAPE AND URBAN HORTICULTURE

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ANNI
2016/2017; 2017/2018; 2018/2019

ISBN: 978-88-99108-15-1

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Preface

This historical moment is characterized by a growing interest on climate change issues and by several environmental events and campaigns, where the need of clarifications about the benefits and the values of nature, especially in urban environments, is urgent.

Following this need, riding on political interests and the latest research on green area planning and management, the thesis focuses on ecosystem services provided by landscape and urban horticulture.

Being a topic of multidisciplinary interest in increasing evolution, the objective of the thesis is to map and assess quantitatively and qualitatively the ecosystem services provided by urban green areas at different scales. Specifically, the approach is aimed at mapping and assessment of ecosystem services provided by green areas at city level, then to understand how ecosystem services are perceived by users and finally to analyze the role of the tree and shrub component in providing ecosystem services in urban green spaces.

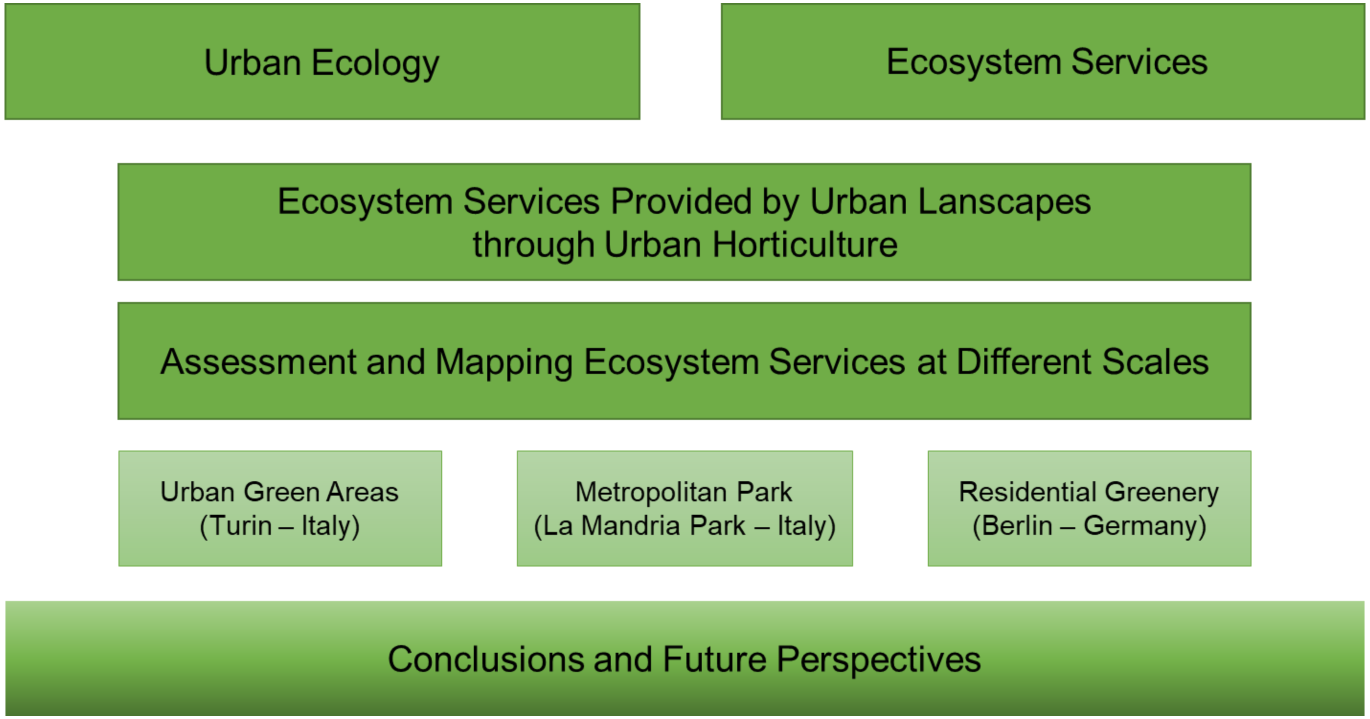
The thesis therefore opens with a brief introduction on urban ecology and a general overview of ecosystem services, then focuses on ecosystem services in urban areas and finally concentrates on three selected case studies. The thesis presents: the first analysis of ecosystem services carried out in the city of Turin (Chapter 2 - Paper I); the analysis of cultural ecosystem services perceived by the users of La Mandria Park (Chapter 3 - Paper II); the analysis of the tree and shrub component of the residential greenery in Berlin (Chapter 4 - Paper III). Finally, the conclusion section discusses the final remarks of the thesis and highlights the future perspectives.

Behind the objectives of the research, the need to share and render the results available and applicable on the territory has always been considered. For this reason, since the concept of ecosystem services is strongly anthropocentric, the social component has always been included in the research, directly involving the stakeholders.

In order to allow everyone to quickly access and share the results, the findings were published on International Peer-Reviewed Open Access Journals.
The research articles reported in the thesis are not in editorial pdf format, to allow easier reading and better understanding of the results.

This PhD thesis is the result of three years of research carried out at the Department of Agricultural, Forest and Food Sciences (DISAFA) of the University of Torino (Italy), at the Technical University of Berlin (Germany) and at Integrative Research Institute on Transformations of Human-Environment Systems (IRI THESys) of the Humboldt University of Berlin (Germany) thanks to the supervision of Dr. Federica Larcher and to the collaboration with Dr. Ina Säumel.

Graphical abstract



Chapter 1

Introduction

“When we speak of nature it is wrong to forget that we are ourselves a part of nature. We ought to view ourselves with the same curiosity and openness with which we study a tree, the sky or a thought, because we too are linked to the entire universe.” (Henri Matisse)

Urban Ecology

"*Urban ecology is the investigation of living organisms in relation to their environment in town and cities, as in ecological studies of forests or the sea*" (Sukopp, 2008).

Urban ecology is a recent study area in relation to ecology as a whole, focusing on the urban ecosystem, dominated by high-density residential and commercial buildings, paved surfaces, and other urban-related features. What can be considered an urban context, is based on a flexible definition, which includes different settings and varies in scale from a metropolitan area to a neighborhood or to a smaller specific study site (Pickett et al. 2006). In such contexts, even what is considered an ecosystem takes on a somewhat different meaning from that of the natural ecosystem, and is defined with flexible terms, as it is described by researchers based on the topic of the research (Rebele, 1994).

In the field of ecology, one of the first distinctions of urban settlements and landscapes can be found in the book *Landscape Ecology* by Forman and Godron (1986). However, the earliest scientific research in this area dates back to a previous decade and took place almost simultaneously in Europe and North America. In Europe, specific studies on urban ecosystems began in the 1970s (Sukopp, 2008) and in the same years (1970-1971) the Man and the Biosphere Programme (MAB) was launched by UNESCO, with the aim of encouraging a sustainable use of the resources of the biosphere and to improve the relationship between humans and the environment (Spooner, 1986). Nevertheless, the concept of urban ecology has been studied with different approaches. While in Europe the biota of urban ecosystem was examined, the American approach was more based on social sciences, as well as the ecosystem fluxes and processes (Wittig and Sukopp, 1993; Pickett et al., 1997). So, urban ecology is a science that includes, in addition to the wildlife of the urban environment, the humans and related social aggregations and their relation with the built environment (Machlis et al. 1997; Tanner et al. 2014).

"*Urban areas are extremely altered, complex systems that provide coincidental habitat for wildlife in an environment designed primarily to provide a variety of socioeconomic services that satisfy human needs, preferences, and desires*" (Melles, 2005).

Urban areas are generally considered something different from nature, due to the succession of historical events aimed to achieve socioeconomic objectives rather than wildlife benefits. The construction of numerous buildings, the sealing of soils and the consequent destruction of forests and green areas have deeply reduced and ruined a relationship with the surrounding environment. However, nowadays the perception and lifestyles in urban areas seem to change by glimpsing some positive characteristics in the urban ecosystem, also from an environmental perspective.
Cities consist of multiple components, such as agricultural areas, green areas, blu infrastructures, buildings, roads, tree lines, etc..
Urban ecology underlines how the simultaneous presence of these components, especially parks, wastelands and ruderal sites, bring many benefits to human society and create essential conditions to sustain the life of many living organisms and thus support a high level of biodiversity, often higher than in semi-natural areas outside the city (Savard et al., 1999; Niemelä, 1999). These benefits seem to be perceived by citizens and the importance towards green areas, urban forestry and urban horticulture issues are growing. This new approach together with the increasing number of people living in cities, urban sprawl, climate change, pollution, migration, development, conflicts, epidemics and economic upheavals represent the new challenges that urban ecology and politics will face in the coming years. In this scenario, urban and periurban green areas and natural areas seem to be necessary tools, both from an ecological and political point of view, to address the current challenges, improving the city resilience (HABITAT III, 2016).The benefits that the ecosystem, even the urban one, provides to humans are defined ecosystem services.

Ecosystem Services

"*Ecosystem services are the ecological characteristics, functions, or processes that directly or indirectly contribute to human wellbeing: that is, the benefits that people derive from functioning ecosystems*" (Costanza et al. 2017; MEA 2005)

Specifically, ecosystem processes and functions describe the biophysical relationships of an ecosystem, whether or not humans benefit from them, while ecosystem services (ES) are the benefits humans derive from those processes and functions (Hein et al., 2016).
Therefore, the concept of ES is anthropocentric, since it exists only if it contributes to human wellbeing and cannot be defined independently (Hunter et al., 2014). This statement, however, considered that humans are part of the ecosystem and that therefore humans and other living species are interdependent.
ES have been classified into four different categories: Provisioning, Regulating; Cultural; Supporting. In order to emphasize the relationship between society and nature, this categorization, proposed by the Millennium Ecosystem Assessment (MEA, 2005) and modified by The Economics of Ecosystems and Biodiversity project (TEEB, 2011), is explained below:

- **Provisioning services** describe the material or energy outputs from ecosystems such as food, timber, fibre, fresh water etc.
- **Regulating services** provide by regulating the quality of air and soil or providing flood and disease control. Some examples are water regulation and purification, air quality regulation, pollination, pest control and climate control.
- **Cultural services** include the non-material benefits humans obtain from ecosystems such as cultural identity, psychological and cognitive benefits, sense of place, aesthetic value, tourism.

Cultural ecosystem services have been the least developed one, and numerous publications have described these services and the associated cultural values in several different forms, without reaching a clear convergence (Costanza et al. 2017).

- **Supporting services** describe the main ecosystem processes and functions that contribute indirectly to human wellbeing by maintaining almost all other services. These ecosystem functions and processes are related to soil formation, primary productivity, biogeochemistry, nutrient cycling, the provision of habitat and the maintenance of genetic diversity.

The theme of ES has evolved over time. About twenty years ago, two publications contributed to the beginning of research, political interest and application of the ES concept: a book published by Gretchen Daily (1997) and an article in Nature on the value of ecosystem services (Costanza et al., 1997). Initially, this concept was based almost exclusively on economic and ecological disciplines to address ecosystem degradation (Chaudhary et al., 2015), and the main ES analysed were provisioning services, while other services, such as cultural ones, were hardly considered and valued.
Few exceptions were highlighted by the review of Escobedo et al. (2019) underling a different perception and use of the term ES in urban forestry. Specifically, it is noted that about ten years ago, European literature emphasized cultural ES, whereas literature from the United States and Canada emphasized the environmental functions. Currently, however, in Europe, but also in China, Australia and Latin America, there is now a common tendency to emphasize the environmental aspects of ES (Roy et al., 2012; Escobedo et al.,2019).
Moreover, there was a tendency to analyse one service at a time and little consideration was given to the supply of multiple ES. However, it is well known that ecosystems are multidimensional even if a distinction between direct and indirect contributions to human well-being is complex (Costanza et al., 2017).

Above all, there was a lack of understanding that policy and management choices are the basis of synergies or trade-offs (the supply of one ES is reduced as a consequence of increased use of another ES) and the supply-demand balance of ES by citizens and other stakeholders was not considered (Rodriguez et al., 2006). However, the possibility of miscommunication, or rather the use of terms such as ES, which are poorly understood and less preferred than nature's benefits or nature's value (The Nature Conservancy, 2010) should be highlighted. The terms used may therefore not be as important as the message they contain, i.e. the importance of the multiple natural functions that can benefit both nature and humans (Escobedo et al.,2019).
In order to correctly convey the importance of ES and to implement actions and management practices based on ES, several projects have been carried out over time. At the European level, issues related to biodiversity and the concept of ecosystem services are included in the European Union Strategy for 2020, which proposes to map and assess the state of ecosystems, their services and economic values with the aim of halting the loss of biodiversity and ecosystem services (EU, 2020).
Nowadays, the interest in ES, with particular reference to cultural services, is growing and the awareness to include these concepts in the planning and management of the city and especially of green areas is increasing (McPhearson et al., 2014). Many scientists from different disciplines are exploring these topics, from different perspectives, bringing new points of view to these issues and raising the awareness of various stakeholders on ES concepts (Schaich et al. 2010; Cáceres et al., 2015). However, humans do not always derive a benefit, but sometimes there is a disservice, or rather from the processes and functions of the ecosystem derive damages, costs (Shapiro and Báldi, 2014; Sandbrook and Burgess, 2015) and negative effects of nature on human well-being (Shackleton et al. 2016). Nevertheless, there is no equal consideration of services and disservices and more research needs to be performed (Schaubroeck, 2017). The integration of both concepts is fundamental, especially in planning and

management activities, with the aim to improve human well-being (von Döhren and Haase, 2015).
This need arises from the altered ability of ecosystems to buffer disturbances due to human actions, with a recent understanding of the necessity to live in resilient environments that can guarantee a flow of ecosystem services (Elmqvist et al., 2003). To mitigate negative effects, numerous research projects regarding ES have followed one another over time (IUCN, 2019). Nevertheless, much more effort and bold action is needed to be taken in a short time, because as underlined by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the health of the ecosystems on which we and all other species depend is deteriorating more rapidly than ever (IPBES, 2019).
Research on ES should therefore focus not only on the natural ecosystems on which we depend, but also on urban ecosystems, as more than half of the world's population lives in cities (Haase et al. 2014a). Although there are several studies that have analysed global ES, few have focused on urban ecosystem services (UES) supplied in a specific set of habitats, such as green spaces, including parks, urban forests, cemeteries, campus areas, and blue spaces, including streams, lakes and ponds (Hubacek and Kronenberg, 2013). Generally, UES are characterised by a high intensity of demand/use due to a very high number of immediate local beneficiaries, compared to e.g. ecosystem services generated in rural areas far from densely populated areas (Elmqvist et al. 2015).
Moreover, the social aspect of urban ecosystems is as important as the physical environment to ensure their proper functioning, as it is impossible to protect and manage urban green spaces for inhabitants if they are not involved in these processes (Kronenberg, 2015).
In order to increase public engagement and involvement in order to have more ecologically conscious cities, more education is needed, especially environmental ones (Kronenberg, 2015; Battisti et al., 2017). In addition, the co-design and management of biodiversity-friendly green spaces,

positively valued by several European citizens, can integrate ES concepts into urban development plans (Fischer et al., 2018).
Moreover, the issue of perception aimed at understanding what ES are recognized and how they are perceived by citizens, especially in specific geographical contexts, considering the structure, the management and spatial arrangement of urban green spaces, is increasingly evolving and needs further research (Buchel and Frantzeskaki, 2015; Lafortezza and Giannico, 2019).

To fill the gaps stated above, the issue of ecosystem services and related mapping and assessment methods, provided by green areas and urban horticulture is subsequently examined.

Urban horticulture is integrated into the theme of urban agriculture, which means any agricultural activity, with particular attention to the cultivation of vegetables, ornamental and medicinal plants in cities (Brock and Foecken, 2006). There are many forms of urban horticulture, but the most common are represented by allotment and community gardens (Tei and Gianquinto, 2010).

The multifunctional role of urban horticulture has been recognized and has become over time one of the main goals to be achieved to live in resilient and ecologically aware cities (Larcher et al.2017). This important role is the result of increasing urbanization and the consequent increase in land consumption, which over time has made it necessary to ensure a high quality urban ecosystem for all people living in and around. Cities are growing rapidly and the number of people living in them is constantly increasing: 55% of the world's population is urban, growing to 68% by 2050 (UN, 2018).

Urban horticulture plays an important role in these contexts, as it is based on scientific principles to define and assess how much and how the various components of urban green areas can provide several benefits to society. This growing attention to the theme of urban ecology, as anticipated previously, was born around the 1970s, trying to change the point of view and therefore the way of designing cities, thus considering them ecosystems, although highly energetic and constantly evolving. If urban environments are ecosystems, they therefore provide ES. Future challenges are based on ensuring human well-being in expanding cities, avoiding that urbanization negatively affects the supply of ES, specifically in terms of habitat loss and fragmentation, pollution and water and air management, while creating resilient cities by integrating urban ecology principles into design and management actions (McDonnell and MacGregor-Fors, 2016).

Focusing on the multiple components of urban green areas and with particular reference to urban horticulture, the supply of the different ES is analysed below.

Provisioning

ES provisioning is manifold such as growing food, raw materials and plants used as medicines in the pharmaceutical industry.

In the urban ecosystem, the agricultural component plays a fundamental role in landscape management, ensuring numerous social, aesthetic and environmental functions in and around cities. As regards the supply of ES, agricultural areas, microfarms, allotment and community gardens, rooftop gardens, contribute to the availability of fresh food, and plants with medicinal value (Tei and Gianquinto, 2010; Morel et al. 2017). Despite increasing land use, the expansion of cities offers new challenges for urban horticulture, specifically the growing consumer demand for high quality regional products such as vegetables and ornamental plants (Larcher et al., 2017). To meet these demands it is therefore necessary to use environmentally friendly and sustainable cultivation techniques, safeguarding soil fertility and promoting biodiversity conservation (Tscharntke et al., 2012). The reason for the use of such techniques is also aimed at containing and reducing the disservices that can occur in urban horticulture, such as crop pests and pathogens that can reduce productivity and especially affect those products whose price is directly related to quality (Zhang et al., 2007). In order to cultivate food, however, it is necessary to use also specific constructed spaces. Rooftops stand out among the most suitable spaces for such activities. In the Mediterranean area, where the presence of buildings with roofs that can allow such activities is greater than in other areas with colder climates, the cultivation of vegetables is increasing, and the possibilities are considerable. Taking for example the city of Bologna in Italy, it has been estimated a potential arable area of about 82 ha that could satisfy 77% of the demand for vegetables in the city (Orsini et al. 2014). Moreover, allotments and especially community gardens offer different opportunities both for management and control of the territory, especially in the suburbs, but also for the promotion of educational activities, concepts related to economic and environmental sustainability as well as food knowledge and awareness (McClintock, 2010; Bergamaschi, 2012). As an example, the metropolitan city of Turin (Italy) has identified urban agriculture as a response to the need to reduce costs in the management of green areas, promoting local and conscious food consumption. To this end it is worth highlighting a project "Torino città da coltivare" (Tecco et al., 2017) that from 2013 to 2017 has enhanced and increased the area allocated to urban gardens, exceeding 100 ha 5 m^2/inhabitant. Also in Turin there are European (Life, H2020, Interreg programmes) and regional research projects to evaluate the urban strategy for the implementation of ES provided by urban horticulture and more generally by green areas (Larcher et al., 2017). At the metropolitan level, the inclusion of specific food production strategies, including different initiatives and forms of urban horticulture, in a city plan could increase the number of alternative food networks and increase the sensitivity and awareness of the younger generations on these topics.

Supporting

Underlying Supporting ES is the habitat for species and the maintenance of genetic diversity in ecosystems. Ecosystems represent living spaces for all living beings and are characterized by biogeochemical processes and therefore interactions between biotic and abiotic components that determine the quantity, quality and reliability of ecosystem services. If the physical, chemical and biological characteristics of the ecosystem change, the processes and consequently the ES will also change (Mace et al., 2012). Ecosystems therefore provide important habitats for many species and when the number of species is particularly high they are identified as biodiversity hotspots. Genetic diversity is the basis for well adapted species and cultivars at the local level and constitutes a gene pool for the development of crops of agricultural and ornamental and officinal interest (FAO, 2020). The importance of biodiversity is also crucial for people's well-being and livelihood (Balvanera et al., 2012). Urban green areas such as parks, cemeteries, railways, but also elements characterizing urban horticulture such as allotment gardens, community gardens and green rooftops, represent fundamental habitats in the city, especially for many species of insects, including pollinators (Ksiazek et al., 2012; MacIvor et al., 2015). Thanks to the presence of green areas, European cities seem to contain higher levels of biodiversity than semi-natural areas. Specifically, a study conducted on 15 urban and suburban parks in Belgium revealed that these green areas have very high percentages of wild plant species, birds, butterflies and amphibians, thus representing hotspots for biodiversity (Alvey, 2006). In Stockholm, allotment gardens are often rich in varieties of vegetables, with more than 440 species in 400 m^2 (Colding et al., 2006), while in Toronto, in order to probably cope with the presence of populations of different ethnic groups, in addition to the classic vegetables, 16 Asian vegetables have been grown to meet local demands (Baker, 2004). Moreover, it is likely that the composition of green spaces, understood as variation in plant cover, species diversity and their location and structure influence both biodiversity but also the quantity and quality of ES provided in urban environments (Lin et al. 2015).

However, although biodiversity is generally considered to be fundamental to the provision of multiple ES, research on these issues can be challenging and contradictory (Kremer et al., 2016). It should be considered that sometimes some species have negative effects in relation to ES by generating ecosystem disservices, and sometimes the loss of some species in an area may not have a negative influence on ES supply, but rather influence it positively (Gómez- Baggethun and Barton, 2013; Voigt and Wurster, 2015). Therefore, species conservation and the maintenance of genetic diversity should also be assessed according to the contribution of the species to ES supply, not only focusing on the preservation of rare species, but also and especially on the species that best support the supply of multiple ES, which are often the most common and abundant (Kremer et al., 2016). Instead, further studies are needed on the report supporting ES and the issues of food safety, water safety, air quality while maintaining high biodiversity in urban areas (Lin et al., 2015). In the urban context, at the design level, the use of native species, wild flowers, perennials and shrubs and non-native, but non-invasive or harmful to humans, could be a winning choice. The design of new urban green areas should not be based on standard lists of plants for a given climate zone, but local botanical-ecological research should be carried out, with the help of botanical gardens, in order to have also a high landscape diversity (Jim, 2013; Larcher et al., 2017).

Regulating

Regulating ES include: local climate and air quality, carbon sequestration and storage, moderation of extreme events, waste-water treatment, erosion prevention and maintenance of soil fertility, pollination, biological control and regulation of water flow (FAO, 2020).

Many of these ES in urban ecosystems are provided by green spaces and urban horticulture, the following are the main ones.

Specifically, the local climate and air quality in the urban environment is greatly influenced by trees, green roofs, even cultivated trees and green walls. In Tuscany (Italy), the urban forest have retained several pollutants such as O_3, CO, SO_2, NO_2, demonstrating a removal capability of about 72.4 kg per hectare per year (Paoletti et al. 2011). In the United States, the amount of air pollution (O_3, PM10, NO_2, SO_2, CO) removed from urban trees and shrubs was estimated at 711,000 t per year (Nowak, 2006). Obviously, the presence of certain plant species and their choice in the design of new green areas is fundamental, and evergreen and tomentose species with a large leaf area index are particularly effective, especially if located near the sources of pollution (Janhäll, 2015; Marando et al. 2016). Also in this case it is necessary to remember the disservices that can be provided by urban greenery and urban horticulture, such as the allergenic potential of some plant species, especially in highly polluted areas, but also the emission of volatile organic compounds (Sicard et al., 2018).

With regard to the topic of heat island in urban environments, it has been demonstrated that the tree-lines, the vegetation of parks and green roofs and walls contribute to a clear reduction of temperatures especially during the warmer seasons (Norton et al., 2015). This is particularly important for human well-being, reducing serious health problems due to strong heat waves (Bowler et al., 2010). These considerations could be considered by designers in order to make appropriate decisions regarding the choice of species, size and shape of green areas (Larcher et al., 2017). Moreover, green walls are also a winning choice in many urban contexts, as it has been demonstrated that modular green wall systems provide good thermal transmittance values during both summer and winter seasons (Serra et al., 2017).
Urban green spaces and urban horticulture also play an important role in carbon sequestration and storage. In 2002 it was calculated that urban trees in the United States contributed to the sequestration of 22.8 million tons of carbons per year (Nowak and Crane 2002). Many benefits also relate to water management, both to meet urban water needs and to filter impurities and regulate soil erosion. A study conducted in community gardens in New York City showed that such spaces contribute to retaining millions of liters of water per year, reducing the dangerousness of the urban stormwater runoff and flash flooding, related to impervious surfaces and continued urbanization (Gittleman et al., 2017). In Louisiana, on the other hand, research has shown how wetlands, often present in and around cities, can be alternatives to conventional wastewater treatment, also guaranteeing good cost savings (Breaux et al. 1995). It is therefore necessary to consider these capacities of the urban ecosystem in retaining and using rainwater within cities by developing water-sensitive urban designs (Livesley et al., 2016). Finally, in urban green areas pollination is an important ecosystem service that ensures both good food productivity and biodiversity conservation (Larcher et al. 2017). Taking for example honeybees, urban green areas and urban horticulture guarantee their presence thanks to trees, shrubs, flowerbeds, weeds, but also vegetables

and edible plants (Corbet et al., 2001; Tommasi et al., 2004). In Turin (Italy) was calculated the potential melliferous yield in public and private green areas, highlighting the high amount of bee flora in urban area consisting in melliferous and anemophilous plants, herbs and wild flora that allows urban beekeepers to produce local monofloral and multifloral honey (Vercelli and Ferrazzi, 2014).

Cultural

Cultural ES includes the non-material benefits people obtain from ecosystems, even the urban one, with particular reference to: recreation and mental and physical health; tourism; cultural diversity; educational values; social relations; aesthetic appreciation and inspiration for culture, art and design; spiritual experience and sense of place (MEA, 2005; TEEB, 2011). They represent the interface between nature, culture and human society, contemplating tangible and intangible heritage, biological and cultural diversity (Tengberg et al., 2012). Urban ecosystems therefore offer multiple positive stimuli and possibilities to humans, but they can be stessful for those who decide to have an extremely lively lifestyle by dedicating limited time to reflect and contemplate nature. In reality, urban nature has the advantage over built up areas to be characterized by features and processes that are not challenging but fascinating, so attracting a kind of involuntary attention, influencing the perception of citizens (James, 1892). The theme of perception, with particular reference to that of green spaces and urban horticulture, over time has had a growing interest in research, especially those related to the perception of the management of green areas and the feeling of fear or lack of security that some green areas can provide (Sanesi et al. 2006). A research carried out in Milan (Italy) underlines that citizens' perceptions should be analysed and considered an important basis for the development of sustainable city management strategies (Canedoli et al., 2017). Moreover, the urban nature is a source of educational values, and a process of civic engagement and ES management can be supported by expanding opportunities for education,

promoting community building and increasing people awareness of biodiversity (Andersson et al. 2014; Carrus et al., 2015). In addition, the emotional engagement of individuals contributes to forming and increasing a positive awareness and attitude towards nature, especially in school gardens, allotment and community gardens, also resulting in greater participation in environmental and eco-sustainable decisions (Somajita and Nagendra, 2017; Russo et al., 2017; Battisti et al., 2017).
The integration of vegetation in the urban environment, especially thanks to urban horticulture in neighborhoods, increases the network of relationships and therefore social cohesion and social activities, reducing violent conduct and crimes (Kuo and Sullivan 2001; Sullivan et al. 2004). The benefits brought by urban green spaces also concern human well-being. Even hospitalized patients who can look at green areas have shorter recovery time, thus reducing healthcare costs (Ulrich et al. 2008). Finally, the aspect related to tourism is to be consudered both for an economic return and for a maintainance aspect when planning green areas' management. The creation of greenways, which increase the value of biodiversity in cities by connecting various green areas, allow the creation of tourist routes that can also consider aspects of ancient cultures based on the role of nature and wildlife in hosting good and bad spirits (FAO, 2020).

It is necessary to invest human and financial capital in the restoration, enhancement and protection of urban green areas and related ES. Therefore, since many policy actions are aimed at generating a benefit to citizens, it is desirable that the mapping and quantification of ES are considered in the decision-making processes of urban management plans.
Finally, multifunctional networks in cities, such as greenways, riverways, blue-green networks that guarantee connectivity in urban ecosystems and actions and projects undertaken in the frame of nature based solutions, represent keypoints to make cities more liveable and resilient (Ignatieva et al., 2011; Larcher et al., 2017).

The concept of ecosystem services also underpin the European Union (EU) Strategy for 2020, which includes the proposal to map and assess the state of ecosystems, their services and economic values with the aim of halting the loss of biodiversity and ecosystem services in the EU. (EU, 2019).
There are several methods to map and assess ecosystem services, some of which are quantitative and others qualitative. The methods are based on specific measurement, such as tonne/ha/year to quantify the provisioning services of a wheat field, while others are based on mathematical indexes or different and combined methods, for instance questionnaires, to define at quantitative or qualitative level especially cultural ecosystem services, as the aesthetic perception of green areas.
Generally, in urban or regional contexts, numerous methods are based on a spatial quantification of services that allows to establish links between the supply of ecosystem services and the landscape structure (Burkhard et al., 2014). However, it should be pointed out that while most studies attribute the provision of ES to a habitat or land use type, studies that consider biodiversity-ES relationships are more likely to recognize a specific functional group, community or population as the key provider of ES (Ziter, 2016).

"There is not one right way to assess and value ecosystem services. There is however a wrong way, that is, not to do it at all." (Costanza et al., 2017)

It is therefore possible to apply multiple methods in order to achieve specific objectives. Some of the methods that can be used and most of the bibliography to be read for the evaluation of ecosystem services in urban and peri-urban areas is reported in the following chapters (Paper I; Paper

II and Paper III). In order to achieve the objectives of the the thesis, the methods used provided for different approaches, but preference was given to the field data collection and to the involvement of various stakeholders (Paper II and Paper III). The reason is that the ideal scale for analysing ES and detecting environmental stress in an urban ecosystem is the parcel-scale, as it is possible to acquire more detailed data, avoiding the loss of detail in the collection of coarser spatial data (Dizdaroglu et al. 2014)

However, also the mapping and assessment of ecosystem services based on spatial analysis through intensive and almost exclusive use of information technology is useful to achieve specific objectives and, as in Paper I, this method can include a series of meetings with stakeholders in order to acquire specific data and refine the research through fruitful discussions.

Together with the evolution of the concept of ecosystem services, many tools that can be used to map and assess multiple ecosystem services have been developed (Turner et al., 2016). Analyzing the most common tools, in order to achieve the objectives of the thesis, it was chosen to use a selection of specific methods, which are currently not included in a single tool.

It is necessary to underline that approaches to the analysis and evaluation of UES are relatively new and evolving, and consist of numerous indicators and metrics with different quality and applicability in use. The most common and developed indicators are those for provisioning ecosystem services, probably for data availability. However, the conceptual basis and data underpinning the indicators remain underdeveloped and the choice of services to be assessed and indicators to be used in evaluations is often determined by policy objectives and data availability. (Haase et al. 2014b)

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Chapter 2

Assessment and Mapping Green Areas Ecosystem Services and Socio-Demographic Characteristics in Turin Neighborhoods (Italy)

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Forests 2020, 11(1), 25; https://doi.org/10.3390/f11010025

Abstract: The ecosystem services (ES) and human well-being are keywords that guide the Italian strategy on urban greening. The development of ES priorities linked to specific land uses help to guide the drafting of management plans. The aim of the research was to assess and map green areas ecosystem services and socio-demographic characteristics in Turin neighborhoods in order to identify where to improve the provision of ecosystem services and the socio-demographic conditions. The Preliminary Assessment Method (PAM) was used for the assessment of provision and regulating services based on land use. The Species-specific Air Quality index (S-AQI) was used to assess the regulating services provided by trees. Three socio-demographic characteristics were analyzed at the neighborhood level—age index, housing density, and % of economically assisted citizens. PAM results show that Turin provides more ecosystem services in peripheral areas of the city. Trees with high S-AQI values represent 21% of the censed trees. Not recommended trees are 18%. The neighborhoods with higher S-AQI values are not always characterized by a higher number of trees/km^2 or species richness. Results show that the northern part of the city is characterized by higher values of ES and socio-demographic conditions than the central-southern part. This aspect is related to the conspicuous presence of agricultural land uses and water bodies, together with the presence of tree species with a high S-AQI values and high or medium socio-demographic conditions. 57% of the neighborhoods present low results for both aspects. Actions to improve the quality of green spaces in those neighborhoods could have great effects on liveability. Future management and planning strategies for increasing citizens' well-being through urban greening should consider the proposed approach.

Keywords: ornamentals; well-being; management; urban horticulture; green infrastructure; air quality

1. Introduction

Urbanization is increasing globally, creating opportunities and challenges to promote people's quality of life in a sustainable way [1]. Worldwide, the number of people living in urban areas is higher than in rural areas, with 55% of the world's population living in urban areas in 2018 and 68% of the world's population expected to be urban by 2050 [2]. Ecosystem services are used for the development of sustainable goals and to support environmental policy objectives at all levels of urban governance [3]. Specifically, cultural and regulating ecosystem services, such as air pollution removal, urban cooling, and recreation, seem to be particularly important in urban contexts [4]. The EU Biodiversity Strategy 2020 called on the Member States to map and assess the state of ecosystems and their services within their national territory in order to create a basis for developing Europe's green infrastructure. In addition, information and data on actual demand for ecosystem services (ES), beneficiaries and potential mismatches with their location of supply, as well as on the quality and quantity of ES, are essential to make informed decisions for the proper management of natural resources [5]. Moreover, human well-being is positively influenced by the level of biodiversity present in urban and peri-urban green spaces [6], which must be maintained or increased through effective management of plant and animal species, improving the quality of existing habitats through management [7]. In addition, socioeconomic inequalities in health are less pronounced in people with greater exposure to green space than in those with less exposure [8].

As many ecosystem services are provided by urban green spaces, these will need to be better managed and planned to ensure a high standard of living in urban areas [9]. For the assessment of ecosystem services in urban areas, several methods can be applied [10–12]. Some of them are based on spatially explicit biophysical indicators to analyze the spatial distribution of ES delivery [13], others on suite of models or web-based modeling platforms for the spatially-explicit assessment of ecosystem services [14,15], and finally some of them are supported by qualitative tools based on a set of expert judgments [16]. However, the governance of socio-ecological systems to maximize the provision of ecosystem services suffers from the uncertainty of responses and the complexity of managing urban contexts [17].

Certainly, the development of ecosystem service priorities linked to specific land uses would also help to guide the drafting of management plans [18].

Among the land uses that contribute most to providing ecosystem services in urban areas, there are the green areas [19–21]. Specifically, although herbaceous vegetation plays an important role in providing ecosystem services in urban areas [22], the tree component is certainly the most studied and is considered the most important in such contexts, especially for air pollution removal [23–26] and for the interaction between air pollution and pollen emission [27,28]. To this end, there are several possibilities for assessing ecosystem services and specifically the air pollution removal potential, by using specific models and tools [29], or selected indicators [30,31].

As urban forestry has become a valuable tool in recent years to address a number of urban challenges in the development of a more sustainable and resilient city model, the paper focuses on this issue, specifically also analyzing the ecosystem services provided by trees in the urban environment. The importance of these concepts is extensively described in the 'Guidelines on urban and peri-urban forestry' published by the Food and Agriculture Organization of the United States in 2016 [32], by the World Health Organization [33], which highlights the relationship between trees and human well-being and is promoted by the Tree Cities of the World program [34]. In this paper, the combination of services offered by land uses, and the urban tree component is particularly and likewise important.

The lack of wealth of information on the current state of specific resources, such as an accurate tree inventory and an assessment of the current state of the urban forest, is probably the basis for specifically planning urban development [35].

In addition, the analyses carried out on the tree bark to monitor air quality, which reflect a long-term and multi-year average air contaminant load [36], were interesting, indicating that plants are also excellent indicators. However, plants tolerate air pollution levels differently [37], showing different growth rates in high-polluted areas [38] retaining pollutants according to the size of trees with particular reference to the canopy cover [39,40] and becoming a relevant aspect in future city planning activities [41].

In Italy, a national urban green strategy was proposed in 2018 [42], based on three essential elements: moving from square meters to hectares, reducing asphalted areas, and adopting urban forests as a structural and functional reference for urban greening. The aim is to achieve the goals of sustainable growth and the environment, set out in the Conference of the Parties [43] in 2015, in particular concerning the containment of emissions and the adaptation to climate change. The ecosystem services and human well-being are keywords that guide the national strategy. In Italy, there are several levels of governance, from the regional to the metropolitan and urban scale. However, at the management level, in urban areas, the reference unit is the neighborhood. Neighborhood-level analyses are particularly useful because population and land use classes are not evenly distributed across the city and are often influenced by distance from the city center [44].

For this reason, it is useful to understand if urban green planning can focus on priority areas of intervention. In order to address this question, the aim of the research was to assess and map green areas ecosystem services (provisioning and regulating) and socio-demographic characteristics (aging index, housing density, and economically assisted citizens) in Turin neighborhoods.

Future management and planning strategies for increasing liveability should take the results into consideration.

2. Materials and Methods

2.1. Study Area

The city of Turin (Piedmont, Italy) is located in the Po Valley, is bordered by four rivers, and extends over a flat urban area (239 m a.s.l.), and in a hilly area that reaches an altitude of 715 m a.s.l. The city's surface extends for 130.2 km^2, where 878,074 inhabitants live [45].

Turin has very high levels of air pollution [46]: the average PM10 of 2018 measured in the center of Turin is 33.0 μg m^{-3}, and the maximum daily value, set at 50 μg m^{-3}, was exceeded 55 times [47]. The level of pollution in Turin was found to be very harmful to the citizens' health, both for adults and children, causing various respiratory problems [48–50].

Figure 1 reports Turin's land use classes elaborated starting from Urban Atlas—Copernicus Land Monitoring Service and Municipality's data. Artificial surfaces that comprise construction sites, continuous and discontinuous urban fabrics, roads and associated lands, industrial, commercial, public, military and private units, isolated structures, land without current use, dumpsites, railways, and associated lands, sports and leisure facilities, is the main land-use class in the city center. Quite the opposite, urban green areas are present all around the city but to a greater extent in the peripheral neighborhoods, and especially, in the hilly neighborhoods. The latter (hilly neighborhoods, specifically Madonna del Pilone and Borgo Po e Cavoretto) are particularly characterized by forest. Agricultural land uses (arable lands, urban horticulture, pastures and permanent crops) are mainly located in the northern part of the city. Water bodies mainly consist of small artificial lakes and rivers that cross the entire city.

The city of Turin has a public geodatabase that contains information about the city. A web application called Albera.TO is used for trees management, and it is dedicated to technicians and specialists [51]. Most of the trees located in the city center and along the main roads are more than 50 years old [52]. It follows that the management of urban greening is essential to maintain such an important heritage and that some green areas and trees will have to be redesigned and replaced over time.

Figure 1. Land-use classes in Turin neighborhoods.

2.2. Methodological Framework

To achieve the objective, the research was divided into several phases (Figure 2). The evaluation and mapping of ecosystem services and socio-demographic characteristics led to the elaboration of different maps on an urban and neighborhood scale. Meta results were finally elaborated in a final qualitative evaluation map.

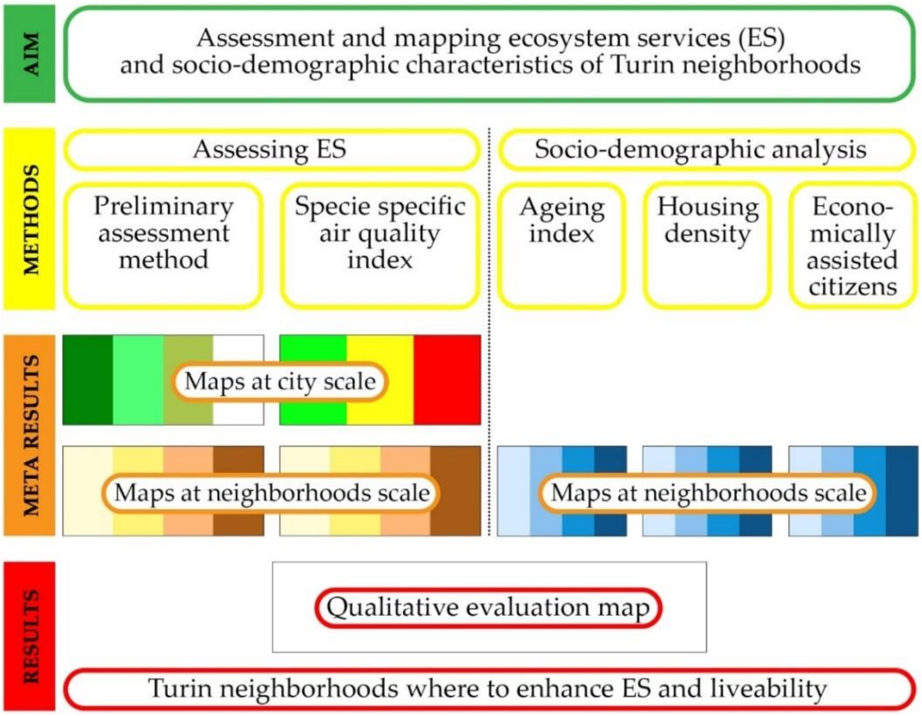

Figure 2. Methodological framework of the research.

2.3. Ecosystem Services Assessment Methods

In order to analyze the provisioning and regulating services of the city of Turin, related to the categories of land use and to the benefits provided by trees to citizens, two different methods were applied. All the analyses were carried out using QGIS 2.18.1 software (Open Source Geospatial Foundation, Beaverton, Oregon, USA) and refer to the neighborhood level. The reason was to understand which neighborhood in the city provided more or less the ecosystem services analyzed. Since ecosystem services are benefits that are provided to humans, it was necessary to understand the socio-demographic characteristics of the neighborhoods in order to identify which neighborhood would need to benefit most. The data provided by the Turin City's statistical office and the Giorgio Rota Report [53] were used and analyzed for this purpose.

2.3.1. Preliminary Assessment Method (PAM)

The matrix for the qualitative assessment of ecosystem services was selected as the first method. The matrix linked land cover types to the ecosystem service supply capacity and was initially proposed by Burkhard et al. in 2009 [54]. It is a general methodology for assessing the supply of ecosystem services of different landscapes, including the concept of ecological integrity as a prerequisite for providing ecosystem goods and services to humans [55]. From the matrix, it is possible to create maps that show the spatial potential of ecosystem services, and can be used in the landscape planning process.

Specifically, the approach proposed by Zepp et al. in 2016 was applied [56]. It is also based on a matrix for the qualitative assessment of ecosystem services and is defined as the Preliminary Assessment Method (PAM) and classified as a Phenomenological model by ESMERALDA (Enhancing ecoSysteM sERvices mApping for poLicy and Decision mAking) project, that provide methodologies to assess ecosystem services in EU states [12]. The assessed ecosystem services were provisioning and regulating.

PAM is focused on Urban Ecosystem Services (UES), mapped indirectly through land cover and land use. In this context, land cover information is based on the Urban Atlas (EEA 2018) [57] that provides European land use data for urban areas. To improve the quality of the information analyzed, the Urban Atlas map has been integrated with information from more accurate maps provided by Turin Municipality. The data sets analyzed consist of 18 land use classes. The minimum mapping unit varies from 0.25 ha for settlement areas and 1.0 ha for agricultural land, forests, and water bodies. Therefore, this method can be applied for homogeneous spatial units exceeding 50 m × 50 m, equivalent to 0.25 ha.

The ecosystem services considered are those present in the Common International Classification of Ecosystem Services (CICES) from the European Environment Agency [58], reported in Supplementary Materials Table S1. For each class of land use, in the matrix, was attributed a value of ecosystem service supply (expert-based evaluation) classified into four categories: P—Priority; S—Significant; I—Insignificant, N—Non-relevant.

Once the values have been assigned to each land-use class, the number of priority and significant potential UES values are counted, and the potential overall ES supply of each land cover unit is calculated. Then it is calculated the UES Significance according to the following formula and classified according to Supplementary Materials Table S2. The four classes identified in Supplementary Materials Table S3 indicate high levels of supply of ecosystem services (1st class); medium levels of supply of ecosystem services (2nd class); low levels of supply of ecosystem services (3rd class); and no significance in supply ecosystem services.

$$\text{UES Significance} = \sum_{S=1}^{n} * wS + \sum_{P=1}^{n} * wP \quad (1)$$

where the weight of significant services (wS) = 0.5 and the weight of priority services (wP) = 1. Insignificant and non-relevant categories were not considered in the formula.

For more information about the ecosystem services analyzed, based on the CICES v.5.1 and the method used to calculate UES Significance for each land use, please refer to Tables S1 and S2.

In addition, an average value of UES Significance has been calculated for each neighborhood of Turin, and the values have been grouped into four categories: ≤4 low supply; 4.1–6 medium-low supply; 6.1–8 medium-high supply; >8 high supply.

2.3.2. Air Quality Index

The second method applied is based on the ability of trees to provide benefits to humans, with specific reference to the reduction of air pollution. The reduction of air pollution, especially in urban areas, is due to the presence of trees that remove large amounts of pollutants improving urban air quality [40,59].

For the purposes of the study, it was necessary to find an index that:

- was a tool for ranking common urban plant species on the basis of their ability to improve the air quality, so as to be able to map and attribute a value to the trees of the City of Turin present on the Albera.To system;
- that considered the Ozone (O_3), which especially in Turin, but also in other Italian cities, is present in high concentrations [60];
- that considered the climate of the Mediterranean areas, with specific reference to the Italian reality.

The Air Quality Indexes evaluate the overall air pollution level based on multiple air pollutants, to measure the air quality with respect to its effects on human health [61–67].

Species-specific Air Quality index (S-AQI), proposed by Sicard et al. in 2018 [68], which considers the main disservices (pollen and biogenic volatile compounds emission) and the main benefits, such as the capacity of filtering air pollutants, tolerance to pollution and drought of tree and shrub species, was used. This method has, therefore, deepened a benefit that is part of regulating services.

The S-AQI considers the main disservices (pollen and biogenic volatile compounds emission) and the main benefits, such as the capacity of filtering air pollutants, tolerance to pollution, and drought of tree and shrub species. The index was applied to the trees of Turin based on Albera.TO system (updated to March 2019).

The values of the S-AQI, are based on a scale of 1 to 10, subsequently grouped into three categories of values: 1–4 not recommended; 8–10 recommended plant species for city planting program, 4.1–7.9 neither recommended nor discouraged. S-AQI does not consider some parameters among which the different dimensions of the trees, the canopy density, and water-use strategy. This index can be used at the neighborhood scale. To each tree in the Albera.TO system has been assigned an S-AQI value and have subsequently been grouped into three categories: S-AQI values <4 low values; $\geq 4 - < 8$ medium; ≥ 8 high. The weighted average value of the S-AQI of the city of Turin (6.4) was calculated and considered as medium-low value. The same procedure was applied to each neighborhood, and the values were grouped into four categories: <6 low values; 6–6.5 medium-low values; 6.51–7 medium-high values; >7 high values.

2.4. Socio-Demographic Analysis

To assess the socio-demographic characteristics of Turin neighborhoods, data collected by the Municipality's statistical office, and Giorgio Rota Report 2015 [53] were analyzed, using formulas reported in Table 1. The characteristics analyzed were aging index, housing density, and economically assisted citizens. In order to compare the neighborhoods, all the results were grouped into four categories: low, medium-low, medium-high, and high values. The attribution to one of these four classes is not to be understood in absolute value, but in relative value compared to the other neighborhoods.

Table 1. Applied formulas and classes' subdivision for socio-demographic analyses at the neighborhood scale.

Index	Formula	Unit of Measurement	Classes			
			Low	Medium-Low	Medium-High	High
Ageing index [69] [1]	$\frac{P1}{P2} * 100$	-	≤150	151–200	201–250	>250
Housing density [70] [1]	$\frac{P3}{S}$	Inhabitants/km^2	≤3000	3001–9000	9001–15,000	>15,000
Economically assisted citizens [2]	$\frac{P4}{P3} * 100$	%	≤0.5	0.51–1	1.10–1.50	>1.50

P1: Population aged 65 years or over; P2: Population aged 14 years or less; P3: Total number of inhabitants; S: Neighborhood's surface; P4: number of economically assisted citizens. [1] Data analyzed refer to 31 December 2018 and were provided by the Turin City's Statistical Office. [2] Elaboration of data published on the Giorgio Rota Report. Data referred to 2015.

2.5. Qualitative Evaluation of Socio-Demographic Characteristics and Ecosystems Services

In order to respond to the proposed objective, the results of PAM, S-AQI, and socio-demographic analysis (aging index, housing density, and economically assisted citizens) have been used to dress a qualitative evaluation map at the neighborhood level.

As shown in Table 2, it was attributed gradually negative values to the increase of aging index, housing density, and economically assisted citizens at the neighborhood scale (−1 for medium-high values, −2 for high values). At the same time, it was ascribed gradually positive values to their decrease (+1 for medium-low values, +2 for low values). Indeed, the increase of the three parameters is an aspect that affects the life quality negatively at the neighborhood scale. Particularly, where aging index is high, there is a greater probability of finding more people who need care and are more susceptible to chronic diseases than neighborhoods where the index is low [71]. A high population density leads, instead, to high anthropic pressure and causes an increase in the air pollution [70]. For these reasons, low values of the three parameters were considered as a condition of good liveability.

On the opposite, human well-being is positively influenced by the increase of provisioning and regulating services. Therefore, were attributed: −2 to low values, −1 to medium-low values, +1 to medium-high values, and +2 to high values.

Table 2. Assigned values to four classes where are grouped the socio-demographic characteristics and ecosystem services supply at the neighborhood level. (**A**) Aging index; (**B**) Housing density; (**C**) Economically assisted citizens; (**D**) Provisioning and Regulating Services; (**E**) S-AQI index.

	A	B	C	D	E
Low	2	2	2	-2	-2
Medium-low	1	1	1	-1	-1
Medium-high	-1	-1	-1	1	1
High	-2	-2	-2	2	2

As shown in Supplementary Materials Table S5, values attributed to each neighborhood for socio-demographic characteristics have been combined. Similarly, values concerning ecosystem services were combined. Final values highlighted the level of ecosystem services and socio-demographic conditions at the neighborhood scale. Results, divided into three classes, were shown on a qualitative map, where:

- high represents the sum of assigned values > 0;
- medium represents the sum of assigned values = 0;
- low represents the sum of assigned values < 0.

However, it is worth noting that the aspects analyzed include a selection of ecosystem services provided by different land uses. Green spaces are among the most important land uses in urban areas, because their quantity and quality contribute to reducing environmental injustice on public health [72,73] and how certain levels of canopy cover [74,75] contribute to increasing the level of human well-being, reducing air temperatures and air pollution. Nevertheless, there are other aspects that influence human well-beings, such as psychological or hydrotherapeutic effects [76] and the sense of safety given by urban green areas [77].

3. Results

3.1. Provisioning and Regulating Services at the City Scale

Provisioning and regulating services of the City of Turin were analyzed using PAM. Figure 3 reports the UES Significance (Table S3) of overall values of provisioning and regulating services at the urban level.

The city exhibits a fine-grained pattern in which a core-periphery-gradient is quite distinct. The urbanized area extends from north to south of the territory, with two large areas at the municipal limits used for industrial purposes. These are areas with no UES (urban fabric > 50%). Instead, the area to the north-west of the city has a high potential for UES because of agricultural land uses, as well as the area to the east of the city, which is a hilly forested area. The Po and Dora Rivers cross the whole city, constituting very important ecological corridors, increasing the UES potential in the surrounding areas.

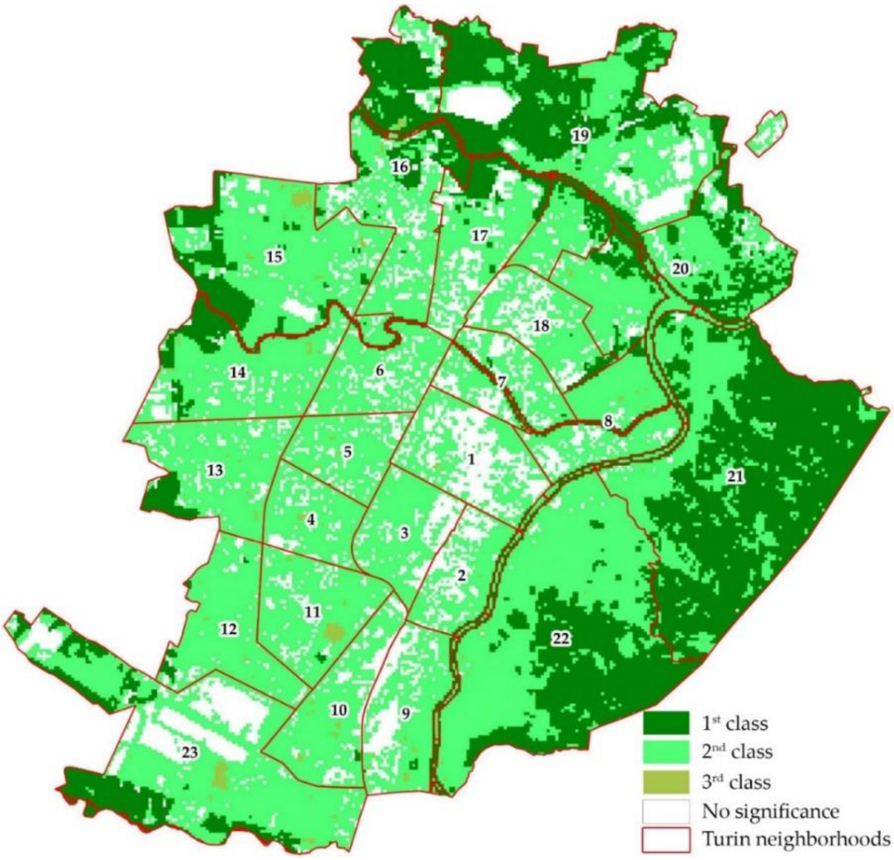

Figure 3. Provisioning and regulating services obtained by the Preliminary Assessment Method. Urban Ecosystem Services (UES) significance: 1st class: >7.5; 2nd class: ≤7.5, >3.0; 3rd class: ≤3.0, >0.5; no significance: ≤0.5.

3.2. Species Specific Air Quality Index at City scale

The results of the Specie Specific Air Quality Index (S-AQI) application on the trees of the city of Turin, refer to 51,148 trees. The trees analyzed were divided by neighborhood, and the species richness was calculated (Table 3).

Table 3. Area, number of trees per km^2, and tree species richness of Turin neighborhoods.

Neighborhoods	Area (km^2)[1]	N° Trees/km^2	of Tree Species Richness
1. Centro	3.77	1051	75
2. San Salvario	2.34	1222	81
3. Crocetta	2.77	1417	42
4. San Paolo	2.22	917	52
5. Cenisia	2.33	1019	71
6. San Donato	3.02	818	56
7. Aurora	2.67	980	53
8. Vanchiglia	3.38	965	59
9. Nizza Millefonti	3.51	370	52
10. Mercati Generali	3.46	883	70
11. Santa Rita	3.57	1190	78
12. Mirafiori Nord	3.79	1240	74
13. Pozzo Strada	4.22	1112	73
14. Parella	4.91	815	98
15. Le Vallette	7.54	487	68
16. Madonna di Campagna	7.40	282	81
17. Borgata Vittoria	3.86	355	55
18. Barriera di Milano	2.83	507	52
19. Falchera	12.62	180	66
20. Regio Parco	6.92	318	69
21. Madonna del Pilone	15.5	-	-
22. Borgo Po e Cavoretto	13.61	-	-
23. Mirafiori Sud	11.44	451	77

[1] The surfaces do not consider the areas occupied by rivers.

Table 3 shows that the number of trees per km^2 is higher in districts 1, 2, 3, 5, 11–13 that are located in the south-central part of the city. However, the highest values of species richness where found in districts 2, 14, and 16 that are located in the north-west of the city with the exception of neighborhood 2 that is close to the city center, and has a historical park with a high level of biodiversity.

Each tree species analyzed was assigned an S-AQI value. Tree species with S-AQI values <4 are not recommended, while values >8 are recommended for city planting programs. For more information about the detail of each species, see Supplementary Materials Table S4.

Trees data and S-AQI values were reported on a map (Figure 4). The hilly neighborhoods 21 and 22 (Madonna del Pilone and Borgo Po e Cavoretto) were excluded because the management, the monitoring, and tree' census systems are different as the forest is the main land-use.

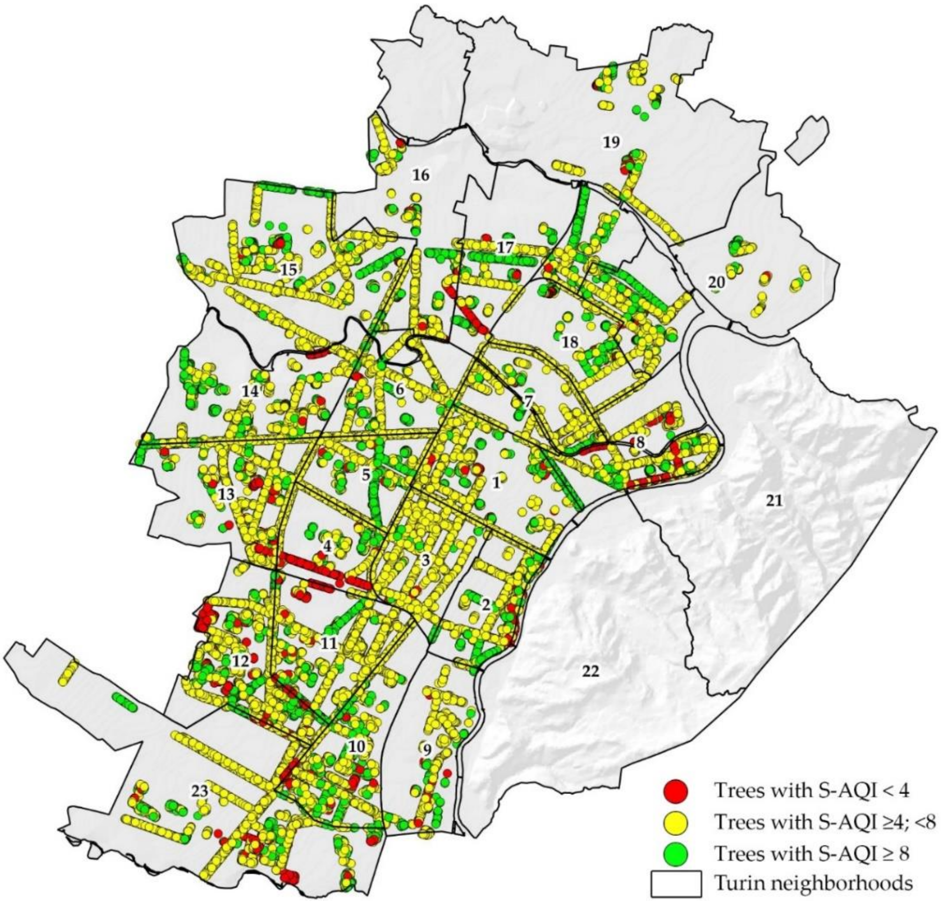

Figure 4. Trees present on Albera.To system classified by their S-AQI values.

Figure 4 shows that most of the trees are included in the ranking value 4–8 and are present in almost all avenues that link the periphery with the historical city center. Trees with S-AQI >8 are widespread throughout the city but were less planted to realize lines of trees. Trees with high S-AQI values represent 21% of the censed trees that belong mainly to the following species: *Acer platanoides* L., *Acer pseudoplatanus* L., *Carpinus betulus* L., and *Prunus* spp. Finally, trees not recommended in urban planning are the 18% and are present in few avenues in different part of the city. The main species located in the lowest class and present in Turin are *Quercus robur* L., *Aesculus hippocastanum L.* and *Populus* spp.

The species most used in the 1800s for the realization of the avenues in Turin were *Platanus* spp., and *Tilia* spp. (S-AQI ≥4; <8), probably more for the ornamental rather than environmental characteristics, which were appreciated at the time.

3.3. Provisioning and Regulating Services at Neighborhood Scale

In order to highlight the differences between Turin's neighborhoods in the provision of ecosystem services, the results obtained from the application of PAM and S-AQI have been divided into four categories (Figure 5).

Figure 5A shows the UES Significance of overall average values of provisioning and regulating services (PAM) of the Turin neighborhoods, while Figure 5B shows weighted average values of S-AQI at the neighborhood scale. The subdivision into four categories (from low to high) is intended in relative terms, in order to compare the districts among them. Regarding S-AQI, for example, no one neighborhood presents average values not recommended (<4), but some neighborhoods are characterized by a lower value than others.

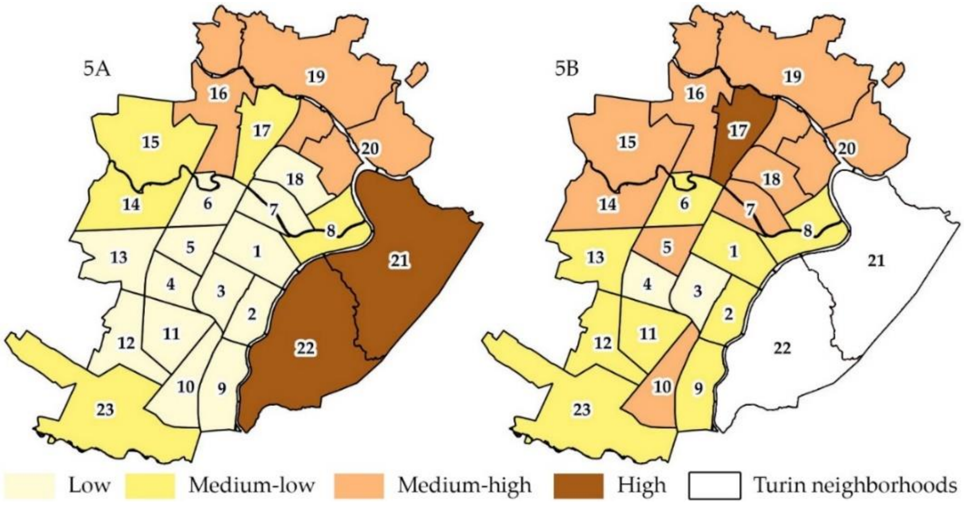

Figure 5. (**A**) Average values of the Provisioning and Regulating services of Turin neighborhoods—PAM; (**B**) Average values of S-AQI at the neighborhood scale; for neighborhoods 21 and 22 data are not available.

The PAM results (Figure 5A) show that Turin provides more provisioning and regulating ecosystem services in peripheral areas of the city than in the city center. Indeed, the highest supply of selected ecosystem services (Table 2) occurs in the hilly neighborhoods (21 and 22), where the forest is the main lan- use. In these areas, the number of trees is very high, and the urbanized surface is very reduced. The northern neighborhoods (16, 19, 20) are characterized by a medium-high provisioning and regulating services, because arable lands, pastures, and permanent crops are more represented on average in the neighborhoods. Due to the application of PAM, the results highlight how the neighborhoods of the city where the urban fabric is denser, the supply of ecosystem services is lower. In these neighborhoods, the ES supply is assigned to urban green areas that, as seen in Figure 1, are not too extended.

Regarding S-AQI (Figure 5B), 48% of neighborhoods, representing 10 neighborhoods out of 21 (Madonna del Pilone and Borgo Po e Cavoretto are excluded) are comprised in the range of medium-low values while 42%

are characterized by medium-high values. Borgata Vittoria has the best result with a high value. Only two neighborhoods (Crocetta and San Paolo) are comprised in the low category, due to the high number of trees with very low S-AQI values, such as *Quercus robur* 'Fastigiata'. Therefore, the city has a great possibility to enhance the delivery of ecosystem services by planning a future replacement of trees or increasing the number of them, choosing species that can increase the provision of multiple ecosystem services. Neighborhoods should have S-AQI value >8, which is the range identified by Sicard et al. [68] like optimal for urban areas. In addition, the neighborhoods with higher S-AQI values are not always characterized by a higher number of trees/km^2 or species richness (Table 3).

3.4. Socio-Demographic Characteristics of Neighborhoods

Figure 6 shows the results of descriptive analyses at the neighborhood scale, where it is possible to highlight that citizens' socio-demographic characteristics and green urban area's distribution are not evenly distributed around the city.

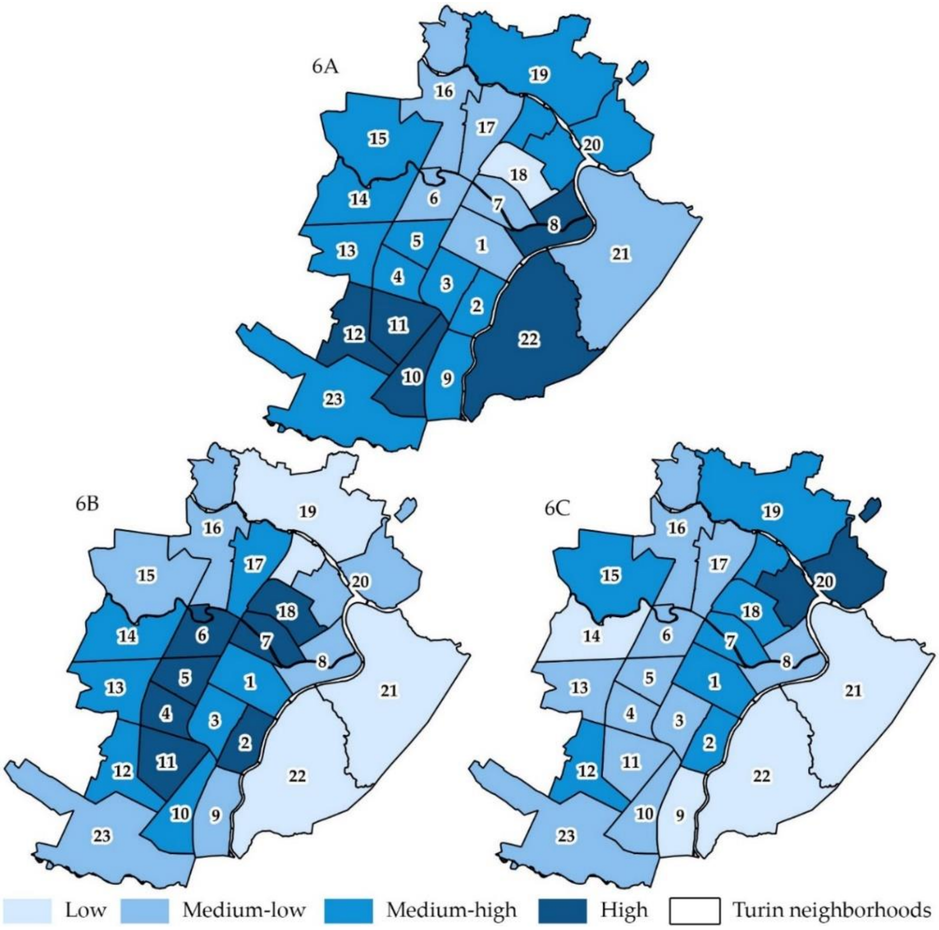

Figure 6. Socio-demographic characteristics of the neighborhoods' (**A**) Aging index; (**B**) Housing density; (**C**) Economically assisted citizens.

The aging index is low in *Barriera di Milano* (18), where the housing density is high, and the percentage of economically assisted citizens is medium-high. Quite the opposite, in neighborhood 22 lives part of the oldest range of population, in the condition of low housing density and in an optimal class of economic resources. Generally, do not seem that exists a close relationship between the aging index and the housing density because in some cases (8, 9, 15, 19, 20, 22, and 23) where the housing density is lower, the aging index is higher, but in other cases (2–5,10–14,) neighborhoods have quite similar classes of two parameters, and only in four cases (1, 6, 7, 17) high or medium-high housing density corresponds to a low aging index. Instead, the relationships between housing density and the percentage of economically assisted citizens are more evident. In neighborhoods around the city center (11, 4–6), for example, housing density is high, while the percentage of economically assisted citizens is medium-low. Hilly neighborhoods (21 and 22) are, instead, characterized both by a low housing density and a low percentage of economically assisted citizens. In the same way, it is possible to see that there is a relationship between the aging index and the citizen's economic resources; where the citizens are older (the aging index is high or medium-high), the percentage of citizens with low economic resources is low or medium-low (3, 4, 8–14, 22, 23). Regarding urban green areas, it is possible to see that the neighborhoods in the city center have the lowest percentages and that the quantity of green areas increases with increasing distance from the center.

3.5. Qualitative Evaluation Map of Turin Neighborhoods

Figure 7 is the final qualitative evaluation map, that shows the level of ecosystem services and socio-demographic conditions (high, medium, and low) in each neighborhood. The results contribute to identifying neighborhoods where to improve the provision of ecosystem services and the socio-demographic conditions. Specifically, it can be observed that the northern part (16, 17, 19) of the city is characterized by better results than the central-southern part. This aspect is related to the conspicuous presence of agricultural land uses and water bodies, together with the presence of tree species with a high S-AQI values and high or medium socio-demographic conditions. 57% of neighborhoods present low results for the both aspects. The actions to improve the quality of green spaces in those neighborhoods could have great effects on liveability. Otherwise, the same actions in neighborhoods where socio-demographic conditions are medium or high (6, 8, and 9) would be less effective.

It should also be pointed out that the historical city center is characterized by low values, but it would provide high cultural services, not considered in the research.

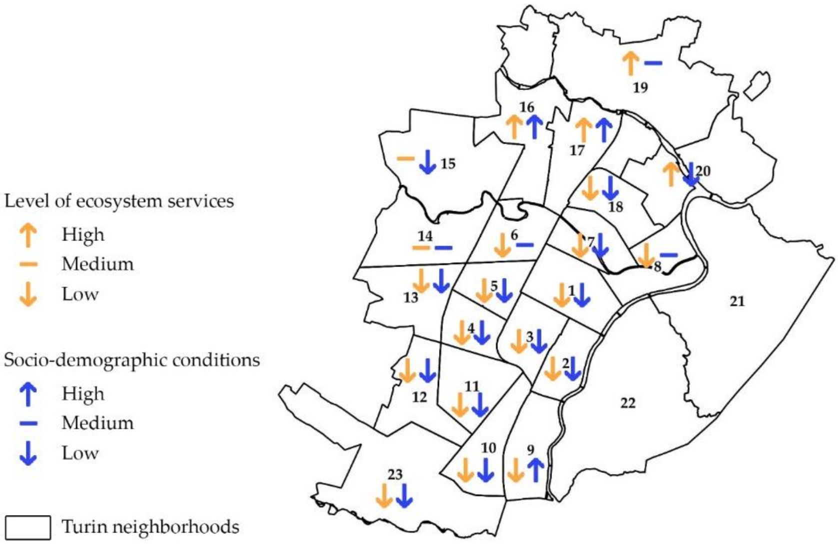

Figure 7. Qualitative evaluation (high, medium, low) map of Turin neighborhoods, according to ecosystem services levels and socio-demographic conditions. For neighborhoods 21 and 22 data are not available.

4. Discussions and Conclusions

Since ecosystem services is an anthropocentric concept [78], the socio-demographic component must be considered in the drafting of a management plan or in the city's future planning activities. This is why the proposed methodology considered socio-demographic characteristics, albeit partially, together with the ES provided by the land uses and the urban greening, specifically the trees, of the city of Turin.

Braveman et al. in 2005 [79] indicated that more research is needed on the relationship between health and the characteristics of both individuals and their neighborhood. In particular, urban green areas are beneficial for human health [80], especially for the elderly [81] and for pregnant women of lower socioeconomic status [82]. Furthermore, at the urban level, the theme of the perception and attitude that citizens have towards green areas and trees is fundamental, especially for the design and management of new green areas. Although some specific studies have investigated the theme of the perception of safety in urban green areas [77] and the attitudes of professionals and nonprofessionals towards urban trees [83], more studies should focus on the management and aesthetic perception of urban green areas emphasizing the difference in perception between different genders [84].

The aim of the research was to assess and map ecosystem services and socio-demographic characteristics in Turin neighborhoods in order to identify where (greening) actions are needed to improve the provision of ecosystem services and/or the socio-demographic conditions.

The proposed qualitative methodology is a combination of different methods, applied at the neighborhood scale. The neighborhood scale is useful from both an environmental and a social point of view [81,82].

The research results show that intervention priorities should be addressed in several neighborhoods, mainly located in the central-southern part of the city. This means that more than 50% of the city strongly needs actions (such as increasing the number and surfaces of urban green areas, as well as trees, based on S-AQI values) to improve human well-being through the provision of ecosystem services. The proposed methodology allows deepening the specific situation of each neighborhood, individually analyzing each method and index used. Therefore, it will be possible to identify the actions (a change in land use or a selected choice of trees in the neighborhood) to be adopted or policy to protect the most efficient individuals of trees (e.g., ancient or the biggest trees) and define the economic resources needed to achieve the objective.

Specifically, interventions at the neighborhood level should be based on the results of the scientific methods used for the assessment of provisioning and regulating services, PAM, and S-AQI.

Regarding PAM, the Urban Atlas map was integrated with information from maps provided by Turin Municipality, improving the quality of the information analyzed, reducing the limit of the method [56]. It is also possible to make comparisons with other cities where the method of ecosystem services assess was applied, such as Poznań [56]. Specifically, it is possible to highlight how Poznań and Turin have a common feature, namely that the first city is the green belt of the Ruhr area, while Turin is characterized and surrounded by the 'Green Crown', a network of green areas enhanced and protected, by the Piedmont Region. The ecosystem services analyzed are, therefore, greater in the peripheral areas of the two cities than in the central area. However, among the limits of the study, it is highlighted that the quality of land uses was not considered.

Regarding the S-AQI, it considers numerous aspects related to well-being (i.e., allergenicity) and some parameters such as species tolerance to pests and diseases, drought tolerance, and O_3 sensitivity, which are fundamental at the level of tree management. Among the limits of the study, it is necessary to point out that S-AQI does not consider the age and size of trees [68], even though these aspects have a great influence on the provision of ecosystem services. The highest weighted average values of the S-AQI per neighborhood, do not correspond to the neighborhoods that have the highest value of species richness. However, a study shows that as species diversity increases, so does human well-being [6]. It may be useful to increase the value of biodiversity when designing new green areas or to restore existing ones, but choosing among plants that also provide an advantage in terms of reducing air pollution. Globally, cities are experimenting with different ways to increase and support tree species richness, thanks to environmental and land cover heterogeneity and socioeconomic factors, in order to deliver ecosystem stability and services [85].

New tree species, after assessing allergenic potentials and stress tolerances [86], could be planted in residential greenery, which has a high renaturation potential, creating new urban realms for urban biodiversity and resilient neighborhoods [87]. Moreover, since many trees of the avenues of Turin are becoming mature, it is possible in the future to replace them, using species suitable for urban conditions, useful to reduce air pollution, allergenicity, and adaptability to the conditions dictated by climate change.

However, a complete and updated *census* of urban greening is mandatory for planning and managing green areas. The management of urban green areas is essential because there is a close relationship between trees and human health. Specifically, Donovan et al. in 2013 [88] have shown that loss of trees to the emerald ash borer, increased mortality related to cardiovascular and lower-respiratory-tract illness, especially in Counties with above-average median household income.

In addition, our research focused on trees, but it would be interesting to deepen the studies on the role that shrubs play in urban increasing human well-being [89].

The methodology does not presume to be exhaustive from a social point of view, but unlike other methods, explicitly includes this concept in order to identify where there is a greater need for green actions in order to increase the provision of ecosystem services where the socio-demographic indices used to indicate a worse situation. However, a comprehensive database of the socioeconomic characteristics of the people living in the city is needed in order to compare the social demand with the available resources, and plan the development of the city accordingly.

Additional socioeconomic and ecological indicators may be added to the proposed methodology, incorporating local perceptions, and the valuation of other ecosystem services. It is necessary to consider that to preserve the biodiversity of urban green areas, the collaboration of different stakeholders is necessary in order to engage in interdisciplinary research and debate the management, design, and planning of urban biodiversity [7].

Future management and planning strategies for increasing citizens' well-being should consider the results and the methodology proposed, with the aims of improving the supply of ecosystem services in the city and the preservation of urban biodiversity.

Supplementary Materials:

Table S1: Classes of Provisioning and Regulating Services (according to CICES, v.5.1 [38]) selected for a preliminary assessment in urban landscapes. Modified by [36]. Table S2: Calculation of the number of priority and significant potential UES values and the potential overall ES supply of each land cover unit [36]. P—Priority; S—Significant; I—Insignificant; N—Non-relevant. Table S3: Classification of areas with provisioning and regulating ecosystem services [36]. Table S4: Species, Total number, Species-Specific Air Quality Index (S-AQI) values, and ranking values of trees (modified by [49]) in the City of Turin. Data modified by Albera.TO of March 2019. Table S5: Assigned values to each neighborhood for the following parameters: (A) Ageing index; (B) Housing density; (C) Economically assisted citizens; (D) Provisioning and Regulating Services; (E) S-AQI index.

Table S1: Classes of Provisioning and Regulating Services (according to CICES, v.5.1 [38]) selected for a preliminary assessment in urban landscapes. Modified by [36].

Provisioning		
Class	**Class Type**	**CICES Code**
Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes	Crops by amount, type (e.g. cereals, root crops, soft fruit, etc.)	1.1.1.1
Animals reared for nutritional purposes	Animals, products by amount, type (e.g. beef, dairy)	1.1.3.1
Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	Plants, algae by amount, type	1.1.5.1
Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	Plants, algae by amount, type	1.1.5.2
Wild animals (terrestrial and aquatic) used for nutritional purposes	Animals by amount, type	1.1.6.1
Surface water for drinking	By amount, type, source	4.2.1.1
Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials)	Material by amount, type, use, media (land, soil, freshwater, marine)	1.1.1.2
Fibres and other materials from reared animals for direct use or processing (excluding genetic materials)	Material by amount, type, use, media (land, soil, freshwater, marine)	1.1.3.2

Surface water used as a material (non-drinking purposes)	By amount & source	4.2.1.2
Cultivated plants (including fungi, algae) grown as a source of energy	By amount, type, source	1.1.1.3
Regulating		
Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	By type of living system, or by water or substance type	2.1.1.2
Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	By depth/volumes	2.2.1.3
Pollination (or 'gamete' dispersal in a marine context)	By amount and pollinator	2.2.2.1
Seed dispersal	By amount and dispersal agent	2.2.2.2
Regulation of chemical composition of atmosphere and oceans	By contribution of type of living system to amount, concentration or climatic parameter	2.2.6.1
Regulation of temperature and humidity, including ventilation and transpiration	By contribution of type of living system to amount, concentration or climatic parameter	2.2.6.2

Table S2: Calculation of number of priority and significant potential UES values and the potential overall ES supply of each land cover unit [36]. P – Priority; S – Significant; I – Insignificant; N – Non-relevant.

Land cover classes after Urban Atlas (EEA 2018)	Provisioning Services								Regulating services					Overall ecosystem services		
	1.1.1.1 & 1.1.3.1	1.1.5.1 & 1.1.5.2	1.1.6.1	4.2.1.1	1.1.1.2	1.1.3.2	4.2.1.2	1.1.1.3	2.1.1.2	2.2.1.3	2.2.2.1 & 2.2.2.2	2.2.6.1	2.2.6.2	Sum of S	Sum of P	UES Significance
Continuous Urban Fabric (S.L. > 80%)	N	N	N	N	N	N	N	N	N	N	I	N	N	0	0	0
Discontinuous Dense Urban Fabric (S.L.: 50% - 80%)	I	N	N	N	N	N	N	N	I	I	I	N	N	0	0	0
Discontinuous Medium Density Urban F. (S.L.: 30% - 50%)	I	N	N	N	I	N	N	I	I	S	I	I	S	2	0	1

Discontinuous Low Density Urban F. (S.L.: 10% - 30%)	I	N	N	N	I	I	N	I	I	S	I	I	S	2	0	1
Discontinuous Very Low Density Urban F. (S.L.: < 10%)	S	N	N	N	I	I	N	I	S	P	I	I	P	2	2	3
Isolated Structures	N	N	N	N	N	N	N	N	N	N	N	N	N	0	0	0
Industrial, commercial, public, military and private units	N	N	N	N	I	I	N	N	I	N	I	N	N	0	0	0
Construction sites	N	N	N	N	N	N	N	N	N	I	N	N	N	0	0	0
Fast transit roads and associated land	N	N	N	N	N	N	N	N	N	N	N	N	N	0	0	0
Other roads and associated land	N	N	N	N	N	N	N	N	N	N	N	N	N	0	0	0
Railways and associated land	N	N	N	N	N	N	N	N	I	N	I	N	N	0	0	0
Land without current use	N	N	N	N	N	N	N	N	I	I	S	I	N	1	0	0,5

Sports and leisure facilities	N	N	N	N	N	N	N	N	S	S	S	I	I	3	0	1,5
Green urban areas	N	N	N	N	N	N	N	I	P	P	S	S	S	3	2	3,5
Agricultural + Semi-natural areas + Wetlands	P	S	P	N	P	P	N	P	P	P	P	S	S	3	8	9,5
Forests	N	P	P	N	P	N	N	P	P	P	P	P	P	0	9	9
Water bodies	N	I	P	P	S	N	P	N	P	P	N	S	P	2	6	7
Mineral extraction and dump sites	N	N	N	N	N	N	N	N	N	S	N	N	I	1	0	0,5

Table S3: Classification of areas with provisioning and regulating ecosystem services [36].

	UES Significance
1st class	>7,5
2nd class	≤ 7.5; > 3.0
3rd class	≤ 3.0; > 0.5
no significance	≤ 0.5

Table S4: Species, Total number, Specie-Specific Air Quality Index (S-AQI) values and ranking values of trees (modified by [49]) in the City of Turin. Data modified by Albera.TO of March 2019.

Tree species	N°	S-AQI	Ranking values
Acer platanoides 'Crimson King'	2	9,3	high
Acer platanoides 'Faassen's Black'	294	9,3	high
Acer platanoides f. *globosum* (G.Nicholson) Schwer.	23	9,3	high
Acer platanoides f. *schwedleri* (K.Koch) Schwer.	126	9,3	high
Acer platanoides L.	686	9,3	high
Acer platanoides var. *drummondii* J.Drumm. ex Schwer.	48	9,3	high
Acer pseudoplatanus f. *atropurpureum* Schwer .	89	8,9	high
Acer pseudoplatanus f. *leopoldii* Schwer.	41	8,9	high
Acer pseudoplatanus L.	1750	8,9	high
Carpinus betulus f. *pyramidalis* Dippel	1935	8,4	high
Carpinus betulus L.	966	8,4	high
Cedrus atlantica (Endl.) Manetti ex Carrière	198	8	high
Cedrus atlantica var. *glauca* Carrière	162	8	high
Cedrus deodara (Roxb. ex D.Don) G.Don	97	8	high
Cedrus libani A.Rich.	3	8	high
Crataegus x lavallei Carrierei	1	9,1	high
Crataegus azarolus L.	8	9,1	high
Fagus sylvatica f. *pendula* (Lodd.) Dippel	33	8	high
Fagus sylvatica L.	429	8	high
Fagus sylvatica var. *purpurea* Aiton	141	8	high
Juglans nigra L.	368	7,1	high
Juglans regia L.	16	7,1	high
Larix decidua Mill.	3	8,6	high
Liriodendron tulipifera L.	392	8,2	high
Prunus avium 'Flore-Pleno'	278	9,1	high

Prunus fruticosa 'Globosa'	10	9,1	high
Prunus pissardii 'Nigra'	1762	9,1	high
Prunus serrulata 'Kanzan'	69	9,1	high
Prunus armeniaca L.	45	9,1	high
Prunus avium (L.) L.	153	9,1	high
Prunus cerasifera Ehrh.	49	9,1	high
Prunus domestica L.	58	9,1	high
Prunus persica (L.) Batsch	2	9,1	high
Prunus serrulata Lindl.	56	9,1	high
Pyrus calleryana Decne.	5	7,1	high
Pyrus communis L.	170	7,1	high
Tilia cordata 'Green Spire'	5	7,1	high
Tilia cordata Mill.	156	7,1	high
Acer campestre L.	550	6,7	medium-high
Cupressus sempervirens L.	3	6,8	medium-high
Fraxinus excelsior L.	1088	6,9	medium-high
Fraxinus excelsior var. *pendula* Aiton	11	6,9	medium-high
Gleditsia triacanthos L.	180	6,9	medium-high
Malus domestica Borkh.	16	6,9	medium-high
Malus floribunda Siebold ex Van Houtte	25	6,9	medium-high
Abies alba Mill.	18	6,5	medium-low
Acacia dealbata Link	3	6	medium-low
Acer negundo 'Foliis Argenteis'	13	6,2	medium-low
Acer negundo 'Odessanum'	33	6,2	medium-low
Acer negundo L.	1829	6,2	medium-low
Castanea sativa Mill.	2	6	medium-low
Celtis australis L.	6359	6	medium-low
Celtis davidiana Carrière	70	6	medium-low
Celtis occidentalis L.	9	6	medium-low
Cercis siliquastrum L.	367	6,5	medium-low
Fraxinus americana L.	2	6	medium-low
Fraxinus angustifolia Vahl	3	6	medium-low
Ginkgo biloba L.	154	6,5	medium-low

Metasequoia glyptostroboides Hu & W.C.Cheng	9	6,5	medium-low
Morus alba L.	250	6,2	medium-low
Olea europaea L.	13	6,2	medium-low
Pinus pinea L.	32	6,2	medium-low
Pinus sylvestris L.	81	6	medium-low
Platanus hispanica Mill. ex Münchh.	2146	6,2	medium-low
Platanus occidentalis L.	3297	6,2	medium-low
Platanus orientalis L.	10491	6,2	medium-low
Tamarix gallica L.	1	6,2	medium-low
Tilia × europaea L.	2163	6,5	medium-low
Ulmus carpinifolia Rupp. ex Suckow	19	6	medium-low
Ulmus minor Mill.	158	6	medium-low
Ulmus parvifolia Jacq.	14	6	medium-low
Ulmus pumila L.	1979	6	medium-low
Ulmus laevis Pall.	21	6	medium-low
Acer rubrum L.	15	3,8	low
Aesculus × carnea Zeyh.	8	5,2	low
Aesculus hippocastanum L.	4197	5,2	low
Alnus glutinosa (L.) Gaertn.	3	4,7	low
Betula alba L.	250	4,7	low
Chamaecyparis lawsoniana (A.Murray bis) Parl.	39	4,9	low
Ficus carica L.	119	4,9	low
Koelreuteria paniculata Laxm.	5	4,3	low
Liquidambar styraciflua L.	347	3,8	low
Magnolia × soulangeana Soul.-Bod.	55	4,3	low
Magnolia grandiflora L.	136	4,3	low
Magnolia obovata Thunb.	4	4,3	low
Magnolia stellata (Siebold & Zucc.) Maxim.	27	4,3	low
Parrotia persica C.A.Mey.	4	2,5	low
Picea abies (L.) H. Karst.	274	5,2	low

Pinus nigra J.F. Arnold	527	5,8	low
Pinus wallichiana A.B. Jacks.	91	5,8	low
Pinus halepensis Mill.	1	4,1	low
Pinus mugo Turra	21	5,8	low
Pinus strobus L.	268	5,8	low
Populus nigra L.	320	3,6	low
Populus × canadensis Moench	9	3,6	low
Populus × canescens (Aiton) Sm.	2	3,6	low
Populus alba L.	86	3,6	low
Populus nigra var. *italica* Münchh.	380	3,6	low
Populus tremula L.	21	3,6	low
Quercus coccinea Münchh.	2	3,6	low
Quercus petraea (Matt.) Liebl.	1	3,6	low
Quercus robur 'Fastigiata'	349	3,6	low
Quercus crenata Lam.	3	3,6	low
Quercus ilex L.	6	3,6	low
Quercus pubescens Willd.	8	3,6	low
Quercus robur L.	182	3,4	low
Quercus rubra L.	774	3,6	low
Quercus suber L.	1	3,6	low
Robinia pseudoacacia 'Bessoniana'	59	4,1	low
Robinia pseudoacacia 'Fastigiata'	11	4,1	low
Robinia pseudoacacia 'Monophylla'	108	4,1	low
Robinia pseudoacacia 'Umbraculifera'	54	4,1	low
Robinia pseudoacacia L.	27	4,1	low
Salix alba L.	10	2,7	low
Salix babylonica L.	19	2,7	low
Salix babylonica var. *pekinensis*'Tortuosa'	7	2,7	low
Sambucus nigra L.	17	4,7	low
Sequoia sempervirens (D.Don) Endl.	3	4,5	low
Sorbus aucuparia L.	33	5,8	low
Styphnolobium japonicum (L.) Schott	84	5,6	low
Taxus baccata L.	143	4,9	low

Table S5: Assigned values to each neighborhood for the following parameters: (A) Ageing index; (B) Housing density; (C) Percentages of economically assisted citizens; (D) Provisioning and Regulating Services; (E) S-AQI index.

Neighborhoods	**A**	**B**	**C**	**D**	**E**	**Sum**
1. Centro	1	-1	-1	-2	-1	-4
2. San Salvario	-1	-2	-1	-2	-1	-7
3. Crocetta	-1	-1	1	-2	-2	-5
4. San Paolo	-1	-2	1	-2	-2	-6
5. Cenisia	-1	-2	1	-2	1	-3
6. San Donato	1	-2	1	-2	-1	-3
7. Aurora	1	-2	-1	-2	1	-3
8. Vanchiglia	-2	1	1	-1	-1	-2
9. Nizza Millefonti	-1	1	2	-2	-1	-1
10. Mercati Generali	-2	-1	1	-2	1	-3
11. Santa Rita	-2	-2	1	-2	-1	-6
12. Mirafiori Nord	-2	-1	-1	-2	-1	-7
13. Pozzo Strada	-1	-1	1	-2	-1	-4
14. Parella	-1	-1	1	-1	1	-1
15. Le Vallette	-1	1	-1	-1	1	-1
16. Madonna di Campagna	1	1	1	1	1	5
17. Borgata Vittoria	1	-1	1	-1	2	2
18. Barriera di Milano	2	-1	-1	-2	1	-1
19. Falchera	-1	2	-1	1	1	2
20. Regio Parco	-1	1	-2	1	1	0
21. Madonna del Pilone	1	2	2	2	1	8
22. Borgo Po e Cavoretto	-2	2	2	2	1	5
23. Mirafiori Sud	-1	1	1	-1	-1	-1

Acknowledgments: We are grateful to the Green Office of the Municipality of Turin for the data and suggestions provided.

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Chapter 3

Management and Perception of Metropolitan Natura 2000 Sites: A Case Study of La Mandria Park (Turin, Italy)

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Sustainability 2019, 11(21), 6169; https://doi.org/10.3390/su11216169

Abstract: The European Commission promotes management practices for nature conservation and human well-being, requiring the involvement of users in Natura 2000 sites. The research aim was to investigate the user's aesthetic perception in relation to the adoption of different management measures, within an Italian metropolitan Natura 2000 site. The research was performed in La Mandria Park in 2018 (1780 ha). The method was based on a participatory approach (interviews, questionnaires and participatory mapping), involving both park managers and users. Four main landscape elements were identified: lawns, woodlands, lines of trees and water bodies. Questionnaires (N = 232) were analyzed by descriptive and regression analysis. Mapped preferred places were analyzed using ecological indexes on 500 m land use buffers. A gendered perception of the aesthetic quality was detected, demonstrating that women are more strictly connected to nature than men. Users involved in park activities better perceived the aesthetic quality, while regular visitors had a worst perception. From participatory mapping (N = 137), it emerges that the eight preferred places are characterized by a mixed land use with different maintenance regimes and ecological values. Users' perceptions should be integrated in a co-management plan in metropolitan Natura 2000 sites, combining nature conservation with user enjoyment.
Keywords: ecosystem services; stakeholders; questionnaires; urban horticulture; gendered perspective; aesthetic quality

1. Introduction

Natura 2000 sites are networks of protected sites for rare and threatened species, stretched across 28 countries in Europe [1]. There are 27,758 Natura 2000 sites covering 18% of the EU territory [2]. Some of these sites are located in urban areas, where the human–nature interaction is more present and where attention to management issues must be specific [3].

The 'Natura 2000 and Forest' technical report [4] encourages "forest protection and enhancement of ecosystem services", arguing that Member States "should achieve a significant and measurable improvement in the conservation status of forest species and habitats by fully implementing EU nature legislation and ensuring that national forest plans contribute to the adequate management of the Natura 2000 network by 2020".

In 2018, the EU Commission focuses on Article 6 (92/43/EEC), indicating the importance of management plans in Natura 2000 sites, with the involvement of stakeholders [5]. This participatory approach to decision making in Natura 2000 sites is essential [6], with the aim of conserving habitat biodiversity and ensuring proper local economic development [7]. It should take into account the knowledge and the needs of users of Natura 2000 sites [8,9], integrating social and ecological aspects in the management plans [10]. In this regard, the Guidelines on Wilderness in Natura 2000 [11] highlight the need to re-build relationships with people who live, work or visit the sites with specific and differentiated communication strategies in order to increase public awareness of nature conservation [12,13]. It was noted that people have difficulty in understanding the Natura 2000 network [14], even though a greater awareness and a more positive attitude are accompanied by a higher level of education [3].

There is the need to investigate people's perception over time, to study the potential effects of educational programs and changes in attitudes [14]. These issues related to aesthetic, perceptual, educational and recreational values are part of cultural ecosystem services and are of great importance in Natura 2000 sites [15,16]. Cultural ecosystem services are also considered central to human well-being and important for environmental decision making [17]. A range of landscape characteristics have been associated with, and influence at different scales of perception, the values of cultural ecosystem services [18]. On the other hand, managers have to understand how people perceive different management practices that would affect the environment and human well-being, in order to avoid controversy [19].

In this context, the aim of the research was to investigate the users' aesthetic perception (cultural ecosystem services) in relation to the adoption of different management measures, related to different land use categories, within a metropolitan Natura 2000 site. The research was performed in 2018 on La Mandria Park (Site code: IT1110079), a Natura 2000 site located in the Turin metropolitan area, in Italy. The method was based on a participatory approach (interviews, questionnaires and participatory mapping), involving both park managers and users. Results can be used to set up a long-term co-management plan [20] combining nature conservation with user enjoyment.

2. Materials and Methods

2.1. Study Area

The metropolitan city of Turin in Piedmont (Italy), comprises 2,269,120 inhabitants, with an area of 682,691 ha, comprising 19.8% green areas—4.5% of which are protected natural areas [21]. La Mandria Park is a regional protected area since 1978, located between the Stura di Lanzo stream, the Ceronda stream and the northern part of the Turin urbanized area (Figure 1).

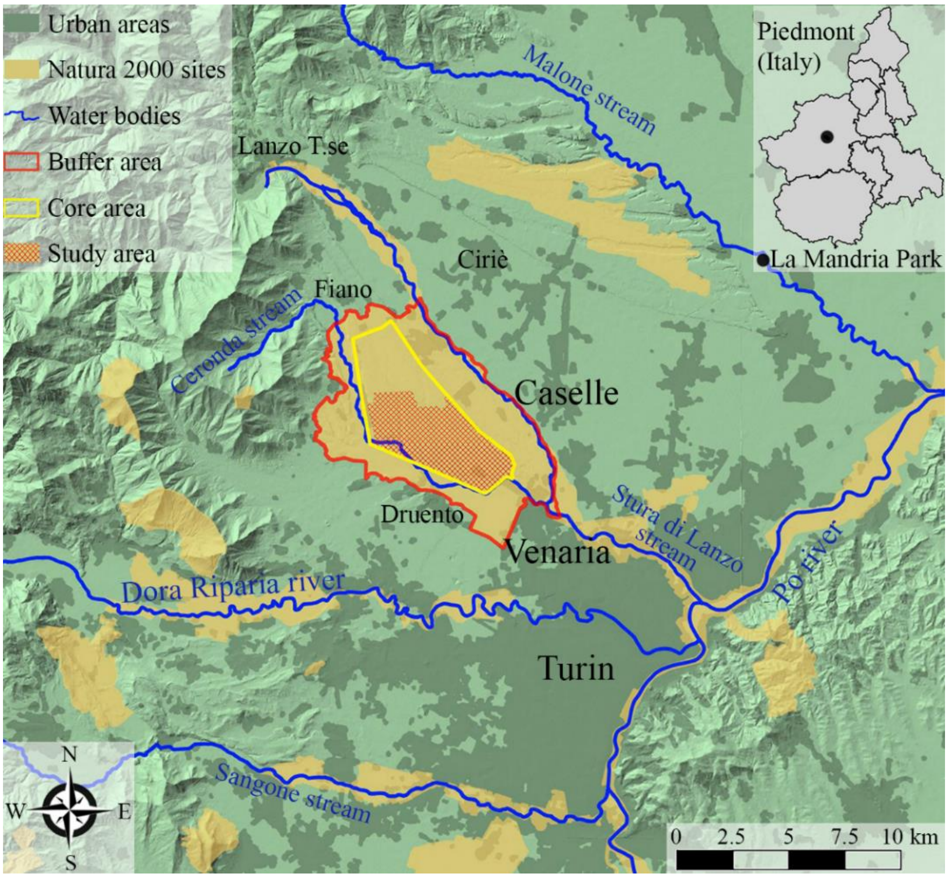

Figure 1. Classification of La Mandria Park, indicating buffer, core and study areas.

La Mandria Park is characterized by a buffer area (6557 ha) and a core area (3125 ha). The core area is surrounded by approximately 30 km of walls and is partly privately owned and partly publicly (Piedmont Region) owned. The study area (1780 ha) is the public area within the core area. La Mandria Park has gently undulated surfaces varying between 250 and 420 m asl, with more clayey soils in the higher-lying areas and sandy soils in the lower-lying areas, derived from alluvial deposits, dating back to the Mindel and Riss glaciations [22]. The mean annual rainfall is 938 mm and the mean annual temperature is 14.8 °C (data from Turin weather station, 238 m asl and Caselle weather station 301 m asl). The La Mandria Park is a Special Area of Conservation (SAC) and part of the Natura 2000 network, preserving the most significant example of lowland forest in Piedmont. The protected regional area also hosts two United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Sites (1997), which are part of the Residences of the Royal House of Savoy (called 'Corona di Delizie') in and around Turin: Reggia di Venaria Reale and Borgo Castello.

The study area (Figure 2A) is composed of a mosaic of wooded (65%) and open patches (35%).

The wooded patches are characterized by an oak-hornbeam forest of *Carpinion betuli* and *Quercus robur* on sandy plains, while the open patches are characterized by pastures and sparsely wooded grasslands. The composition of trees in the study area is varied, but the most common species are *Quercus robur* L., *Carpinus betulus* L., *Fraxinus excelsior* L., *Prunus avium* L. and *Alnus glutinosa* (L.) Gaertn. [23].

Water bodies are important elements of the landscape, even though they represent only 1.18% of the study area. There are streams, canals and five artificial lakes used for fishing and as water reservoirs [24]. It is possible to access the park through 6 entrances located in different municipalities, visit the castle and see the Church of San Giuliano and 15 farmsteads that characterized in the past (and still today) the life within the area.

For management purposes, the park is divided into four areas, based on the level of protection identified for each zone (Figure 2B): zone A— strict nature reserve (strict protection of ecosystems, almost without allowing the presence of humans, in order to safeguard flora and fauna); zone B—permit-only access reserve (access is permitted only for carrying out agricultural activities that characterize the landscape); zone C—controlled reserve (areas with tourist facilities and for recreational use); zone U—urbanized area (buildings or structures generally of historical and cultural value).

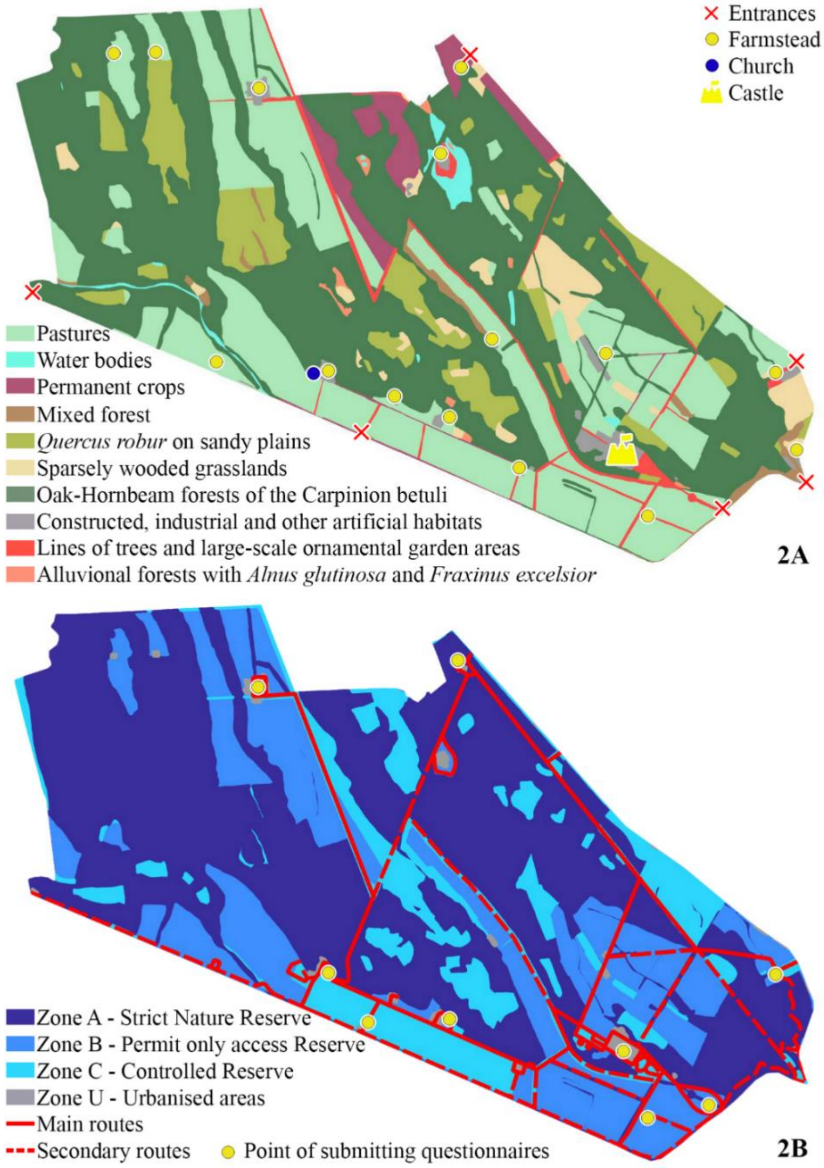

Figure 2. Land use and main elements (entrances, farmsteads, church and the castle) that characterize La Mandria Park (2A) and levels of protection divided by zones (A, B, C, and U) and routes available (of different sizes) within the park (2B).

La Mandria Park offers different services and possibilities for leisure and educational activities. The routes open to the public are nearly 40 km in length, for hiking, walking, running and also traveled by a touristic train. It is possible to access the park throughout the year, from 08:00 to 20:00 during the summer period, and from 08:00 to 17:00 during the winter period. However, it is possible to stay in touch with nature even at night, through guided tours, especially to listen to the roaring of the deer, one of the symbols of the park. Special huts for sighting are available for naturalist photographers. However, the number of users per year is not registered.

2.2. Study Design and Data Analysis

In order to achieve the research aims, the study area was analyzed through field visits. During these inspections, four main landscape elements were identified: lawns, woodlands, lines of trees and water bodies. The four landscape elements were used to gather information from park managers and users. The main phases, methods and attended results are reported in Table 1.

Table 1. The main phases, methods used and attended results of the research.

Phases of the Research	Methods	Attended Results
Involvement of park managers	Qualitative analysis of semi-structured interviews	Management operations carried out in the park based on the four main landscape elements (lawns, woodlands, lines of trees and water bodies).
Involvement of users	Questionnaires submission and statistical analysis of questionnaire data	Users' knowledge of the park; users' aesthetic perception of the four landscape elements.
Involvement of users	Participatory mapping	Users' preferred places within the park.

2.2.1. Interviews of Park Managers

In order to understand the management activities pursued and the activities that will be carried out in the future, semi-structured interviews of the park managers were performed in March 2018, using the criteria for urban forest sustainability identified by Clark et.al., [25] as a starting point for the discussion. The questions mainly concerned aspects of the management and maintenance of the Park, the application of the European directives on Natura 2000 sites and the management of tourist flows. The first part was aimed at understanding the main management activities carried out in the park, related to the four main landscape elements (lawns, woodlands, lines of trees and water bodies). Then, the critical points and suggested proposals for management practice improvement were discussed. The results of this phase were used to develop the questionnaire and analyze its results.

2.2.2. Questionnaires to Users

In order to investigate the value of aesthetic perceptions and the habits and mode of park users, a self-completion questionnaire was prepared. The questionnaire consisted of the following sections:

- general information about the respondents (age, gender, education and proximity to the park);
- the aesthetic quality perception of respondents with regards to lawn, woodland, waterbodies and routes. The questions were formulated on a 5-point Likert scale;
- the general knowledge of the respondents of the park. In such sections, the questions were formulated using a yes/no option;
- the frequency of visits and involvement in park activities. In such sections, the questions were formulated using both yes/no options and a 5-point Likert scale.

Even though the questionnaire consisted of several other sections and questions, only those presented above were employed in the analysis.

Nederhof [26] suggests guaranteeing anonymity for the respondents in order to reduce social desirability bias. Indeed, in the field of social science, such a bias represents a type of response bias where respondents provide an answer to a question in a manner that will be viewed favorably by others. For such reasons, the questionnaire was administered in anonymous form.

The questionnaire was subjected to a pre-test phase (30 completed questionnaires) to verify the layout, content and wording of the questions. During the survey, respondents were informed about the objectives of this study and the time required to complete the questionnaire (approximately10 min). Table 2 presents the main questions, options and related variables used.

The questionnaire was submitted from April to November 2018 in 9 places (five entrances; three farmsteads and the complex of Borgo Castello—Figure 2B) located along the main routes in order to reach the highest number of respondents. A total number of 232 completed questionnaires were collected. This sample is comparable to that used by other similar research in Natura 2000 sites [16,27]. Some descriptive statistics about the respondents are presented in Table 3.

Table 2. Questions, multiple-choice options and related variables used in the questionnaire.

Questions	Options	Variables
Where do you live?	Cities that have direct access to the park; Metropolitan area of Turin; Piedmont; other Italian regions; other countries	Proximity
Age; gender; education	< 18, 18–30, 31–45, 46–60, > 60; M/F; primary, secondary, high school, university degree	Age; gender; education
Do you know that La Mandria Park is a protected park?	yes/no	Environmental knowledge
How many times do you come here in a year? / On which days of the week?	less than once, up to 10 times, more than 10 times / Saturday/Sunday/days off; during the week	Frequency of visits
How do you rate the aesthetic value of lawn areas? / Why?	1—great; 2—good; 3—sufficient; 4—low; 5—bad / well maintained; poorly maintained; tall grass; presence of flowers and bees; other	Quality perception
How do you rate the aesthetic value of woodland areas? / Why?	1—great; 2—good; 3—sufficient; 4—low; 5—bad / well maintained; poorly maintained; presence of dead wood; presence of birds and mammals; other	Quality perception

How do you rate the usability of the main routes consisting of lines of trees? / Why?	1—great; 2—good; 3—sufficient; 4—low; 5—bad / well maintained; poorly maintained; I reach my favorite places; not suitable for use by all; other	Quality perception
How do you rate the aesthetic value of water bodies? / Why?	1—great; 2—good; 3—sufficient; 4—low; 5—bad / well maintained; poorly maintained; it is difficult to enjoy all the areas; presence of fishes and waterfowls; other	Quality perception
Are you aware of the paid cultural activities that take place within the area?	yes/no	Park knowledge
Have you ever participated in a cultural activity?	yes/no	Involvement

Table 3. Descriptive statistics about the age and gender of park users (N = 232 completed questionnaires).

Age	**Number**	**Percentage**
Less than 18	37	16%
Between 18 and 30	39	17%
Between 31 and 45	36	16%
Between 46 and 60	58	25%
Older than 60	62	27%
Gender		
Female	131	56%
Male	101	44%

Aesthetic quality perception was then measured adapting the items (questions) used by Dimitrakopoulos et al. and Vodouhê et al. [16,27]. In detail, four items (questions) were developed to measure such quality perception, and respondents graded their opinion on using a 5-point Likert scale (ranging from "great quality" to "bad quality"). Answers were statistically analyzed. Items were merged into a single factor by first checking the internal consistency using Cronbach's Alpha, which equaled 0.78. In most social science studies, a reliability coefficient greater than 0.70 is considered acceptable. Then, the analysis of the determinants of quality perception was conducted by a multinomial logistic regression analysis, more in detail, due to the categorical nature of the variables we decided to perform an ordinal logistic regression. Such a method allows analyzing the relation between a dependent variable and several independent variables, indicating whether the independent variables have a significant relationship with a dependent variable and the relative strength. In our investigation, the measure of quality perception was used as a dependent variable. On the other hand, the remaining variables assessed in the questionnaire were used as independent variables. As Peterson and Harrell [28] suggest, the main assumption of the regression model is represented by the fact that the cumulative odds ratio for any two values of the covariates is unchanging across response categories. The likelihood ratio test to assess such an assumption was used showing no main concerns. Moreover, the presence of multicollinearity was checked by calculating the tolerance and variance inflationary factors (VIFs) for all variables; no problems were underlined. Finally, the presence of common method variance also was assessed by conducting Harman's single-factor test and the results indicate that common method variance does not occur.

2.2.3. Participatory Mapping

The third phase was participatory mapping [29,30], which allowed users to indicate their preferred area with a pencil on a map.

Participatory mapping involved 137 respondents. This information was used to understand which places are more visited and appreciated in order to set up priorities in future management practices, considering these anthropogenic pressures and expectations. The answers obtained were related to eight specific points of the park such as areas of historical and cultural interest or areas equipped for stopover. From these points, a 500 m buffer was created to analyze the land use around the preferred points [18]. QGIS software (version 2.18.1) (Open Source Geospatial Foundation, Beaverton, Oregon, USA) was used for mapping elaborations.

In order to study the relationship between landscape diversity and users' aesthetic preferences, the buffer zones were ranked along a gradient of landscape diversity and evenness. To this end, the calculated indices are the number of patches, Shannon evenness index and Simpson's index using LecoS, a specific plugin for QGIS [31,32]. Shannon evenness shows the distribution of the patches within the total area. It varies between 0, when the landscape contains only one patch (no diversity), and 1, when the distribution of each class surface is equitable. Simpson's index defines the probability that two objects, selected at random, belong to different categories. It varies between 0 to 1 (when the diversity is higher). The indexes increase under situations where the number of land cover types increases, or/and the equitability of the distribution of land among the various cover types increases [33].

Results were qualitatively compared with user's aesthetic preferences and adopted management regimes.

2.3. Ethics Statement

The park managers expressed their consent to the use of information for research purposes. The information acquired concerns only the management practices of the area, which is public information. No personal data were requested and acquired. Moreover, the questionnaires to users were self-completion questionnaires and did not require the presence of researchers. The questionnaires were freely available, and data were anonymously collected only for research purposes, as mentioned. No data on respondents' health were collected and no contact between respondents and researchers occurred.

3. Results and Discussions

3.1. Interviews of Park Managers

Over time, the La Mandria Park has undergone deep transformations, especially in the XIX and XX Centuries. As highlighted by Laurora et al. [22], there have been significant changes in the territory due to agricultural practices, hunting and forestry activities. Nowadays, management is fundamental for landscape conservation and maintenance of the ecological characteristics. The main management operations carried out in the park, referred to as the four landscape elements, are summarized in Table 4.

Table 4. The main management operations, referred to as the four landscape elements.

Elements	Management Operations
Lawns	Mowing of lawn: three times per year
Woodlands	Pruning, felling, removal of trees; standing dead trees (*Quercus robur* L.); sale of standing timber (*Quercus rubra* L.)
Lines of trees along routes	Visual Tree Assessment; pruning
Water bodies	Chemical-physical analyses

The park does not have a management plan. The management of the lawns is almost entirely delegated to farmers. In the lawn areas (not irrigated), nearly 20,000 q/year of hay on approximately 320 ha are produced. Farmers have obligations under the management contract, such as ensuring the presence of buffer strips at the edges of the fields, so as to preserve biodiversity. Access to almost all of the lawns is prohibited, with the exception of specially marked areas equipped for rest and refreshment.

Woodland management concerns: trees present in wooded areas; lines of trees; monumental trees. Trees in wooded areas can be subjected to three main management practices: i) pruning, felling and removal of trees, if necessary; ii) the dead trees are left on the ground or some trees are managed as "totem trees" (standing dead tree), so as to provide habitat for protected species; iii) standing timber can be sold, especially invasive species, such as *Quercus rubra* L.

Regarding lines of trees, a visual level check is carried out and, if necessary, a Visual Tree Assessment (VTA) [34] is carried out, with any subsequent pruning. In this case, the trees are checked and the operations carried out are monitored. As far as the monumental trees are concerned, the main access avenue to the area (now closed to use for safety reasons) is one of the most valuable naturalistic sites of the park for the presence of 96 secular *Quercus robur* L.—one-third of which have diameters between

100 and 140 cm. These trees host a rich entomofauna, including the *Osmoderma eremita* (Directive 92/43/EEC), indicating a high species richness, as it is an umbrella species [35].
The management of woodlands and lines of trees must consider two fundamental aspects. First, the presence of *Osmoderma eremita* is associated with a category of high falling risk of trees and this entails a risk for the use of specific areas [36]. Second, the management of invasive species must be accurate, as a pedological study conducted in the park on low fertility well-developed soils shows how the presence of invasive species, such as *Quercus rubra* L., could change the ecosystem functionality by complicating the restoration of the original forests [37].
There is currently no protocol for pests and disease control, but targeted measures are taken to remove *Quercus rubra* L. and *Prunus serotina* Ehrh. With regards to water body management, chemical-physical analyses have been carried out, not on a regular basis, in order to monitor their quality over time.

3.2. Questionnaires to Users

During the period April–November 2018, 232 questionnaires were collected.
The sample of respondents comes from different territories: 12% live in the municipalities bordering La Mandria Park, 54% from other municipalities of the Metropolitan City of Turin, 22% from Piedmont, 10% from other Italian regions and 2% from other countries (Switzerland, Germany and USA). The sample's level of education is quite varied: 5% elementary school; 25% secondary school; 37% high school; 19% scientific university; 12% humanistic university. In total, 88% of the people know that La Mandria Park is a protected area. The frequency of visits to the park is divided as follows: 38% less than once a year; 23% up to 10 times a year; 40% more than 10 times a year. There are no differences between people who visit the park during public holidays or during the week; neither are there differences in the use of the park in the morning or in the

afternoon. More than 60% of the sample are aware of the cultural activities proposed in the park, but only the 32% actively participate in them. The main reason seems to be related to hours of activity that are not in line with working hours. A lack of publicity of the events has been pointed out too.

By analyzing answers to the four questions referring to quality perception of the area, Table 5 reports the frequency (%) of the selection of the options based on a 5-point Likert scale, ranging from "great quality" to "bad quality".

Table 5. Frequency (%) of selected options (based on a 5-point Likert scale, ranging from "great quality" to "bad quality") of perceived aesthetic quality in relation to four landscape elements (N = 232).

Elements	Frequency (%) of Selected Options				
	Great	Good	Sufficient	Low	Bad
Lawns	31.7	49.8	13.7	3.5	1.3
Woodlands	22.3	49.1	18.9	6.9	2.8
Routes	35.6	46.2	13.9	2.8	1.5
Water bodies	20.2	46.3	20.5	8.0	5.0

The four landscape elements are perceived as of good quality by the respondents. We can see a tendency to great quality especially with regard to lawns and routes, while there are higher percentages of selection of the categories of low and bad quality for woodlands and water bodies.

In total, 80% of users considered the lawns of good and great aesthetic quality, referencing good management operations and the presence of flowers and insects. Those who perceived low or bad quality, identified the presence of tall grass among the main reasons.

As for the woodlands, in total, 50% of respondents indicated that they are well maintained. However, the presence of dead wood was perceived as a

negative element for the aesthetic quality. Nevertheless, the presence of birds and mammals is related to a great level of perception.
Furthermore, the perception of the routes, characterized by the presence of lines of trees, is in line with that of the lawns and the woodlands. Approximately 60% of respondents indicated that the routes are well maintained, and low or bad quality perception is mostly related to limits in accessibility.
As far as the water bodies are concerned, the perception of quality differs a little from the other three landscape elements. The respondents who had a medium-high quality perception (55%) indicated that the water bodies are well maintained and that the presence of fish and water birds is a positive value. Respondents with a sufficient, low or bad quality identified that the main reasons are linked to a low management level and to a difficulty in use, because not all water bodies are easily accessible or visible.
Using the same data, the mean aesthetic quality perceived by users is 3.92, thus expressing a good value.
In order to develop a model able to identify the determinants of aesthetic quality perception, a multinomial logistic regression was performed (Table 6).

Table 6. Results of the regression analysis.

Variable	Coef.	Std. Err	z	[95% Conf	Interval]
Proximity	0.0770	0.0866	0.89	−0.0928	0.2469
Age	−0.0679	0.0599	−1.13	−0.1854	0.0495
Education	0.0787	0.0675	1.17	−05361	0.2111
Gender	0.5123**	0.1631	3.14	0.1926	0.8321
Environmental knowledge	0.2706	0.2742	0.99	−0.2667	0.8081
Regular visitor	−0.1652**	0.0710	−2.33	−0.3044	−0.0260
Park knowledge	−0.1151	0.1690	−0.68	−0.4465	0.2163
Involvement	0.3925*	0.1838	2.14	0.0322	0.7528

*p < .01; **p < .001

Results highlight several interesting aspects. In particular, women have a slightly higher perception of quality, which is in line with other studies [38]. Several studies have demonstrated that women are more strictly connected to nature and its values [39], and therefore they perceived and experiment higher environmental pollution and natural resources depletion [40]. Women are more sensitive to ecological aspects in mobility [41]; use distinctively natural space [42]; have a very impressive view of natural ecosystems [43]; and are deeply touched by climate change dynamics [44]. This study's findings on a gendered perception of esthetic quality of the protected area support conclusions developed by MacBride-Stewart and colleagues [45]. Therefore, they suggest women have a higher perception of cultural ecosystem services (i.e., give more value to and achieve more benefit from). Our study supports in a quantitative way that women's perception of aesthetic value of a natural space is higher than that of men. Therefore, it could be assumed that they benefit more from the cultural ecosystem services provided by a given ecosystem. The other variables did not show significance in the regression (i.e., age, education, proximity to the park, environmental and park knowledge). Moreover, the results outlined that being a regular visitor resulted in negative and statistically significant results as a predictor of quality perception. Thus, visiting the park only a few times results in a higher quality perception. Such a link has been marginally investigated by the current literature and the few studies on the topic are in contrast with our finding. For example, Chen et al. [46], analyzing the tourist satisfaction in visiting the Kinmen National Park (Taiwan), showed that there were no significant differences between quality perception and number of visits to the park. Similar results were found by Akama and Kieti [47] in analyzing tourist satisfaction and quality perception in Tsavo West National Park (Kenya).

Finally, users involved in the park activities have a slightly higher perception of the quality of the park. Relationships between aesthetic quality perception and users' involvement in recreational activities seems to be largely unexplored. Nevertheless, a number of previous studies have argued that direct sensory experience can be a crucial way for determining environmental quality perception [48,49]. Other studies have measured a positive and significant effect between perceived aesthetic beauty and perceived community fulfillment [50]; between engagement in outdoor leisure and water quality [51]; and between recreational activities and pro-environmental behaviors [52].

3.3. Participatory Mapping

The participatory mapping phase involved 137 users, who selected their favorite places in La Mandria Park on a map. Each person could select more than one favorite place. Favorite places have been identified as points. Eight favorite places were chosen, with a total of 221 selections. Around each selected place, a 500 m buffer has been created to highlight what was present in the surrounding area.

The buffers were crossed with the land use map (Figure 3A) and with the map of the level of protection (Figure 3B). This procedure was useful for analyzing the main ecological characteristics of each buffer area.

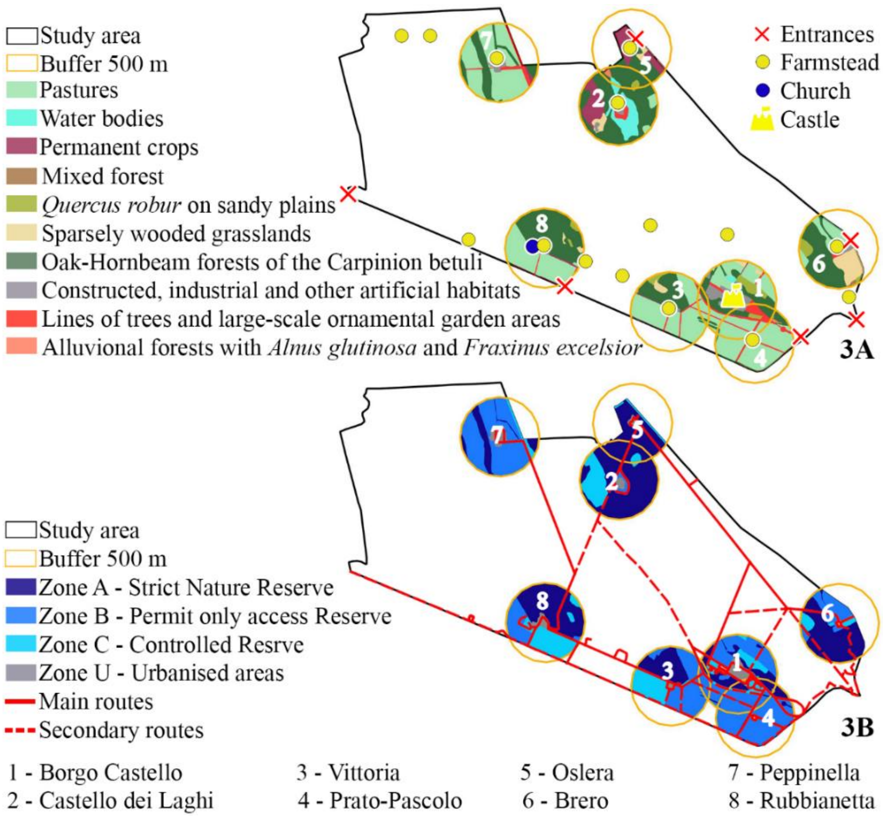

Figure 3. Land use in the eight buffers related to favorite places (3A) and levels of protection divided by zones (A, B, C, and U) (3B). The main cultural elements and routes were reported.

For each buffer, the percentages of areas by zones, A, B, C, and U, are reported in Table 7. The percentages of areas affected by land cover categories, the number of patches, Shannon's equitability index (DIV_EV) and Simpson's diversity Index (DIV_SI) of patches have been calculated (Table 8), using LecoS.

Table 7. Percentages of buffers affected by zones (A, B, C, and U).

	Borgo Castello (N[a] = 44)	Castello dei Laghi (N = 44)	Vittoria (N = 30)	Prato-Pascolo (N = 29)	Oslera (N = 29)	Brero (N = 19)	Peppinella (N = 14)	Rubbianetta (N = 12)
	%	%	%	%	%	%	%	%
Zone A[b]	28,5	76,1	32,2	19,7	93,2	69,2	20,8	54,4
Zone B	45,7	3,7	40,8	70,9	0,0	21,7	68,2	15,9
Zone C	19,2	18,8	25,7	8,4	4,2	8,3	6,2	26,8
Zone U	6,6	1,4	1,4	1,1	2,6	0,8	4,8	3,0

[a] N: number of selections. [b] A—strict nature reserve; B—permit-only access reserve; C—controlled reserve; U—urbanized areas.

Table 8. Land cover categories, number of patches (N), Shannon's equitability index (DIV_EV) and Simpson's diversity index (DIV_SI) of favorite places selected by users (1-8).

		Patches (N)							
	Favorite places	***1*** [a]	***2***	***3***	***4***	***5***	***6***	***7***	***8***
Land cover categories	Water bodies	1	7	0	3	5	0	0	0
	Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*	1	2	1	1	1	0	0	1
	Constructed, industrial or other artificial habitats	3	2	2	3	2	2	1	1
	Lines of trees and large-scale ornamental garden areas	3	1	2	2	1	2	3	3
	Sparsely wooded grasslands	2	1	1	0	29	2	0	2
	Permanent crops	1	2	2	0	2	0	1	3
	Pastures	11	2	16	5	0	9	5	3
	Oak-hornbeam forests of the *Carpinion betuli*	6	1	6	4	18	2	4	2
	Quercus robur on sandy plains	2	1	1	1	1	2	0	2
	Mixed forest	0	0	15	5	0	1	0	12
	Total number of Patches	30	19	46	24	59	20	14	29
	DIV_EV	0.69	0.64	0.52	0.47	0.62	0.73	0.58	0.50
	DIV_SI	0.72	0.63	0.57	0.47	0.64	0.69	0.48	0.59

[a] 1—Borgo Castello; 2—Castello dei Laghi; 3—Vittoria; 4—Prato-Pascolo; 5—Oslera; 6—Brero; 7—Peppinella; 8—Rubbianetta.

Results show that four selected places are characterized by more than 50% of the surface in zone A. All the selected places are characterized by a percentage higher than 70% of zone A plus zone B. It can therefore be assumed that the different levels of protection, and therefore of management, of the La Mandria Park influence place preference. Specifically, it is possible to notice that respondents prefer points from which it is possible to observe low maintained areas where access requires a permit or is prohibited (zones A and B). This could also be due to the fact that there are some known beneficial physiological effects that occur when a man observes wilderness [53].
With the aim to understand whether the preference of a place was influenced by a higher or lower number of patches, and therefore whether the buffers were more or less heterogeneous in the composition of land cover categories, an ecological analysis was performed. It is possible to point out that the places preferred by the respondents are not characterized by having a similar total number of patches, nor by having in common similar numbers of patches covered by the same category (Table 8).
However, it is possible to highlight how the three land cover categories always present within the buffers are: oak-hornbeam forests of the *Carpinion betuli*; constructed, industrial or other artificial habitats, and lines of trees and large-scale ornamental garden areas. Moreover, the presence of pastures seems to characterize the spatial composition of the preferred places; in fact, the number of pasture patches is higher than the number of other land categories and they are present in seven buffers out of eight.
Analyzing the DIV_EV and the DIV_SI, it is possible to note that the DIV_EV values of the buffers are between 0.47 and 0.73, while the DIV_SI values are between 0.47 and 0.72. The mean values of DIV_EV and DIV_SI are, respectively, 0.63 and 0.68. These values are comparable to those of other Natura 2000 areas close to urban centers in Italy [54,55]. It is interesting to note that the general index of perceived

esthetic quality (3.92—good) is substantially aligned to medium/medium–high ecological values.

The highest ecological values were found in the buffers Borgo Castello and Brero. These areas do not have strongly dominant classes and are characterized by richness in the composition of the environmental mosaic and a tendency toward the equidistribution of cover categories. A reverse trend was found in the Prato-Pascolo buffer, which has the lowest values of DIV_EV and DIV_SI.

This outcome is also supported by the questionnaire results, which show that environmental and park knowledge are non-significant variables. This is probably due to the fact that some services offered by the anthropic component, and not by the strictly environmental one, favor the choice of preferred places. It is possible, however, to highlight that even if the choice of the preferred places does not seem to be based exclusively on ecological characteristics, the buffers around the chosen points are characterized by open (mainly pastures) and wooded patches. This result is also found in the work by Hakim [56], in which it is reported that agroforestry landscapes provide man-made ecosystems that can enhance tourism.

This outcome is also interesting from an ecological point of view. From a study conducted on dung beetle within the park [57], it is possible to evince how the patchy ecosystems, made up of open and wooded patches and inhabited by several ungulate species, can support the highest levels of diversity.

The results could lead to the assumption that there are many factors that contribute to the choice of the preferred place within La Mandria Park: the possibility to observe places where management is reduced and where it is difficult to access; and the constant presence of farmsteads, castle, oak-hornbeam forest and lines of trees (Figure 3A).

It is important to note that through the participatory mapping phase, specific preferred points were selected by users. These points are assumed to be representative of a wider areas (500m buffer zones). Therefore, the choice of preferred places by users is associated with the benefit obtained from the provision of ecosystem services (especially cultural ones) in those places, although it is necessary to highlight how the links between well-being, historical/cultural values, ecosystem services and preferred places are complex [18].

4. Conclusions

The management of green areas requires a multi-stakeholder approach and must be addressed from a socio-ecological point of view, increasing human well-being conditions for future generations [58]. In particular, the integration and inclusion of different stakeholders (e.g., farmers and users) in the process of planning, managing and monitoring of agroforestry landscapes is a winning solution [59].

Moreover, knowledge of users' perceptions can produce useful information that could be integrated into the decision-making process and lead to the resolution of conflicts between the users' will and the park managers' needs in order to positively improve the users' attitude towards conservation measures [27]. However, within the limits of this study, it is possible to highlight that not all the results underlined by the questionnaire can be reflected in practical actions that can be used in a management plan. Nevertheless, an effective communication plan with users is essential to help them to be more aware and informed.

In order to be more effective, these processes should also consider a gendered perspective. In fact, our study shows that women’s perception of the aesthetic value of a natural space is higher than men’s perception. It would be interesting to analyze in further studies whether the perception of other cultural ecosystem services is also higher and whether ecosystem disservices are also more deeply perceived.

Users involved in the park activities better perceived aesthetic quality, while regular visitors had a worse perception. This evidence might be related to the aspects investigated as proxies of quality perception, by the

natural park under analysis and the related attraction offered and by the other cultural variables.
Further research is needed to deepen this relationship, in particular by framing the analysis on the influence of the 'first time impression' on specific natural and historical sites such as La Mandria Park. However, similar consideration can be made regarding the existing tie between the activism in Natura 2000 (cultural and recreational) activities and aesthetic quality perception. It could be useful to investigate whether some kinds of activities are more strictly correlated with a higher aesthetic quality perception and how to promote these results in communication and in stakeholder engagement processes. Moreover, the socio-cultural profile of users of Natura 2000 metropolitan sites should be compared with that of urban parks that are not protected.
In addition, evidence on the perceived aesthetic quality of an area should play a critical role in defining management priorities and in designing communication activities related to objectives, problems and other issues connected to the governance of the site [60]. This could be useful to achieve a more aware and responsible citizenship, capable of the sustainable management of its territory and participatory choices [61].
Therefore, Natura 2000 sites included in the urban context have to satisfy two main requests: to be a protected area with great ecological characteristics; to provide services (tourist facilities, cultural and recreational activities) that allow full enjoyment on visits.
From the results obtained through the different methods of investigation, it can be stated that policies and investments aimed at maintaining habitat quality and the inclusion of multiple ecosystem services in conservation planning approaches [62,63] are needed.
The proposed methodology must be continued over time in order to collect more information, involving more stakeholders, with the aims to assess the provision of other ecosystem services and to co-design a long-term management plan, an essential tool to reconcile nature conservation with user enjoyment.

Acknowledgments: Thanks to Enrico Pomatto for his contribution in map elaboration and Walter Gaino for helping us in collecting questionnaires. We are grateful to Giuseppina Rezza, Antonella Pogliano, Roberto Filipello (Managers of Ente di gestione delle aree protette dei Parchi Reali) and all the respondents.

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Chapter 4

Residential Greenery: State of the Art and Health-Related Ecosystem Services and Disservices in the City of Berlin

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Sustainability 2019, 11(6),1815; https://doi.org/10.3390/su11061815

Abstract: Inclusively accessible green areas are essential for livable cities. The residential greenery on a door's step of urban dwellers has rarely been the subject of research. Here we provide insights into the state of the art of residential greenery in Berlin, Germany. We focus on socially disadvantaged neighborhoods exposed to high loads of environmental stressors and belonging to four relevant building types of Central European cities. 32 plots in eight sample areas were randomly chosen and surveyed during 2017 and 2018. We surveyed the presence of structural elements, the presence and abundance of woody species and the health-related ecosystem (dis-)services (i.e., species' air filtration and allergenic potential). We analysed the similarity among tree species to assess plant use patterns. The air cleaning and allergenic potential of woody species were assigned based on literature. In order to discuss strategies to improve residential greenery, we performed an analysis of strengths, weaknesses, opportunities and threats of these green spaces. We revealed a high dissimilarity of woody species assemblages across sites and within different building types, indicating no common plant use fashion. Recorded species provide moderate to high air filtering capacity. One to two third of all trees have a high allergenic potential that has to be addressed in future plant use decisions. Bike racks, benches, lights and playgrounds are common elements, whereas bioswales, facade-bound greening, atrium, fountains or ponds are rare. Their implementation can enhance the health and wellbeing of local residents. Building-attached greenery can improve densely built up areas of the Wilhelminian period, whereas space-intensive measures can be implemented in the spacious greenery of row-buildings settlements of the 1920s–1970s and of large housing estates of the 1970s–1980s. We revealed a high motivation for (co-)design and care by residents and discussed strategies on transformation towards multi-functional, healthy and biodiversity-friendly residential greeneries.

Keywords: allergenic potential; ecosystem services; green gentrification; wellbeing; multifunctional living environments; urban horticulture

1. Introduction

The quality of the living environment, especially in urban areas, has become an important issue for residents and a fundamental theme in spatial planning [1]. Low quality of air, water, climate and the decreasing availability of green space per capita affect the physical and mental health of urban residents [2–5]. Consequently, urban planners and policymakers have to address easy access and high quality green areas as a part of common health promotion [5].

Contact with urban nature such as public parks fosters wellbeing and human health in cities [6,7]. Access to green space is associated with a greater probability of being physically active [5]. Moreover, species richness present in a green area and perceived by local people is positively linked to a greater connection with nature and a better site satisfaction [8]. If the environment is aesthetically appealing and space allows opportunities for gardening and for recreation, people are encouraged to visit it, improving social cohesion within the neighborhood, which in turn can generate beneficial effects on wellbeing [9,10]. In addition, trees provide several ecosystem services that contribute to increase human wellbeing and can mitigate the negative impacts of urbanization, e.g., [11,12]. Citizens seem to have a greater sense of community when more commonly shared green space is around their house [13]. Up to now urban planning has not taken the development of a city as a socio-ecological and macroeconomic system into proper consideration [14].

Urban greenery research generally focuses more on parks and public gardens [15–17], whereas the residential greenery has not been investigated. We defined residential greenery as mainly semi-public green spaces with direct connection to residential buildings, regularly created during the construction of the buildings with great importance for less-mobile people, for children and for after-work recreation [18].

To close this research gap, our study focused on the residential greenery of the four most relevant building types in Berlin, which are also representative of other Central European cities. As quality of and access to local green affects mainly low-income people [19], we focused our analysis on disadvantaged neighborhoods in Berlin. Our objective was to provide a description of the status quo of the residential greenery. We focused on tree and shrub composition and the structural elements (e.g., benches, paths, parking areas) that determine health-related ecosystem services such as cooling and air filtering and foster physical activity and the wellbeing of residents. We also included the allergenic potential of the plants as a health-relevant disservice [20–23]. We explored the strengths, weaknesses, opportunities and threats (SWOT analysis) of residential greenery to develop general strategies to enhance health-relevant ecosystem services and social cohesion.

2. Materials and Methods

2.1. Study Area

Berlin, the capital of Germany, is the largest city in the country, with 3.65 million inhabitants [24]. It covers an area of approximately 892 km^2, resulting in a population density of 4170 people/km^2. Two thirds of the population are living in housing complexes of modernism of four different eras: 1. Five story block-edge development with cross buildings enclosing several courtyards (the classical Wilheminian tenements of the 1870s to 1920s, Figure 1A); 2. five story block-edge development with green courtyards (the reformed block edge developments of the 1920s to 1940s, Figure 1B); 3. up to five story row-buildings settlements of the 1920s to 1970s (Figure 1C); and 4. large multi-storied housing estates of the 1960s to 1980s (Figure 1D).

Berlin is widely acknowledged as a green city and meets the planning target of 6m^2 of green space per inhabitant [25]. The city administration aims to face the increasing demand of affordable housing by intensified internal development and consolidation, leading to greater pressure towards urban green spaces within the city namely towards the semi-public residential greenery.

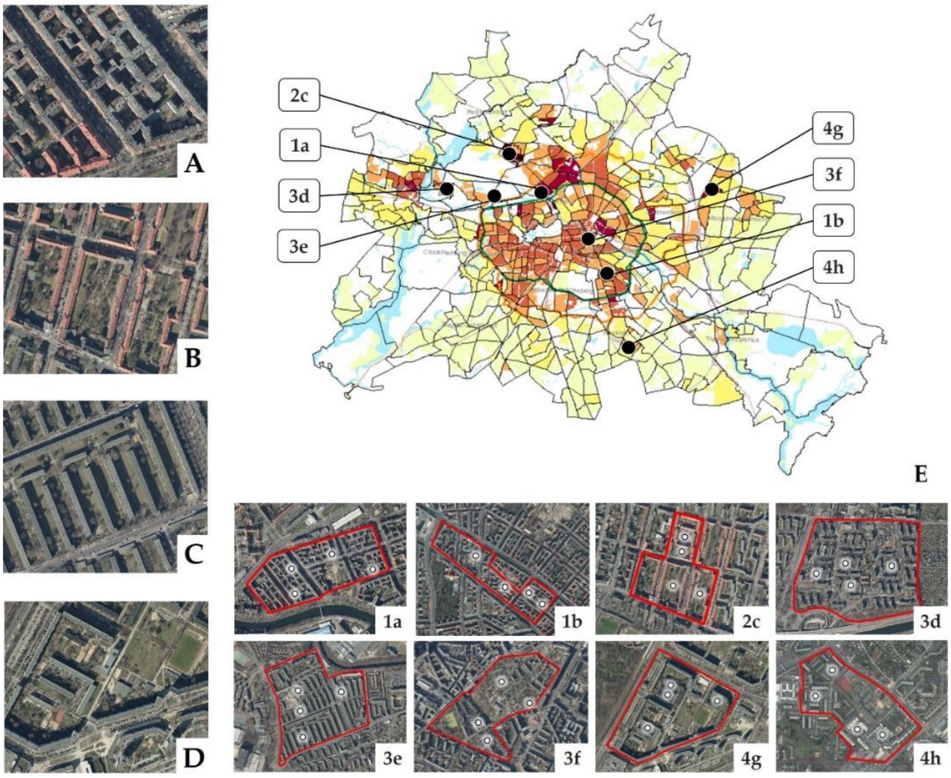

Figure 1. (A–D) Overview of typical building structures of Berlin ((**A**) dense and closed block-edge development from 1870s to 1920s; (**B**) block-edge development with large green backyards from 1920s to 1940s; (**C**) parallel and free row development with a landscaped residential greenery from 1920s to 1970s; (**D**) large housing estates with towers and high rise buildings from 1960s to 1980s). (**E**) Study areas in Berlin in residential areas with low social status and high level of environmental stressors, based on Berlin's Map of Environmental Justice [26]. For indicator values of each study area see Table 1. Red lines indicate the study areas (1a, Sprengelkiez, Wedding; 1b, Ideal-Passage, Neukölln; 2c, General Barby Siedlung, Reinickendorf; 3d, Paul-Hertz-Siedlung, Charlottenburg; 3e, Haselhorst, Spandau; 3f, Alte-Jakobstrasse, Mitte; 4g, Marzahn; and

4h, Gropiusstadt, Neukölln). White spots indicate the sample plots. Adapted from Fisbroker/Umweltatlas Maps of Berlin [26].

2.2. Study Design and Data Analysis

Firstly, we analysed the map of different building structures and selected all areas of the housing complexes of the four main construction eras in Berlin. Then, using the Berlin map on environmental justice [26], we assigned the health-relevant characteristics (i.e., air and noise pollution, bioclimatic stress, access to green space and social status) to these areas. The noise indicator estimates the average noise load. Bioclimatic stress is estimated by the thermal index PET (Physiologically Equivalent Temperature). Air pollution was determined by considering the highest level of $PM_{2.5}$ or NO_2. The access to green areas describes the availability of green spaces for a given housing block. The social status index is based on unpublished data from the Berlin monitoring on social urban development in 2013 and is calculated from the status indicators (i.e., unemployment and child poverty). Finally, we selected and characterized eight study areas with a low social status index, high levels of environmental stressors and low access to public green (Table 1 and Figure 1).

Single houses or flats within houses of the classical Wilheminian tenements are partially owned by natural persons, whereas the other areas are commonly owned and managed by different real estate companies. In contrast to other European countries, 86% of all apartments in Berlin are rented and not owned by the residents [27].

After defining eight study areas in Berlin, four sample plots were randomly chosen within those sites (Figure 1E). To exclude edge effects of neighboring public green spaces, we excluded sites where there are public green spaces situated at a distance of less than 500 m from the center of the housing blocks, which corresponds to five to ten minutes walking, and are, therefore, easily accessible to local residents. The sample plots correspond to the central space between two or more communicating building rows. The geometric shape of each sample was kept as simple as possible, following building edges, fences and paths. In each plot we accounted the structural elements of the residential greenery by field surveys: Number of green balconies, bioswales, laundry drying areas, ground-based and façade-bound greenery, atrium, fountains, ponds, parking areas, paths, playgrounds, bike racks, lights and benches.

We recorded the presence and abundance of tree species in each sample plot. Mature and newly transplanted trees were considered. We analyzed the degree of similarity among the tree species present in the eight sample areas, performing the Jaccard and the Bray-Curtis indexes, two widely used abundance-based similarity indexes [28]. For calculation we used the software Past 3.14 [29]. The Jaccard index (d_J) is related to the total number of species (presence/absence) that the sample areas have in common. For binary data, the absence is coded as 0 and the presence is coded as 1. When comparing two rows, a match is counted for all columns with presences in both rows. Past 3.14 uses M for the number of matches and N for the total number of columns with a presence in just one row; so that we have:

$$d_J = M/(M+N) \tag{1}$$

The Bray-Curtis index (d_{BC}) is based on the abundance of species:

$$\boldsymbol{d_{BC} = 1 - \frac{\sum_i |x_{ji} - x_{ki}|}{\sum_i (x_{ji} + x_{ki})}} \tag{2}$$

where x_{ji} represents the entry in the i^{th} row and j^{th} column of the data matrix. Similarly, x_{ki} is the count for the i^{th} species in the k^{th} sample.

The presence/absence of shrub species was also surveyed. The abundance was not calculated because shrubs were often found in large and dense planting areas with mixed species. The woody species seedlings (born spontaneously) were not considered as they are subjected to maintenance operations, such as the mowing of lawns. Lawns were always present in the sample plots, except for Sprengelkiez and Ideal-Passage Neukölln, as the general matrix of residential greenery. The field data collection was carried out from April to August 2017 and 2018.

We evaluated health-related ecosystem services of woody species based on a literature evidences analysis. Reference selection was carried out using the PRISMA Protocol [30]. Three search engines were used: PubMed, Web of Science and JSTOR. The keywords used were: "Tree" AND "Ecosystem Services" AND "City" AND "Health". Taking into consideration the papers published in English in the last 20 years, 1466 titles and abstracts were analyzed. In total, 17 scientific papers have been selected to cover three categories of benefits provided by woody species in urban environments. Trees, depending on species, considerably remove air pollution (e.g., [4,8,14,31–33]). The main difference is between conifers (high capacity of air pollution removal) and broadleaf trees. The latter are divided into deciduous (moderate capacity) and evergreen (high capacity) trees (e.g., [31,32]). Bioclimatic stress is reduced by the shading and cooling of trees (e.g., [12,34–36]). In addition, trees provide a wide set of social benefits such as building a stronger sense of community, improving overall wellbeing and providing opportunities for residents to experience nature [11,37–41]. Ecosystem disservices, such as those related to the allergenic potential of trees, cannot be neglected [42–45].

Consequently, the surveyed woody species in the 32 sample plots were analyzed, assigning a level of allergenic and air pollution removal potential, based on the published literature.

Table 1. General characterization of study areas regarding building type and period, study area, code used in this study (see Figure 1), health relevant characteristics (i.e., air and noise pollution, bioclimatic stress, access to green space and social status), total sample area, population density and percentage of pervious and impervious surface (adapted from [26]). For details on relative environmental justice indicators see the Materials and Methods section. We surveyed two types of block-edge development (Type I: Dense and closed block-edge development from the 1870s to 1920s; and Type II: Block-edge development with large green backyards from the 1920s to 1940s, see Chapter Study Area and Figure 1A, B).

Building type (construction period)	Study area	Code	Noise	Air pollution	Access to public green spaces	Bioclimatic stressors	Social status index	Total sample area (ha)	Number of residents per ha	% of pervious mean surface	% of impervious mean surface
Lock-edge developments (Type I, 1870s–1920s)	Sprengelkiez, Wedding	1a	Low	High	Low	High	Low	16.5	517	22	78
	Ideal-Passage, Neukölln	1b	Medium	High	Low	High	Low	12.6	533	17	83

(Type II, 1920s–1940s)	General Barby Strasse, Reinickendorf	2c	High	High	Low	High	Low	9.6	201	51	49
Row-building settlements (1920s–1970s)	Paul-Hertz Siedlung, Charlottenburg	3d	Medium	High	Medium	High	Low	35.5	208	57	43
	Haselhorst, Spandau	3e	High	Medium	High	High	Low	33.8	232	52	48
	Settlements along Alte-Jakobstr., Mitte	3f	High	High	Medium	High	Medium	28.7	315	61	39
Large housing estates (1970s–1980s)	Marzahn	4g	Medium	High	Low	High	Low	30	337	55	45
	Gropiusstadt, Neukölln	4h	Medium	Medium	Medium	High	Low	23.6	312	55	45

In order to discuss the strengths, weaknesses, opportunities and threats of residential greenery and to point out the strategies to improve it, a SWOT/TOWS analysis was performed [18,46].

3. Results

3.1. Structural Elements and Woody Species Composition

Block-edge developments of the Wilhelminian era (Figure 1A) have the highest population density and lowest percentage of pervious surface compared with other types (Table 2). This results in the lowest availability of residentially greenery for local residents. In the following construction period of block-edge developments with large green backyards in the 1920s to 1940s (Figure 1B), half of the areas are unsealed. The percentage of pervious surface of the other building types is similar or higher than in this type (Table 1). Population density depends on the floor numbers and is higher in the large estates of Marzahn and in the row-building settlements of Mitte (Figure 1: 3f, 4g) than the other same-aged building types considered.

Green spaces are an integral part of a town and have characterized residential greenery since the 1920s (Table 2). Lawns were always present as the general matrix of residential greenery (except in Sprengelkiez and Ideal-Passage, both from the Wilhelminian era). We identified a set of elements almost present in the residential greenery of all construction periods including bike racks, benches, lights and playgrounds. The number of benches, bike racks and lights varied largely between the areas and depended on the average size of the sample plots (Table 2). The laundry drying areas, often present in Germany, were found in the study areas of Alte Jakob Str., Mitte and Marzahn. Bioswales were only located in the sampling area of Haselhorst. Some elements were not detected: Façade-bound greening, atriums, fountains and ponds.

The tree and shrub species richness was similar in all building types (Table 3). In the 32 sample plots, 60 species of plants were identified, with 523 trees sampled (Appendix A). The most common species were:

Acer platanoides L., *Betula pendula* Roth, *Quercus robur* L. and *Tilia cordata* Mill. The rare species were: *Corylus colurna* L., *Fagus sylvatica* L., *Alnus glutinosa* (L.) Gaertn. and *Celtis australis* L. Considering the number of trees of each species in each sample plot, we could determine the most frequent tree species. In some cases, the presence of one common species (the number of individuals is at least double compared with the other species) was detected, such as *Aesculus hippocastanum* L. in one of the block-edge developments of the Wilhelminian era (i.e., Sprengelkiez Wedding) and *Pinus sylvestris* L. in the green spaces around the large housing estates of Gropiusstadt (Neukölln)

Table 2. Number of the structural elements of the residential greenery recorded in the sampling areas of this study (for details see the Materials and Methods sections, Table 3 for most frequent species and Appendixes A and B). We surveyed two types of block-edge development (Type I: Dense and closed block-edge development from the 1870s to 1920s; and Type II: Block-edge development with large green backyards from the 1920s to 1940s, see Chapter Study Area and Figure 1A, B).

Building type (construction period)	Neighborhood	Code	Mean sample plot size (m^2)	Green balconies/all balconies (%)	Bioswales	Laundry drying areas	Ground-based greening	Parking areas	Paths	Playgrounds	Lights	Bike racks	Benches
Block-edge developments (Type I, 1870s–1920s)	Sprengelkiez, Wedding	1a	620	17/40 (43%)	0	0	1	1	0	1	3	8	2
	Ideal-Passage, Neukölln	1b	440	0	0	0	0	0	2	1	0	13	3

(Type II, 1920s–1940s)	General Barby Strasse, Reinickendorf	2c	8430	123/163 (75%)	0	0	0	0	3	2	9	8	21
Row-building settlements (1920s–1970s)	Paul-Hertz Siedlung, Charlottenburg	3d	1500	93/128 (73%)	0	0	0	0	3	2	10	10	3
	Haselhorst, Spandau	3e	3330	114/208 (55%)	4	0	0	2	0	0	7	3	1
	Settlements along Alte-Jakobstr., Mitte	3f	3030	127/200 (64%)	0	2	3	3	2	3	18	12	10
Large housing estates (1970s–1980s)	Marzahn	4g	5700	199/428 (46%)	0	1	0	2	0	2	1	9	11
	Gropiusstadt, Neukölln	4h	3000	157/313 (50%)	0	0	0	1	1	4	8	5	8

Regarding shrubs, the species richness varies between 6 and 10 among all building types (Table 3). The presence of the shrub species in the study areas is reported in Appendix B. In some cases, such as *Carpinus betulus* L., some species have been considered as shrubs for the function performed and the growing habit and dimensions. The most frequent species in the areas are *Mahonia aquifolium* (Pursh) Nutt. and *Syringa vulgaris* L. Table 4 reports the results of the Jaccard and Bray-Curtis indexes. The matrix similarity of abundance and presence of woody/tree species across different building types shows that there is no similarity, because the values are lower than 0.5 (0 means no similarity; 1 means full similarity). Even within the same building type (e.g., 1a and 1b), similarity is not detectable. Therefore, planting patterns of residential greenery do not follow common design lines, unlike the built parts

Table 3. Shrub and tree species richness and frequent trees species of the residential greenery mapped in the sample plots. Species were considered frequent if their presence was more than 10% of the total number of trees sampled. Bold species dominated tree composition, as the number of individuals was at least double compared with the number of individuals of other tree species (for details see Appendixes A and B). Neighborhood codes: 1a, Sprengelkiez, Wedding; 1b, Ideal-Passage, Neukölln; 2c, General Barby Siedlung, Reinickendorf; 3d, Paul-Hertz-Siedlung, Charlottenburg; 3e, Haselhorst, Spandau; 3f, Alte-Jakobstrasse, Mitte; 4g, Marzahn; and 4h, Gropiusstadt, Neukölln. Bold characters indicate the most frequent species.

Building type (construction period)	Code	Species richness		Frequent tree species
		Trees	Shrubs	
Block-edge developments (Type I, 1870s–1920s)	1a	12	6	***Aesculus hippocastanum*** L.; *Acer platanoides* L.; *Fraxinus excelsior* L.; *Juglans regia* L.; *Pinus sylvestris* L.; *Prunus avium* L.; *Quercus robur* L.
	1b	13	8	*Betula pendula* Roth; *Acer pseudoplatanus* L.; *Taxus baccata* L.

Block-edge development with large green backyards (Type II, 1920s–1940s)	2c	23	9	***Betula pendula*** Roth; *Abies alba* Mill.; *Acer platanoides* L.; *Crataegus monogyna* Jacq.; *Ilex aquifolium* 'J.C. van Tol'*; Pinus strobus* L.; *Robinia pseudoacacia* L.
Row-building settlements (1920s–1970s)	3d	17	8	***Styphnolobium japonicum*** (L.) Schott; *Acer negundo* L.; *Acer platanoides* L.; *Ailanthus altissima* (Mill.) Swingle; *Betula pendula* Roth; *Ginkgo biloba* L.; *Malus domestica* Borkh.; *Prunus avium* L.
	3e	15	8	***Betula pendula*** Roth; ***Pinus strobus*** L.; *Acer negundo* L.; *Acer platanoides* L.; *Pinus nigra* J.F. Arnold; *Prunus avium* L.; *Prunus cerasifera* Ehrh.; *Robinia pseudoacacia* L.
	3f	15	10	*Acer campestre* L.; *Acer platanoides* L.; *Pinus sylvestris* L.; *Populus alba* L.; *Prunus*

				cerasifera 'pissardii nigra'; *Robinia pseudoacacia* L.; *Taxus baccata* L.; *Tilia cordata* Mill.
Large housing estates (1970s–1980s)	4g	32	9	***Quercus robur*** L.; *Acer platanoides* L.; *Betula pendula* Roth; *Carpinus betulus* L.; *Prunus serotina* Ehrh.; *Tilia cordata* Mill.
	4h	13	10	***Pinus sylvestris*** L.; *Acer platanoides* L.; *Styphnolobium japonicum* (L.) Schott

Table 4. Matrix similarity of abundance of woody or tree species across different building types using Jaccard and Bray-Curtis (italic) indexes. Building types: Block-edge developments (Type I: Without large green backyards of the 1870s–1920s; Type II: With large green backyards of the 1920s–1940s); row-building settlements of the 1920s–1970s and large housing estates of the 1970s–1980s. Neighborhood codes: 1a, Sprengelkiez, Wedding; 1b, Ideal-Passage, Neukölln; 2c, General Barby Siedlung, Reinickendorf; 3d, Paul-Hertz-Siedlung, Charlottenburg; 3e, Haselhorst, Spandau; 3f, Alte-Jakobstrasse, Mitte; 4g, Marzahn; and 4h, Gropiusstadt, Neukölln.

		Jaccard Index							
Building types		Block-edge developments			Row-building settlements			Large housing estates	
		Type I		Type II					
		1a	1b	2c	3d	3e	3f	4g	4h
Bray-Curtis Index	1a	1	0.19	0.30	0.12	0.13	0.42	0.26	0.39
	1b	*0.20*	1	0.20	0.07	0.17	0.12	0.25	0.30
	2c	*0.18*	*0.13*	1	0.18	0.36	0.36	0.31	0.24
	3d	*0.16*	*0.11*	*0.17*	1	0.23	0.14	0.17	0.25
	3e	*0.18*	*0.18*	*0.37*	*0.33*	1	0.32	0.31	0.23
	3f	*0.37*	*0.13*	*0.31*	*0.12*	*0.27*	1	0.31	0.33
	4g	*0.18*	*0.12*	*0.37*	*0.12*	*0.22*	*0.25*	1	0.32
	4h	*0.24*	*0.18*	*0.18*	*0.21*	*0.16*	*0.27*	*0.23*	1

3.2. Ecosystem Services and Disservices Provided by Trees in the Sample Areas

Starting from the census of all trees in the residential greenery, the air pollution removal potential and allergenic potential were calculated for each sample area and building type (see Appendix A for potential value for air removal and allergy found in literature for each species in the sample areas, and Table 5 for a general summary of those data). The air pollution removal potential and the allergenic potential have been attributed to each tree species of the 32 sample plots (93% of the species are represented, no specific data were found in the literature for the remaining 7%).

Of the tree species sampled, 79% had a moderate potential to remove air pollution (i.e., deciduous trees, which represented 75% of all individual trees). Paul-Hertz-Siedlung and Marzahn had the lowest percentage of species with a high potential to remove pollution. Over all sampled areas, all trees had a moderate to high potential to remove pollution (Table 5). Tree composition in the study area of Gropiusstadt was ranked best as 60% of the plants showed a high value due to the frequent use of conifers, while it was inferior to 25% in all the other sample areas (Table 5). Air pollution in Gropiusstadt was considerably lower compared to other study areas also due to the position outside the inner city of Berlin (Table 1).

Table 5. Tree composition in the study areas according to air pollution removal potential (modified by [13,23]) and allergenic potential (modified by [42–45], 93% of tree species are represented). Building types: Block-edge developments (Type I: Without large green backyards of the 1870s–1920s; Type II: With large green backyards of the 1920s–1940s); row-building settlements of the 1920s–1970s and large housing estates of the 1970s-1980s. Neighborhood codes: 1a, Sprengelkiez, Wedding; 1b, Ideal-Passage, Neukölln; 2c, General Barby Siedlung, Reinickendorf; 3d, Paul-Hertz-Siedlung, Charlottenburg; 3e, Haselhorst, Spandau; 3f, Alte-Jakobstrasse, Mitte; 4g, Marzahn; and 4h, Gropiusstadt, Neukölln.

	All sampling areas				Building type							
					Block-edge developments			Row-building settlements			Large housing estates	
					Type I		Type II					
	Species		Individuals		1a	1b	2c	3d	3e	3f	4g	4h
	(n)	(%)	(n)	(%)	(% of trees per area)							
Air pollution removal potential												
moderate	49	79	395	75	80	88	82	95	78	76	94	40
high	13	21	113	22	20	13	18	5	23	24	6	60
Allergenic potential												
low	22	38	122	25	16	25	34	26	30	22	30	5
moderate	12	21	152	31	36	13	28	34	38	41	9	66
high	18	31	141	29	40	44	14	24	15	33	41	23
very high	6	10	80	16	8	19	24	16	18	4	21	6

Regarding the allergenic potential of plants (i.e., an ecosystem disservice) in the 32 sample plots, 18 species had a high allergenic potential while 6 species had a very high allergenic potential (Table 5). Over all sampled areas, two thirds of all species and three quarters of all trees had a moderate to very high allergic potential (Table 5). Considering the number of plants, 31% had a moderate allergenic potential while 45% had a high or very high allergenic potential value. Analyzing the percentages of trees, it was noticeable that in areas of Sprengelkiez, Ideal-Passage in Neukölln and Marzahn, nearly half or more of the trees (48%, 63%, and 62% respectively) had a high or very high allergenic potential. Lower allergenic potential was detected in General Barby Siedlung, Haselhorst and Marzahn (34%, 30% and 30% respectively).

3.3. Results of the SWOT Analysis

We detected the following strategies to address the strengths, opportunities, weaknesses and threats of the residential greenery across all our sample plots. Up to now green spaces have been designed and maintained in top down approaches by planners and gardeners of the real estate companies. Thus, green spaces invite residents to stay and use, but not to participate in the design and maintenance processes. Here, co-creation of the ongoing optimization processes is a helpful strategy to involve local citizens, foster the responsibilities of local residents to enhance welcoming qualities and care for the adaptations of greenery to changed needs (Table 6).

We identified strategies to improve the residential greenery (Table 6) considering external (threats and opportunities) and internal (weaknesses and strengths) factors of the residential greenery of our study areas, resulting in a strategy based on four different combinations [47].

Table 6. Examples for strategies to improve residential greenery by SWOT/TOWS matrix (see Methods).

	OPPORTUNITIES	THREATS
STRENGTHS	**SO-Strategies** • Co-design and Co-implementation (e.g., nature based solutions for health risks, biodiversity friendly playgrounds and experience trails) • Transfer of responsibilities for design, care and maintenance to residents • Implementation of missing residential greenery elements to foster cooling and filtering and biodiversity effects	**ST-Strategies** • Organisation of initial meetings and communication events to overcome barriers • Financial benefits with appropriate management • Plant use guide to reduce disservices of ornamental plants and enhance cooling and air filtering effects
WEAKNESSES	**WO-Strategies** • Transformation to multi-functional, healthy and biodiversity-friendly areas • Enhance welcoming qualities and motivation to be physically active (e.g., by implementation of barefoot paths and sport devices) • Empower integration friendly places for resilient neighborhoods	**WT-Strategies** • Foster easy-to-implement and low-cost solutions to avoid hard-to-transfer "lighthouse projects" or green gentrification • Information campaigns and workshops

4. Discussion

The residential greenery in the past has often been considered as the empty space between buildings or an area for ornamental purposes, rather than a green area with multiple functions serving the wellbeing of local residents. Figure 2 shows the main elements of the residential greenery in the study areas. It is mainly determined by design and plant use choices. Interestingly, we found no similarity in terms of abundance and presence of woody species within residential greenery (Table 3). Even within the same building type, similarity i low. The planting patterns of residential greenery do not follow common design guidelines or maintenance practices when individual trees or shrubs are replaced. We detected a largely unused potential to enhance health effects of residential greenery by a predominant use of woody species that provide health-relevant ecosystem services.

In general, urban trees in our study areas provide moderate to high benefits by absorbing air pollution. Evergreens and conifers play an important role in this regard [31,32]. Across all sampling sites, we revealed that one to two thirds of all trees have a high to very high allergenic potential (Table 5). Their presence, growth and management must be considered at the planning phase to maximize the provision of ecosystem services and to reduce potential disservices [23,42–44]. Instead of an increasing body of literature on health impacts of allergenic plants in urban areas [48–50], this topic has been scarcely considered in public or semi-public green area design. A plant use guide for residential greenery will assist real estate companies and managers of residential greenery to address this issue. High allergenic species such as *Alnus glutinosa* (L.) Gaertn., *Betula pendula* Roth, *Carpinus betulus* L., *Corylus colurna* L., *Cupressus sempervirens* L., *Fagus sylvatica* L., *Fraxinus excelsior* L., *Morus alba* L., *Quercus robur* L. and *Ulmus laevis* Pall. have to be avoided in these green spaces.

In the classic buildings of the Wilhelminian period in Germany (1870s to 1920s), different building laws and economic factors led to a perimeter block development without a noteworthy open-space structure and almost no living environment. The typical late 19th century courtyards in Berlin, with several backyards, used as traffic and storage areas, formed an almost complete overbuilding of the inner city. The residential greenery in the block-edge developments of the Wilhelminian area is smaller than in the other areas studied. Over 500 inhabitants are living in these areas per hectare with low access to public greenery, high air pollution and high bioclimatic stress. Eighty per cent of the surface is sealed (Table 1). The main elements of this era were street trees and some trees and shrubs in the small backyards. Commonly, the presence of plants is limited to a few individuals, however the number of trees per area is not significantly different from the other areas. Only a few benches, lights, playgrounds or paths were found mainly due to the small size of greenery (Table 2); however, the number of bike racks demonstrates that the use of bicycles and related physical activity is very common in Berlin's inner city districts. The number of balconies is low compared to other areas and 43% of them are greened by residents. Due to the lack of open space, we identified the need for the implementation of building-attached green (e.g., green wall measures, green roof or pervious parking areas, Figure 2B). Installing some more benches could provide meeting points in the small green realms of these densely over-built areas.

Occasionally socio-political cooperatives implemented reform ideas of green block courtyards at the beginning of the 20th Century (e.g., study area in Reinickendorf and Figure 1A). At the end of the First World War, there was a lack of housing and a promotion of small residential complexes with gardens (1924). In that historical period there was the need to ensure 'air and light' for all residents, creating a free space in the housing area and pouring into the building of row constructions. The quantity and the quality depended on whether the land for the settlement was owned by the city or not, and on the level of involvement of builders and planners in the surrounding green spaces [18]. The residential greenery in these modernist settlements of the 1920s contrasts sharply with the Wilhelminian period. The percentage of unsealed surface increased (e.g., 49% in Reinickendorf, Table 1). Both the tenants' gardens and the shared lawns were present, along with different structural elements such as laundry areas, playgrounds, paths and seating areas. Our study area in Reinickendorf presents a great diversity of woody species; real estate companies there pay particular attention to the maintenance of residential greenery. The number of balconies and number of benches increased manifold in this building type (Table 2). Seventy-five per cent of the balconies are greened by the residents. Due to the large size of the greenery, elements such as bioswales or ponds can be implemented, enhancing biodiversity, providing cooling effects and functioning for effective stormwater management.

The construction of multi-storey housing in the 1920s–1970s (e.g., sample areas of Paul Hertz Siedlung, Haselhorst and Mitte) was linked to modernist settlement ideas [18]. The row-building settlements were built loosely and criss-crossed by green spaces, where the inhabitants could walk and enjoy greenery on different paths. More than the half of the areas remain unsealed and the number of inhabitants per hectare is low (Table 1). The design of open spaces followed mainly two different ideas of parceling as tenants or the design of the area as a "park landscape". Tenant gardens were seen as a way to save costs of land care, a way of self-sufficiency of the inhabitants (especially after the Second World War) and as recreational areas [18]. The buildings have a high number of balconies often greened by residents (Table 2). The residential greenery in the study areas of Haselhorst and Mitte does not present particular plant composition, but offers ample space to spend pleasant moments, especially during the summer. Paul Hertz Siedlung holds a greater diversity of plant species compared to the other two study areas of this era (Table 2). Bioswales are implemented in one of our sample plots in Haselhorst.

The largest areas of residential greenery with integrated gardens, playgrounds and benches are typical for large housing estate of the 1960s to 1980s; however, welcoming qualities have been questioned as they were mostly designed from the perspective of architects and not of local residents [10]. Real estate companies in Berlin Hellersdorf and Hohenschönhausen (both neighboring quarters of Marzahn) addressed this with the successful implementation of gardens attached to the buildings, where local residents can co-design their private planting lot within the semi-public green spaces [51]. Recently the companies of Gropiusstadt invested money in the reconstruction of some gardens.

Figure 2. Residential greenery of the study areas (**A**, pervious parking in a courtyard in Sprengelkiez; **B**, courtyard in Neukölln with big improvement potential; **C**, playground in Haselhorst; **D**, disabled old lady with young adult sitting on a bench in the residential green area of Paul-Hertz-Siedlung; **E**, swale in Haselhosrt; **F**, newly-built greenery in Gropiusstadt; **G**, self-made garden in Gropiustadt; **H**, playground in Gropiusstadt; **I**, green alley between buildings, Gropiusstadt; photos: Pille).

In general, the residential greenery has an easy access for residents and invites to relate and communicate with neighbors. It is possible to enjoy the benefits of urban nature directly on the doorstep. Almost all residential greeneries examined in this study have a high diversity of tree and shrub composition. Parking lots and garages are rarely present, leaving space for lawns and ornamental plants. Up to now, only a few ground-based greening and bioswales were implemented (i.e., Haselhorst, Table 2). The laundry-drying areas, elements historically present in the residential greenery in Germany, unfortunately disappeared with the technical development of washing machines with dryers and today can be found as relicts in the study areas of Mitte/Alte Jakob Str. and Marzahn. The playgrounds are fairly distributed in the sites and are generally in good condition.

Paths especially designed to enhance physical activities, such as bare foot paths or devices for sport and physical exercises beyond classical play grounds are missing. Bike racks are common elements of all sample areas, but residents' demands in the sample plots are often higher. This leads to an accumulation of bicycles on the corners of the green areas, especially in the block-edge developments of the Wilhelminian area. To enhance the adaptability of residential greenery to changing residents' needs, multifunctionality of these areas has to be fostered also including the organization of social and sport activities with the aim to improve the fruition of those spaces.

The current state in residential greeneries, however, demonstrates the (partially) small size and high fragmentation of these green areas. Sometimes, if not designed and managed with care, the residential greenery does not have high welcoming qualities (i.e., Marzahn, Haselhorst). Usage conflicts (e.g., parking and dumpsters versus leisure and pleasure) are also evident for the residential greenery. Finally, these green spaces are perceived predominantly as a functional space for parking and waste management rather than as a space for recreation, physical activities, education or to come together with neighbors. Thus, our field survey highlighted these conflicts within usage among local citizens. As an example, while some enjoy using the residential greenery with their children, older neighbors complain about the noise generated.

The possibility of implementing residential greenery, enhancing the supply of ecosystem services and improving the wellbeing of the inhabitants are many. Among the elements that can be implemented, worthy of note are the green walls, which can help to increase the level of biodiversity and reduce the urban heat island effect [52,53]. This improves the aesthetic quality of the residential greenery, encouraging residents to stay longer in the area.

Residential greenery has a high re-naturation potential (i.e., using nature-based solutions) and there is a current trend that invites urban gardening activities. All this means it is useful to have new urban realms for urban biodiversity and to respond to the need to create resilient neighborhoods by increasing the identity of the place and its security, while creating a strong sense of community. The image of the residential greenery will change by visible transformations that are more accepted and used and better maintained when residents are invited to co-create their green spaces on their door steps in bottom-up processes, rather than in top down designs. There is the fear of contact with neighbors or an initial difficulty in relationships due to social and cultural barriers. Moreover, the poor maintenance and care of the residential greenery can return as a negative image of the place, which can lead to an increase in vandalism. The responsibilities and especially the initial costs of building and managing such green areas are high, potentially implying the green gentrification [54,55]. We also revealed evidence for a high motivation for (co-)design and care by residents with reimbursement effects also for the housing estate companies (i.e., General-Barby Str.).

5. Conclusions

Residential greenery is an essential and low cost tool to enhance sustainable social cohesion and the health and wellbeing of local residents. Here, we analyzed the state of the art of residential greenery in disadvantaged neighborhoods of Berlin considering structural elements, woody species and its health-related ecosystem services and disservices. These green areas are impressively significant within the city, both for their accessibility to the local population and for their contribution to the biodiversity of Berlin's greening. Our results highlight the extremely differentiated character of residential greenery among different neighborhoods and within the same neighborhood. We identified strategies to foster health relevant ecosystem services, physical activity and wellbeing of residents. Health-adapted plant use guidelines have to consider the allergenic potential of ornamental plants and the enhancement of cooling and air-filtering effects. Moreover, it is crucial to enhance welcoming qualities and the motivation to be physically active (e.g., by implementation of structural elements such as bike racks, barefoot paths or sport devices). The multifunctionality of residential greenery has to be fostered to maximize the adaptability to diverse and changing residents' needs across different cultures and generations. Moreover, there is a high motivation for co-creation of inclusive green spaces and care by residents on their door-step with long-term reimbursement effects also for the housing estate companies. The same approach can be used in other cities, focusing on wellbeing and the willingness of residents to improve the state of green areas. Design and management of residential greenery requires an inclusive multi-stakeholder approach, a cross-sectoral integration of existing knowledge from sociology, planning, ecology, agronomy, landscape architecture and urban planning, among others. These needs, which can no longer be postponed, must be addressed from a socio-ecological point of view in order to increase urban wellbeing conditions for the future generations.

Acknowledgments: We thank our *Healthy Living* research team members Sylvia Butenschön, Frederike Büttner, Ewelina Skulimowska, Sonja Mohr Stockinger, Jan Hogrefe, Hannah-Lea Schmid and Lea Matscheroth for field assistance and fruitful discussion on health-related ecosystem services of residential greenery. We thank the reviewers for their helpful suggestions to improve the manuscript.

Appendix A

Table A1. List, number, air pollution removal potential (modified by [31,32]) and allergenic potential (modified by [42,43,45,48], 93% of tree species are represented) of all woody and tree species sampled in the 32 sample plots divided by building type. Building types: Block-edge developments (Type I: Without large green backyards of the 1870s–1920s; Type II: With large green backyards of the 1920s–1940s); row-building settlements of the 1920s –1970s; and large housing estates of the 1970s–1980s. Neighborhood codes: 1a, Sprengelkiez, Wedding; 1b, Ideal-Passage, Neukölln; 2c, General Barby Siedlung, Reinickendorf; 3d, Paul-Hertz-Siedlung, Charlottenburg; 3e, Haselhorst, Spandau; 3f, Alte-Jakobstrasse, Mitte; 4g, Marzahn; and 4h, Gropiusstadt, Neukölln.

Building types	Number of trees per sample area								Total number of trees across sampled areas	Allergenic potential	Air pollution removal potential
	Block-edge developments			Row-building settlements			Large housing estates				
	Type I		Type II								
Species	**1a**	**1b**	**2c**	**3d**	**3e**	**3f**	**4g**	**4h**			
Abies alba Mill.	1	0	4	0	0	2	1	3	11	low	high
Acer campestre L.	1	0	1	0	0	3	0	0	5	moderate	moderate
Acer negundo L.	0	0	2	2	3	1	4	0	12	moderate	moderate

Acer platanoides L.	3	0	6	2	4	4	12	10	41	high	moderate
Acer platanoides 'Crimson King'	0	0	0	1	0	0	0	0	1	high	moderate
Acer pseudoplatanus L.	0	2	0	0	0	0	8	3	13	high	moderate
Acer saccharinum L.	0	0	0	1	0	0	0	0	1	moderate	moderate
Aesculus hippocastanum L.	6	1	1	0	1	2	4	3	18	moderate	moderate
Ailanthus altissima (Mill.) Swingle	0	0	0	3	0	0	0	0	3	high	moderate
Alnus glutinosa (L.) Gaertn.	0	1	0	0	0	0	1	0	2	high	moderate
Betula pendula Roth	0	2	20	4	6	0	22	3	57	very high	moderate
Betula utilis D.Don	0	0	1	0	0	0	0	0	1	high	moderate

Carpinus betulus L.	0	0	0	1	1	2	9	2	15	very high	moderate
Carpinus betulus 'pyramidalis'	0	0	0	0	0	0	6	0	6	-	moderate
Castanea sativa Mill.	0	0	2	0	0	0	0	0	2	moderate	moderate
Catalpa bignonioides Walter	0	1	0	0	0	0	1	2	4	high	moderate
Celtis australis L.	0	0	0	0	0	2	0	0	2	high	moderate
Citrus spp.	0	1	0	0	0	0	0	0	1	low	high
Corylus colurna L.	0	0	0	1	0	0	0	0	1	very high	moderate
Crataegus monogyna Jacq.	0	0	8	0	0	0	0	0	8	low	moderate
Cupressus sempervirens L.	0	0	3	0	0	0	0	0	3	very high	high

Eriobotrya japonica (Thunb.) Lindl.	0	0	0	0	0	0	3	0	3	low	high
Fagus sylvatica L.	0	1	0	0	0	0	0	0	1	very high	moderate
Fagus sylvatica 'atropurpurea'	0	0	0	0	0	0	0	3	3	-	moderate
Fraxinus excelsior L.	2	0	0	0	0	0	1	0	3	very high	moderate
Ginkgo biloba L.	0	0	0	2	0	0	0	0	2	moderate	moderate
Gleditsia triacanthos L.	0	0	0	0	0	0	2	0	2	low	moderate
Ilex aquifolium 'J.C. van Tol'	0	0	15	0	0	0	0	0	15	-	high
Juglans regia L.	2	1	1	0	0	0	1	0	5	high	moderate
Malus domestica (Borkh.) Borkh.	0	0	1	5	0	0	0	0	6	low	moderate
Morus alba L.	0	0	0	1	0	0	0	0	1	high	moderate

Picea glauca (Moench) Voss	0	0	0	1	0	0	1	0	2	low	high
Pinus nigra J.F. Arnold	0	0	0	0	3	0	0	0	3	moderate	high
Pinus sylvestris L.	2	0	0	0	0	4	2	46	54	moderate	high
Pinus strobus L.	0	0	8	0	6	0	0	0	14	moderate	high
Populus alba L.	0	0	0	0	0	4	0	0	4	moderate	moderate
Populus nigra 'Italica'	0	0	1	0	0	0	0	0	1	high	moderate
Populus tremula L.	0	0	0	0	0	0	4	0	4	-	moderate
Prunus avium L.	2	1	3	3	5	0	1	1	16	low	moderate
Prunus cerasifera Ehrh.	0	0	2	0	4	0	1	0	7	low	moderate
Prunus domestica L.	0	1	0	0	0	0	0	0	1	low	moderate
Prunus persica (L.) Batsch	0	0	0	0	1	0	0	0	1	low	moderate

Prunus cerasifera 'pissardii nigra'	0	0	1	0	1	3	3	0	8	low	moderate
Prunus serotina Ehrh.	0	0	0	0	0	0	14	0	14	low	moderate
Pseudotsuga menziesii (Mirb.) Franco	0	0	0	1	0	0	5	0	6	low	high
Quercus robur L.	3	0	2	1	0	2	35	2	45	high	moderate
Quercus robur 'fastigiata'	0	0	0	1	1	0	0	0	2	high	moderate
Quercus rubra L.	0	0	0	0	0	0	1	0	1	high	moderate
Rhus typhina L.	0	0	0	0	0	0	1	0	1	low	moderate
Robinia pseudoacacia L.	0	1	13	0	2	5	3	0	24	moderate	moderate
Salix caprea L.	0	0	0	0	0	0	1	0	1	high	moderate
Salix matsudana 'contorta'	1	0	0	0	0	2	0	0	3	high	moderate

Sorbus aucuparia L.	0	0	1	0	0	0	0	0	1	low	moderate
Sorbus intermedia (Ehrh.) Pers.	0	0	0	0	0	0	2	0	2	low	moderate
Styphnolobium japonicum (L.) Schott	0	0	0	8	0	0	0	5	13	moderate	moderate
Taxus baccata L.	1	2	2	0	0	5	1	2	13	high	high
Thuja orientalis (L.) Franco	1	0	0	0	0	0	0	0	1	low	high
Tilia americana L.	0	1	0	0	0	0	0	0	1	low	moderate
Tilia cordata Mill.	0	0	13	0	1	5	11	0	30	low	moderate
Ulmus laevis Pall.	0	0	0	0	1	0	1	0	2	high	moderate
									Mean ± SD		
Tree species richness	12	13	23	17	15	15	31	13	17 ± 6		

Appendix B

Table A2. Presence/absence of shrub species and shrub species richness in the study areas. N: Number of sample areas with species presence. Building types: Block-edge developments (Type I: Without large green backyards of the 1870s–1920s; Type II: With large green backyards of the 1920s–1940s); row-building settlements of the 1920s-1970s and large housing estates of the 1970s–1980s. Neighborhood codes: 1a, Sprengelkiez, Wedding; 1b, Ideal-Passage, Neukölln; 2c, General Barby Siedlung, Reinickendorf; 3d, Paul-Hertz-Siedlung, Charlottenburg; 3e, Haselhorst, Spandau; 3f, Alte-Jakobstrasse, Mitte; 4g, Marzahn; and 4h, Gropiusstadt, Neukölln.

	Presence (+) of shrubs species								
Building types	**Block-edge developments**			**Row-building settlements**			**Large housing estates**		
	Type I		**Type II**						
Shrub Species	**1a**	**1b**	**2c**	**3d**	**3e**	**3f**	**4g**	**4h**	**N**
Berberis darwinii Hook.							+		1
Berberis thunbergii 'atropurpurea'			+						1
Camelia japonica L.		+							1
Carpinus betulus L.								+	1
Cornus alba 'elegantissima'						+			1
Cornus kousa Buerger ex Miq.			+						1
Cornus mas L.					+				1
Ligustrum ovalifolium Hassk.								+	1
Photinia x fraseri			+						1

Spiraea japinoca L.					+				1
Cotoneaster dammeri C.K. Schneid			+						1
Cupressocyparis leylandii (Dallim. & A.B. Jacks.) Dallim.		+							1
Wisteria sinensis (Sims) Sweet		+							1
Hibiscus spp.								+	1
Ilex aquifolium L.							+		1
Pittosporum tobira Thunb.) W.T. Aiton	+								1
Lonicera nitida E.H. Wilson				+			+		2
Partenocissus quinquefolia (L.) Planch.					+	+			2
Rhododendron spp.	+							+	2
Corylus avellana L.		+		+			+		3
Berberis thunbergii DC.				+		+		+	3
Kerria japonica (L.) DC.		+			+	+			3
Parthenocissus tricuspidata (Siebold & Zucc.) Planch.			+		+			+	3
Juniperus spp.			+			+	+	+	4
Crataegus oxyacantha L.			+	+	+			+	4
Hedera helix L.	+	+		+		+			4
Sambucus nigra L.		+		+		+	+		5

Prunus laurocaerasus L.	+	+			+	+	+		5
Mahonia aquifolium (Pursh) Nutt.	+		+	+	+	+	+	+	7
Syringa vulgaris L.	+		+	+	+	+	+	+	7
									Mean ± SD
Shrub species richness	6	8	9	8	8	10	9	10	9 ± 1

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Chapter 5

Conclusions and Future Perspectives

The results presented in the thesis made it possible to achieve the PhD objective, delving into the issues of mapping and assessment of ecosystem services provided by landscape and urban horticulture. According to the outcomes of the research, the health and well-being of urban residents depends greatly on locally produced ES, even though it is essential to examine the environment at a wider scale, as if the environmental conditions change at the boundary, the supply of ES at the local level may change. Specifically, results show how the socio-ecological provision of ES is context-specific, and requires knowledge of both ecological and social dynamics, values and cultural traditions that influence the demand and supply of ES.

Whereas the future challenges for ES are numerous - such as the improvement of urban resilience through the supply of ES and the development of new tools/methods for ES assessment - the involvement of stakeholders in mapping and assessment of ES is of major importance. In order to achieve the objective, it is necessary to better communicate the importance of mapping and quantifying ES and to perform research at the territorial level, in contact and collaboration with stakeholders, using bottom-up processes. In addition, the knowledge of the perception of ES by citizens or users of urban green areas is essential to set up long-term management plans, reducing conflicts between the needs of managers and those of users. As the thesis reveals, the perception of ES is highly gendered, underlining the importance of accurately assessing the relationships between people and ecosystems, especially the urban ones.

It is necessary to highlight that even ecosystem disservices are intertwined with the life patterns of the urban population. As reported in the previous chapters, the mapping and assessment of disservices is therefore necessary, identifying those who may be affected, trying to understand how the population perceives them and monitoring this perception over time.

In the immediate future, therefore, there should be two main strands of research: the first should map and quantify the ecosystem disservices of cities, at different scales, from urban to neighborhood scale; the second should integrate social sciences to a greater extent in order to better understand citizens' perceptions of ES and implement educational strategies to form a more ecologically aware citizenship. Research could investigate services and disservices in different climate zones, underlining possible differences in the perception and the demand/supply relationship of ES in different environmental contexts.

Such research must, however, have practical implications in the territories analysed: to include both services and disservices in a long-term urban management plan, adequately funded; to increase the amount of green spaces in cities, and to use natural components and related processes to reduce the ecological footprint, increase resilience and ehnance human well-being; to better consider that green spaces and ES are effective tools to address social justice and gentrification problems and at the same time can provide job opportunities.

Anyway, in order to avoid disservices, a careful design of urban green areas is mandatory, selecting species aimed at increasing synergies between various ES. In particular, Paper I and Paper III suggest how specific information of disservices related to woody species are useful in urban contexts, even though it is possible to highlight poor data availability for shrubs.

Nowadays, although interest and care for ecosystems is growing, the values of biodiversity and ES are still considered disconnected from resilience in urban contexts, considered both for climate change events and for social and economic changes.

ES must be considered as one of the tools to be used to design and manage urban and peri-urban green areas, with the aim to reduce human impacts on the environment, improving meantime human well-being.

Publications and Participation to Congresses

International journals w/ peer reviews – ISI journals:

Battisti L., Pille L., Wachtel T., Larcher F., Säumel I. (2019) Residential Greenery: State of the Art and Health-Related Ecosystem Services and Disservices in the City of Berlin. Sustainability, 11(6), 1815.

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International book chapters:

Larcher F., **Battisti L.**, Bianco L., Giordano R., Montacchini E., Serra V., Tedesco S. (2018) Sustainability of Living Wall Systems Through An Ecosystem Services Lens. In: D. Nandwani (ed.), Urban Horticulture, Sustainable Development and Biodiversity 18, Springer International Publishing AG, part of Springer Nature 2018.

Other international journals w/ peer reviews – ISI journals:

Larcher F., **Battisti L.**, Gaino W., Devecchi M. (2017) Evaluation of Alternative Substrates and Fertilizer Regimes for the Nursery Cultivation of Phyllostachys pubescens (Carrière) J. Houz. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 45(2):442-445.

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National Congresses

Turin, 16th December 2016 (Italy)
(S)RADICAMENTI, Giornata di studio della Società di Studi Geografici.
Battisti L.; Larcher F.; Devecchi M. *L'orto come strumento di educazione ambientale e inclusione sociale. Esperienze multidisciplinari nella Città di Torino.* Oral Presentation

Palermo, 12-15 November 2019
XII Congresso Nazionale SISEF. La Scienza Utile per le Foreste: ricerca e trasferimento
Battisti L.; Larcher F. *Including visitors' perception in the management plan for urban Natura 2000 sites: the case of La Mandria Park (Turin, Italy).* Poster Presentation

International Congresses

Bologna, 12-15 September 2017 (Italy)
International Symposium on Greener Cities for More Efficient Ecosystem Services in a Climate Changing World.
Battisti L., Gullino F., Larcher F. *Using the ecosystem services' approach for addressing peri-urban farming in Turin Metropolitan Area.* Oral Presentation

Istanbul, 12-16 August 2018 (Turkey)
XXX International Horticultural Congress: IHC2018
Battisti L.; Pille L.; Larcher F.; Butenschön S.; Säumel I. *Managing Urban Greening for Improving Well-being in European Cities.* Poster Presentation

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48th Annual Meeting of the Ecological Society of Germany, Austria and Switzerland (GfÖ)
Battisti L.; Pille L.; Wachtel T.; Larcher F.; Butenschön S.; Säumel I. *Residential greenery as a tool for improving human well-being.* Oral Presentation

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10th IALE WORLD CONGRESS
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Turin, 17 November 2017 (Italy)
Suolo, servizi ecosistemici, infrastrutture verdi e blu, resilienza e pianificazione (In Italian).

Mantova, 28 November – 1 December 2018 (Italy)
World Forum on Urban Forest.

Other scientific activities

Co-supervisor of a Master Thesis. Technical University of Berlin - Department of Ecology - Research Group Multifunctional Landscapes.
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Hogrefe J. (2019) *The Status Quo and Optimization Potential of Residential Greenery in Berlin, Germany -Differences in Residents' Use and Perceptions-*
Peer Review Summary
Luca Battisti performed 4 reviews for journals including International Journal of Environmental Research and Public Health and Sustainability between January 2019 and January 2020. https://publons.com/a/3177950

Aknowledgements

During these years of my PhD there are so many people I have to thank.
I would like to thank Dr. Federica Larcher, Prof. Marco Devecchi and the colleagues of the research group, without whom the PhD path would never have been possible.
Dr. Ina Säumel, Suhana E.Reddy, Thomas Wachtel; Julia Santolin; Paola Pozo; Leonardo Ramirez; Sergio Lopez Hildago, Barbara Martins Carneiro, Barbara Niedermeyer, Sören Miehe for the technical-scientific support both at TU Berlin and at IRI THESys - Humboldt University of Berlin.
Bruno, Ralph, Sergey, Greg, Momo, Ewelina, have contributed to make my experience of studying and living in Berlin possible and unique.
Giusi Rezza; Antonella Pogliano and Roberto Filipello who dedicated their precious time to me to set up my research on La Mandria Park.
Thanks also to all the people who answered the questionnaire.
Finally, I would like to thank my family for providing me with unfailing support and continuous encouragement throughout my years of study and during the process of researching and writing this thesis.